FINAL REPORTS SUMMARIES

EARTH OBSERVATION BY SATELLITE TELSAT 4

SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY SPSD 1

This booklet is realised in the framework of the Scientific Support Plan for a Sustainable Development Policy (SPSD I). Available publications are:

- *"Antarctica"*
- *"Levers for a sustainable development policy"*
- *"Earth observation by satellite" TELSAT 4*
- *"Prenormative research in the food sector"*
- *"Global change and sustainable development"*
- *"Sustainable management of the North Sea"* (available from spring 2003)
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Rue de la Science 8
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B-1000 Brussels
Belgium
Tel: 32/2/238.34.11 – Fax: 32/2/230.59.12
http://www.belspo.be (FEDRA)

Contact person:
Mrs Carine Petit (peti@belspo.be)
Secr: 32/2/238.34.10

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"EARTH OBSERVATION BY SATELLITE" TELSAT 4

Following on the commitments made by Belgium to the European Space Agency (ESA) and to the French "Satellites Pour l'Observation de la Terre" (SPOT) programme, a national satellite remote sensing research programme, called TELSAT, was set up in 1986. The main objective was the building up of a Belgian expertise in spatial earth observation techniques and applications, and to develop a recurrent market with regard to the use of satellite data. TELSAT has since evolved from an exploratory phase (TELSAT I, 1985-1989), over a phase of development of applications (TELSAT II, 1989-1993) to a phase addressing concrete user information needs (TELSAT III, 1993-1996). The fourth phase of the programme, called TELSAT 4 (1996-2000), was part of the Sustainable Development Programme. This report covers the main results of the projects funded by OSTC's TELSAT 4 programme.

The TELSAT 4 programme aimed at anchoring the methods and results of earlier phases of the programme within the community of final users, that is scientists, public administrations and the private sector, as well as NGO's. Various opportunities for international action relating to the new sensors developed by the space agencies received support in order to achieve the set objectives. The total budget of the TELSAT 4 programme was about 6,346 MEUR (256 MBEF), covering the four-year period.

Four key themes and one trans-sectorial technical action line have been defined to fulfil the programme objectives:

- Global change (terrestrial ecosystems, soil moisture);
- Inventory and management of environmental resources (sustainable agriculture, spatial planning and sustainable management of the sea);
- Natural hazards and protection of the population (floods, geological risks);
- Sustainable development of tropical countries (natural resources, green accounting, humanitarian aid);
- Trans-sectorial measures aiming at developing robust working tools (quality control, monitoring and warning systems).

The programme was built on a twofold strategy, answering the need for "Supporting Research" on the one hand, and "Transfer of Technology" on the other hand, and was addressed by four types of projects.

The *"Research support"* axis financed about 22 research projects aiming at solving technical problems and the use of data from new generation sensors.

The *"Feasibility studies"* (30 granted projects) served to demonstrate the potential uses of remote sensing. They consisted of a technical demonstration or an economic feasibility analysis for a specific application area. These short-term studies were undertaken at the request of potential users, and opened the way to larger-scale projects.

"Pilot projects" (16 supported projects) offered the transfer of newly gained knowledge to operating environments. A pilot project is based on needs expressed by a user-partner, from either the public or the private sector, and a technical solution provided by the project's scientific partner. This means that pilot projects were undertaken in partnership. The OSTC provided the financing for the scientific partner, whilst the user-partner put up at least 50% of the total project costs.

The CEO (Centre for Earth Observation) launched and managed by the European Union aims at promoting the use of earth observation data. The OSTC financial contribution concerned Belgian projects selected by the Commission (RDT "Environment and Climate" programme, area 3.3) under the system of shared cost action or concerted action. OSTC financing was addressed at business companies and assimilated research institutes and does not exceed 25% of the total project cost. The *"CEO Projects"* concerned one granted project and was an accompanying measure directed at the private sector.

Moreover, the TELSAT programme was bound, via the "Earth Observation" platform of the "Information Society" plan, to provide scientific and technical support to other research programmes which were part of the Sustainable Development Plan. The "Earth Observation Platform", as part of the OSTC action plan in support of the Information society", aimed at:

- Providing permanently accessible information on earth observation data, images and products and their use (via the electronic TELSAT GUIDE);
- Supplying, distributing and archiving Earth Observation data;
- Ensuring a user help service for various types of users;
- Supporting education and training opportunities relative to satellite data and applications. This part of the programme supported several valorisation actions.

This report is organised in ten thematic chapters:

(I) Forest and Natural Vegetation
(II) Agriculture
(III) Hydrology, Geology and Soils
(IV) Oceans and Coasts

(V) Weather and Climate
(VI) Natural Hazards and Disasters, Humanitarian Aid
(VII) Cartography and Geographical Information Systems (GIS)
(VIII) Land Planning and Infrastructure, Urban and Suburban Environment
(IX) Market Research
(X) Valorisation

Within each chapter, research projects, pilot projects and feasibility studies were grouped. For each project, this report provides the reader with practical information (scientific partner(s), user partner(s), execution period, addresses) and scientific information (context and objectives, data, methodology, output and results, executive summary).

The detailed final reports of the different projects of the TELSAT 4 programme are available at OSTC.

CHAPTER I

FOREST AND NATURAL VEGETATION

RESEARCH CONTRACT T4/DD/001

REMOTE SENSING OF LAND-COVER CHANGE AND BIOMASS BURNING IN THE TROPICS

E. LAMBIN

UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL)
DEPARTMENT OF GEOLOGY AND GEOGRAPHY
LABORATORY OF REMOTE SENSING AND LAND USE CHANGES
Place Louis Pasteur 3, Bâtiment Mercator
B – 1348 LOUVAIN-LA-NEUVE
BELGIUM

1. CONTEXT AND OBJECTIVES

The overall objective of the proposal is to develop a set of remote sensing-based techniques to improve the monitoring and modelling of processes of Land cover change and biomass burning at regional scales. The *monitoring* techniques will be based on indirect indicators of Land cover change such as biomass burning and landscape features. They will be complementary to techniques, which are based on a direct detection of changes (currently developed in parallel efforts). The *modelling* techniques will be aimed at projecting future patterns of Land cover changes from spatially explicit observations by remote sensing.

2. DATA

Geographic study area: Africa

Satellite imagery used:

SPOT XS, LANDSAT TM, LANDSAT MSS, NOAA AVHRR, ERS-1 ATSR

Other data: Field observations

3. METHODOLOGY

Module 1: Characterisation from space of the pattern of biomass burning at regional scales

Improved remote sensing-based techniques will be developed to characterise in an accurate way the spatio-temporal distribution of biomass burning at broad scales. These techniques will combine the detection of active fires with the detection of burnt areas. Change detection techniques adapted for the spatio-temporal characteristics of biomass burning data will be developed to identify exceptional biomass burning activities which could potentially be related to Land cover change processes. Specific model designs will be developed for the assessment of the impacts of biomass burning on Land cover changes, using data derived by remote sensing.

Module 2: Identification of remote sensing-based indicators of land cover change hotspots

Remote sensible landscape features closely associated with Land cover change processes will be identified to allow for a rapid identification and, if possible, anticipation of land cover change "hotspots" in an alert system operating at regional scales for unexpected Land cover change processes.

Module 3: Projection of spatio-temporal patterns of land cover changes from remote sensing observations

A remote sensing-based technique to project future spatio-temporal patterns of Land cover changes from observations of recent patterns of changes will be developed. This technique will be grounded in the theory of "national land-use morphology". It will rely on direct observations of the spatio-temporal patterns of Land cover changes by remote sensing.

4. EXECUTION

Period: 01/12/1996-31/03/1999

Laboratory:

UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL)

Department of Geology and Geography

Laboratory of Remote Sensing and Land Use Changes

Place Louis Pasteur 3, Bâtiment Mercator, B-1348 Louvain-la-Neuve, Belgium

Tel: +32 10 47 44 77 (or 28 73) Fax: +32 10 47 28 77

E-mail: lambin@geog.ucl.ac.be URL : www.geo.ucl.ac.be

5. RELATED DISCIPLINES

Atmosphere

Forest & natural vegetation

Agriculture

Environment

Natural hazards & disasters

6. EXECUTIVE SUMMARY

Module 1: Remote sensing of biomass burning

Several global datasets on fire distribution are being generated from remotely sensed data to support research on the ecological impacts of biomass burning. This paper examines the strengths and weakness of a number of approaches to the monitoring of biomass burning at a regional scale and suggests how to best combine the information content on fire distribution provided by different earth observation satellites. Remotely sensed data acquired over Central Africa from a variety of sensors (airborne video camera. SPOT XS. LANDSAT Thematic Mapper, NOAA Advanced Very High Resolution Radiometer and ERS-1, Along Track Scanning

Radiometer) were used to provide quantitative measurements of the spectral separability, and temporal and spatial sampling associated with the detection of burnt areas and active fires. Three main strategies to the monitoring of biomass burning were analysed: detection of burnt areas at a fine spatial resolution, detection of burnt areas at a coarse spatial resolution and high temporal frequency, and detection of active fires at a coarse spatial resolution and high temporal frequency. In each case, we assess the detectability of the selected biomass burning indicator, the statistical representativity in time and space of the sample detected and whether the sample observations are an unbiased estimator of the total biomass burning events in the region. We conclude that, whilst active fires detection remains important in defining the seasonality, timing and interannual variations in biomass burning, the most reliable strategy for estimating biomass burning at a regional scale is a multisensor approach in which regional burnt areas estimates at coarse spatial resolution data are calibrated on the basis of a sample of fine spatial resolution estimates of burnt areas, using a double sampling with regression estimator approach.

Publication

EVA H. and LAMBIN E. F., 1998. Remote sensing of biomass burning in tropical regions: sampling issues and multisensor approach: Remote Sensing of Environment, **64** (3): 292-315.

Along Track Scanning Radiometer (ATSR-1) data over Central Africa were used to detect areas affected by burning during the 1994-1995 dry season. A method based on temporal spectral profiles for every pixel was developed. When a time trajectory exhibits a sharp fall in the short-wave infrared reflectance with a simultaneous rise in the surface brightness temperature, the pixel is labelled as being affected by burning. The resulting map showed good agreement with contemporaneous airborne video data and LANDSAT TM data, which cover a number of the predominant ecosystems in the region. Some 52% of the 1-km pixels in the Guinean savannahs and 28% of the pixels in the Sudanian savannahs within the study area had been affected by fire during the period from mid-October 1994 to early March 1995. These figures are lower, at the regional scale, than the estimates by Menaut *et al*. (1991) over West Africa. The later figures had been unduly extrapolated to all African savannahs in calculation of atmospheric emissions by fires in Africa. When combined with information on biomass loading and vegetation types, such a map is a useful input to estimate greenhouse gas emissions from savannah fires at regional levels and to investigate potential impacts of biomass burning on land cover.

Publication

EVA H. and LAMBIN E.F., 1998. Burnt areas mapping in Central Africa from ATSR data. International Journal of Remote Sensing, **19** (18): 3471-3473.

Module 2: Identification of "hotspots" of land cover changes

Land cover changes are measured at increasingly broader spatial scales. Yet, understanding and modelling change processes with a satisfactory accuracy require fine scale observations. The objective of this study is to design and test a methodology to detect tropical deforestation "hotspots" at broad spatial scales. This methodology is designed to allow concentration of the data collection and modelling of change processes only on the areas characterised by a high rate of change. The procedure is based on a hierarchical set of decision rules with selection criteria being, first, measured on an exhaustive basis at a global scale and, then, only for the areas retained in the first sorting, with increasingly selective constraints. The first set of criteria – i.e. proportions in key land covers, landscape fragmentation and fire activities – were derived from subcontinental scale remote sensing data. Socio-economic variables were also measured at that scale. These different variables were combined over West Africa and the northern boundary of the Central African evergreen forest to identify potential tropical deforestation fronts. Different models were used to generate maps of deforestation hotspots. These were validated with data from the literature

Publication

LAMBIN E.F. and EHRLICH D., 1997. Identification of tropical deforestation fronts at broad spatial scales. International Journal of Remote Sensing. **18** (17): 3551-3568.

Quantitative data on where, when and why Land cover changes take place are still incomplete. Remote sensing techniques allow a systematic collection of data on land cover at a range of spatial scales. Spatial modelling techniques based on geographic information systems can support a better understanding of the major determinants of Land cover change processes. First, a continental-scale analysis of Africa was conducted to detect Land cover change "hotspots". Processes such as drought impact and forest clearings were identified at a broad scale. Second, fine scale remote sensing data were used for validation and to better understand the land cover change processes. A sample of fifteen intensive study sites, well distributed across Africa, was selected. Time series of remote sensing data and long-term field data have been assembled to identify generic trajectories and processes of change.

Third, spatial statistical models of Land cover change were developed for each site. The approach consists in analysing the location of different categories of Land cover changes in relation to natural and cultural landscape attributes. One output is a projection of areas at risk of being affected by Land cover conversion in the future and the simulation of possible impacts.

Publication

MERTENS B. and LAMBIN E.F., 1999. Modelling Land cover dynamics: Integration of fine scale land cover data with landscape attributes. International Journal of Applied Earth Observation and Geoinformation, **1**, (1): 48-52.

A common view is that tropical farming systems tend, over the years, towards more intensive cultivation and more market-oriented production in response to demographic growth and urban demand for food crops. However, sudden and abrupt ecological or socio-economic changes can have a major impact on such trajectories of change. It is the case for areas affected by natural hazards, such as floods, droughts or volcanic eruption, or by political and socio-economic events, such as conflicts, changes in political regime or major fluctuations of prices for commodities. In that case, the equilibrium state or development trajectory of a land use system is periodically disrupted by exogenous disturbances. The story of Shompole, a small village located in the Rift valley of Kenya, as a special one as abrupt and periodic shifts in the location of a neighbouring swamp modifies in a drastic and sudden way the livelihood of the local community. A time series of fine spatial resolution remote sensing data spanning 25 years, complemented by land cover information derived from an old topographic map, illustrates several east-west shifts of a swamp and marsh areas between the successive periods of observation. The cause of these successive shifts is not clearly elucidated. It is generally associated with heavy rains, such as those of 1998, during the "El Nino" year.
There are two main consequences of these shifts in swamp location. The first concerns the rich wildlife of the area. Actually, the extent of the swamp area is of great importance for the fauna and flora biodiversity. Changes in swamp location leads to periodic changes in habitat, which is a major disturbance for resident species. The second consequence concerns the farming system of the community at Shompole. Farmers have to change periodically the location of their fields to follow the swamp. This involves periodic reinvestments in the preparation of plots and in the digging of drainage and/or irrigation channels. More importantly, when the swamp is located on the eastern side of Shompole, it seriously decreases the practicability of the road to Magadi, especially in the wet season. As this road is

used for the commercialisation of the agricultural products, the periodic changes in the swamp location seriously decreases, for certain years, the potential of the local population to develop a market-oriented agriculture. On the contrary, when the swamp is located west of Shompole, the village is accessible to the urban centres and a market-oriented production can be developed.

Publication

LAMBIN E.F. and MERTENS B., 2001. Abrupt and periodic shifts in a marsh location, and their impact on biodiversity and farming activities in Shompole, Kenya. International Journal of Remote Sensing, **22**, (5): 711-716 + cover page.

The objectives of this study were: (i) to investigate the influence of the nature of the deforestation process on an empirical spatial model of deforestation and (ii) to test a remote sensing-based methodology to define the appropriate spatial entities for modelling deforestation. The study area is located in southern Cameroon. The study included the production and integration in a geographic information system (GIS) of a database on natural and cultural landscape variables. An empirical spatial model of deforestation was developed by relating a set of variables measuring landscape attributes to the frequency of occurrence at deforestation. The main conclusion of the study is that the definition of the spatial entities used to calibrate a spatial model of deforestation has a significant impact on the model design but not, in this case, on the predictive power of the model. The interpretation of the spatial pattern of forest-non forest interfaces as detected by remote sensing proved to be efficient in identifying regions affected by different deforestation processes.

Publication

MERTENS B. and LAMBIN E.F., 1997. Spatial modelling of deforestation in southern Cameroon: Spatial disaggregation of diverse deforestation processes. Applied Geography, **17**, (2): 143-162.

The objectives of this study are to understand, based on remote sensing data, land cover change processes and to test a Markov-based model to generate short-term Land cover change protections in a region characterised by exceptionally high rates of changes. The region of Lusitu, in the Province of Gwembe in Zambia, has been a Land cover change "hot SPOT" since the resettlement of 6000 people in the Lusitu area and the succession of several droughts. The Land cover change process was studied on the basis of a temporal series of SPOT data in four steps: (i) Land cover change detection was performed by combining post classification and image differencing techniques; (ii) the change detection results were examined in terms of proportions of Land cover classes and (iii) in terms of change trajectories; (iv) the Land cover change process was modelled by a Markov chain to predict Land cover distributions in the near future. By addressing the *"when?"*, *"where?"* and *"how?"* questions about the past, the analysis of the three Land cover classifications gave a quantitative and spatially explicit basis to the field impressions. The remote sensing approach allowed: (i) to quantify Land cover changes in terms of percentage of area affected and rates of change; (ii) to qualify the nature of the major changes in terms of impact on the natural vegetation; (iii) to detect and map the spatial pattern of the Land cover change process. Land cover change trajectories highlights the dynamic character of Land cover changes. The results obtained by applying a Markov chain for future evolutions shows the continuing upward trend of bare soils and cultivated land, and the rapid downward trend of forests and natural vegetation covers. The two approaches are thus highly complementary.

Publication

PETIT C., SCUDDER T. and LAMBIN E.F., 2001, Understanding land cover change process from remote sensing observations: Resettlement and rapid Land cover changes in south-eastern Zambia. International Journal of Remote Sensing, **22**, (17): 3435-3456.

Module 3: Projection of future patterns of land cover changes

The objective of this study is to better understand the complexity of deforestation processes in southern Cameroon by testing a multivariate, spatial model of Land cover change trajectories associated with deforestation. The spatial model integrates a spectrum of independent variables that characterise land rent on a spatially explicit basis. The use of a time series of high spatial resolution remote sensing images (LANDSAT MSS and SPOT XS) spanning two decades allows a thorough validation of spatial projections of future deforestation. Remote sensing observations reveal a continuous trend of forest clearing and forest degradation in southern regions of Cameroon, but with a highly fluctuating rate. A significant proportion of the areas subject to a Land cover conversation experienced other changes inn the following years. The study demonstrates also that modelling Land cover change trajectories over several observation years allows a better projection of areas with a high probability of change in land cover than projecting such areas on the basis of observations from the previous time period alone. Statistical results suggest that, in our southern Cameroon study area, rods mostly increased the accessibility of the forest for migrants rather than providing incentives for a transformation of local subsistence agriculture into market-oriented farming systems.

The spatial model developed in this study allows simulations of likely impacts of human actions leading to a transformation of the landscape (e.g. road projects) on key landscape attributes (e.g. biodiversity). Currently, several road projects or major logging concessions exist in southern Cameroon.

Publication

MERTENS B. and LAMBIN E.F., 2000, Land cover change trajectories in southern Cameroon. Annals of the Association of American Geographers, September issue, **90**, (3): 467-494.

The integration of information from household surveys and data on Land cover changes derived from remote sensing improves our understanding of the causes and processes of land-use/Land cover changes. A household survey was carried out in the East province of Cameroon. This survey, covering 552 households in 33 villages, focused on land-use changes since the 1970s. Those data were related to time series of remote sensing satellite data. A major interest of the field data lies in the longitudinal framework of the survey. It highlighted the evolution of the household and its land-use over three periods related to the key macro-economic periods, and corresponding to the dates of acquisition of remote sensing data. The research results demonstrate that the macro-economic changes affecting Cameroon have played a fundamental role in the way land-use practices influence the forest cover. The results show that the annual rate of deforestation increased after the economic crisis as compared to the previous period. The household survey information enables identification of the causal relationships and the processes of land-use and Land cover changes. We observed that the beginning of the economic crisis (1986) is associated in time with a strong increase of the deforestation rate related to the population growth, increased marketing of food crops, modification of farming systems, and colonisation of new agricultural areas in remote forest zones.

Publication

MERTENS B, SUNDERLIN W., NDOYE O. and LAMBIN E.F. 2000. Impact of macro-economic changes in deforestation in south Cameroon: Integration of household survey and remotely sensed data. World Development, **28**, (6): 983-999.

The objective of this study is to test, based on a geographic database of ecological and economic variables related to forests in the East province of Cameroon, the value of the concept of the net commercial value of standing timber in predicting the impact of logging activities on forest-cover modifications. The study area is particularly interesting as it contains major primary forests and contributes largely to the national timber production of Cameroon. Geographic information system techniques were used in combination with remote sensing data to define the net commercial value of standing timber in the East province of Cameroon. Taking into account the potential commercial value of standing timber allow for an improvement of our understanding of the spatial determinants of logging activities and of the resulting forest-cover modifications. The occurrence of logging-induced forest-cover modifications increases with the value of forest rent. In one of the site, half of the very high rent areas have already been logged. Therefore, in that site, mostly the low rent or marginal forest area remains unlogged. It is not the case everywhere however, as shown by the observations in another site.

Publication

MERTENS B., FORNI E. and LAMBIN E.F. 2001, Potential forest rent and logging activities: A case study in the East province of Cameroon. Journal of Environment Management, **62**, (1): 21-36.

RESEARCH CONTRACT T4/DD/002

RESEARCH CONTRACT T4/DD/003

LAND COVER CLASSIFICATION AND ESTIMATION OF LAND COVER PROPORTIONS AT A GLOBAL SCALE

F. CANTERS (1)

H. DECLEIR (1)

H. EERENS (2)

F. VEROUSTRAETE (2)

VRIJE UNIVERSITEIT BRUSSEL (VUB) (1)
CENTRE FOR CARTOGRAPHY AND GIS
DEPARTMENT OF GEOGRAPHY
Pleinlaan 2
B – 1050 BRUSSEL
BELGIUM

VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK (VITO) (2)
Boeretang 200
B – 2400 MOL
BELGIUM

1. CONTEXT AND OBJECTIVES

A good knowledge of the spatial distribution of major biome types on a global scale is of critical importance for global environmental research. To accurately measure changes in global biome distribution, sensors on satellite platforms may be used. One of these sensors is the VEGETATION instrument, which was launched on the SPOT 4 platform in March '98. The objective of this project is to conduct research in the prospect of the development of a future VEGETATION biome product. More in particular, research is conducted: (a) to identify the needs of present and future users of global biome information; (b) to develop a strategy for the characterisation and automatic classification of important biome types, using spatially aggregated sensor data; (c) to define and evaluate methods for the reduction of proportional bias in biome class area estimates, caused by aggregation of data from 1-km resolution to coarser resolutions. As no VEGETATION data for a full yearly vegetation cycle will be available until mid 1999, methodological developments in this study have been based on the use of NOAA-AVHRR data.

2. DATA

Geographic study area: global scale

Satellite imagery used:

1-km AVHRR Global Data Set (USGS-EROS Data Centre) (1992 – 1993)

3. METHODOLOGY

The aim of this project is to develop a strategy for biome classification at a global scale, based on phenological differences between different cover types. In developing this strategy the following issues have been addressed: (a) the extraction of undisturbed NDVI profiles from 10-daily NDVI time series taken from the EROS dataset; (b) the derivation of suitable phenological attributes that are independent from seasonal phasing; (c) the classification of the data, using the standard maximum likelihood method, as well as a newly developed, non-parametric version of the Bayes classifier. To account for the loss of proportional accuracy caused by spatial aggregation of 1-km sensor data two different approaches for the correction of biome class proportions have been explored: (a) regression of fine-scale class proportions (derived from non-aggregated data) on coarse-scale class proportion measurements (derived from aggregated data) for blocks of coarse-resolution pixels; (b) sub-pixel estimation of class proportions using class membership probabilities for each coarse-resolution pixel, produced by soft classification.

4. OUTPUTS AND RESULTS

A supervised approach for global biome classification is proposed, based on five phenological attributes, derived from monthly NDVI growth curves, and the altitude above sea level, derived from a digital elevation model. The approach has been applied to spatially aggregated NDVI-data for the entire African continent, using the Simple Biosphere Model classification key. Depending on the level of spatial aggregation and the type of classifier the overall accuracy of the classification is between 78% and 87%. Accuracy is the highest for the NPB-classifier, which also has a much higher processing speed than the ML algorithm. For the reduction of proportional bias, a class- and context-dependent strategy is proposed, involving separate modelling of class proportion transition curves for groups of pixel blocks (or groups of individual pixels) with a similar class composition at the coarse resolution. Application of this strategy to 8-km and 16-km aggregated NDVI-data, using the block-based calibration approach, leads to an overall reduction of proportional bias by 26% (8km) and 33% (16km). With the sub-pixel correction method proportional bias is reduced by 18% to 44% for the 8-km scenario, and by 27% to 56% for the 16-km scenario, depending on the type of biome class that is considered. It remains to be investigated how well the proposed strategy for the removal of proportional bias will work when more biome classes are involved. Also, the whole procedure for classification and area correction that has been presented, and applied to NDVI data for Africa, needs to be translated into a standard procedure for the production of global biome information, adjusted to the use of VGT-PS data. These issues will be the subject of future research within the TELSAT programme.

5. EXECUTION

Period: 01/12/1996-30/11/1998

Laboratories:

VRIJE UNIVERSITEIT BRUSSEL (VUB)
Centre for Cartography and GIS
Department of Geography
Pleinlaan 2, B – 1050 Brussel, Belgium
Phone : +32 2 629 33 83 Fax +32 2 629 33 78
E-mail : hdecleir@vub.ac.be URL : www.vub.ac.be

VLAAMSE INSTELLING VOOR TECHNOLOGISCH (VITO)
Boeretang 200, B – 2400 Mol, Belgium
Phone : +32 14 33 68 46 Fax : +32 14 32 27 95
E-mail : frank.veroustraete@vito.be URL : www.vito.be

6. RELATED DISCIPLINES

Forest & natural vegetation
General Earth observation

7. EXECUTIVE SUMMARY

Notwithstanding recent advances in optical remote sensing techniques at the level of the multitemporal estimation of biophysical characteristics, robust monitoring as well as early warning systems, based on global observation data, are not developed at their full scale capacity at this moment. Especially with respect to shifts in biome distributions, very few global and operational monitoring systems or approaches exist. The objective of this project was to conduct basic research in the prospect of the development of a future VEGETATION biome product that will be able to meet important requirements, as expressed by the user community of global EO data. In the long run, it is hoped that the work that is presented in this study will contribute to a better monitoring and understanding of environmental changes at the global scale.

More specifically, research was conducted: (a) to identify needs of present and future users of global biome information, (b) to develop a strategy for the characterisation and automatic classification of important biome types, using spatially aggregated sensor data, (c) to define useful methods for the reduction of proportional error for major biome classes, caused by aggregation of data from 1km to coarser resolutions. As no VEGETATION data for a full yearly vegetation cycle will be available until mid 1999, methodological developments in this study have been based on the use of NOAA-AVHRR data. Most of the case studies that are presented in this report are based on the use of AVHRR-NDVI data for the entire African continent.

In the first chapter of this study the most important needs of present and future users of global biome information are summarised. The recommendations that are made based on a detailed survey that was set up by the authors of this report in the summer of 97. Chapters two and three deal with the problems of biome classification. Chapter two starts with an evaluation of the EROS data set that was used in this project and explains the different phases in the processing of NOAA-AVHRR data that are required before classification is carried out. The chapter focuses on the extraction of a non-disturbed NDVI profile, and describes various methods for the aggregation of sensor data that have been implemented during the project. Chapter three reviews the most important problems of global biome classification and describes the definition and extraction of suitable phenological

attributes, the classification strategy that has been applied, and the results of the classification.

In chapter four and chapter five attention is focused on the correction of class proportions for various biome classes, obtained through classification of spatially aggregated AVHRR-NDVI data. Chapter four deals with correction models that are based on the definition of a direct relationship between class proportions measured at fine and coarse scales. Special attention is paid to the use of spatial structure as an additional variable in these models. Chapter five is devoted to the estimation of sub-pixel class proportions for various biome classes, using class membership probabilities that are produced by a probabilistic classifier. Chapter six reviews a number of important operational issues. Several suggestions for further research are made, with special emphasis on the optimisation and valorisation of the proposed methods in connection with the operational production of global biome data sets, using VGT-PS data.

RESEARCH CONTRACT T4/DD/005

BIOPHYSICAL CHARACTERISATION OF TROPICAL ECOSYSTEMS BY SPACEBORNE SYNTHETIC APERTURE RADAR REMOTE SENSING (ECOSAR I)*

FIRST PART

M. LEYSEN
B. DERONDE
J. VAN RENSBERGEN

VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK (VITO)
Boeretang 200
B – 2400 MOL
BELGIUM

* This project was performed in collaboration with A. GUISSARD (UCL – Research contract T4/DD/006)

1. CONTEXT AND OBJECTIVES

Installing a land use policy aiming at long term sustainability needs to be based on a sound knowledge of the impact of policy measures in the specific environmental, economic and sociologic context of the region at stake. Adapting the management practices of the natural resources to support a growing population pressure and at the same time guarantee long-term environmental stability, has become a high priority task in the tropical regions. Remote sensing techniques can contribute significantly to the assessment of the current status of the environment, evolution monitoring and management control, and to environmental impact evaluation. The launch in the early nineties of the operational satellite borne Synthetic Aperture Radar (SAR) sensors has improved the image availability over tropical regions. These active imaging systems operating in the microwave domain allow for the acquisition of earth observation data day and night regardless of atmospheric conditions.

The project seeks to work out an adapted rationale for interpreting SAR image data over tropical vegetation based on the formulation of the physical interaction of the incident wave with the target and its relevant characteristics.

By providing a physical basis to the development of the image interpretation techniques for mapping and quantitative information extraction, a method is aimed for that can be repeated under different situations in time and space.

2. DATA

Geographic study area : Ivory Coast

Satellite imagery used : ERS SAR and JERS SAR

3. METHODOLOGY

Iterative sensitivity analysis aims at realistic target properties of the vegetation and parameters varying with the vegetation and environmental conditions. Guidelines for the image interpretation are formulated regarding the driving factors behind stable and dynamic components of the vegetation types studied.

Two of the operational spaceborne SAR instruments (ERS and JERS) operate at different wavelengths, and are therefore expected to contain complementary

information due to the sensitivity for vegetation elements of different size. Comparable analyses regarding the thematical issues at stake are proposed.
The sequence of elaboration of the thematical study topics is determined by an approach narrowing down from the general to the detailed, both in a spatial and a thematic perspective. Starting with the delineation of the large Land cover units, the foundations are laid for the analysis of the phenologic features of selected representative Land cover units, as for the analysis of the composition and structure of the forested areas.

4. EXECUTION

Period : 01/12/1996-28/02/1999
Laboratory :

VLAAMSE INSTELLING VOOR TECHNOLOGISCH (VITO)
Boeretang 200, B – 2400 Mol, Belgium
Phone : + 32 14 33 68 00 Fax : + 32 14 32 27 95
E-mail : marc.leysen@vito.be URL : http://www.vito.be/docs/expert/tap/tap_en.htm

5. RELATED DISCIPLINE

Forest & natural vegetation

6. EXECUTIVE SUMMARY

This research has been carried out jointly by the Centrum voor Teledetectie en Atmospherische Processen of the *Vlaamse Instelling voor Technologisch Onderzoek* (CTAP/VITO – project T4/DD/005) and the Laboratoire de Télécommunications et Télédétection of the *Université catholique de Louvain* (TELE/UCL). In this summary, we present the results of the work performed at CTAP/VITO.
The core objective of the EcoSar project is to develop a physically based SAR interpretation scheme for application to the mapping and monitoring of tropical vegetation. Biophysical characterisation of the vegetation refers to the identification of distinct land cover units as well as to the assessment of the condition of the vegetation cover. The approach applies to natural as well as man-made ecosystems, and is elaborated over a well documented study area on the forest-savannah interface in West-Africa.
This report describes the results obtained during the first phase of the EcoSar project. This first phase had methodological as well as thematic objectives with a view to develop and demonstrate a scientific basis upon which refinements and validation activities could be build in the second phase (EcoSar II, 1999-2001).

On the methodological side, the project envisaged the formulation of clear rules on how and under which conditions successful repeated application of a SAR data interpretation scheme is obtained. The main results regarding technical developments are : the development of a complete SAR processing chain (pre-processing, speckle filtering, time series processing), the combined use if multi-temporal and multi-sensor SAR observations, and the interaction between radiative transfer modelling and observed signal analysis. Detailed information on the multi-temporal speckle filter will be published as soon as the patent that is pending at the moment is regulated. Another major technical improvement is the successful implementation of segmentation techniques on SAR data.

On the thematic side, three main research avenues are explored along the central approach towards the quantitative assessment of biophysical characteristics : the mapping of meaningful discrete vegetation cover units, the determination of seasonal behaviour (phenology) by time series analysis and the characterisation of spatial structure (canopy architecture) by SAR image texture measurements. To test the repercussions of the technical developments, the first thematic analysis were performed with success.

Finally, an extensive DIS data has been developed containing forest maps of different scale and content, additional information on lakes, roads, cities and administrative boundaries, as well as detailed fields observations.

RESEARCH CONTRACT T4/DD/006

BIOPHYSICAL CHARACTERISATION OF TROPICAL ECOSYSTEMS BY SPACEBORNE SYNTHETIC APERTURE RADAR REMOTE SENSING (ECOSAR)*

SECOND PART

A. GUISSARD
E. ROBIN
D. LEMAIRE
T. KULCAR

UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL)
LABORATORY OF TELECOMMUNICATIONS AND REMOTE SENSING
Place du Levant 3, Bâtiment Maxwell
B – 1348 LOUVAIN-LA-NEUVE
BELGIUM

* This project was performed in collaboration with J. VAN RENSBERGEN (UCL – Research contract T4/DD/005)

1. CONTEXT AND OBJECTIVES

Installing a land use policy aiming at long term sustainability needs to be based on a sound knowledge of the impact of policy measures in the specific environmental, economic and sociologic context of the region at stake. Adapting the management practices of the natural resources to support a growing population pressure and at the same time guarantee long-term environmental stability, has become a high priority task in the tropical regions.

Remote sensing techniques can contribute significantly to the assessment of the current status of the environment, evolution monitoring and management control, and to environmental impact evaluation. The launch in the early nineties of the operational satellite borne Synthetic Aperture Radar (SAR) sensors has improved the image availability over tropical regions. These active imaging systems operating in the microwave domain allow for the acquisition of earth observation data day and night regardless of atmospheric conditions.

The project seeks to work out an adapted rationale for interpreting SAR image data over tropical vegetation based on the formulation of the physical interaction of the incident wave with the target and its relevant characteristics.

By providing a physical basis to the development of the image interpretation techniques for mapping and quantitative information extraction, a method is aimed for that can be repeated under different situations in time and space.

2. DATA

Geographic study area: Ivory Coast

Satellite imagery used: ERS SAR and JERS SAR

3. METHODOLOGY

- Iterative sensitivity analysis aims at realistic target properties of the vegetation and parameters varying with the vegetation and environmental conditions. Guidelines for the image interpretation are formulated regarding the driving factors behind stable and dynamic components of the vegetation types studied.
- Two of the operational spaceborne SAR instruments (ERS and JERS) operate at different wavelengths, and are therefore expected to contain complementary

information due to the sensitivity for vegetation elements of different size. Comparable analyses regarding the thematical issues at stake are proposed.

- The sequence of elaboration of the thematical study topics is determined by an approach narrowing down from the general to the detailed, both in a spatial and a thematic perspective.
- Starting with the delineation of the large Land cover units, the foundations are laid for the analysis of the phenologic features of selected representative Land cover units, as for the analysis of the composition and structure of the forested areas.

4. EXECUTION

Period: 01/12/1996-28/02/1999

Laboratory:

UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL)
Laboratory of Telecommunications and Remote Sensing
Place du Levant 3, Bâtiment Maxwell, B – 1348 Louvain-la-Neuve, Belgium
Phone : +32 10 47 23 00 Fax : +32 10 47 20 89
E-mail : guissard@tele.ucl.ac.be

5. RELATED DISCIPLINE

Forest & natural vegetation

6. EXECUTIVE SUMMARY

This research has been carried out jointly by the Centrum voor Teledetectie en Atmospherische Processen of the *Vlaamse Instelling voor Technologisch Onderzoek* (CTAP/VITO – project T4/DD/005) and the Laboratoire de Télécommunications et Télédétection of the *Université catholique de Louvain* (TELE/UCL). In this summary, we present the results of the work performed at TELE/UCL.

The general field of this study is related to the determination of the present state of the environment, the follow-up of its evolution and to the evaluation of the human impacts on it, a domain to which remote sensing can provide a significant contribution. Spaceborne radar instruments, and more specifically synthetic aperture radars (SAR), are able to provide all-weather observations, a capability which is particularly important for tropical regions. More specifically, we intended to analyse in more details, and in a quantitative way, the contribution of the SAR for the biophysical characterisation of tropical ecosystems.

The general goal was to set up an electromagnetic diffraction model, starting from existing developments at UCL, and to proceed to a sensitivity analysis. The model required to be upgraded and extended, in order to better describe the contributions of the various constituents within a forest cover, to include savannah cover, and to account for spatial in homogeneity and natural variability of the observed scenes. The sensitivity analysis should allow to extract the most important parameters and their frequency signature with in view future quantitative inversion techniques.

The main objective of the global project was to develop on a sound physical basis, an interpretation scheme of the data collected from spaceborne SAR's, for the characterisation of tropical vegetation. The aim was to emphasise the following points: appropriate methods of data processing, the interaction between radiative transfer modelisation and analysis of the observed signals, a combined use of multi-temporal and multi-mode SAR observations and a thematic approach for the quantitative determination of biophysical characteristics.

The more specific objective of our study was to proceed into the development of a radiative transfer model (UCLRTM) for radar observation of tropical ecosystems, including forest cover and savannah. The study of the interaction between the signal and the target should allow, though a sensitivity analysis, to determine what biophysical parameters have the dominant influence on the radar echo and could be quantitatively evaluated from an inversion procedure.

Conclusion

Other radiative transfer models already exist. The specificity of our model is to be fully polarimetric, to include the reciprocity effect for double-bounce mechanisms, and to provide a great flexibility in introducing distributions of dimensions, orientations and density of the various vegetation of forest components. In its previous version, it was more specifically developed for pine forest. It has been extended to deciduous forest and to low vegetation, such as encountered in savannahs. It has also been improved and a number of deficiencies have already been corrected. After a short section recalling some required basic notions in polarimetry and calling the attention to the importance of coherence in the conventions, the upgrading of the model and of the algorithm have been presented in details. The input data file is described and commented. In the next section, two tests are discussed for bare soil and for pine Forest: the results obtained with the algorithm in its present form are compared to previous results in order to validate the modifications.

Next, three kinds of forests have been considered: tropical forest, secondary forest, and tek plantation. The main characteristics of these targets were available through VITO. They were however in a format that cannot be directly transposed to the UCLRTM input file format, and some effort was required to make the transformation. We should mention that the ground data are probably very approximate; moreover the specified soil correlation length of 0.5 cm for the tek plantation seems to be very small and should be checked. The algorithm is applied for the computation of the backscattering coefficient for these three forests for three frequency bands: P-, L- and C-band, three polarisations: HH, VV and HV, and various incidence angles. The general behavior is similar for the three kinds of forests. We note the higher response in C-band for the tek plantation that is probably related to the dominant response of the tek canopy, which contains very large leaves. We have also showed some examples of polarimetric signatures, in order to illustrate the capabilities of the code.

In the next section, the extension to grass leaf structure has been discussed. A detailed presentation is given of Mathieu's functions that provide a useful tool for describing elongated leaves. The algorithm allows entering leaves with circular, rectangular or elliptical form. It is applied to two kinds of savannahs, called natural savannah and elephant savannah, for which data were provided by VITO. The main difference is that elephant savannah has longer and wider leaves with higher density. For the soil, no data were available and we had to assume the same characteristics as for the tropical and secondary forests. The general trend for the two kinds of savannahs is similar. The soil contribution is dominant in P- and L-band, while the canopy contribution is more important in C-band. We also give an example of polarimetric signature. One of the difficulties in modelling savannah is related to the leaves curvature. In the above computations, the leaves are assumed to be plane. In an attempt to simulate the effect of the curvature on the radar response, we replaced the given distribution of leaves by shorter leaves with higher density, determinated in such a way that the total area is equal. The changes are very important and this clearly illustrates the need for a good geometrical description of the vegetation characteristics.

One of the tasks foreseen in the project was to extent the model and the algorithm to spatially heterogeneous scenes. This should allow simulating the radar response to open forest or savannah with isolated trees for instance. The problem is quite difficult, because a large number of different situations may occur. The basic philosophy has been developed and has been presented here. However it will require a large amount of further works to develop an operational algorithm.

Another question that was foreseen in the proposed project was to analyse the influence of the variability of natural targets, composed of soil covered by vegetation or forest. The algorithm allows introducing probability distributions with a variance that can be specified at will. We have compared the previous calculations, where the natural variability is introduced by specifying the variances, tot the results obtained by suppressing all variances. This exercise has been performed in two cases: the tropical forest and the natural savannah. In both cases significant differences appear. For the tropical forest the backscattering generally increases when introducing the variability. For the natural savannah, there is either an increase, or a decrease, depending on the frequency band and on the incidence angle. The difference in behaviour can be related to the fact that the soil has a more important contribution for savannahs than for tropical forest.

It was foreseen that a comparison would be presented between the UCLRTM model and other simulation models, ea. the UTARTCan from the University of Texas at Arlington. The code was made available at VITO and the calculations performed there. The results will appear in the VITO contribution to this report.

The last section is devoted to a detailed sensitivity analysis. We have considered successively: the contribution of the separate components to the backscattering from the three forest types, the influence of the leaves and branches on the radar echo from tek plantation, the sensitivity to the leaves dimensions in natural and elephant savannah, and finally the influence of the soil parameters on the soil contribution.

For the forest, the direct canopy contribution generally dominates the contributions by other scattering mechanisms, especially in C-band. This is particularly true for the tek plantation, characterised by very large leaves. For the savannahs, the contribution of the soil largely dominates in P-band, but decreases with increasing incidence frequency. The canopy contribution tends to increase with increasing incidence angle, in particular in C-band. We observe a special behaviour of the soil contribution in C-band that needs to be explained.

For the tek plantation, we observe that replacing the large leaves (34cm diameter) by smaller leaves (20-cm diameter), does not change much the radar echo. Also suppressing the branches has not much influence. However the suppression of the leaves increases the backscattering by 5 to 10 dB, depending on the frequency band. This is probably explained by the high attenuation produced by the leaf equivalent radius (radius of circular leaves (2.50 m) as specified in the data, with shorter leaves of half length, equal axial ratio and equal density. We observed rather large effects on the backscattering, with a difference of 5 dB or more in the copolar cases.

Finally for the soil, we evaluated with the IEM model of Fung, the influence of the correlation length, the rms height, and the soil composition moisture. We observe that the direct ground contribution seems to go through some maximum value for specific values of the correlation length and of the rms height that decrease with increasing frequency. We also observed that the backscattering increases, as expected, with the soil moisture, and depends to some extent on the soil composition.

To conclude, we have developed an algorithm whose performances have been evaluated in a number of cases: bare soil, pine forest, tropical forest, secondary forest, natural savannah and elephant savannah. A very important work remains to be performed to: (i) introduce a number of improvements that would give much more flexibility to the code, (ii) simplify the procedure for entering the data, (iii) introduce new classes of elements ea. of leaves, (iv) analyse further the possibility to extent the code to the case of heterogeneous targets, (v) introduce an automatic choice between the various models available for each class of component, (vi) verify the validity conditions of each particular model and provide an information to the user, (vii) put all the various parts of the code in modular form with well defined inputs and outputs for each module, in such a way that new lasses and models can easily be introduced, and finally (viii) transform the code from a draft into an efficient and convivial tool.

RESEARCH CONTRACT T4/10/010

GEOSTATISTICAL INTEGRATION OF BIOPHYSICAL VARIABLES MEASURED AT DIFFERENT SPATIO-TEMPORAL RESOLUTIONS

P. DEFOURNY
P. GOOVAERTS

UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL)
DEPARTMENT OF ENVIRONMENTAL SCIENCES AND LAND USE PLANNING - GEOMATICS
Place Croix du Sud 2 bte 16
B – 1348 LOUVAIN-LA-NEUVE
BELGIUM

1. CONTEXT AND OBJECTIVES

A major challenge facing ecologists studying the earth as a dynamic system is the mapping of vegetation quantities over time as over large areas in order to parameterise biogeochemical cycle and climate models. The role of remote sensing data, as key source of quantitative information for the regional and the global scale is no longer discussed.

Today, the data interpretation relies on a fitting of a linear or polynomial semi-empirical models based on the relationships between the field-measured variable and the sensor signal. This simplistic calibration between observations at non-compatible spatial resolutions can no longer be supported. According this approach a point measurement is directly related to a pixel signal corresponding to an area as large as one square kilometre. This research proposes to tackle the upscaling issue between observation level using the recent evolution of geostatistics.

The overall objective is to develop methods for estimating LAI variables derived from satellite data based on geostatistics concepts. The latter would provide the basic approach to take advantage of the spatial autocorrelation of these variables.

The goal is a functional characterisation of vegetation cover by biophysical variables for various aggregation levels from local to regional scale. At the same time this study would also develop a method of quantitative assessment of seasonality and spatial variability of the vegetation cover. Moreover, the proposed approach gives a way for new upscaling methods between different observation levels in order to enhance the semi-empirical modelling based on relationships between measured and remotely sensed variables.

2. DATA

Geographic study area: N: 3°40'-4°10' and E: 17°00'-17°30 (south-western part of the Central African Republic)

Satellite imagery used: 6 SPOT XS, 1 SPOT, ATSR and NOAA images.

Other data: Field data (LAI), NOAA images, aerial photographs.

3. METHODOLOGY

The research consists in statistical and geostatistical analysis of an unique and original data set on the tropical forest biome. Synchronised field data and SPOT XS times series have been acquired over a dense humid tropical forest in Central African Republic

Geostatistics are used first to describe and quantify the variability of the field-measured and remotely sensed variables in both space and time. Based on these results, the development of a space-time kriging approach allow to predict, at unsampled locations and times, the value of the field-measured variable using field-measured and remotely sensed data available at different spatial and temporal resolutions. This approach provides an assessment of the uncertainty attached to geostatistical prediction through non-linear geostatistics and conditional simulations. Finally, the use of the model of space-time uncertainty to investigate the impact of different scenarios.

4. OUTPUTS AND RESULTS

Products of the research are both methodological and thematic.

The first project output is to make available methods of geostatistics adapted to remote sensing data analysis and especially to scaling up between different levels of observations. A new calibration model of semi-empirical relations between remotely sensed and locally observed variables is developed. The prediction performances of geostatistical approach for mapping quantitative variables of vegetation is compared with those of classical calibration techniques that ignore the space-time dependence of observations. Finally, a procedure of field sampling optimisation based on spatial structure of variables as on signal pattern is also proposed.

From the thematic point of view, this research allows for the first time to document the temporal variability of LAI of a humid tropical forest at a scale compatible with climatic models.

This research suggest that structural information can be retrieved from images whose pixel size exceed that of the elementary objects constituting the target, at the condition to dispose of images of the same target but with different geometries of observation.

5. EXECUTION

Period: 15/12/1996-31/05/1999

Laboratory:

UNIVERSITÉ CATHOLIQUE DE LOUVAIN (UCL)

Department of Environmental Sciences and Land use Planning – Geomatics

Place Croix du Sud 2 bte 16, B - 1348 Louvain-la-Neuve, Belgium

Phone : + 32 10 47 23 74 Fax : + 32 10 47 88 98

E-mail : defourny@mila.ucl.ac.be

URL: http://www.agro.ucl.ac.be/biom/index_eng.html

6. RELATED DISCIPLINE

Forest & natural vegetation

7. EXECUTIVE SUMMARY

Since the forest structure plays a key role in the ecology of the tropical forest, an important challenge is to better assess the forest structure from earth observation data. This experiment is an original exercise towards a multi-scale synthesis between tropical forest ecology and canopy observation from ground and space. The research consists in statistical and geostatistical analysis of a unique and original data set on a semi-deciduous tropical forest. The analysis of the remotely sensed signal and field measurements related to the forest structure and biomass addressed the following issues:

- The spatial variation of field measured Leaf Area Index (LAI) in the tropical forest,
- The scale dependency of the spatial patterns observed by remote sensing data,
- The spatial variation of coarse resolution images over a dense tropical forest and its change over a period of several months,
- The sensitivity of the NIR and Red signals to target modifications, atmosphere composition, and geometry of observation,
- The interaction between the forest architecture and the signal BRDF,
- The forest type detection.

A 7-month field campaign in the semi-deciduous forest of Ngotto in Central African Republic was carried out synchronously with NOAA and SPOT time series acquisition. Leaf Area Index was measured on monthly or fortnightly basis for different square sites to document the foliage seasonality during the dry season. The LAI was also the variable used to assess the spatial structure of the forest along transect of various lengths and with various resolutions. This data set was completed with simulated data.

From the field data, space-time analysis methods provide very interesting results with regards to three critical issues: (i) the sensitivity and the reliability of the LAI ground measurement using the commonly used LAI 2000 sensor; (ii) the characterisation of the seasonality and the temporal correlation between measurements made at different moments; (iii) the characterisation of the spatial variation of the structure and the LAI. Furthermore, an optimal sampling scheme to assess an accurate LAI from ground measurements allowing interpolation with SPOT data is proposed.

From the satellite point of view, a SPOT scene was regularised to very large supports using a uniform and a gaussian averaging procedure. At each support size, the spatial structure in the image was quantified using the variogram for both the red and NIR bands. Regularised variogram models exhibited a higher overall variance than the regularised experimental variograms for corresponding sizes of support.
Variograms of NOAA AVHRR and regularised SPOT HRV images showed comparable anisotropy in the NIR band images. The monthly changes of observed anisotropy for the red band images were attributed to the satellite geometry variations.

The simulations show that both SPOT and NOAA satellites are sensitive to a seasonal variation occurring over tropical areas, but do not behave the same way. These variations have similarities with the seasonal stage of the vegetation, at least concerning its LAI, but are not directly related to it. In addition, it has been observed that the NIR channels, of both time series, are highly affected by the geometry of observation. The simulations reveal that there is an interaction between the geometry of observation and the aerosol optical thickness. Finally, by combining the information retrieved from the simulation and the analyses of the time series, it was concluded that a seasonal variation of 15% of the NIR channel of NOAA, could be shared between the seasonality of the target (3%), the atmosphere composition (3 to 4%) and the geometry of observation (7 to 8%).
The pixels of 6 SPOT images corresponding to three structurally distinct forest sites have been analysed upon their average reflectance and standard deviation. Texture information are retrieved from geostatistic features (sill, range and first lag) of directional variograms for the NIR and Red channels. The results demonstrate the strong relationship between the size of the elements contributing to the forest structure (mainly tree crowns and gaps) and the characteristics of the images according their illumination conditions and geometry of observation. The detectability of tropical forest structure with SPOT images depends strongly on the geometry of observation and the pixel size but not on the quantity of the biomass and its distribution within the canopy. This research shows that structural information can be retrieved from images whose pixel size exceed that of the elementary objects constituting the target, at the condition to dispose of images of the same target but with different geometry of observation. The BRDF of a structured target is pixel size dependent. Furthermore, textural information has been proven to be reliable for interpretation of forest types.

RESEARCH CONTRACT T4/10/031

DERIVATION OF LAND COVER CHANGE DATA AND THEIR ASSIMILATION IN ECOSYSTEM MODELS (MODULES 2 AND 4)*

FIRST PART

E. LAMBIN

UNIVERSITE CATHOLIQUE DE LOUVAIN-LA-NEUVE (UCL)
DEPARTMENT OF GEOLOGY AND GEOGRAPHY
LABORATORY OF REMOTE SENSING AND LAND USE CHANGES
Place Louis Pasteur 3, Bâtiment Mercator
B – 1348 LOUVAIN-LA-NEUVE
BELGIUM

* This project was performed in collaboration with P. COPPIN (KUL – Research Contract T4/01/032)

1. CONTEXT AND OBJECTIVES

Context: Most of the world's vegetation is in a constant flux at a variety of spatial and temporal scales. These changes are driven by seasonal and interannual climate variations, long-term climatic shifts, vegetation successions and human or natural disturbances (Hobbs, 1990). Changes in the important cycles on the land surface occur on the regional scale of landscapes and are strongly influenced by human activities. They materialise in different ways depending on the regional combination of climate, surface conditions and human impacts. In order to cope with the challenges imposed by the necessity for sustainable management and development it is necessary to develop an understanding of the metabolism of these landscapes. This is possible through the right combination of process models and remote sensing measurements, which actually observe the way in which landscapes evolve.

Objectives: The general objective of the research is to develop new methodologies, and to advance and refine existing methodologies to allow for: (i) a more realistic description of long term processes of land cover changes, based on a variety of data sources, (ii) a better integration of remote sensing data into ecosystem models in order to better address key issues on land cover changes.

2. DATA

Geographic study area:

- Module 2: Zambia
- Module 4: Central Africa (region of the campaign IGBP/IGAC EXPRESSO) and West Africa (region of the transect IGBP/GCTE SALT)

Satellite imagery used:

- Module 2: SPOT1 129-382 11/08/1986 08:24:03 1 X, SPOT 1 129-382 23/06/1992 08:21:32 1 X, SPOT2 129-382 22/10/1997 08:19:32 2 X.
- Module 4: five images: SPOT XS and/or LANDSAT TM, covering period 1999-2000, satellite imagery of campaign EXPRESSO.

Other data:

- Module 2: aerial photographs (1954, 1970, 1980, and 1991), topographic maps.
- Module 4: data on vegetation cover, available in FIRE project.

3. METHODOLOGY

- Module 2: Detection of land cover change trajectories with long temporal series of data from a variety of sources.

Dataset acquisition and database assembly; data aggregation experiments; measurement of landscape metrics as an indicator of maps; detection of complex trajectories of Land cover changes.

- Module 4: Assimilation of remote sensing-based land cover change data in ecosystem models.
  Regional scale emissions from biomass burning.

4. OUTPUTS AND RESULTS

- Module 2: Database (aerial photographs, maps, satellite images) + Diagnostic of different spatial aggregation methods
  Method for homogenising a time series of land cover data.
  Method for change detection on long-term time series.
- Module 4: Database
  Detection algorithm for vegetation change
  Methodology: Sensitivity of emission models to biomass burning input data derived by remote sensing.

5. EXECUTION

Period: 15/12/1998-14/04/2001

Laboratory:

UNIVERSITÉ CATHOLIQUE DE LOUVAIN (UCL)
Department of Geology and Geography
Laboratory of Remote Sensing and Land Use Changes
Place Louis Pasteur 3, Bâtiment Mercator, B-1348 Louvain-la-Neuve, Belgium
Phone: + 32 10 47 44 77 (or 28.73) Fax: + 32 10 47 28 77
E-mail :lambin@geog.ucl.ac.be URL : http://ftp.geog.ucl.ac.be/TDAR/Ftdar.html

6. RELATED DISCIPLINES

Forest & natural vegetation
Agriculture
Environment
Natural hazards & disasters
General Earth observation

7. EXECUTIVE SUMMARY

The report provides an overview of the main scientific findings and achievements of the research project. After outlining the results of two of the four modules, it summarises the integrating activities and cross-fertilisation between modules:

Modules 1 and 3 (KUL – Research contract T4/01/32) and Modules 2 and 4 (UCL – Research Contract T4/10/031).

Module 2: Detection of land cover change trajectories with long temporal series of data from a variety of sources

Objective

The objectives of this module were: (i) to design data aggregation techniques to join in a single, homogeneous time series data coming from a variety of sources (e.g. historical maps, aerial photographs, satellite remote sensing data from different sensors), by addressing the issues of level of spatial generalisation of the land cover information, and (ii) to design change detection techniques to deal with such long temporal series of land cover data (e.g. 50 years or more) which display complex trajectories of change (i.e. non-linear, reversible fluctuations as opposed to secular, monotonic trends).

Evaluation and relevance of research results

The main findings are:

- We developed a method to increase the comparability between land cover maps coming from panchromatic aerial photographs and SPOT XS (multispectral) data by equalising their level of thematic content and spatial details. The methodology was based on the hypotheses that: (1) map generalisation can improve the integration of data for change detection purpose, and (2) the spatial structure of a land cover map, as measured by a set of landscape metrics, is an indicator of the level of generalisation of this map.
- Results revealed that, by controlling successively the parameters that influence the level of map generalisation, the percentage of agreement between near synchronous land cover maps can be increased from 42% to 93%. The computation of five landscape metrics for a set of generalised land cover maps and for the target map allowed us to optimise the level of generalisation by measuring the similarity in landscape pattern of the maps.
- The optimum level of generalisation of the land cover map obtained from the aerial photographs for comparison with a land cover map derived from SPOT XS data was found at a resolution of 41 m for two generalisation levels of the thematic content.
- The same method was applied to measure land use/cover dynamics over the last 225 years at the landscape scale on the basis of a time series of land cover data coming from six historical maps and one satellite image.
- Results reveal that the rates of land cover change obtained by integrating the time series by pair of successive maps are more accurate than these rates obtained by integrating by reference to the initial date. By integrating the time

series by reference to the initial date, it was possible to reconstruct and understand the land use/cover change at the landscape scale over a long period.

- After integrating the data, it is no possible to analyse the entire time series at a common spatial resolution that would be close to the optimal resolution for each pair of successive maps. Integrating the data by reference to an initial map or by pairs of successive maps do not give equal annual rates of change.
- Performing data integration by reference to an older and more generalised map leads to coarser optimal spatial resolutions, less precise estimation of the annual rates of change, and lower rates of certain changes. Consequently, working with heterogeneous times series of land cover data implies trade-off between going as far back in time as possible versus performing change detection as accurately as possible.

Concerning land cover change analysis in a semi-arid Sahelian region to derive indicators of land degradation, our results reveal that:

- There are large interannual variations both in the strength and in the parameters of the relationship between integrated NDVI and biomass. Thus, in semi-arid regions, NDVI values integrated over the growing season are not a very robust proxy variable for biomass.
- The relationship between rainfall and biomass (or integrated NDVI) is statistically significant but not very strong. Thus, event though rainfall controls a large part of the spatial and temporal variations in biomass (and integrated NDVI) at the regional scale, it is clear that, at the local scale, there are considerable variations in the response of vegetation to rainfall.
- The influence of soil type on the response of vegetation to rainfall is low.
- Just after a drought, a given increase in rainfall results in less biomass production than it is the case for normal years. Thus, vegetation only partially recovers in the first year following a drought. It takes longer for the vegetation to fully recover, depending on the species composition. However, integrated NDVI data are less likely to reveal this decrease in ecosystem resilience than biomass data.
- Over a decade, we observe an overall decrease in rain use efficiency for sites affected by land degradation. This decrease was not always continuous over the observation period. All the other sites displayed a more stable pattern in rain-use efficiency over the decade, without a particular trend. This declining trend was only demonstrated by the biomass-rainfall ratio, and not by the NDVI-rainfall ratio. The inadequacy of integrated NDVI may relate to the coarse spatial resolution of AVHRR data. However, other vegetation indices derived from remote sensing data may prove to be more adequate, such as soil-

adjusted vegetation indices or indicators of vegetation cover rather than biomass.

- When analysing the ranking in species for each site, no consistent trend in the relative abundance of the species was visible at the scale of the decade. This was also the case for sites affected by degradation. For most sites, some species appear and disappear either erratically, or in response to changes in rainfall. In the later case, they reappear at their initial rank in the following year(s).
- Only a few species seem to be good indicators of drought conditions. The resilience of ecosystems after a drought, measured by changes in their floristic composition, was high. Based on our limited observations, no species appeared to be a good indicator of degradation. Note that the patterns of degradation represented in our sites mostly cover a decrease in tree cover and soil erosion. Other processes of land degradation (e.g. overgrazing, leaching) may have a greater impact on the floristic composition of the herbaceous layer.
- From all the possible indicators of ecological conditions that were tested in this study (i.e. biomass, integrated NDVI, ecosystem resilience, rain use efficiency and floristic modification), the indicator that is most likely to reveal a continuous trend in land cover modification at the scale of a decade, independent of interannual fluctuations in rainfall conditions, seems to be rain-use efficiency. However, it has to be measured based on biomass data rather than on remotely sensed vegetation index data. Actually, at a local scale, integrated NDVI is not a perfect proxy variable for biomass in this environment. As biomass is not directly measurable by remote sensing, this is an obstacle for the continuous updating and spatially explicit assessment over large areas of land cover modifications in semi-arid regions.

  The implications of these results for the development of remote sensing techniques for rangeland monitoring are important, especially given the finding that NDVI data were less likely to reveal trends in degradation than biomass data. There is therefore a need for more robust and accurate methods to estimate biomass or related biophysical variables from remote sensing data. This probably requires moving away from empirical approaches, based on vegetation indices, in favour of physical model inversion methods.
- The poor performances of NDVI versus biomass data might also be explained by the spatial integration of heterogeneous landscapes in the AVHRR 1.1 x 1.1 km pixel for the former data. The implication would, in this case, be that finer spatial resolution data are required at a high temporal frequency. It is also essential to measure biomass and rainfall in a consistent way, at the same spatial and temporal resolutions, to estimate rain use efficiency in a reliable way.

- Any remote sensing-based monitoring system of dry land degradation must be complemented by field data collection, in particular to collect data on floristic composition which is not detectable, from space, even at fine spatial resolutions.

Publications

Articles in international reviewed journals

PETIT C. and LAMBIN E.F., 2001. Integration of multi-source remote sensing data for land cover change detection. International Journal of Geographical Information Science, **15** (8): 785-803.

PETIT C. and LAMBIN E.F., 2002. Impact of data integration technique on historical land use/cover change: comparing historical maps with remote sensing data in the Belgian Ardennes. Landscape Ecology, **17**: 117-132.

DIOUF A. and LAMBIN E.F., 2001. Monitoring Land cover changes in semi-arid regions: Remote sensing data and field observations in Ferlo, Senegal, Journal of Arid Environments, **62** (1): 21-36.

LAMBIN E.F., "Land-use/Land cover changes at local to regional scales in global change research: A key role for geographers", The 29th International Geographical Union Congress, *Special lecture for Chairpersons of Commissions and Study Groups,* Seoul (Korea), 13 August 2000.

Module 4: Assimilation of remote sensing-based land covers change data in ecosystem models

Objective

This module tested the sensitivity of a model for regional scale emissions from biomass burning to the type, quality and format of data used as input. One of the objectives of this study was to test remotely sensed indicators of burning efficiency for savannah and forest fires in Central Africa. The timing of fire with respect to vegetation senescence, the rate of post-fire recovery of vegetation and the spatial pattern of burning were potential indicators of burning efficiency. The interaction between fires and land cover change were investigated. Another objective was to understand the role of fires on land cover changes, and conversely the role of vegetation cover as a controlling factor of fires.

Evaluation and relevance of research results

Our main findings are:

- Statistical analyses were conducted to assess whether the values of a vegetation index, (NDVI) and surface temperature (Ts) were different at different stages of the burning season for burnt and unburnt areas, fragmented and continuous burnt patches, and early and late fires.
- Results show that fires affect areas with the lowest NDVI and highest Ts values.
- Continuous and fragmented burnt patches are associated with vegetation covers in different states prior to a fire.
- The rate of recovery of vegetation after a fire depends on ecotypes (periforests recover more slowly than savannahs), burning intensity and completeness (areas affected by fragmented burnt patches recover more quickly than areas affected by continuous burnt patches) and timing of the fire (areas affected by early fires recover more quickly than areas affected by late fires).
- The results suggest that combustion efficiency is lower for fragmented burnt areas compared to continuous burnt areas. It would thus be possible to decrease uncertainties on estimates of trace gaze emissions from fires by replacing fixed burning efficiency values in emission models by values that would vary in space and time, based on measures of the spatial pattern of burnt areas as detected by remote sensing.
- In dense forests, burning is strongly associated with land cover changes while in savannahs, the occurrence of (mostly) early fires does not lead to land cover change.
- Fires associated with continuous and fragmented burnt patches have the same impact on vegetation cover.
- Dense semi-humid forests of the study area were affected by a high level of burning due to land use activities at their periphery.
- Our results confirm recent findings concerning the human control on the timing of burning in savannahs. Early fires fragment the landscape and prevent the spatial diffusion of later damaging fires. Where no human settlements are present, late fires become more prevalent.
- Finally, this study measured an increase in vegetation cover in a few areas affected by very early burning.
- Using burnt area rather than active fire data allowed to better analysing spatial associations between landscape attributes and burning events.

Publications

Articles in international reviewed journals

LAMBIN E.F., GOYVAERTS K. and PETIT C., 2003. Remotely sensed indicators of burning efficiency of savannahs and forest fires, International Journal of Remote Sensing, in press.

BUCINI G. and LAMBIN E.F., 2002. Fire impacts on vegetation in Central Africa: A remote sensing-based statistical analysis. **22** (1): 27-48.

Presentations at international congresses and symposia

LAMBIN E.F., "Information needs for land-use/land-cover change research" (Guest speaker), Fourth SAI Annual User's Seminar, Baveno (Italy), 18-19 May 1999.

LAMBIN E.F., "Land Use and Land Cover Change Studies from Satellites" (Guest speaker), "Blue Planet, Green Planet", International conference UNISPACE-III, Vienna, 19-30 July 1999.

LAMBIN E.F., "Land-use changes in the Tropics: case studies on the role of forest and on the impact on wildlife", George Perkins Marsh Distinguished Lecturer, Clark University, Worcester (USA), 7-8 November 1999.

Integrating activities across modules:

Research partners met on a regular basis to exchange ideas and present progress research and thinking throughout the project duration. This has allowed cross-fertilisation and enhanced research expertise of the two partners. This has also led to a number of exchanges of methods and algorithms across the partners. While it is not possible to be exhaustive on the exchanges, here are the more concrete forms of research interactions:

- The change detection methods developed under Module 1 (KUL) have been tested on the dataset used for Modules 2 (UCL) and 4 (UCL);
- Principles from the ground sampling scheme and scaling developed under Module 3 (KUL) have been applied in the analysis of NDVI *versus* biomass data measured in the field in the study on Ferlo as part of Module 2 (UCL);
- The historical perspective on land cover change and the requirement to integrate heterogeneous data sources, as developed under Module 2 (UCL), were considered as constraints in the development of land cover change methods under Module 1 (KUL).
- The regional scale view of the impact of fires on land cover change and the need to produce regional scale estimates of burning efficiency, as part of

Module 4 (UCL), were integrated in the thinking on ground sampling schemes and scaling up in Module 3 (KUL).

- All four modules have contributed to a general assessment of achievements and shortcomings related to the monitoring of land cover change by Earth Observation satellites.

RESEARCH CONTRACT T4/01/032

DERIVATION OF LAND COVER CHANGE DATA AND THEIR ASSIMILATION IN ECOSYSTEM MODELS (MODULES 1 AND 3)*

SECOND PART

P. COPPIN

KATHOLIEKE UNIVERSITEIT LEUVEN (KUL)
FACULTY OF AGRICULTURAL AND APPLIED BIOLOGICAL SCIENCES
LABORATORY FOR FOREST, NATURE AND LANDCAPE RESEARCH
Vital Decosterstraat 102
B – 3000 LEUVEN
BELGIUM

*This project was performed in collaboration with E. LAMBIN (UCL – Research Contract T4/10/031)

1. CONTEXT AND OBJECTIVES

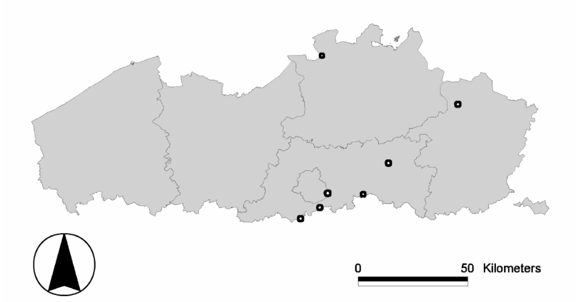
In order to be able to characterise subtle changes in Land cover from space, the change detection procedures have to be tested and optimised towards the change phenomena and scale of interest. Second, adequate measurement techniques have to be developed to assess accurate scale-integrated ground reference data needed for the calibration of remotely sensed data.

The specific objectives are:

- Optimisation of change indicator extraction procedure from medium resolution satellite imagery for the detection of subtle Land cover change.
- The quantification and modelling of the natural variability of LAI for three important forest communities in Flanders based on yearly-repeated monthly measurements.
- Development of a general data acquisition technique for field measurements.
- Development of a specific data-aggregation method to move from in-situ point measurements to spatial measurements. This includes also the up-scaling from community level quantitative data to complex spatial data units to be assimilated into ecosystem models.

2. DATA

Geographic study area: Flanders Module 1&3 (KUL): Flanders: forest communities: Pijnven, Kalmthout, Meerdaalwoud, Zoniënwoud, Walenbos en Hallerbos.



Satellite imagery used:

LANDSAT 5 Multispectral Floating Quad scenes (11QN)

Path oriented, 1G processing level, NN resampled, CEOS data format
PATH 198, ROW 24/25
50°59'N 04°46'E (scene centre)
20/08/1998; 05/03/1999; 23/08/1999; 25/05/2000

SPOT Panchromatic
1B Processing level
51°30'N 4°10'E - 50°35'N 5°30'E
10/07/1999; 27/01/2000

ERS-2 SAR SLCF/I
Orbit: 21820 Frame: 2579
23/06/1999

Other data:

LAI measurements with Licor LAI-2000 PCA
Digital hemispherical photographs (Nikon Coolpix 950 & FC-E8)

3. METHODOLOGY

- An optimised sampling scheme (design and intensity) for LAI measurements was developed based on Monte-Carlo simulations given a limited set of high-precision (spatial) reference dataset.
- An analytical canopy model was developed and used to derive a correction model for indirect LAI measurements based on hemispherical fractal dimension.
- Subtle change experiments were set-up within each of the main forest communities in Flanders by means of controlled girdling and thinning practices.
- A comparative study based on an extensive ground reference data set allowed the selection of the most appropriate change detection procedure for forest cover change and the improvement of the traditional Change Vector Analysis technique.
- The Metatruth image concept was developed to model data-accuracy of change images at pixel level.

4. OUTPUTS AND RESULTS

- Selection of optimal sampling scheme for indirect LAI measurements
- Geometrical Canopy Model and optimisation of indirect LAI measurements
- Optimisation of change detection procedures for the detection of subtle forest cover changes

- Development of a network of controlled field experiments
- Coppin P., Nackaerts K., Queen L., Carpenter W. 1999. Operational monitoring of green biomass change for forest management. Photogrammetric Engineering and Remote Sensing, 67(5): 603-612.
- Vaesen K., Nackaerts K., Muys B., Coppin P. 2000. Performance of a modified change vector analysis approach in forest change detection. Remote Sensing of Environment. In Press.
- Vaesen K., Nackaerts K., Lizarraga I., Muys B., Coppin P. 2000. Use of a Metatruth Image concept to assess forest change detection accuracy at pixel level. International Journal of Remote Sensing, In Review.
- Nackaerts K., Coppin P., Muys B., Hermy M. 1999. Sampling methodology for Leaf Area Index measurements with LAI-2000 in small forest stands. Agricultural and Forest Meteorology, 101:247-250.
- Nackaerts K., Sterckx S., Muys B., Coppin P. submitted. Fractal dimension based optimisation of indirect Leaf Area Index measurements for digital change detection. Remote Sensing of Environment.
- Presentations at international congresses and symposia.

5. EXECUTION

Period: 15/12/1998-15/03/2001

Laboratory:

KATHOLIEKE UNIVERSITEIT LEUVEN (KUL)
Faculty of Agricultural and Applied Biological Sciences
Laboratory for Forest, Nature and Landscape Research
Vital Decosterstraat 102, B – 3000 Leuven, Belgium
Phone: +32 16 32 97 40 Fax: +32 16 32 97 60
E-mail : Pol.Coppin@agr.kuleuven.ac.be
URL : http://www.agr.kuleuven.ac.be/lbh/lbnl/lbnl_home_en.htm

6. RELATED DISCIPLINE

Forest & natural vegetation

7. EXECUTIVE SUMMARY

Introduction

This report provides an overview of the main scientific findings and achievements of the research project. After outlining the results of two of the four modules, it summarises the integrating activities and cross-fertilisation between modules: Modules 1 and 3 (KUL – Research contract T4/01/32) and Modules 2 and 4 (UCL – Research contract T4/10/31)

<u>Module 1: Characterisation from space of subtle changes in land cover</u>

Objective

A new approach based on the integration of remotely sensed and ground-measured information was developed to characterise subtle changes in land cover. The methodology was process-predicated in the sense that changes within land cover types, or mosaics thereof, were quantified in a continuum using models that correlate numeric indicators of these processes with spectral change response indices. Change quantification was calibrated for natural variability via controlled experiments and was specific, not at the more traditional global or regional scale, but at the local natural community level.

Evaluation and relevance of research results

Out of the on-going research several results were obtained

- Digital change detection routines were optimised. Subtle changes could be detected, primarily in a qualitative, but still detailed way, by means of a newly developed change detection routine.
- The impact of change indicator – change algorithm selection on overall accuracy parameters was analysed. The best combination in order to monitor change was obtained, as well as the influence of change indicator or change algorithm selection separately. This knowledge can help in refining qualitative predictive change models towards quantitative change detection. A detailed study on the at pixel-level accuracy produced in the selected change detection routines, demonstrated their potential of detecting and identifying change events very accurately.
- The quantitative change detection study demonstrated that the Maximum Likelihood and Mahalanobis classification procedures perform better in digital change detection. The need for detailed and accurate ground reference data was also proven.

- Measurement techniques in order to build up a qualitative and exhaustive reference dataset were tested, optimised and standardised (See Module 3). The dataset is being explored at the moment and can serve for the further development of a qualitative change prediction model.

- Although the development of a predictive change detection model was set out as an objective at the start of the project, lack of data did prevent it. However at the end of the project, qualitative change data measured at the ground are available for a time interval of 2 years. It is only now that the predictive model can be developed. Therefore, two M. Sc. Students, supervised by one Ph.D. student, are continuing the research in this direction.

PUBLICATIONS

Articles in international reviewed journals

Coppin, P., Nackaerts, K, Queen, L., Carpenter, W. 1999. Operational monitoring of green biomass change for forest management. Photogrammetric Engineering and Remote Sensing, In press.

Vaesen, K, Nackaerts, K, Muys, B., Coppin, P., 2000. Performance of a modified change vector analysis approach in forest change detection. Remote Sensing of Environment, In press.

Vaesen, K, Nackaerts, K, Lizarraga, L, Muys, B., Coppin, P., 2000. Use of a Metatruth Image concept to assess forest change detection accuracy at pixel level. International Journal of Remote Sensing, In review.

Presentations at international congresses and symposia

K Nackaerts, P. Coppin, 1999. Operational monitoring of green biomass change for forest management. In Proceedings of the IUFRO '99 Conference on Remote Sensing and Forest Monitoring, 1-3 June 1999, Rogow, Poland.

K. Vaesen, K Nackaerts, S. Gilliams, P. Coppin, 2000. Impact of change indicator - change algorithm selection on overall accuracy in forest monitoring. In press in Proceedings of the Second International Conference on Geospatial Information in Agriculture and Forestry, 10- 1 2 January 2000, Orlando, USA.

Vaesen, K., Lizarraga, I., Nackaerts, K., Coppin, P., 2000. Spatial Characterisation of uncertainty in forest change detection. In Proc. of the 4th International Symposium on Spatial Accuracy Assessment in Natural Resources and Environmental Sciences, Amsterdam, The Netherlands.

Module 3: Validation and calibration of remote sensing-based land cover change data with field measurements - the case of LAI

Objective

The objective of this Module was to design an approach to validate land cover change data, based on field measurements. An appropriate data aggregation method and integrated sampling scheme were developed to relate point-level biophysical attribute data to area-level remotely sensed data. A Monte Carlo simulation of the process elements was used to model the impact of the sampling scheme and data aggregation method on the relative accuracy of the estimated attribute value. For this, different sampling schemes (design and intensity) and aggregation methods were tested on the simulated data sets. Because the simulated attribute values were based on indirect measurements, new techniques were developed to determine a calibration factor, relating directly retrieved stand-level data to the simulated data.

EVALUATION AND RELEVANCE OF RESEARCH RESULTS

Out of the on-going research several results were obtained:

- Measurement techniques using the Licor-2000 PCA were optimised, operationalised and standardised. Operational settings take the influences of (in)direct sunlight and of areas of interest into account.

- Although not planned at the beginning of the project, explorative research on available datasets made it necessary to look for procedures to correct for the assumptions of randomness of leaf distribution in forest canopies. This part of the research was time consuming (more than was expected) but appeared to be efficient at the end of the exercise.

- Optimal measurement set-ups to guarantee sufficient accuracy were set out using Monte Carlo simulation analysis. As such, an experimental sampling design was developed. Moreover, the errors generated in estimating LAI in a certain forest stand were quantified.

- Enormous efforts were undertaken to deal with the upscaling problem. Although the results were not satisfactory until now, the exploration of new strategies (s.a. the development of upscaling models based on the simulation of images of virtual forest stands; new sensors. e.g. polarimetric radar sensors) was promising.

PUBLICATIONS

Articles in international reviewed journals

K. Nackaerts, P. Coppin, B. Muys and M. Hermy, 1999. Sampling methodology for Leaf Area Index measurements with LAI-2000 in small forest stands, Agricultural and Forest Meteorology, 101: 247-250.

K. Nackaerts, S. Sterckx, B. Muys and P. Coppin, Submitted. Fractal dimension based optimisation of indirect Leaf Area Index measurements for digital change detection, Remote Sensing of Environment.

Presentations at international congresses and symposia

Nackaerts K, S. Sterckx and P. Coppin. 1999. Fractal dimension as correction factor for stand-level indirect Leaf Area Index measurements. In Proceedings of the EOS/SPIE Symposium on Remote Sensing, 20-24 September 1999, Firenze, Italy.

K. Nackaerts, T. Wagendorp, P. Coppin, B. Muys and R. Gombeer. 1999. A correction of indirect LAI measurements for a non-random distribution of needles on shoots. In Proceedings of the ISSSR Symposium, 31 October - 4 November 1999, Las Vegas, Nevada, U.S.A.

K. Nackaerts, P. Coppin, B. Muys and M. Hermy, in press. Modelling variability and scale integration of Leaf Area Index measurements, In: Proceedings of the International Conference on the Inventory and Monitoring of Forested Ecosystems on Integrated Tools for Natural Resources Inventories in the 21st Century, August 1. 6-20, 1998, Boise-Idaho, USA.

Integrating activities across modules:

Research partners met on a regular basis to exchange ideas and present progress research and thinking throughout the project duration. This has allowed cross-fertilisation and enhanced research expertise of the two partners. This has also led to a number of exchanges of methods and algorithms across the partners.

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- Principles from the ground sampling scheme and scaling developed under Module 3 (KUL) have been applied in the analysis of NDVI *versus* biomass data measured in the field in the study on Ferlo as part of Module 2 (UCL);
- The historical perspective on land cover change and the requirement to integrate heterogeneous data sources, as developed under Module 2 (UCL), were considered as constraints in the development of land cover change methods under Module 1 (KUL).
- The regional scale view of the impact of fires on land cover change and the need to produce regional scale estimates of burning efficiency, as part of Module 4 (UCL), were integrated in the thinking on ground sampling schemes and scaling up in Module 3 (KUL).
- All four modules have contributed to a general assessment of achievements and shortcomings related to the monitoring of land cover change by Earth Observation satellites.

RESEARCH CONTRACT T4/02/035

IMAGING RADAR FOR MAPPING AND MONITORING OF WETLAND ECOSYSTEMS IN THE CHAD BASIN

R. DE WULF

UNIVERSITEIT GENT (RUG)
FACULTY OF AGRICULTURAL AND APPLIED BIOLOGICAL SCIENCES
LABORATORY OF FOREST MANAGEMENT AND SPATIAL INFORMATION TECHNIQUES
Coupure Links 653
B – 9000 GENT
BELGIUM

1. CONTEXT AND OBJECTIVES

Wetlands in Africa in general, and in the proposed test zone in the Chad Basin in particular, are of paramount ecological and economical importance, but are threatened by population pressure, with serious implications for the local population and their environment. Management authorities need up-to-date spatial data that is able to provide an accurate picture of present land use and the extent of the flooded area. In view of the very dynamic nature of wetlands, research to characterise these spatio-temporal patterns is a considerable added value. Research on the usefulness of imaging radar is being presented with the following objectives:

- Quantitative investigation of the radar backscatter signal in relation to wetland ecosystem components (aquatic, macrophytic, and terrestrial in the agricultural buffer zone) through statistical separability measures and testing against existing theoretical backscatter models.
- Optimisation of cartography of wetlands by development of procedures for image segmentation and classification: multi temporal classification and image fusion: visible/NIR and microwave data.

2. DATA

Geographic study area: Lake Chad Basin, Sahelian wetlands, and Logone floodplain.

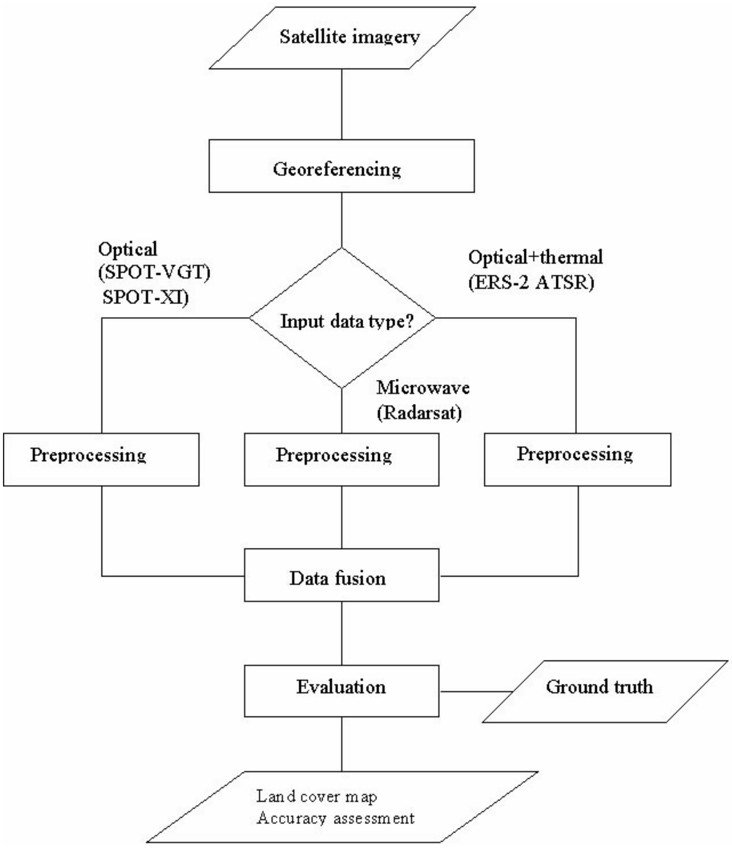
Satellites imagery used:

- RADARSAT SAR : 02/11/1999, 12/11/1999, 16/11/1999
- SPOT-4 VEGETATION S-10 images from August 1998 till June 1999
- 30 images ERS-2 ATSR from April 1999 till December 1999

3. METHODOLOGY

Image processing chain

The general workflow applied can be seen in the figure below.



Processing chain

The processing chain can take different image combinations as input (optical plus microwave, optical plus optical or optical plus thermal). The output will be a classified image (land cover map) with an estimate of the map's accuracy. Different steps need to be taken before the final result is obtained.

Georeferencing

The first step (after importing the images into the image processing software) is georeferencing. This needs to be done as accurately as possible, as this step will strongly influence the quality of the final result. In the case of multispectral fusion the digital numbers will be fused on a pixel-by-pixel basis, so that even the slightest misregistration will result in erroneous values. In the case of multiresolution, the effect will noticeable in the sub-pixel classification or fuzzy classification. The detrimental effect of misregistration on the classification accuracy is well known (e.g. Ouaidrari *et al.*, 1996). As the soft classification serves as input to the second step (the sub-pixel mapping) it is very important to produce an accurate sub-pixel classification. Gross and Schott (1998), who sharpened soft classifications using image fusion techniques, also stress this point. They conclude that inaccurate unmixing yields irrecoverable error during the sharpening process.

All images were imported into ERMapper and Idrisi, and an initial georeferencing was performed using the information present in the respective headers. Subsequent control revealed that fairly large collocation errors existed (> 100 m), especially when the S7 (low incidence angle) RADARSAT image was compared to the SPOT-XI image. This problem has been corrected by coregistering the two radar images to the SPOT image. This guarantees a good relative coregistration, even if in absolute terms a (small) error is likely to be present. The difficult accessibility of the area and the absence of 'sharp' reference points (e.g. cross roads, bridges,…) from the area prevented a more accurate georeferencing, even when field observation became available.

Pre-processing

The pre-processing steps differ depending on the image type involved. The SPOT-VEGETATION images do need not any pre-processing, as the ten-day synthesis (S-10) image products are used. Pixel values represent reflectance values. The vendor has applied both radiometric and geometric corrections in order to enhance product quality. Furthermore the images have been synthesised in order to minimise the effect of cloud cover. The only pre-processing step applied to the SPOT-XI images consists of a nearest neighbour resampling from 20 m to 50 resolution, necessary for the multispectral data fusion. The radar images do necessitate a considerable amount of pre-processing. The data volume is reduced (halved) by converting the 16 bits to 8 bits, using a linear transformation between limits containing 99% of all pixel values. Subsequently the spatial resolution of the radar images is reduced from 12.5 to 50 metres by applying an averaging procedure in a 4 by 4 window. While allowing faster processing by further reducing the data volume, the averaging also removes some of the speckle present in the radar images. The next step consists of speckle filtering. Although filters have been developed specifically for this purpose, previous research (Verhoeye and De Wulf, 1999) has indicated that the best results (in terms of subsequent classification accuracy) are obtained by applying a Sigma filter. This has the added advantage that no time consuming data conversion between software packages is needed, as this filter is present in all general-purpose image processing software. ERS-2 ATSR images contain information that indicates potential errors in the digital numbers. These pixels are assigned negative values, either an error code ranging from –1 to –8, or negated pixel values. Negative values in the 11 µm and 0.67 µm wavebands indicate a *cosmetic fill* (the pixel value has not been registered by the sensor but rather copied from its nearest neighbour). Negative values in the 12 µm and 0.87 µm wavebands indicate the presence of a *blanking pulse* (the fact that other instruments were active when the ATSR registration occurred and thus the possibility that the observation may be biased). It should be noted that there was no evidence of such interference during the ERS-1 ATSR mission. Negated pixel values can easily be turned into positive ones by taking the absolute values of the digital numbers.

Data fusion

This topic will be fully discussed in the next chapter. Two methods will be explored: multispectral and multiresolution data fusion. The first, also called multisensor fusion, is based on the simultaneous processing of information originating from different parts of the electromagnetic spectrum. This process will be applied to the combination of optical and microwave data (SPOT-XI and RADARSAT). Multiresolution data fusion refers to the process where images with differing spatial resolution are fused. Two image combinations will be explored: SPOT-XI and SPOT-VEGETATION (with identical spectral characteristics), and SPOT-XI and ERS-2 ATSR (with differing but related spectral characteristics).

Evaluation

The evaluation of the classification result is done by comparison to ground truth data. The measures for accuracy assessment are calculated according to formulas described by Bishop *et al.* (1980) and Rosenfield and Fitzpatrick-Lins (1986). These formulas have been implemented as a C-program.

4. EXECUTION

Period: 15/12/1998-30/09/2001

Laboratory:

UNIVERSITEIT GENT (RUG)
Faculty of Agricultural and Applied Biological Sciences
Laboratory of Forest Management and Spatial Information Techniques
Coupure Links 653, B – 9000 Gent, Belgium
Phone: +32 9 264 61 10 Fax: +32 9 264 62 40
E-mail:Robert.DeWulf@rug.ac.be URL : //allserv.rug.ac.be/~fvncoill/index.html

5. RELATED DISCIPLINE

Forest & natural vegetation

6. EXECUTIVE SUMMARY

The lack of up-to-date maps containing the basic information for land management purposes is well known, especially in developing countries. The application of remote sensing data is a fast and cost effective method to supply the information needed.

This research focuses on Sahelian wetlands, which have suffered recently from adverse effects caused by large-scale hydro-agricultural projects.

The remote sensing data available comprise both optical and microwave images. Moreover, spatial resolution varies from low to high. This allows research on digital image fusion in which images from different sensors are combined. Two methods will be explored: multispectral and multiresolution data fusion. The first is based on the simultaneous processing of information originating from different parts of the electromagnetic spectrum. The latter uses images with a differing spatial resolution but with a high correlation between spectral bands.

A processing chain has been developed for multispectral fusion which can yield either pixel or object level fusion images. Optical and microwave images can serve as input. Pixel level fusion is achieved through principal component transformation, while object level fusion implies weighed averaging of pixel values based on their statistical properties. Visual evaluation of the results shows that haze, present in the optical images, can be successfully eliminated, while clouds remain a problem. Numerical evaluation yields rather diverse results: low accuracy for pixel level fusion products, partly due to the persistence of radar noise. Object level fusion gives better results, on condition that the appropriate segmentation level is chosen. Multispectral fusion thus yields visually attractive results, though not especially suited for land cover mapping. Multiresolution fusion is achieved in two steps: sub-pixel classification and sub-pixel mapping. Sub-pixel classification (or pixel unmixing) can be achieved through linear unmixing. Mixed pixels result when the sensor's instantaneous field-of-view includes more than one land cover class on the ground. Linea pixel unmixing assigns a pixel to several land cover classes in proportion to the area of the pixel that each class covers. These fraction values can be assigned to sub-pixels through sub-pixel mapping. This is based on the assumption of spatial dependence and the application of linear optimisation techniques. A newly proposed sub-pixel mapping algorithm was first applied to a synthetic data set with a 1-km resolution, derived from a 20 m resolution image. This algorithm yielded land cover maps at 500, 200 and 100 m resolution with accuracy close to 89%. Subsequent mode filtering further increased these values. When applied to a real data set, the accuracy reached 78%. While this study suggests the potential of the proposed technique, there is still ample cope for improvements and extensions.

RESEARCH CONTRACT T4/67/036

BIOPHYSICAL CHARACTERISATION OF TROPICAL ECOSYSTEMS BY SPACE BORNE SAR REMOTE SENSING (ECOSAR II)*

FIRST PART

J. VAN RENSBERGEN

VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK (VITO)

Boeretang 200

B – 2400 MOL

BELGIUM

*This project was performed in network with A. GUISSARD (UCL – Research Contract T4/10/037)

1. CONTEXT AND OBJECTIVES

Possibilities and limitations of SAR-imagery and texture extraction, with respect to tropical vegetation classification. The scope of the ECOSAR project is to develop a methodology for the mapping and monitoring of tropical vegetation based on SAR-data and texture extraction.

2. DATA

Geographic study area: Forêt classée du Haut Sassandra

Satellite imagery used:

ERS-2 SAR PRI – (track/frame/orbit:) 194/3447/31611, 194/3465/31611,194/3447/30609, 194/3465/30609, 423/3447/30838,423/3469/30838, 194/3447/31110, 194/3465/31110, 194/3447/32613, 194/3465/32613, 423/3447/32842,423/3465/32842, 423/3447/32842,423/3465/32842

LANDSAT 7 path/row 198/055; date 7/02/2000
RADARSAT Orbit 28558 Ascending, date 24/04/2001

Other data: ERS1-2 '95-'96

3. METHODOLOGY

- Coregistration by means of cross-correlation to generate a speckle filtered SAR-image without losing resolution
- Segmentation of statistically homogeneous areas by own written segmentation algorithm
- Texture extraction by means of derivation of 2nd order statistics on a pixel base but taking into account segment-border pixels
- Data-reduction by applying a multilevel-mask to this texture extraction and principal component analysis
- Classification
- Comparison with LANDSAT classification and terrain validation

4. OUTPUTS AND RESULTS

- Texture extraction algorithm developed in user-friendly environment.
- LANDSAT classification of area at stake and terrain validation with satisfying results
- Difficulties with classification of tropical vegetation based on SAR-imagery and texture extraction

5. EXECUTION

Period: 01/10/1999 -31/12/2001

Laboratory:

VLAAMSE INSTELLING VOOR TECHNOLOGISCH (VITO)
Boeretang 200, B – 2400 Mol, Belgium
Phone: + 32 14 33 68 00   Fax: + 32 14 32 27 95
E-mail: marc.leysen@vito.be URL: http://www.vito.be/docs/expert/tap/tap_en.htm

6. RELATED DISCIPLINES

Forest & natural vegetation
Agriculture
Environment
General Earth observation
Hardware & software

7. EXECUTIVE SUMMARY

The scope of the *Ecosar* project is to develop a methodology for the mapping and monitoring of tropical vegetation, based on SAR-data.

Apart from the straightforward advantage of SAR, compared to 'conventional' optical techniques, of being an active system and not disturbed by clouds, SAR-imagery is highly textured due to its side-looking geometry. In this way, it's the technique 'par excellence' for texture analysis. One could imagine that an accurate description of texture could be comparable to the information contained in different bands of optical techniques.

The method is innovative in the way it tries to use SAR-imagery to classify the tropical vegetation. In a related project, the VITO-'SarScape'-project, SAR-imagery and texture analysis were used to classify the impact of landscape on Winfield.

In the case of Ecosar, 'la forêt classée du Haut Sassandra' and its environments are taken as study area.

The scientific report is conceived as follows:

- The image processing, with emphasis on the texture extraction algorithm.
- The LANDSAT ETM+ classification and the terrain validation
- SAR-analysis of the study area and conclusive remarks

As to the image processing, the different steps are explained in detail. The texture extraction algorithm is innovative, taking into account 2-dimensional 2nd order statistics (the way variance is related to distance).

The four main steps are:

- Fine coregistration of about 10 acquisitions by means of a cross-correlation method, and taking the median of this multi-band image ; in this way, a speckle-filtered image is obtained while preserving the original resolution
- Segmentation of this image to define statistically stationary areas[1]. At first, commercial software (Caesar©) was used, but in the course of the project, an algorithm was developed by ourselves, called 'Amoeba-Segmentation'. Also, the eCognition© -segmentation algorithm was tried out. All the developed software is integrated into a user friendly ENVI©-environment. In this way, the entire processing chain can be executed on one platform, and within the ENVI©-environment. The algorithm will be explained extensively in the scientific report.
- Texture analysis by means of a moving window of <u>each</u> pixel's surrounding. Precautions or taken for pixels at the edges of the segment (in order not to disturb the homogeneous surrounding (defined by the segmentation) by other pixels, belonging to neighbouring segments). The Fourier power spectrum (or autocorrelation function[2]) for each pixel's surrounding is calculated. Numerous parameters can be defined (e.g. the quantity derived, the size of the surrounding). Also this step is made user friendly (i.e. widget based).
- This results of course in a huge amount of data. Therefore, this information is <u>reduced</u> as follows :
    - A multi-level mask is applied to the power spectrum, resulting in a multi-band 'texture' image (one band for each level, from the lowest to the highest frequency). The number of levels and the resolution of the mask are adjustable parameters.
    - Taking the average value of all pixels within each segment, and doing this for each band. This approach supposes of course that the segmentation could well define homogeneous areas. Practice in the SarScape project (Flanders region) learns that this is actually the case.
    - Performing principal component analysis (it appears that the number of bands can be reduced from e.g. 9 or 15 to about 3 to explain more than 90% of the variation)

Before treating the SAR-texture analysis on the area at stake, a recent (February 2000) cloud free LANDSAT ETM+ image was classified (as a reference) on a pixel base, using a well known unsupervised classification algorithm

[1] Stationary area : a stationary area is an area with homogeneous statistical properties, independent of sampling location. The term 'area' is used for a two-dimensional (spatial) signal of arbitrary shape, corresponding to a segment

[2] Using the power spectrum or the autocorrelation spectrum is mostly a matter of 'taste'. In the subsequent part of the report, we will use the power spectrum, also because it was more 'convenient' to deal with spatial frequencies.

('ISODATA' in ENVI©). This already gave very good results and corresponded well with our knowledge of the ecosystems at stake and maps. The area within the 'forêt nationale of Haut Sassandra' could be classified in primary forest, secondary forest and forested savannah (3 classes cover practically completely the 'forêt classée'), and the surrounding mainly as water bodies or rivers, grassland/agriculture mixture, plantation, pure grassland (completely degraded forest), bare soil, village or pure agriculture (very small parts).

The terrain validation, performed by 2 botanists of the Abidjan Universities, is treated next, and shows good agreement with the LANDSAT classification. The researchers made some 130 observations, measured the co-ordinates, described the environment and took photographs. While a great deal of the area is very disperse - resulting in small segments (especially grassland and agriculture), it was very difficult to uniquely link field observations with the LANDSAT classification. However, they confirmed to a great deal the classification results.

Both steps (classification and terrain validation) were dealt with to get well acquainted with the area at stake.

Actually, the project aimed at coming to at least comparable results starting from the SAR data, as the results which were obtained after the classification of the LANDSAT data.

A number of experiments were done on a speckle filtered image, based on 10 overpasses, covering most of the 'forêt classée du Haut Sassandra', and the area west of it.

Special attention was paid on the enclave of Gbébli. Indeed, this enclave, immediately east of the river Sassandra (and furthermore surrounded by the 'forêt classée'), is marked by a lot of plantations. If the SAR-imagery, together with the texture extraction algorithm, was not able to clearly distinguish between this enclave and the tropical forest, this would be a serious indication that the SAR-texture analysis is not the most appropriate way to classify tropical ecosystems.

Unfortunately, this was actually the case. In the scientific report, some examples are given of a larger area, covering almost completely the 'forêt classée du Haut Sassandra'.

Depending on the value of the adjustable parameters of the parameters of the segmentation, one gets

- very small segments, or
- a mixture of a few, very large segments and a number of very small segments.

Both situations bear however no physical relevance.

Moreover, it seems not to be a problem of the segmentation algorithm as such, while already in the original speckle-filtered image very detailed classification seems problematic (for instance, the entire 'forêt classée' shows little variation).

A discussion of possible causes and cures for this lack of usable results is given (while in the 'SarScape' case, the texture analysis gave at least moderate results). One can put questions on the implemented texture analysis method, or additional temporal information could be advantageous. Nevertheless, the project was an interesting exercise considering the possibilities and limitations of SAR-imagery and texture extraction, especially with regard to tropical vegetation classification.

The scope of the project was initially larger, but numerous complications rose.

- For instance, it was also our purpose to compare the situation of 1996 and 2001 (evolution in 5 years), but due to the technical problems of the ERS-2, we got only images of the core site in the wet season, which makes them incomparable with the situation of '96. Indeed, the SAR backscatter image contains both informations on top-of-canopy topography as humidity (dielectric constant). The images of '96 are acquired mostly in dry season.
- Also, the political situation in Ivory Coast made us decide not to do the terrain validation ourselves, but by people of the university of Abidjan, which was of course not the ideal way to work and was also a cause for delay.

RESEARCH CONTRACT T4/10/037

BIOPHYSICAL CHARACTERISATION OF TROPICAL ECOSYSTEMS BY SPACE BORNE SAR REMOTE SENSING (ECOSAR II)*

SECOND PART

A. GUISSARD

UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL)
LABORATORY COMMUNICATIONS AND REMOTE SENSING
Place du Levant 3, Bâtiment Maxwell
B – 1348 LOUVAIN-LA-NEUVE
BELGIUM

*This project was performed in collaboration with J. VAN RENSBERGEN (VITO – Research Contract T4/67/036)

1. CONTEXT AND OBJECTIVES

- Producing operational versions of the laboratory developments (model and speckle filter) by incorporating validity range checks, restricting input to significant parameters, and providing it with a graphical user interface and full documentation;
- Validating the thematic results obtained with the methods, developed based on historical data, with real-time reference measurements and outlining their range of validity;
- Upgrading the conceptual water balance model to a physical model at the same time calibrating it with real time field observations;
- Demonstrating the value of the methods developed at a scale representative for the TELSAT programme objectives through co-operation agreements established with the JRC on interpretation of large-scale forest mapping exercises using ERS and JERS SAR data.

2. DATA

Geographic study area : Forêt classée du Haut Sassandra
Satellite imagery used:
ERS-2 SAR PRI – (track/frame/orbit)
194/3447/31611, 194/3465/31611,194/3447/30609, 194/3465/30609,
423/3447/30838,423/3469/30838, 194/3447/31110, 194/3465/31110,
194/3447/32613, 194/3465/32613, 423/3447/32842, 423/3465/32842,
423/3447/32842,423/3465/32842

LANDSAT 7 path/row 198/055; date 7/2/2000
RADARSAT Orbit 28558 Ascending, date 24/04/2001
Other data: ERS1-2 ’95-’96

3. EXECUTION

Period: 15/12/1998-31/12/2001
Laboratory
UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL)
Laboratory Communications and Remote Sensing
Place du Levant 3, Bâtiment Maxwell, B – 1348 Louvain-la-Neuve, Belgium
Phone : +32 10 47 23 00   Fax : +32 10 47 20 89
E-mail : guissard@tele.ucl.ac.be

4. RELATED DISCIPLINES

Forest & natural vegetation
Agriculture
Environment
General Earth observation
Hardware & software

5. EXECUTIVE SUMMARY

A polarimetric radiative transfer model was previously developed for forested areas but applied only to coniferous forest. The model has been extended to any kind of forest and to low vegetation covers, such as savannah. It starts from existing scattering models for plates and cylinders and for the soil, that have been carefully reviewed and updated. The forest is represented by three superposed layers: ground, trunks and canopy. For low vegetation, only two layers are considered: ground and vegetation cover.

The model developed at UCL provides more flexibility than other available models: it includes size distributions, it accounts for the reciprocity effect, and it allows vertical distributions within the canopy and provides a more precise description of the vegetation components. It is a fully polarimetric radiative transfer model that accounts for the enhancement effect. It allows to calculate the complete scattered Stokes vector, and therefore the complete polarimetric response of a distributed target. The various scattering mechanisms considered are: the direct canopy contribution, the canopy ground contribution, the ground canopy ground contribution, the trunk ground contribution, the direct ground contribution, and the double canopy contribution (double bounce within the canopy). However, since this last mechanism requires a very long computation time and provides in the most cases a rather low contribution, it is not yet included in the programme.

For the soil, we have implemented the so-called Integral Equation Method (IEM) developed by Fung and colleagues. The surface scattering model requires as input: the geometric properties of the surface (rms height and slopes), and the electric properties of the soil, i.e. the permittivity, directly related to soil moisture and water salinity.

Our volume electromagnetic scattering model is based on the radiative transfer theory. It is a polarimetric approach and handles concrete objects such as branches, leaves and trunks. The theory is based on the fundamental assumption that the scattering processes from the various constituents are incoherent, and that consequently powers (and more generally Stokes parameters) add up. However caution has been taken to handle properly particular situations of backscattering enhancement, related to double bounce cases. The canopy is represented by a distribution of branches and leaves, or needles, with random dimensions and orientations. The branches are modelled by circular cylinders, the leaves by circular or elongated flat dielectric plates, and the needles by thin circular cylinders. The trunks are modelled either by dielectric circular cylinders or by dielectric circular cones, with a distribution of inclination angles with respect to the vertical.

RESEARCH CONTRACT T4/DD/039-040

GLOBAL SCALE BIOME CLASSIFICATION AND ESTIMATION OF BIOME PROPORTIONS USING VEGETATION DATA

T. VAN DE VOORDE & F. CANTERS [(1)]
H. EERENS, E. SWINNEN & F. VEROUSTRAETE [(2)]

VRIJE UNIVERSITEIT BRUSSEL (VUB) [(1)]
CENTRE FOR CARTOGRAPHY AND GIS
DEPARTMENT OF GEOGRAPHY
Pleinlaan 2
B – 1050 BRUSSEL
BELGIUM

VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK (VITO) [(2)]
Boeretang 200
B – 2400 MOL
BELGIUM

1. CONTEXT AND OBJECTIVES

In recent years there is an ever-growing demand for actual and reliable information on the spatial distribution of the main terrestrial ecosystems (biomes). Land cover is indeed a driving variable in many models for the simulation and/or forecasting of weather, possible climate changes, carbon sequestration, erosion risk, etc. - and actual biome maps form a valuable instrument for the verification of international environmental treaties like the Kyoto-Bonn protocol. One of the main goals of the project was to investigate to what extent images of the earth observation system SPOT-VEGETATION (VGT) can be used for the mapping of these biomes. Existing methods, developed for similar data (NOAA-AVHRR), are slow, tedious and require a lot of human interaction and expert knowledge. In this project we specifically focused on automated procedures which can be applied on a continental to global scale and repeated on a regular base, with a minimum interference of operators. Traditional approaches are mostly based on "hard" classifiers, which assign each pixel univocally (i.e. with its entire surface) to one of the terrain classes in the considered biome legend - thereby overlooking the intrinsically mixed nature of the 1km²-pixels. From an algorithmic point of view most attention was thus devoted to the development of "soft" algorithms, which attempt to reveal the acreages occupied by the different classes at the sub-pixel level.

2. DATA

Geographic study area: For the soft and sub-pixel classification: Europe and Africa; For the (hard) global classification: the entire world.

Satellite imagery used: One full year cycle of global 10-daily MVC-composites of SPOT-VGT (April 1998-March 1999), at 1km²-resolution (delivered by the Global Vegetation Monitoring Unit of the JRC in Ispra, Italy).

Other data : For the calibration/validation of the sub-pixel methods: the European Land cover database CORINE (original, vectorial version) and high-resolution Land cover maps over Africa derived from SPOT-XS (partly by others, partly during a work visit at JRC-GVM). For the training of the hard classification: the IGBP DISCover global land classification (derived from AVHRR-imagery of 1992/3). As additional classification variable: the Digital Terrain Model GTOPO30.

3. METHODOLOGY

- The pre-processing of the 10-daily VGT-composites included the following steps: data reduction (from 360 Gb to 30 Gb per year), elimination of cloud noise and computation of more powerful classification variables: bimonthly MVC-data, vegetation indices based on the SWIR-band, attributes of the annual phenology, etc.

- For the hard classification on a global scale, a supervised decision tree algorithm was developed, which was applied in an iterative way on "tiles" of 1000km x 1000km, and trained with information from the DISCover-map of 1992.
- Different techniques for the sub-pixel estimation of Land cover class proportions at the continental scale were developed and tested on Europe, using the CORINE Land cover database as a source for calibration and validation. These techniques included: linear unmixing and maximum likelihood classification methods based on the results of canonical discriminant analysis, neural networks, and classification strategies that combine different approaches. The best performing methods were also applied to three test zones in Africa.

4. OUTPUTS AND RESULTS

On the global scale, and quasi-operational:

- An innovative method for the compression of the immense data sets delivered by SPOT-VGT (or similar sensors)
- An update of the DISCover IGBP-classification of 1992/3, derived from the VGT-imagery of 1998/9 (product and method).
- In an experimental stage, and mainly tested for Europe:
- A comprehensive evaluation of the performance of different sub-pixel classification strategies applied at the continental scale (part of Europe covered by CORINE + three test zones in Africa)
- Sub-pixel proportion estimates for various Land cover classes at 1km x 1km and 10km x 10km resolution for the entire European continent
- Aggregated data on Land cover class proportions and maps of proportional error for 19 European countries, at the regional and national levels

5. EXECUTION

Period : 01/10/1999-30/06/2001

Laboratories :

VRIJE UNIVERSITEIT BRUSSEL (VUB)
Centre for Cartography and GIS
Department of Geography
Pleinlaan 2, B – 1050 Brussel, Belgium
Phone : +32 2 629 33 82 Fax : +32 2 629 33 78
E-mail : hdecleir@vub.ac.be
URL : http://www.vub.ac.be/DGGF/ccg/welcome.html

VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK (VITO)
Boeretang 200, B – 2400 Mol, Belgium
Phone : +32 14 33 68 46 Fax : +32 14 32 11 85
E-mail : frank.veroustraete@vito.be URL : www.vito.be

6. RELATED DISCIPLINES

Forest & natural vegetation
General Earth observation
Cartography

7. EXECUTIVE SUMMARY

Since 1998 the complete earth surface is daily scanned by the earth observation system SPOT-VEGETATION (VGT). Although this VGT-system is obviously inspired on the American example of NOAA-AVHRR, it offers some important advantages and new facilities. All registrations are immediately transferred to the central processing unit at VITO in Mol (Belgium), where they are corrected with standardised procedures and assembled into daily or 10-daily mosaics with global coverage and a resolution (pixel size) of 1km. Especially the 10-daily syntheses (S10) are highly appreciated because they offer a magnificent overview of the earth surface, in its actual state and with an unseen degree of detail – at least for such a vast area. The analysis of multitemporal series of VGT-S10 syntheses offers new opportunities for the timely extraction of information on biophysical state variables and dynamic processes taking place at the earth's surface.

This document presents the results of a two-years study performed by the Flemish Institute for Technical Research (VITO) and the Free University of Brussels (VUB), under sponsorship of the Belgian Science Policy Office (DWTC-SSTC). The study investigated to what extent the VGT-S10 imagery can be used for the extraction – by

means of automated classification procedures – of maps with the geographic distribution of the earth's main ecosystems (biome). Although traditional "hard" classification methods were considered as well, most attention was paid to modern "fuzzy" techniques which estimate the acreage proportion of the different terrain classes at the sub-pixel level. As a test data set, the EU Joint Research Centre in Italy (ISPRA) provided us with a full yearly set of global VGT-S10 images covering the period from April 1998 until March 1999.

In a previous research stage (*Canters et al.*, 1988), which only dealt with AVHRR-images, our first attempts to realise a global classification failed, due to the huge amount of data. As s consequence, in this second stage we first developed a procedure for "transversal data reduction" which compresses the yearly S10-series from 360 Gb to a more handy size of 30 Gb (8%) in a reversible way and with limited loss of information. All further operations can directly be applied on the resulting "pseudo-images") such that only the final classification has to be reconverted to the (space consuming) normal image format. In order to prepare the data set for classification purposes, a number of additional pre-processing steps were performed: elimination of cloud perturbations, addition of vegetation indices (a.o. the SWIR-based NDWI), and computation of new images with phenological information on a yearly basis.

An important part of the research was devoted to the development of methods for the interference of the sub-pixel class proportions from the VGT-S10 imagery. This topic was mainly elaborated for the European continent. Thanks to its diverse and fragmented landscape this is an excellent study area for the evaluation of the sub-pixel classification techniques on a continental scale. Moreover the CORINE land cover database represents an extensive high-resolution reference set, which is indispensable for the calibration and validation of the procedures. Various sub-pixel classification methods (linear unmixing, maximum likelihood, neural networks) were implemented and tried out on different legends with a varying number of classes. Experiments pointed out that the neural network approach yields the best results, especially as to the detection of the predominant class, and when the number of considered classes increases. An analysis of the proportional errors was performed on the results of the sub-pixel classification of Europe into 6 classes. For this evaluation, the original 1km pixels were considered as well as cells of 10x10km size. All this shows that the best result is obtained by the neural networks. However, the ML-classification with post-calibrated class-proportions produces comparable results. The mean proportional error per class calculated for the neural network strategy is maximum 21.6% on 1km resolution and 12.4% on 10km resolution. Proportion estimates were also aggregated to and mapped on the level of European regions and countries. This analysis showed that, although good results are obtained at the continental level, there are significant differences is accuracy between the regions.

From this, one could decide to use a stratified approach in future. The methods for sub-pixel classification developed for the European continent was also applied on three African regions. Even though the lack of sufficient high-resolution reference data did not permit reliable validation, the results showed that the proposed methods of this project are also applicable on other continents.

The development of a hard classification method for the characterisation of the biomes on a global scale was the last part of the research project. The above-mentioned data reduction made it technically possible to produce such a global classification. The proposed method consists of three essential parts: the classification is performed by means of a supervised decision tree algorithm, for the calibration and allocation the land surface is divided into 265 tiles of 1000km x 1000km which are treated separately, and in the allocation stage one has the choice between a normal classification or the actualisation of an existing reference map. In the latter case, only the most deviating pixels are detected and classified differently. The procedure was used to update the IGBP-DISCover-classification of 1992 (Loveland *et al*., 1992) with the recent imagery of 1998. Comparison of both global maps (AVHRR-1992 vs. VGT-1998) pointed out a degree of correspondence of 87%. Although part of the deviations observed on the remaining 13% of the area are probably due to misclassifications (in 1998 or in 1992), a number of "hotspots" can be discerned where real alterations seem to have occurred. These areas certainly deserve further inspection, either by field controls or by the analysis of high-resolution imagery. The methodology developed within the scope of this project is quasi operational, so that periodically updated global biome classifications could be offered as a standard VGT-product to the user-community.

FEASIBILITY STUDY T4/11/045

DETECTION OF INFECTION NIDUSES OF IPS TYPOGRAPHUS IN THE MINED FORESTS OF BOSNIA-HERZEGOVINA

E. WOLFF

UNIVERSITE LIBRE DE BRUXELLES (ULB)
INSTITUT DE GESTION DE L'ENVIRONNEMENT ET D'AMÉNAGEMENT DU TERRITOIRE (IGEAT)
Boulevard du Triomphe – CP 246
B – 1050 BRUXELLES
BELGIUM

1. CONTEXT AND OBJECTIVES

During the civil war, the forest of Bosnia-Herzegovina endured direct damage due to the fights and indirect damage resulting from poor management. These conditions favoured forest pests population increases, particularly for *Ips typographus*. In 1998, an estimated 500,000 ha of conifer forests was attacked at various degrees by this pest.Detection of the insects and their damage is particularly difficult in Bosnia-Herzegovina, especially because sanitary action is impossible in forest mined zones (8% in the Republika Srpska and 18% in the Federation).

In this context, high resolution and very high resolution remote sensing might be very useful to detect attacked trees in the mined areas and to determine the size of infestation spots. Moreover, multi-temporal remote sensing data might allow to characterise the yearly extension of attacked area, to assess the vitality of infestation foci and therefore to assess priorities in terms of de-mining and pest management.

2. DATA

Geographic study area: The survey area is located in the Northwest of Bosnia-Herzegovina in the region of Sipovo.

Satellite imagery used: 2 SPOT-4 images:

- kJ : 073-260 (26/06/1999)
- kJ : 073-261 (14/07/2000)

3. METHODOLOGY

The first phase constituted in the necessary data acquirement to the analysis (topographic map, mined area…). After, 125 forest sites were examined in 1999-2000, their geographical co-ordinates are being taken and all field data were characterised by the Infestation status, the tree cover and the slope.

The images have been geometrically corrected by orthorectification with a digital elevation model.

The different reflectance values were compared to the field-taken infestation status values for every wavelength, using a Kruskal-Wallis test.

Using a multiple linear regression analysis, the level of infestation (dependent variable) was also compared to the spectral bands (independent variables).

The second phase of the analysis concerns directly the treatment of the images (visual interpretation, NDVI, PCA).

We attempted to identify infested zones on the SPOT images with two different approaches: a supervised and a non-supervised classification.

4. OUTPUTS AND RESULTS

For the Kruskal-Wallis test and the multiple linear regression analysis, two analyses were performed. The first one considered all field observations. The second one addressed only the observations made in the pure Norway spruces stands, in order to decrease environmental heterogeneity.

The Kruskal-Wallis test detected only significant difference between infestation levels and reflectance values of the near infrared channel and middle infrared channel and this for all field observations; this is possibly a consequence of the small number of field observations.

The multiple linear regression however, showed a significant relationship between infestation levels and the near infrared channel data and middle infrared channel data. The relationship is stronger ($R^2 = 0.313$) in the pure Norway spruce stands than in the whole set of stands ($R^2 = 0.183$).

The NDVI analysis permitted to create a mask that only takes the forest zones and to eliminate the cloudy zones. We made several PCA with different combinations of spectral bands. Some of these neo - channels created could put in evidence some typical zones our images (road, spruces…).

For the supervised and a non-supervised classification, we made several classification tests, considering different spectral band associations. Each of these classifications was made either inside a mask taking the whole set of stands (conifers + broad-leafs), or inside a mask taking only the pure Norway spruce stands. Whatever the association of spectral bands and the mask used, we could not accurately locate the infested zones.

5. EXECUTION

Period: 01/07/1999-30/04/2001

Laboratory:

UNIVERSITE LIBRE DE BRUXELLES (ULB)
Institut de Gestion de l'Environnement et d'Aménagement du Territoire (IGEAT)
Boulevard du Triomphe – CP 246, B – 1050 Bruxelles, Belgium
Phone : +32 2 650 50 76 Fax : +32 2 650 50 92
E-mail : ewolff@ulb.ac.be URL : http://www.ulb.ac.be/igeat/

User partner:

PROSPECT C & S
Rue des Pierres 29, B – 1000 Bruxelles, Belgium
Phone : + 32 2 514 01 97 Fax : + 32 2 514 55 34

6. RELATED DISCIPLINE

Forest & natural vegetation

7. EXECUTIVE SUMMARY

Bosnia-Herzegovina is a state of Central Europe divided in two entities; the Srpska republic (49% of the territory) and the federation of Bosnia-Herzegovina (51% of the territory). The forest in Bosnia-Herzegovina represents a source of considerable incomes. The country spreads on 27 098km^2 of which 30% of conifers forests, either 53,4% of the total surface of the country.

During the civil war, the forest of Bosnia-Herzegovina endured direct damage due to the fights and indirect damage resulting from poor management. These conditions favoured forest pests population increases, particularly for *Ips typographus*. In 1998, an estimated 500,000 ha of conifer forests was attacked at various degrees by this pest. Detection of the insects and their damage is particularly difficult in Bosnia-Herzegovina, especially because sanitary action is impossible in forest mined zones (8% in the Republika Srpska and 18% in the Federation).

In this context, remote sensing might be very useful to detect attacked trees in the mined areas and to determine the size of infestation spots. Moreover, multi-temporal remote sensing data might allow to characterise the yearly extension of attacked area, to assess the vitality of infestation foci and therefore to assess priorities in terms of de-mining and pest management.

The objective of this survey is to show the technical and economic feasibility of the detection of attacked area by *Ips typographus* in Bosnia-Herzegovina, i.e. in zones where no human intervention could take place during several years (mined zones and therefore inaccessible) with multi - temporal satellite data to high spatial resolution (SPOT images), and to characterise these area with satellite data to very high spatial resolution (IKONOS images).

The decline of the forests, particularly, the forests of spruces, and the damages of scolytidae as *Dendroctonus ponderosae* on *Pinus ponderosa* or *Ips typographus* on *Picea abies* are studied for a long time in remote sensing. According to these studies, it results that a relatively precise classification of damages levels caused by the scolytidae is possible by remote sensing but it requires the integration in the analysis of complementary digitised data, like a digital elevation model and a land cover database most complete possible (species, age, structure, soil). Some studies also insist on the fact that the spatial resolution of the satellites to high spatial resolution (SPOT, LANDSAT) doesn't permit to work to scales superior to the 1/10000, what prevents to detect the small size zones. The hopes of detection of smaller infested area carry in the satellites to very high spatial resolution (IKONOS, EROS) putted recently in orbit.

This survey has been done in the setting of the project SSTC T4/11/45 with as partner user the Prospect C&S office.

The images used in our survey are two SPOT 4 images of June 26, 1999 and July 14, 2000. The survey area has been chosen on criteria of importance of the mined areas and of infested areas in 1998 and also on political criteria (zone astride the federation and the Srpska republic). This zone is located in the Northwest of Bosnia-Herzegovina in the region of Sipovo.

The first phase constituted in the necessary data acquirement to the analysis (topographic map, mined area…). After, the field area was explored twice, by car and afoot. 125 forest sites were examined in 1999-2000, their geographical co-ordinates being taken with a Trimble global positioning system (GPS) using differential correction.

The characteristics of the different sites were recorded, to be matched later with the remote-sensing data:

- Infestation status: trees attacked/unattacked; one/several trees attacked; standing/felled trees; needles present/absent;
- Tree cover: species; spatial structure; density; age; height of the trees;
- Slope: orientation; declivity; position of the site in the slope;

These field data, as well as the road network digitised from the topographic maps and the inaccessible zones to sanitary action has been integrated in a GIS.

The images have been geometrically corrected by orthorectification. The digital elevation model that was needed for this was created by digitising the contour lines on available the 1:25,000 topographic maps of the survey area. By this method, the mean quadratic error is 0.45 pixel in X and 0.47 pixel in Y.

The analysis of correlation and regression are the most common methods to compare the parameters studied to their values of corresponding reflectance.

The different reflectance values were compared to the field-taken infestation status values for every wavelength, using a Kruskal-Wallis test.

Two analyses were performed. The first one considered all field observations. The second one addressed only the observations made in the pure Norway spruces stands, in order to decrease environmental heterogeneity. Using a multiple linear regression analysis, the level of infestation (dependent variable) was also compared to the near infrared channel and middle infrared channel (independent variables).

The Kruskal-Wallis test detected only significant difference between infestation levels and reflectance values of the near infrared channel and middle infrared channel and this for all field observations; this is possibly a consequence of the small number of field observations.
The multiple linear regression however, showed a significant relationship between infestation levels and the near infrared channel data and middle infrared channel data. The relationship is stronger ($R^2 = 0.313$) in the pure Norway spruce stands than in the whole set of stands ($R^2 = 0.183$).

The second phase of the analysis concerns directly the treatment of the images. The two images SPOT underwent a heightening of contrast named " root " in order to discriminate the different zones of our images. The visual analysis of the images permitted us to distinguish the big forest zones (broad-leaved forest, conifers, mixed), the urban zones, the big road axes as well as the reservoirs of water and the fluvial axes. It also permitted us to distinguish some thick clearer zones in the forests of conifers, of which some corresponded to important zones of infestation on the field.

We used a vegetation index (NDVI) in order to put in evidence the vegetable zones of our images. It permitted us to create a mask that only takes the forest zones identified from a threshold value of NDVI (validated on visual identification basis). It also permitted us to eliminate the cloudy zones of the image SPOT from the year 2000. We wanted to compare the NDVI of the two images also. Although the images have not been taken at the same date, we could put in evidence some zones where the NDVI had lowered between 1999 and 2000 more than 0.1 (6% of the data) and we compared them at the zones defined like infested in our summaries. Only two of the infestation data were in these zones where the NDVI had lowered strongly between 1999 and 2000 but only one of them had been defined like infested in the year 2000.

The previous results showed the interest of the middle infrared and his relationship with the level of infestation. We created a new spectral band from a ratio (near infrared / middle infrared) based on the different spectral properties of these two wavelengths on the plant cover. We made several "Principal Component Analysis" (PCA), first on all channels of the two images as well as on their NDVI and their ratio " near infrared / middle infrared", afterwards, two other one on this same channels but for every images taken separately. Some of these neo - channels created could put in evidence some typical zones our images (road, zones of spruces, mixed zones, broad-leaves).

Before to evaluate the possibility to use high spatial resolution remote sensing in the detection of attacked Norway spruces by *Ips typographus*, it seemed indispensable to appreciate its possibility to distinguish the trees species in the forest. We created 3 classes of information inside the forest zone; a class taking the pure Norway spruce zones, a class taking the whole set of stands [conifers (Norway Spruces/firs) + broad-leafs (mainly beech] and a class taking the zones of broad-leaves only. These classes have been defined by threshold in the diagram of scattering between the PC1 and PC3 of the images 1999 and 2000 and have been validated by the visual interpretation and by comparison to the field data. The kappa is of 0,79. What is a satisfactory result although the zone " pure Norway spruce " is unevaluated. These classes of vegetation will be used thereafter like mask in the analysis.

The road network is comfortably visually recognisable on both images (1999 and 2000). We wanted to know if it was possible to isolate it numerically. The road network has been identified numerically by a non-supervised classification on the third first principal components of the picture 1999 (255 taken classes in account). In this classification, we didn't have problems to isolate the main road network in tarmac. On the other hand, the track road network doesn't have been isolated correctly. Indeed, it merged with the surrounding herbaceous zones.

We attempted to identify infested zones on the SPOT images with two different approaches: a supervised and a non-supervised classification.
For the two approaches, we made several classification tests, considering different spectral band associations. Each of these classifications was made either inside a mask taking the whole set of stands [conifers (Norway Spruces/firs) + broad-leafs (mainly beech], or inside a mask taking only the pure Norway spruce stands.
Whatever the association of spectral bands and the mask used, we could not accurately locate the infested zones.

Paradoxically, no very high spatial resolution remote sensing images (IKONOS) can be used in this feasibility survey and this regardless of our responsibility (problems with Space Imaging Europe Company).
The treatment of SPOT images allowed to cartography the types of vegetation and the main road network. This survey didn't permit us unfortunately to delimit infested areas with SPOT images.

The relatively low spatial resolution of these images (20m) is certainly one important explanatory element. Other factors are certainly the relative poorness of the available land cover data, the digital elevation model which was not adapted to the resolution of the SPOT images (its scale should have been inferior to 1: 20 000) and a too small set of field observations. We think that the detection of the infested areas of *Ips typographus* with SPOT and IKONOS images would be possible but it would require the integration in the analysis of a digitised land cover database most complete possible, of a digital elevation model adapted to the resolution of the SPOT (scale < 1:20,000) and IKONOS (scale < 1:10,000) images and a important collaboration with the foresters (especially for identification of the infested areas).

FEASIBILITY STUDY T4/10/046

CONTRIBUTION OF VHR IMAGERY TO THE CHARACTERISATION OF POPULATION, AND MORE IN PARTICULAR OF THE CARRYING CAPACITY FOR LARGE WILD HERBIVORES IN THE FORESTS OF THE WALLOON REGION

P. DEFOURNY

UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL)
DEPARTMENT OF ENVIRONMENTAL SCIENCES AND LAND USE PLANNING - GEOMATICS
Place Croix du Sud 2 bte 16
B – 1348 LOUVAIN-LA-NEUVE
BELGIUM

1. CONTEXT AND OBJECTIVES

The Division of Nature and Forests of the Walloon Region is in charge of managing the red deer populations. To that end, shooting plans of each area where red deer occur must be defined with respect to a sustainable forest balance and according to multiple use forest management.

A relevant planning definition requires the information on the game density and the red deer carrying capacity. The last information is assessed by the "ability index", built upon following parameters: soil, forest, food and shelter distribution, quietness, displacement abilities and topography.

The objective of this study is to demonstrate whether very high resolution images are relevant tools for providing missing information, e.g. forest structure and leaf area index, in building the "ability index".

2. DATA

Geographic study area: St-Hubert Forest (Belgium)

16 000 ha located in the forest districts of St Hubert and Nassogne.

Satellite imagery used: SPOT-4 XS - 14/08/1999

Other data:

- DTM
- Panchromatic aerial photographs from 1995 scanned at 1-m resolution. No stereoscopic pairs
- Colour aerial photographs (1/10 000) from 1999 with an overlap of 60 %
- Data on forest planting from the Division of Nature and Forests

3. METHODOLOGY

- Data collection (field inventory, aerial photographs and satellite images)
- Pre-processing of the images (geometric and radiometric correction)
- Sensitivity analysis of the reflectance with respect to different site
- Characteristics (topography and vegetated surface)
- Iterative thematic processing (thresholding, textural analysis, classification,…)
- On a well documented area
- Validation of the processing on an a priori undocumented area
- Extension of the methodologyCost/benefit analysis and methodological recommendations

Software's used: Easi/Pace (PCI Geomatics) and ArcView (ESRI Corp.).

4. OUTPUTS AND RESULTS

The products provided by this project consist in a new map and a GIS layer (produced from the interpretation of the SPOT image). The map will display the composition and the forest cover rate, and the GIS layer will provide information related to the light penetration through the canopy.

Methodological recommendations

This experiment showed that the multispectral SPOT image allowed identifying:

- For spruce plantations, three classes upon their age and two classes of canopy cover rate; the other resinous species were not considered in this study, because of their marginal proportion inside the clump.
- For broadleaf plantations, two classes of canopy closure.

Nevertheless, the plantations on slopes steeper than 10° show directional effects which require a specific processing.

In order to extract in an optimal way information about the specific composition and the forest cover rate, the study proposes the following method robustness and efficiency:

- Delimiting the clump under investigation, either by visual interpretation on screen, or by exploitation of existing data.
- Determining the forest/no forest mask by unsupervised classification to identify the pixels of the clump which are not vegetated (roads, bare soils, ponds, etc.).
- Unsupervised classification under the forest/no forest mask to distinguish between broadleaf plantations, young spruce plantations, mature spruce plantations, other coniferous trees and the opened canopy areas (clear cutting, felling areas, young plantations, etc.) which are the first class of the canopy closure.
- Visual delimitation or automated delimitation, assisted by a visual interpretation, of the two other classes of the canopy closure within the broadleaf plantations and the spruce plantations.

5. EXECUTION

Period: 01/06/1999-31/10/1999

Laboratory:

UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL)
Department of Environmental Sciences and Land Use Planning - Geomatics
Place Croix du Sud 2 bte 16, B – 1348 Louvain-la-Neuve, Belgium
Phone : +32 10 47 23 74 Fax : +32 10 47 88 98
E-mail : defourny@mila.ucl.ac.be URL : http://www.enge.ucl.ac.be/

User partner:

MINISTERE DE LA REGION WALLONNE
Direction générale des Ressources naturelles et de l'Environnement,
Centre de Recherches de la Nature, des Forêts et du Bois (CRNFB)
Laboratoire de la Faune sauvage et de Cynégétique
Avenue prince de Liège 15, B – 5100 Jambes, Belgium
Phone: + 32 81 33 50 50 Fax: + 32 81 33 51 22
E-mail: dgrne@mrw.wallonie.be
Contact person **:** Prof. de Crombrugghe

6. RELATED DISCIPLINE

Forest & natural vegetation

7. EXECUTIVE SUMMARY

The Division of the Nature and the Forests (DNF) of the Walloon Region (RW) is in charge of managing the *Cervidae* populations. In this context, the DNF must define annually the shooting plans of each game-area of the RW where red deer populations occur. This planning must be done with respect to the sustainable forest balance and according to multiple use forest management. A relevant planning definition requires the knowledge of wildlife behaviour and basically, two main information type: the game density and the *Cervidae* carrying capacity of the area. This last information can be assessed by an index (the ability index) which has been defined by the Research Centre for Nature, Forests and Wood (CRNFB) of the RW and is built from the assessment of several criteria: namely the soil, the forest, the food and shelter distribution, the quietness and the displacement facilities.

Within the study area (the 16.500 ha of the forest of St-Hubert) the CRNFB has already assessed and mapped some of these criteria. However, for others, the assessment of variables such as the light penetration through the canopy and the forest cover rate at a relevant scale and resolution are required.

The objective of this study is thus, to demonstrate that remote sensing is an alternative to field works and interpretation of aerial photographs for providing the information related to the light penetration and the forest cover rate.
The image used for this study consist of a SPOT 4 image acquired the 14th august 1998. Black and white aerial photographs of 1995 scanned at a 1m resolution were used by the CRNFB to classify the forest cover rate. The same exercise has been made on recent (June 1999) colour aerial stereo photographs.

The methodology relies on several steps:

- Data collection (field inventory, GIS layers, aerial photographs and satellite images)
- Pre-processing of the images (geometric correction)
- Sensitivity analysis of the reflectance with respect to different site characteristics (topography and vegetated surface)
- Iterative thematic processing (thresholding, textural analysis, classification,…) on a well documented area
- Validation of the processing on an *a priori* undocumented area
- Extension of the methodology
- Methodological recommendations

The results of this feasibility study consist in a new map and GIS layers for one part and in a sensitivity analysis and methodological recommendations for the other part.
The map is derived from the SPOT image and represents the forest of ST-Hubert classified on the bases of the specific composition and the forest cover rate. Even aged plantation of spruce (*Picea abies* (L.) Karst) have been classified in three classes upon their age. The canopy cover rate of young spruce plantation is classified in the "opened canopy". After more or less 10 years the canopy cover reaches the "closed canopy" class and this till the logging of the parcel except if local damages occur (e.g. storms damages). The broadleaf parcels are generally composed of trees of different ages. Therefore they could not be classified on the bases of the age of the parcel. Two classes of canopy closure rate can be identifiable and classified by on-screen digitalisation. This could be done on parcels installed on ground with slope under 10°.

FEASIBILITY STUDY T4/67/057

PRODUCTION OF A LAND COVER MAP OF CENTRAL AFRICA DERIVED FROM SPOT 4 – VEGETATION DATA

J. VAN RENSBERGEN

VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK (VITO)
Boeretang 200
B – 2400 MOL
BELGIUM

1. CONTEXT AND OBJECTIVES

METAFRO, the information system of the Royal Museum for Central Africa, is interested in the creation (and possibly the yearly update) of a medium resolution land cover map of the Central African region. The product should also be available in vector format, because it has to serve as background base map for the execution of geographical queries on the meta-database of the METAFRO project.

The required land cover map will be produced at 1 km² resolution, based on a full year of NDVI-syntheses (36 consecutive 10-day composites), provided by SPOT4-VEGETATION. The proposed methodology has already been implemented with success on similar data sets of NOAA-AVHRR.

2. DATA

Geographic study area:

- The complete territory of the 8 target countries to be mapped: Burundi, Cameroon, Central African Republic, Congo-Brazzaville, Congo-Kinshasa, Equatorial Guinea, Gabon and Rwanda.
- The Angolan enclave Cabinda, which will also be considered in the map
- Parts of the neighbouring countries, which will not be included in the classification: Nigeria, Chad, Sudan, Uganda, Tanzania, Zambia and Angola.

Satellite imagery used:

INFORMATION LAYER	SOURCE	GOALS	PROJECTION
36 decadal syntheses of SPOT4-VEGETATION over Central Africa (April 98-March 99)	EOWORKS (Benelux-dealer of VGT-products)[1]	Primary image data for the land cover classification	WGS84-Lon/Lat (1/112)°-resolution

1. http://www.eoworks.vito.be/

Other data:

INFORMATION LAYER	SOURCE	GOALS	PROJECTION
Digital Elevation Model (DEM)	Africa Land Cover Characteristics Database (USGS)[2]	Additional image variable for the land cover classification	NAD27-Interrupted Goode Homolosine 1km-resolution
TREES "Vegetation Map of Central Africa" digital version + documentation	JRC, Ispra – Italy Monitoring of Tropical Vegetation Unit[3]	Reference data (ground truth) for the calibration and validation of the new classification	WGS84-Lon/Lat (1/100)°-resolution
Vectorial coastlines and territorial boundaries	ESRI – Digital Chart of the World (DCW)[4]	Additional feature on hardcopy maps	NAD27 – Lon/Lat High resolution
Vectorial course of main rivers and roads	JRC, Ispra – Italy Monitoring of Tropical Vegetation Unit[3]	Additional feature on hardcopy maps	WGS84 – Lon/Lat High resolution
Vectorial boundaries of the administrative units (regions, provinces)	ArcView CD-ROM "ESRI Data & Maps"	Computation of regional statistics	NAD27 – Lon/Lat Low resolution

2. http://www.edcwww.cr.usgs.gov/landdaac/glcc/afdoc.html
3. http://www.trees.gvm.sai.jrc.it/
4. http://www.lib.ncsu.edu/stacks/gis/dcw.html

3. METHODOLOGY

- A supervised classification scheme applied on the seasonal/phenological information extracted from the original NDVI-images.
- A raster-to-vector conversion by "on-screen digitisation" of the discerned land units.

4. EXECUTION

Period: 01/07/1999-30/09/1999

Laboratory:

VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK (VITO)
Boeretang 200, B – 2400 Mol, Belgium
Phone : + 32 14 33 55 11 Fax : + 32 14 33 55 99
E-mail : vito@vito.be URL : www.vito.be

User partner:

MUSEE ROYAL DE L’AFRIQUE CENTRALE (MRAC)
Leuvensesteenweg 13, B – 3080 Tervuren, Belgium
Phone : + 32 2 769 52 11 Fax : + 32 2 769 56 38
E-mail : info@africamuseum.be

5. RELATED DISCIPLINE

Forest & natural vegetation

6. EXECUTIVE SUMMARY

This document presents a new vegetation map of Central Africa, valid for the year 1998 and covering 10 general land cover classes. The map was derived from a full year cycle of 10-daily syntheses of the 1km-resolution earth observation system SPOT4-VEGETATION. The image pre-processing included the following operations: elimination of the severe cloud perturbations, extraction of time series with the Soil Adjusted Vegetation Index (SAVI) and computation of images with more informative phenological variables such as the annual SAVI-mean, the annual SAVI-extremes, a seasonality index and the length of the growing season.

The new vegetation map was realised by applying a Maximum Likelihood classifier on this set of phenological images. The algorithm was calibrated with ground truth extracted from the well-known JRC TREES-map, which depicts the land cover situation around the year 1992. The a priori probabilities were tuned in such a way, that the classification was based for 50% on the situation in 1992 (TREES) and for 50% on the image-derived phenological information of 1998. In this light, the present map should not be considered as a "new", stand-alone product but rather as an update of the TREES-map of the JRC.

The correspondence between both years (1992, 1998) amounts to 89%. Although part of the deviations observed on the remaining 11% of the area are probably due to mis-classifications, a lot of deforestation "hotspots" are manifested which deserve further inspection, either by fields controls or by the analysis of high resolution imagery.

CHAPTER II

AGRICULTURE

PILOT PROJECT T4/42/011

DEVELOPMENT AND LAUNCHING AT THE NATIONAL SCALE OF A MULTI USES DATABASE COMBINING AERIAL PHOTOGRAPHS AND SATELLITE IMAGERY

G. DAUTREBANDE

CENTRE DE RECHERCHES AGRONOMIQUES DE GEMBLOUX (CRAGX)
STATION DE PHYTOPATHOLOGIE - CTS
Rue de Liroux 9
B – 5030 GEMBLOUX
BELGIUM

1. CONTEXT AND OBJECTIVES

Actually, the Belgian Ministry of Agriculture (DG3) dispose, in particular, of a database management system of aerial photographs and of all the numerical orthophotos of Belgium (at a resolution of 1 meter and dated 1995). The database has been developed for the implementation of the Integrated Administration and Control System (IACS), the system concretising the regulation of the new Common Agricultural policy (CAP).

Up to now, this system has given full satisfaction. Consequently the Ministry would like to dispose of functionality's necessary to manage imageries of satellites. Such a development is considered in order to totally integrate the remote sensing control of the farmer's applications in the IACS. The main objectives of this integration to the IACS would be the efficacy increase and the cost decrease of the annual control by remote sensing. In particular, that should conduct to the following strategic advantages for the DG3:

- Maximal operational and computer integration of the control by remote sensing in IACS
- Maximal automation of computing processes
- Early remote sensing control diagnoses
- Computing development amortise thanks to variable applications

2. DATA

Geographic study area: Belgium
Satellite imagery used: SPOT, IRS 1C, LANDSAT
Other data: Aerial photographs, scanned maps

3. METHODOLOGY

In case of collaboration with the SSTC through the pilot project, DG3 would wish to develop a numerical imageries management system with the following properties:

- Geometrical adjustment of all type of useful imageries to the Belgian Lambert 72 referential
- System covering at least all Belgian territory, with possibilities all over the world.
- Capacity to manage multi-levels data's (multi-sensors, multi-bands, multi-resolution, multi-dates)
- Access to data's through a client-server computer model
- Storage of imagery descriptive data's (metadata)
- Input and output compatibility with classical imagery formats and commercial software.

4. OUTPUTS AND RESULTS

The final product consists of a relational database, a Unix (or NT) image server (daemon) and an administrative client application to manage the database.

- The relational oracle database store the images information (Acquisition date, satellite, sensor, localisation, quality,) and the access path to the imagery file;
- The Unix (or NT) server contains the images files and the tools to import, consult, update and delete images;
- The client interface allows to manage users, layers and images. It's possible through this tool to import images (in various format), to consult the catalogue and display images, to export images (in a raw format), to update metadata, etc.

5. EXECUTION

Period: 01/12/1996-31/03/1999

Laboratory:

CENTRE DE RECHERCHES AGRONOMIQUES DE GEMBLOUX (CRAGx)
Station de Phytopathologie - CTS
Rue de Liroux 9, B – 5030 Gembloux, Belgium
Phone : +32 81 62 65 91 Fax : +32 81 62 65 98
E-mail : gilles.dautrebande@cmlag.fgov.be

User partner:

MINISTERE DES CLASSES MOYENNES ET DE L'AGRICULTURE, DIRECTION DE LA GESTION DE LA PRODUCTION AGRICOLE (DG3)
Avenue Prince de Liège 7, B – 5100 Namur, Belgium
Phone : + 81 33 50 50 Fax : + 81 33 53 44
E-mail : dga@mrw.wallonie.be

6. RELATED DISCIPLINES

Agriculture
Environment
Hardware & software

7. EXECUTIVE SUMMARY

This project follows after two previous projects, one carried out at Catholic University of Leuven (KUL) and the other carried out at the University of Gent. These projects lie within the same framework and must provide the Belgian Ministry of Agriculture with

tools needed to achieve encoding, update and control of farmers' area declaration. The objective of this project is to conceive and to develop a relational database intended to store satellite images and aerial photographs.
The Integrated Administration and Control System (IACS) has being progressively set up since 1993, following up the reform of the Common Agricultural Policy (CAP). It has become entirely operational since 1996. The farmers who want to get European aids have to submit a file containing, namely, the localisation of their parcels, the sown crops and the aid regime asked for. Then, the data are encoded in a Geographical Information System (GIS), mainly developed by in-house computer scientists.
The Ministry uses a panchromatic aerial cover of the country as cartographic reference. This cartographic background allows to localise the declared agricultural parcels and to assess their area accurately. However, these images have never been used during their year of acquisition and cannot be used to determine the cultivated crops because of the crop rotation from one year to the next. Thus, the Ministry uses satellite images taken during the crop growth and controls the declaration by means of procedures of automated classifications of the satellite images.
The needs of the Ministry have evolved quickly. It became necessary to develop a database allowing storage and rapid access to this new volume of data (aerial photographs and their regular update, satellite images, cartographic backgrounds from the National Geographic Institute,).
The project progressed in several steps. Firstly, a need analysis allowed defining a metadatabase. Significant information, such as dates of images and photographs, spatial resolution, channels, information about geometric corrections and geo-referencing, were stored in a relational database. Secondly, the software structure was defined and a functional analysis was performed. Two final applications were analysed: (i) the management of the database (images import/export, security, statistical analysis of image uses); (ii) an integration application. This last application aimed at consulting and displaying the images coming from the new tool. So, these images can be overlaid with the data of IACS (agricultural parcels, boundaries of agricultural regions). Thirdly, computer developments were performed and the applications were tested.

In conclusion, the project was a complete success. It provided the Ministry with a new high-performance tool. The client/server structure of the application allows the employees of the provincial offices to access efficiently to the different images. The declaration support given to the farmers was highly improved and the control operations imposed by the European Commission became more and more efficient.

PILOT PROJECT T4/DD/012

STUDY OF SALT INTRUSION, LAND USE AND RICE CROP IN THE COASTAL PLAIN OF THE MEKONG DELTA (VIETNAM), BASED UPON FIELD WORK, REMOTE SENSING AND GIS

M. DE DAPPER

UNIVERSITEIT GENT (RUG)
DEPARTMENT OF GEOGRAPHY
Krijgslaan 281 Gebouw S8/A1
B – 9000 GENT
BELGIUM

1. CONTEXT AND OBJECTIVES

The development of the Mekong delta is an urgent matter for the Vietnamese authorities. It is aimed to improve the cultivation of rice in order to meet the food supply for the increasing population and to stimulate the export facilities for rice. Moreover, large-scale public works are foreseen, including the deepening of the estuary to improve the accessibility of the area. The coastal plain of the Mekong Delta is subject to a severe degree of salt penetration through the major rivers (Mekong, Bassac,...) and creeks that infiltrates in the soil. These salty intrusions form a limiting factor for the development of the rice cultivation.

HAECON n.v. is studying the possibilities for the deepening of the estuary. Questions arise what will be the implications of this deepening on salt intrusions and the agricultural production in general, and for the rice production more specifically. Therefore a better knowledge and mapping of the land use, with emphasis on rice cultivation, is needed.

This project aimed to build a user-friendly tool for the detection and the modelling of salt water penetration in macro-estuary characterised by a tropical hydrology and to evaluate the usefulness of remote sensing in the research of hydro-sedimentological processes of prodeltas.

2. DATA

Geographic study area: Mekong delta (South Vietnam)

Satellite imagery used:

1. LANDSAT Thematic Mapper (date: 06/01/1997)
   Path/row: 125/053
2. Multitemporal set of ERS-2 PRI images
   - 25 May 1997 orbit: 10951
   - 03 Aug 1997 orbit: 11953
   - 12 Oct 1997 orbit: 12955
   - 21 Dec 1997 orbit: 13957

Other data: Topographical maps (scale 1/50 000, 1/10 000 and 1/5 000), agro-climatological map (scale 1/250 000), soil map (1/250 000)

3. METHODOLOGY

Literature review to define the system requirements for remote sensing and GIS in function of saline water intrusion in estuary and delta-system of the humid-tropics.

Fieldwork to:

- Define the relation between saline intrusion, land use/land cover and geomorphology,

- Set up an interpretation key for supervised classification and (3) measure the salinity, speed and sediment load in the Bassac River.
- Preparation of the GIS in ILWIS and ER-MAPPER, including: topography, soil type, salinity intrusion, influence of tides, land use/land cover. These layers will be used to set up the basic scenario for the Mekong delta regarding the salinity intrusion.
- Application of radar-technology for the mapping of the hydrosedimentological evolution in the Mekong delta and prodelta (inundated areas, sediment plumes): Supervised image classification and calculation of change indices.

4. OUTPUTS AND RESULTS

The starting point for the basic scenario regarding the salinity intrusion is the salinity model obtained through the TELSAT III program (Ismailia, Egypt). This model had to be adapted since the source of salinity does not correspond with the salinity source in the Mekong delta. Additional information necessary in the model is: influence of tides (distance to the South-China Sea), influence of intrusion (distance to the main rivers - Mekong and Bassac). During the two field campaigns, it became clear that salinity problems occur mainly in the depressions bordered by sandbars (former coastal ridges). These areas are restricted for the cultivation of rice (one crop/year). The model for salinity intrusion is set up for a test area to the NE of Can Tho. For this area topographical maps (with altitude indications in dm) were available. The obtained result showing zones with high probability for salinity intrusion corresponds to a large extent with the ground truth (field survey). One of the major restrictions in the model is the need for highly detailed altitude information (because of extremely level character of the land and the importance of micro-relief).
Deliverables: model of salt-water intrusion, (analogue/digital maps): DEM, soils, land use/land cover, inundation, 3D views.

5. EXECUTION

Period: 15/12/1996-31/10/1997
Laboratory:
UNIVERSITEIT GENT (RUG)
Department of Geography, Krijgslaan 281 Gebouw S8/A1, B – 9000 Gent, Belgium
Phone: +32 9 264 46 90 Fax: +32 9 264 49 85
E-mail: Morgan.DeDapper@rug.ac.be URL: http://www.admin.rug.ac.be

User partner:
HAECON N.V.
Deinse steenweg 110, B - 9031 Drongen, Belgium
Phone: + 32 9 216 63 63 Fax: + 32 9 227 61 05
E-mail: haecon@haec URL: www.haecon.be
Contact person: Ir. C. De Meyer

6. RELATED DISCIPLINES

Oceans & coasts
Geology & soil
Hydrology & freshwater resources
Agriculture
Environment
Natural hazards & disasters
General Earth observation

7. EXECUTIVE SUMMARY

Estuaries and delta are extremely vulnerable ecosystems: very fertile and subject to high population pressure. This threat is imminent in some developing countries that must expend and intensify the agricultural production because of development and of increasing population. This can lead to problems such as saline water intrusion. The development of the Mekong delta is an urgent matter for the Vietnamese authorities. It is aimed to improve the cultivation of rice in order to meet the food supply for the increasing population and to stimulate the export facilities for rice. Besides, also the increase of employment is foreseen. Therefore, large-scale public works are foreseen, including the deepening of the estuary to improve the accessibility of the area. The coastal plain of the Mekong Delta is subject to a severe degree of salt penetration through the major rivers (Mekong, Bassac) and creeks that infiltrates in the soil. These salty intrusions form a limiting factor for the development of the rice cultivation (from 1 time a ear to 2-3 times a year).

PILOT PROJECT T4/12/021

APPLICATION OF REMOTE SENSING FOR MONITORING A SUSTAINABLE CONTROL OF ANIMAL TRYPANOSOMIASIS IN TOGO

R. DE WULF

UNIVERSITEIT GENT (RUG)
FACULTY OF AGRICULTURAL AND APPLIED BIOLOGICAL SCIENCES
LABORATORY OF FOREST MANAGEMENT AND SPATIAL INFORMATION TECHNIQUES
Coupure Links 653
B – 9000 GENT
BELGIUM

1. CONTEXT AND OBJECTIVES

The task of the TELSAT4 project is to contribute, through means of data obtained from remote sensing, to prepare a rational programme for the integrated control of animal trypanosomiasis. Satellite images offer a feasible opportunity in supporting the monitoring of impacts on the land use by suppression actions and enable the maintenance of an 'early warning system' to prevent the carrying capacity of the land being exceeded. The TELSAT project forms the base for a future extension of the methodology to the entire West African region based on images from the SPOT VEGETATION satellite, launched in 1998.

The project consequently deals with following topics:

- Preparation of a recent nation wide land cover map of Togo (RESURS01).
- Change detection of land cover and land use based on a time series (10 years) of TM images.
- Preparation of a fragility index for three priority areas in the north of Togo, concerning the integration of agriculture and stock breeding, based on parameters derived from satellite images and field measurements.

2. DATA

Geographic study area: West Africa, North of Togo, Region of Savannas, L'Oti and Kara

Satellite imagery used: LANDSAT TM (193/053 - 21/05/1995; 194/052 - 09/05/1995; 194/053 - 09/05/1995; 194/052 - 29/12/1986; 194/053 - 29/12/1986; 153/053 - 22/12/1986) and RESURS01 - MSU-SK scene (mapping service)

Other data: Topographic maps, soil maps, cattle density, agricultural statistics of Togo, vegetation map, degradation map, prevalence of Glossina sp., digitised cantons in Togo, SPOT Vegetation image, NOAA AVHRR.

3. METHODOLOGY

- Image rectification and radiometric correction,
- Digitising of cartographic data and creation of a Digital Elevation Model for the test sites,
- Supervised classification of the LANDSAT TM and RESURS image, based on field verification measurements (GPS positioning) - extending the field control point database with corresponding photographs,
- Change vector analyses and image differencing applied to LANDSAT TM and time series of NOAA AVHRR,
- Calculation of NDVI images for the test sites,

- Creation of a database for the application units of each test site and construction of the data matrix,
- Preparation of a monitoring system that ranks application zones (regions where control actions against trypanosomiasis are considered) according to their priority for intervention based on fuzzy relational calculus.

4. OUTPUTS AND RESULTS

- Digital Elevation model for the north of Togo,
- Digital soil map for the Region Kara,
- Database of available information Region Savannas, L'Oti and Kara,
- Recent land cover map for the whole country of Togo with corresponding
- Database of photographs,
- Land cover maps for the test sites,
- Map indicating seasonal and long-term change in the region, effect of control practices on changes in land cover.
- Map of ranked application units according to their fragility. Those application units that are high ranked have environmental conditions, which allow further cattle breeding and have still the potential of raising the animal production when care is taken to integrate the present agricultural practices with stockbreeding. Those application units that are low ranked are areas where degradation has set in and forms the limiting factor for animal production.
- Flexible monitoring system for the determination of priority areas for control measures, based on fuzzy set theory. This system is not time or space specific, works for all kinds of environmental problems and allows alteration of the decisive parameters and their degree of influence when changes in the environment occur.

A description of the results can be found at
http://allserv.rug.ac.be/~nvancamp/index.html

5. EXECUTION

Period: 15/12/1997 - 31/12/99

Laboratory:

UNIVERSITEIT GENT (RUG)

Faculty of Agricultural and Applied Biological Sciences

Laboratory of Forest Management and Spatial Information Techniques

Coupure Links 653, B – 9000 Gent, Belgium

Phone: +32 9 264 61 10 Fax: +32 9 264 62 40

E-mail: Robert.DeWulf@rug.ac.be

URL: http://allserv.rug.ac.be/~fvncoill/index.html

6. RELATED DISCIPLINES

Forest & natural vegetation

Agriculture

Environment

Natural hazards & disasters

7. EXECUTIVE SUMMARY

In the past, actions taken to control trypanosomiasis concentrated on one particular method at a time. This could be suppression of the vector, use of more tolerant species or the use of chemicals. The projects were mostly on a very large scale, with foreign aid, but seldom offered a sustainable solution. Trypano-tolerant species appeared to be less appreciated by the farmers since they produced less milk or tractive power. With trypanocides problems of local availability, misuse, difficult preservation, bad quality and resistance of some trypanosome strains arose. As a consequence the animal trypanosomiasis remained a tremendous obstacle for the development of animal husbandry and integrated agriculture in large parts of Africa.

Today a sustainable multidisciplinary control of animal trypanosomiasis is preferred over area wide eradication of the tsetse fly. This implies mapping of the environmental stability and requires continuous monitoring. Areas where the environment limits animal production cannot be assigned priority for disease control activities. The inherent vague problem of ranking areas according to their fragility arises. In practical situations there is rarely a crisp boundary between fragile and non-fragile land entities. Furthermore, deciding if a certain parameter augments or decreases the fragility cannot be evaluated with the classical logical system (binary: o or 1). Therefore, to improve representation of such geographical information, another type of membership concept than the one of classical set theory has to be used. Such a concept is provided by the fuzzy set theory, where

parameters describing such problems are assigned grades between 0 and 1 by continuous membership functions. Logical operations on these fuzzy sets enable the hierarchic ranking of environmental entities.

In the Kara and Savannas experimental regions (Northern Togo) a methodology based on this technique is created to define the fragility of application units and according priority for trypanosomiasis control. The parameters per unit are derived from satellite images (LANDSAT TM) and other physical land resources and are stored in a relational database. The attributes are converted to fuzzy values between 0 and 1 (characteristic matrix) depending on the degree of stability enhancement for a unit. Subsequently the fuzzy relations "square-product" and 'sub-product" reveal redundant parameters and rank the application units according to their fragility.

Those who have gained a high ranking come first when control measures are taken against trypanosomiasis, while those with a low ranking represent areas where the limiting factor for animal production id the fragility of the environment. The latter will not render any surplus in agricultural production when control measures are taken against animal trypanosomiasis and do not gain priority when treatment is considered.

This methodology indicates a knowledge–based approach and allows application in different locations of time and space and for all kinds of vector born diseases. With fuzzy relational calculus, a mathematical basis is constructed to deal with all kinds of problems where the "fuzziness" of natural environment cannot be neglected. This introduces a considerable advantage for the manipulation of relational databases in expert systems that support decision-making.

The overall methodology prepared in this project offers the opportunity to extend an integrated trypanosomiasis suppression and maintain a permanent monitoring system for the whole West African region.

PILOT PROJECT T4/DD/023 (a-b-c)

ADAPTATION OF THE EUROPEAN AGRICULTURAL PREVISION SYSTEM TO THE BELGIAN CONDITIONS

R. OGER [(2)]

B. TYCHON [(1)]

F. VEROUSTRAETE [(3)]

FONDATION UNIVERSITAIRE LUXEMBOURGEOISE (FUL) [(1)]
UNITÉ EAU ET ENVIRONNEMENT
Avenue de Longwy 185
B – 6700 ARLON
BELGIUM

CENTRE DE RECHERCHES AGRONOMIQUES DE GEMBLOUX (CRAGX) [(2)]
BIOMÉTRIE, GESTION DES DONNÉES ET AGROMÉTÉOROLOGIE
Rue de Liroux 9
B – 5030 GEMBLOUX
BELGIUM

VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK (VITO) [(3)]
Boeretang 200
B – 2400 MOL
BELGIUM

1. CONTEXT AND OBJECTIVES

The aim of the Belgian Crop Growth Monitoring System project (B-CGMS) is the elaboration of an integrated information system providing reliable, timely and objective estimates of crop yields and calamity monitoring at regional scales (Belgian agricultural regions and circumscriptions). Developing a new crop growth monitoring system for agricultural production forecasting at a regional scale leaves the choice between creating a new system and adapting an existing one. However, if a system has actually proven its operational use, as is the case for the monitoring system established by the European Community (the MARS Project), its adaptation to a new (Belgian) context will save time and financial resources. Moreover, the adaptation of the European forecasting model allows the project participants to profit from all the experience that originated from ancillary research performed in the framework of the model and its development programme.

This two-year research programme is subsidised by the Belgian Ministry of Agriculture, by the Belgian Ministry for Science Policy and by the Vlaamse Instelling voor Technologisch Onderzoek.

2. DATA

Geographic study area: Belgium

Satellite imagery used: NOAA and VEGETATION (Window around Belgium)

Other data: Meteorological, Pedological and Agricultural data

3. METHODOLOGY

Seven major annual crops are implied in the project: winter wheat, barley, fodder maize, rape seed, potatoes, sugar beet and permanent meadow. The main tasks in the adaptation of the European model come down to the completion and the improvement of the data bases that specify the local conditions and particularities of Belgium; to modify the spatial scale of the forecasting system (from a 50 km to a 5 km grid size). After a sensitivity analysis, the adapted forecasting system will be calibrated and validated in its new context. The MARS system should also be modified to be able to incorporate (NOAA-AVHRR) satellite sensor information, while the potential of the SPOT4-VEGETATION sensor to replace NOAA-AVHRR data is foreseen as a specific task as well.

4. OUTPUTS AND RESULTS

The final products of this research project should provide the Ministry of Agriculture and the National Statistical Institute with a renewed and enhanced tool for the

prediction and the estimation of reliable, timely and objective crop yield levels. These products can be utilised as well for an improved delineation of calamity zones at regional scales (Belgian agricultural regions and circumscriptions).
From a scientific point of view, this research should also show the possibilities and possible enhancements of a direct integration of remote sensing data in an agrometeorological model based on both the NOAA-AVHRR and SPOT4-VEGETATION sensors. It will allow us to optimise the grid size according to the Belgian conditions and to verify if the change of scale from Europe to Belgium is realistic without changing the methodologies used to interpolate spatial data and to combine different sources of information necessary for operating the crop growth monitoring system.

5. EXECUTION

Period: 01/07/1998-30/06/2000

Laboratories:

FONDATION UNIVERSITAIRE LUXEMBOURGEOISE
Unité Eau et Environnement
Avenue de Longwy 185, B – 6700 Arlon, Belgium
Phone: +32 63 23 08 29 Fax: +32 63 23 08 00 E-mail: tychon@ful.ac.be
URL: http://www.ful.ac.be/ful/Recherche/Surveillance/surveil.htm

CENTRE DE RECHERCHES AGRONOMIQUES DE GEMBLOUX (CRAGx)
Biométrie, Gestion des Données et Agrométéorologie
Rue de Liroux 9, B – 5030 Gembloux, Belgium
Phone: +32 81 62 65 74 Fax: +32 81 62 65 59
E-mail: oger@cragx.fgov.be

VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK (VITO)
Boeretang 200, B – 2400 Mol, Belgium
Phone: + 32 14 33 68 46 Fax: + 32 14 32 11 85
E-mail: frank.veroustraete@vito.be URL: www.vito.be

User partner :

INSTITUT NATIONAL DE STATISTIQUES (INS)
Rue de Louvain 44, B – 1000 Bruxelles, Belgium
Phone: + 32 2 548 63 65 Fax: + 32 2 548 63 66
URL: http://statbel.fgov.be/

6. RELATED DISCIPLINES

Agriculture

Environment

Natural hazards & disasters

7. EXECUTIVE SUMMARY

Introduction and objectives

Unlike its two larger neighbours (France and Germany), Belgium has not yet developed its crop yield forecasting system. Countries with large agricultural production have a financial interest in production forecasting as production levels have a sensible impact on the product prices at European scale.

For Belgium, which is rather a small agricultural producer within EC, this argument won't stand up. This probably explains why so little was done for agricultural production forecasting up to now. Nevertheless, production-forecasting methods might be useful to solve several other problems concerning Belgian agriculture. For instance, Belgium has no rapid and reliable method to assess the extent of calamity zones due to exceptional climatic conditions (like drought, frost,…). This can result in inadequate political decisions with regard to awarding damages to the farmers. Belgian agricultural statistics could also benefit from such a tool as it allows them to compare their results with those from this new independent one. Moreover some cultures like potatoes do not follow the Common Market Organisation and their prices stay highly dependent on national production. A forecasting system should allow to define better the starting prices of potatoes and to reduce speculation. By using this management tool, farm product and food traders could also enhance their stock strategies and foresee where food for livestock and other agricultural products will be necessary in the near future. All these politico-economical reasons associated with the scientific aspects connected to this theme justify that Belgium should develop its own Crop Growth Monitoring System providing reliable, timely and objective estimates of crop yields and calamity monitoring at regional scales (Belgian agricultural regions and circumscriptions). This is the aim of the Belgian Crop Growth Monitoring System project (B-CGMS). The final products of this research is to provide the Ministry of Small Enterprises, Traders and Agriculture and the National Statistical Institute with a renewed and enhanced tool for the prediction and the estimation of reliable, timely and objective crop yield levels.

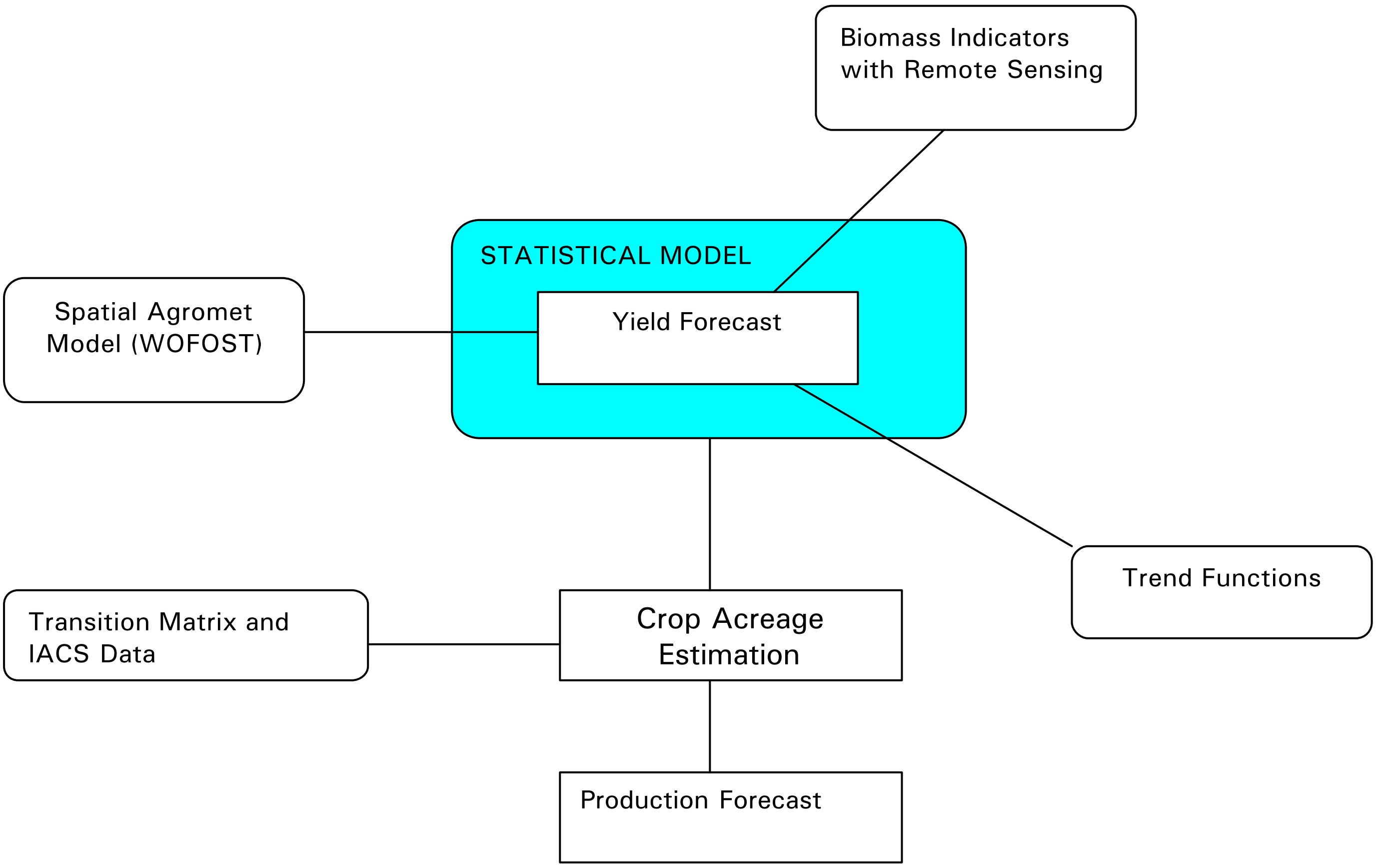
To reach this goal, it has been decided, instead of building a new crop growth monitoring system, to adapt an already existing one that has proved to be operational for yield forecasting at the large scale. For this reason, it is the European Crop Growth Monitoring System developed during the European MARS-Programme (Monitoring Agriculture with Remote Sensing), that has been retained for adaptation

to the Belgian conditions. Indeed, since a few years, this CGMS is used on a continuous base to predict harvests and productions of the main crops in the EU member states (Vossen & Rijks, 1995).
Six major annual crops are implied in the project: winter wheat, winter barley, fodder maize, winter rape seed, potatoes and sugar beet.

Framework of the Belgian Crop Growth Monitoring System (B-CGMS)

Agricultural production is obtained by multiplying the yield with acreage. The estimation of the production will thus depend on the accuracy of the estimation of these two parameters. Actually, the crop yield estimates of the CGMS are the integrated result of three independent procedures: a spatial agrometeorological model, a trend function which copes with the long-term increases due to technological improvements, and the information provided by the 1km²-resolution imagery of the remote sensing systems NOAA-AVHRR and/or SPOT-VEGETATION (Figure 1).
All three approaches provide an independent estimation of the yield. The three results are introduced in a statistical model (multiple regression) and the weight of each component is obtained by statistical fitting.

Figure 1 : Global framework of the B-CGMS approach



This modular approach is extremely flexible and allows to replace easily each of the three modules if updated versions or new models are available. This framework differs from the one used by the EU by the effective and quantitative integration of the remote sensing data in the crop growth model. Indeed presently, for the European Community, remote sensing data are only used in a qualitative way by experts, when writing the agrometeorological bulletin.

Another main difference with the European CGMS comes from the estimation of the acreage of the different crops. In Belgium, the crop surfaces, needed to assess the productions, are derived from the Integrated Administration and Control System (IACS) of the Ministry of Agriculture. This yearly updated, vectorial GIS comprises the boundaries and crop type for all agricultural parcels (± 600 000). This framework is detailed module by module here after.

2. The spatialy-explicit agrometeorological model

2.1 Physiological processes and general framework

As already mentioned, the Belgian Crop Growth Monitoring System is based on the European Crop Growth Monitoring System, (CGMS) (Vossen, 1990; Hooijer & van der Wal, 1994) of the Joint Research Centre of the EU is used. The core of this system is the crop growth simulation model WOFOST that can also be called an agrometeorological model. The principles underlying the WOFOST crop growth model have been presented and discussed by van Keulen & Wolf (1986). The implementation and structure have been described by van Diepen *et al*. (1988; 1989) and Supit *et al.* (1994).

Instantaneous photosynthesis, calculated at three depths in the canopy for three moments of the day, is integrated over the depth of the canopy and over the light period to arrive at daily total canopy photosynthesis. After subtracting the maintenance respiration, assimilates are partioned over roots, stems, leaves and grains according to the development stage, which is calculated by integrating the daily development rate, described as a function of temperature and photoperiod. Assimilates are then converted into structural plant material taking into account growth respiration. Leaf area growth is driven by temperature and limited by assimilate availability (Cf. Figure 2). The model calculates the dry matter accumulation and its distribution over leaves, stems and grains for each Elementary Mapping Unit (EMU) from sowing to maturity on the basis of physiological processes as determined by the crop's response to daily weather (water availability, solar radiation, photoperiod, minimum and maximum temperature and air humidity), soil moisture status and management practices. An EMU is obtained by the overlay of administrative units with the soil map and the meteorological grid. It represents an entity in a given administrative zone where meteorological and soil input data are homogeneous.

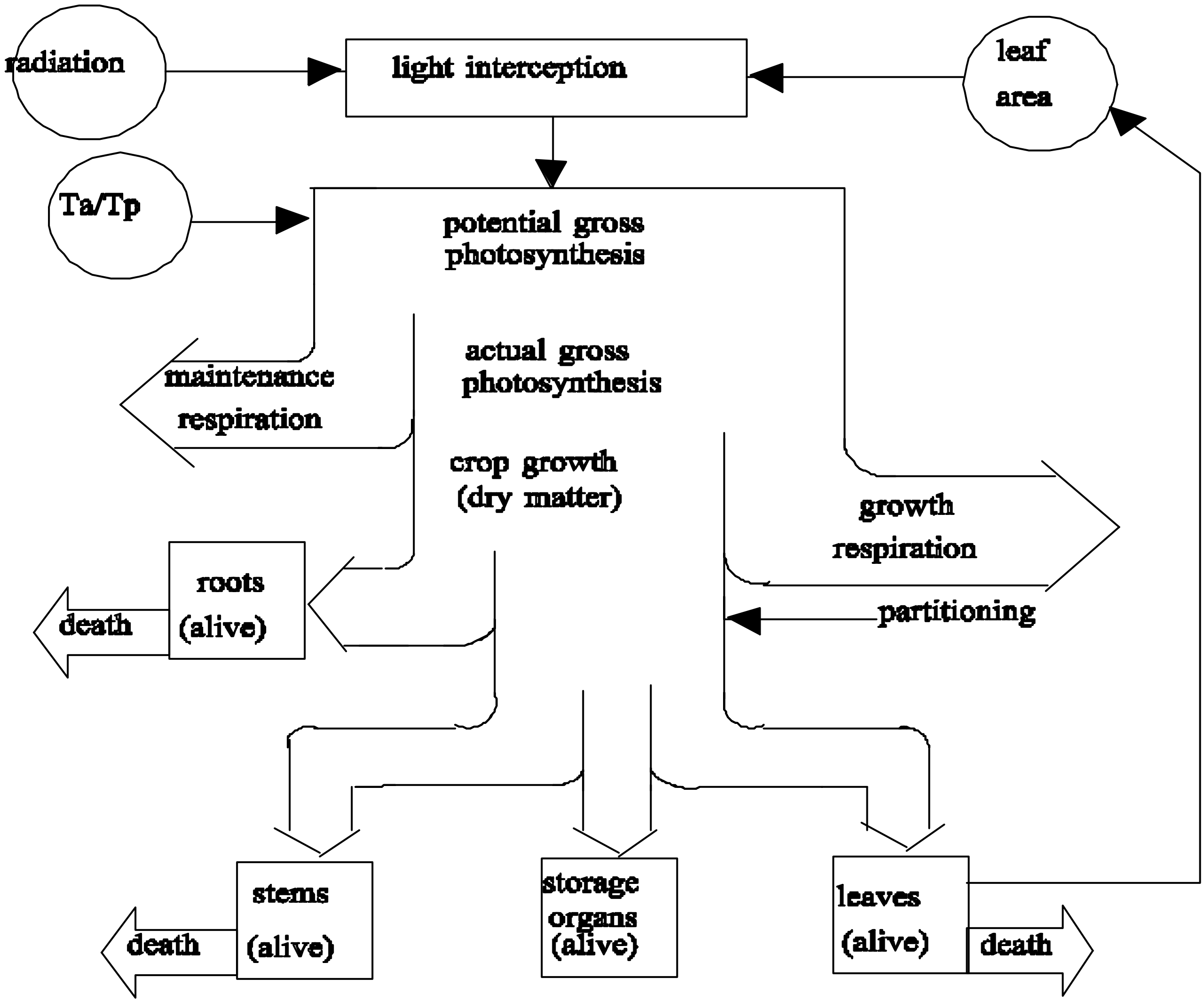


Figure 2: Crop growth processes simulated by B-CGMS. T_a and T_p are actual and potential transpiration rate (de Koning, 1993)

Meteorological input data

B-CGMS operates on grid cells of 10 x 10 km. Trials where also performed on smaller grids (5 x 5 km and 1 x 1 km).

For each grid cell, the required inputs are daily weather data as obtained by interpolation of observations from the existing network of meteorological stations (Beek *et al.* 1992; van der Voet *et al.* 1993), soil characteristics and management practises (i.e. sowing density, planting date, etc.).

Figure 3: Meteorological stations in Belgium.

The station density of the meteorological observation network operated by the Royal Belgian Meteorological Institute is shown in Figure 3. Selected data come from up to 150 meteorological stations at a daily time step for the last ten years, plus three years (1976, 1983 and 1984) with exceptional climatic conditions. Due to the difference in scale, a study on the CGMS meteorological interpolation method became necessary as well.

Sensitivity analyses were performed on meteorological interpolation methods, on the weather station network density and on the meteorological grid size. They confirmed the ability of the European approach to interpolate in the Belgian context (Cf. Table 1). They were used for the selection of the grid size (10 X 10 km) and the density network analysis helped to choose the best number of weather stations for the real time forecasting.

Table 1: Comparison of two interpolation methods with observed values for the weather station of Deurne

	Kriging			EU-CGMS method		
	R^2	y =	RMSE	R^2	y =	RMSE
Tmax [°C]	0.994	0.999x + 0.205	0.601	0.994	x + 0.254	0.638
Tmin [°C]	0.983	0.971x + 0.303	0.834	0.982	0.966x + 0.349	0.866
Rainfall [mm/jour]	0.841	0.838x + 0.270	1.605	0.760	0.782x + 0.251	1.981
Wind speed at 10 m [m/s]	0.925	0.968x + 0.440	0.612	0.909	1.067x + 0.345	0.852
Vapour pres. [hPa]	0.966	1.017x + 0.015	0.854	0.961	0.990x + 0.030	0.869

Soil input data

The spatial soil database was built by applying a method similar to the one used by the Joint Research Centre (JRC) for the elaboration of the EC soil geographic database (for details see King *et al.*, 1996).

First, existing soil map or soil databases in Belgium were studied to fix the possibilities of recovering the parameters required by the CGMS model (i.e. texture classes, organic matter). Subsequently, pedotransfer functions were listed, compared and used to predict the hydraulic properties of soils.

The Belgium territory was divided into 17 pedological zones (figure 4). From this division, a new soil-mapping unit was defined and called "Association Pédologique Régionale" (APR) based on the Marchal and Tavernier (1970) soil map. In order to have reliable data a representative soil profile for soils under cultivation was determined together with its associated physical and chemical data for each of the 226 APR.

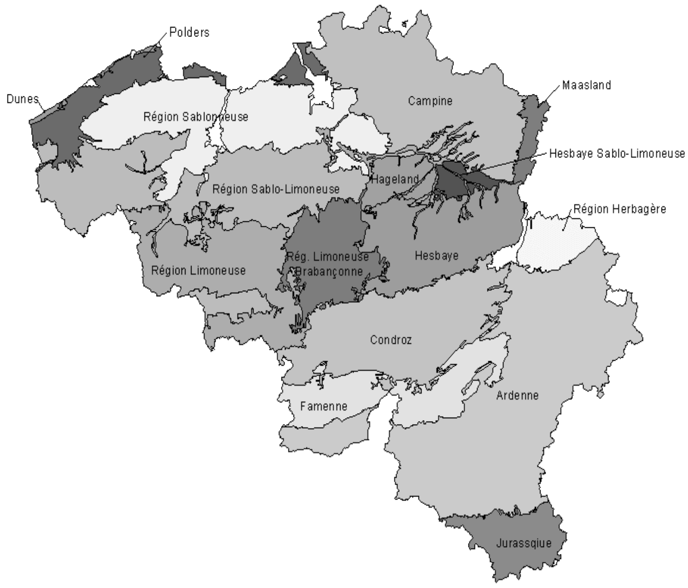


Figure 4: Map of pedological zones

Most of this information comes from the soil profile database AARDEWERK (about 13,000 soil profiles over Belgium) established by Van Orshoven and Vandenbrouke (1993).

Most of the required soil data in CGMS are related to hydraulic properties. Several pedotransfer functions for estimating these hydraulic properties can be found in literature (e.g. the HYPRES project, Vereecken PhD dissertation). After a comparative study, a selection of four pedotransfer functions was made, of which two class pedotransfer functions and two continuous ones. A sensitivity study was conducted in the calibration phase to determine the most appropriate function to be used. At the scale of the agricultural regions or circumscriptions, the sensitivity analysis revealed a high sensitivity of B-CGMS to the soil water content. Moreover this analysis also showed that, even with the large variation of hydraulic conductivities (K_{sat}) estimated with the different pedotransfer functions, B-CGMS appeared quite insensitive to the choice of pedotransfer function. Finally, it was the VEREECKEN pedotransfer function that has been retained as the reference function, as it was established in Belgium, but this function did not improve the predictive quality of the Crop Growth Monitoring System.

To summarise this specific task, a soil geographical database of Belgium was built which consists of two separate parts : a geographic database with a list of soil mapping units and soil typological units, and a semantic database composed of the profile data and the estimated data from the pedotransfer functions. Both databases are geo-referenced, linked and adapted to the CGMS format.

Crop input data

Six major annual crops are concerned: winter wheat, winter barley, fodder maize, winter rape seed, potatoes and sugar beet. Four types of crop data were collected and constitute the crop database:

- Raw yield data on test plots for the period 1988-1997 and for three years with exceptional meteorological conditions (1976, 1983 and 1984).
- Agricultural and phenological data. These are mainly data on the different cultures and varieties used in the different agricultural regions.
- Statistical data from the Naional Institute of Statistics for each selected crop and each agrostatistical unit (agricultural regions and cicumscriptions) over a period of 30 years.
- Agricultural land occupation (per year) from the Integrated Administration and Control System (IACS) of the Ministry of Agriculture.

A sensitivity analysis was performed on the crop calendar because it was clear that some uncertainty remained on sowing days for the different agro-statistical regions (cf. Table 2). Next, because the agrometeorological model only started the first of January for winter crops, another study was performed on the impact of the period from sowing to the end of year (cf. Table 3).

Table 2: Final yield statistics [kg DM/ha] for spring crops compared with reference

	Maize			**Sugar Beet**			**Potatoes**		
	ME	RMSE	R^2	ME	RMSE	R^2	ME	RMSE	R^2
(Start –10 days)	348	723	0.98	233	543	0.98	306	523	0.98
(Start +10 days)	-482	874	0.97	-285	691	0.97	-269	614	0.97
(End –10 days)				-566	611	1.00	-137	399	0.99
(End + 10 days)				419	459	1.00	68	257	0.99

Table 3: Final grain yield statistics [kg DM/ha] for winter crops compared with reference

	Winter Wheat		
Degree days difference with reference	Mean Deviation	RMSE	R^2
-200	412	1340	0.63
-100	467	821	0.89
-50	287	449	0.97
-25	152	232	0.99
0	0	0	1.00
25	-161	246	0.99
50	-333	492	0.97
100	-694	963	0.90
200	-1483	1851	0.74

It appears that the starting dates are more sensitive than the ending dates. The two parameters are sensitive (RMSE of +/- 500 kg DM/ha). For winter crops, the period before January must have an impact if the difference of degree-days with the reference is above 50 degree days. These studied parameters operate in the crops phenological stages. In a future research, a comparison of the observed phenological stages with the simulated ones should be considered because it could globally improve the estimations of the agromet model.

Trend functions

The trend function is used to express the long term change in the different crop yields.

The agrometeorological model WOFOST, that is based on physiological processes does not take into account all the parameters acting on the agricultural production. Especially, new varieties, change in agricultural practises (increase of fertiliser and pesticides), development of technologies and ability of the farmer to adopt them cannot be introduced into the model. Such information is not easy to obtain or is not available rapidly enough to be used for yield forecasting. Therefore a trend function has been estimated for each culture and each agro-statistical region (region or circumscription) based on time series of 15 and 30 years.

The relationships can be of first or second order as follows:

$Y = a + b_1t$ or $Y = a + b_1t + b_2t^2$ with Y = yield and t = time in years

Table 4 summarises the behaviour of the different trend functions in the case of the 26 agricultural circumscriptions with a 30 year data set.

Table 4 **:** Statistical study of the 30 year Trend functions for 6 crops per agricultural circumscription (yield in 100 kg/ha).

Crop	**Residual Stand. Dev.**		**R^2**		**Type of Trend Functions**		
	Min	**Max**	**Min**	**Max**	**No Trend**	**Order 1**	**Order 2**
Winter Wheat	3,57	10,35	0,57	0,83	0	2	24
Fodder Maize	25,76	88,96	0,00	0,25	17	8	1
Winter Barley	2,60	9,87	0,23	0,82	0	9	17
Rape Seed	3,68	5,61	0,10	0,32	0	13	13
Sugar Beet	29,12	69,18	0,19	0,75	0	0	26
Potatoes	30,85	82,51	0,00	0,56	1	1	24

The residual standard deviations show the accuracy that can be expected from such fitting. R^2 coefficients give an indication of the total variability expressed by the trend. Most trend functions are quadratic (order 2) but some have no trends at all (fodder maize). In that case, only the mean of the data set can be used to foresee yield. In the other cases, yield trend on each administrative entity will be used to estimate the yield by extending the curve one time step further.

Biomass Indicators with Remote Sensing

General Approach

As a basic approach for the inference of yield estimates from remote sensing images, daily increases ΔW in dry matter (DM) biomass were computed by means of the widely applied equation of Monteith (1972):

$$\Delta W = S_{par} \bullet fAPAR \bullet \varepsilon(T) \qquad \text{[kg DM/ha/day]}$$

S_{par} is the incoming Photosynthetic Active Radiation in J/ha/day (± 50% of the short-wave spectrum of the sun), *f*APAR is the fraction absorbed by the living vegetation, and $\varepsilon(T)$ is the conversion efficiency in kg DM/J which is simply modelled here as a function of the daily mean temperature T (see Sabbe *et al*., 1999). The necessary meteorological data (S_{par} and T) and the *f*APAR-values were respectively extracted from the B-CGMS databases and the satellite images. The obtained daily growth numbers can be summarised in two ways: in a temporal sense cumulative values W [kg DM/ha] can be computed for specific periods, while in a spatial sense regional averages can be derived.

A parcel-based application of the Monteith approach is a priori excluded, due to the low resolution of the imagery and the small mean parcel size. The large majority of the 1km²-pixels are "mixed pixels", which are covered by different parcels and land use classes, and hence yield a mixed optical signal.

Two alternative methods were evaluated to overcome this problem and to obtain crop-specific yield estimates. First, the classical procedure for linear unmixing was tried out in order to retrieve pure crop signals (see 4.3.). But so far this technique could not be brought to an operational stage. The second method thus simply accepts the mixed nature of the satellite signals and tries to infer crop-specific yield estimates by calibration of image-derived indicators against official harvest data (see 4.4.).

1km²-Resolution Imagery: Data Sets and Preparation

Table 5 gives an overview of the 6 available, yearly image sets: 4 from AVHRR and 2 from VGT. Inspection of the data sets pointed out the superior quality properties of VGT. The SPACE-II AVHRR-data were badly registered (see figure 1.B) and contained a lot of anomalies (missing values/images, striping effects, etc). All syntheses suffered from a very important cloud noise.

Table 5 **:** Overview of the used image sets

Feature	**NOAA-AVHRR**	**SPOT-VEGETATION (VGT)**
Period	4 years: Jan. 1995 - Dec. 1998	2 years: April 1998 – Dec. 1999
Imagery Type	S1: 365/6 daily syntheses / year	S10: 36 decadal syntheses / year
Pre-Processing	SPACE-II (JRC)	CTIV (CNES, Vito)
Projection & Resolution	Albers Equal Area (1.1 km)	Geographic Lon/Lat (1°/112)

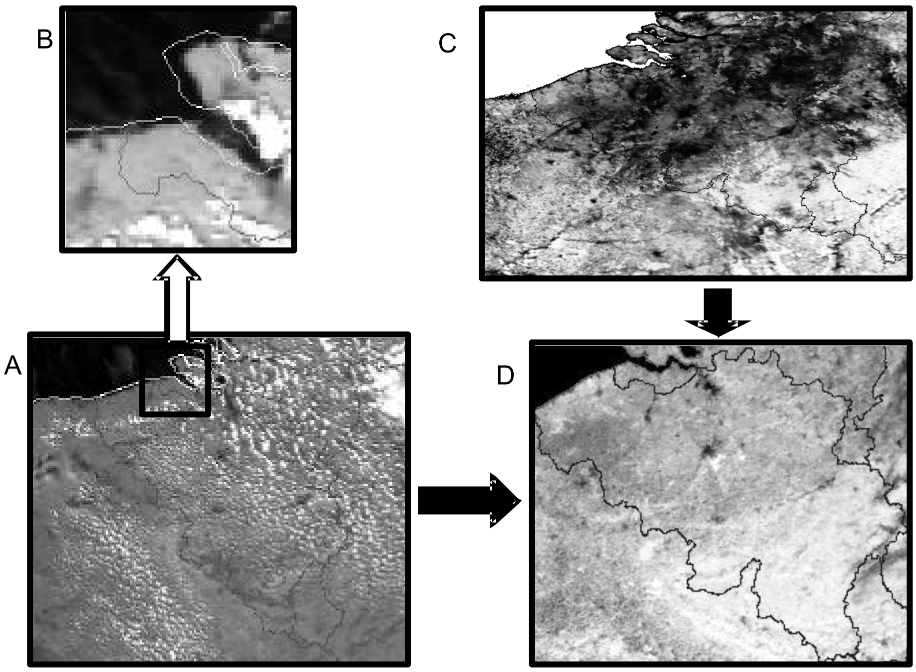


Figure 5: Cartographic conversions : A. Albers Conic Equal Area (AVHRR, S1, NIR-band); B. Idem, but zoom-in over Zeeland; C. Unprojected Lon/Lat-system (VGT, S10-synthesis, NDVI); D. Belgian Lambert Conic Conform (B- CGMS reference, NDVI).

For this research, only the NDVI-information was used (Normalized Difference Vegetation Index).

The six available, full-year image sets were processed as follows

- The NDVI image layers were unpacked from their specific formats and compiled into one single image file per year (365/6 layers for AVHRR, 36 layers for VGT).
- The data were reprojected towards the B-CGMS system (see figure 5.D).
- The NDVI-profiles were cleaned to eliminate the cloud noise (see figure 6).
- The NDVI-data were then converted into *f*APAR-images by means of sensor-specific linear equations (*f*APAR = A + B.NDVI) whose parameters were obtained by means of a simple histogram-analysis (AVHRR: A = –0.27, B = 1.68;
  VGT: A = –0.25, B = 1.54).

In a technical sense (i.e. omitting the intrinsic quality properties), after these preliminary operations both data types (AVHRR, VGT) were completely homogenised.

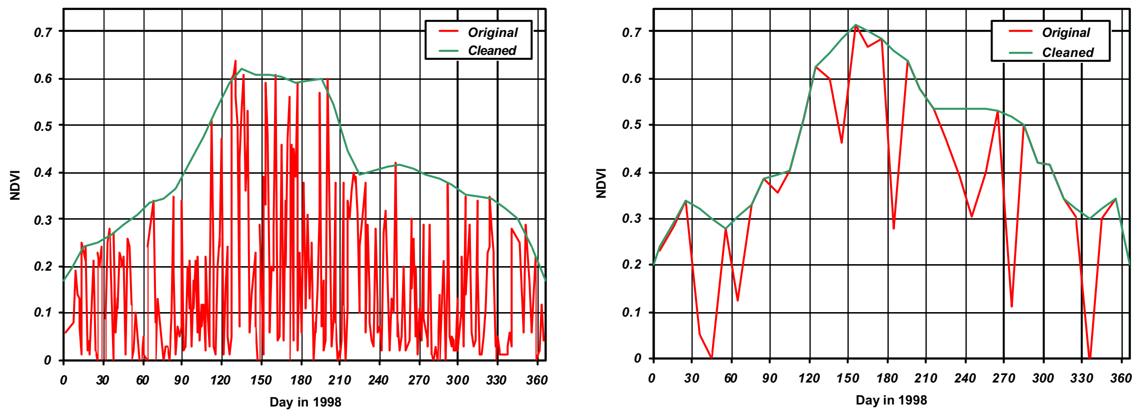


Figure 6: Evolution of the NDVI in 1998 for 2 pixels: original series extracted from the daily syntheses of NOAA-AVHRR (left) and from the decadal syntheses of SPOT-VGT (right). The abrupt local minima are mostly due to clouds. The “envelope” curves (thick lines) are the result of the cleaning procedure.

Linear Unmixing

The method of linear unmixing assumes that the optical signal y_p, registered for the mixed 1km²-pixel p, is equal to the weighted average of the pure signals x_k of the N_k individual terrain classes/crops, with the sub-pixel surface fractions f_{pk} as weights ($y_p = \Sigma f_{pk}.x_k$). For a homogeneous area of N_p pixels one obtains a system of N_p equations, from which the pure signals x_k (regional means) can be retrieved with a simple matrix inversion. In this case, the required surface fractions f_{pk} could be extracted from the IACS-data set of the Ministry of Agriculture. All the non-agricultural destinations, not mentioned in the IACS, were assigned to a single "garbage" class (mostly built-up areas and forests).

The technique was first tried out with three high-resolution images of SPOT-XS, with a pixel size of 20x20m². The images were of 3 different dates in 1997 and they all covered an area of 800 km² in the Hesbaye region, ± northwest of the city of Liège. By confronting these high-resolution data with the IACS-information (vectorial parcel map with crop type for each field), the true x_k-values could be computed in advance. On the other hand, by degradation of the 20x20m²-imagery (taking the mean signal of each cell of 50x50 high-resolution pixels), equivalent low-resolution scenes were simulated with N_p = 800 1km²-pixels. The procedure for linear unmixing was then applied to the latter degraded scenes, and the resulting x_k-estimates were compared with the correct values. These validation tests pointed out that the relative errors (100 (true-estimated)/true%) were generally quite limited and mostly below 10%. This observation agreed fairly well with the findings of Cherchali *et al.* (2000) who performed a quite similar analysis.

The technique worked equally well for the three registration dates (1997: May 30, August 6, September 17) and for the different "optical signals": the individual red and near infrared reflectances and the NDVI. Several classification legends were tried out (from 15 classes to 0/1-systems like wheat vs. non-wheat) as well as various pixel selection methods (e.g. only use the 1km²-pixels which are covered for more than 50% by main crops), but none of these modalities appeared to have a clear and unambiguous influence on the performance of the unmixing technique.

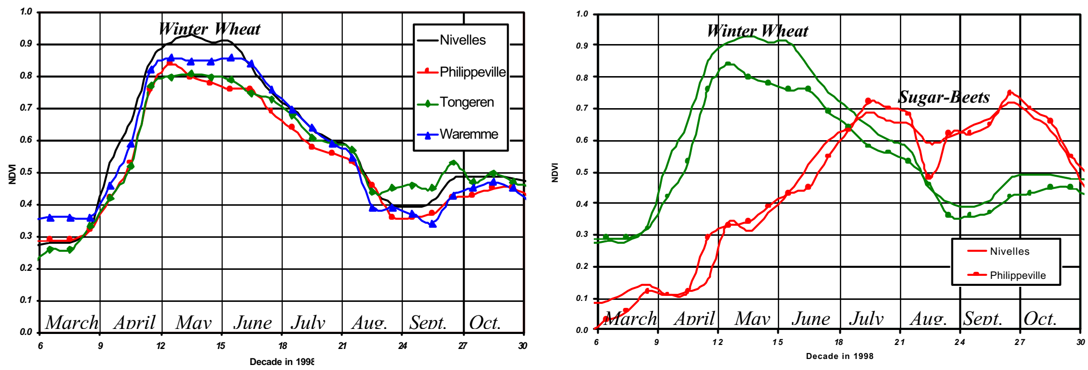


Figure 7: Pure NDVI-profiles in 1998 for winter wheat and sugar beets in different agro-statistical circumscriptions, derived by linear unmixing from the (previously cleaned) image set of SPOT-VEGETATION.

After this validation, the linear unmixing was applied to the real 1km²-imagery of AVHRR and VGT (cleaned NDVI-data). The method was repeated for each of the 26 agro-statistical circumscriptions (Np ≈ 1200) and for each image date, which resulted in temporal NDVI-profiles such as shown in figure 7. These examples reflect fairly well the common agricultural practices in Belgium. Winter wheat restarts its growth by the end of March, it culminates around May, ripens in June-July and is finally harvested in August. The later evolutions are of course irrelevant and vary per parcel. The same holds for sugar-beets in early spring. This crop starts its typically slow growth around May, with the leaf area culminating between July and September.

The unmixed, pure class profiles (x_k) show significantly higher dynamics than the mixed 1km²-signals (y_p). As far as only terrestrial pixels are concerned, the latter are mostly restricted to the NDVI-range 0.15 ... 0.75, while the unmixed NDVI's rather vary between 0.1 and 0.95. Obviously, the quality of the results will also depend on the spatial agreement between imagery and land cover data (IACS). It thus might not surprise that the best results were obtained for the images of SPOT-VGT. The poorer performance for NOAA-AVHRR is certainly due to the less accurate geometric correction.

The unmixed NDVI-profiles can in principle be used in the Monteith approach (after conversion to *f*APAR-values) to obtain crop-specific growth values on a regional base. However, the results were not always as good as in the examples of figure 7. In practice, the method appeared quite unpredictable and in many cases it yielded nonsensical NDVI-curves. Further research is certainly recommended, but for the time being the linear unmixing is not operational and as a consequence it had to be rejected in favour of the procedure described hereafter.

Image-Based Yield Indicators calibrated with Neural Networks

The different versions of this approach always start with the Monteith-computation of the daily growth values ΔW [kgDM/ha/day] on a per-pixel base (i.e. without differentiation between crops). The results are then accumulated over specific periods to DM-biomasses W [kgDM/ha]. Next, regional averages are derived for each of the 26 agro-statistical circumscriptions. This aggregation step only takes into account the pixels, which are covered for more than 50% by cropland (criterion checked with the IACS data set). Finally, crop-specific yield estimates (y_{est}) are defined by calibration of this set of yield indicators (1 or more x_i) against the official harvest statistics (y_{true}). The numbers of available data points per crop are mentioned in table 6 (at most: 6 yearly image sets x 26 circumscriptions = 156).

Our first trial was based on the dry matter biomass W accumulated over the entire growing season of each crop (see table 6 for the specific seasons). In spite of its logic and simplicity (1 single x-indicator), this attempt completely failed. The obtained R^2-values balanced around zero, probably because the approach gives equal weights to every moment in the season, while in practice each crop has its specific critical moments (e.g. flowering for the cereals).

With this lesson in mind, a more refined and multivariate procedure was elaborated which was calibrated separately for each crop with a three-layer "neural network with backpropagation training", as described by Paola & Schowengerdt (1995). The input layer of this network comprises 4-6 nodes, which are fed with the biomasses W accumulated for each month in the crop's growing season (4-6 x_i-values, see "Inputs" in table 6). The hidden layer counts three nodes and the output layer only one: the final crop yield. These networks were calibrated with the official statistics of the NIS (y_{true}). The number of parameters (neural weights) to be estimated in the calibration amounts to about 21. With ±150 data points per crop, this is perfectly feasible. However, in order to achieve an independent and reliable validation, the "Jackknife" method was applied. The sequence 'calibration-validation' was repeated in different steps, and in every iteration 10 data points were selected at random. The network was then trained with the remaining ±140 observations and validated with the 10 test points. This scheme was repeated until each point was used once for validation.

CROP	N	INPUTS	R^2 %	RMSE	Y_{min}	Y_{max}
Winter wheat	155	6 (March-August)	59.8	0.8	2.9	10.8
Sugar-beets	138	6 (May-October)	48.4	5.3	34.8	80.0
Fodder maize	155	6 (April-September)	35.8	3.7	28.4	58.6
Winter barley	144	5 (March-July)	21.5	0.9	3.0	9.3
Potatoes	149	5 (April-August)	13.2	8.2	7.6	57.4
Winter rapeseed	81	4 (March-June)	6.8	0.5	2.0	4.5

Table 6 : Results of the image-based procedure for yield assessment (neural network + independent "Jackknife" validation): N=number of data per crop, RMSE=Root Mean Square Error (ton/ha), Y_{min}/Y_{max}=extreme values (ton/ha) in the NIS-data set (1995-1999, 26 circumscriptions).

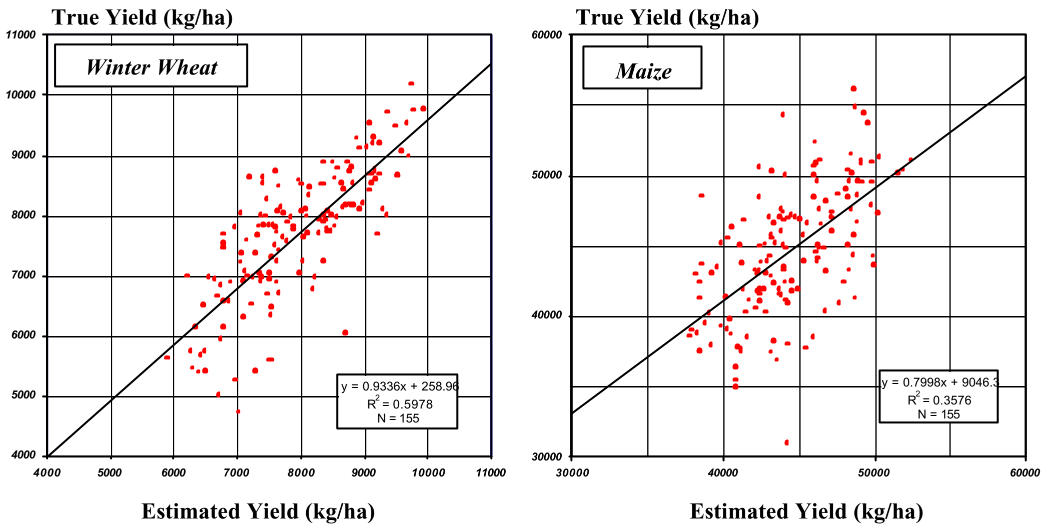
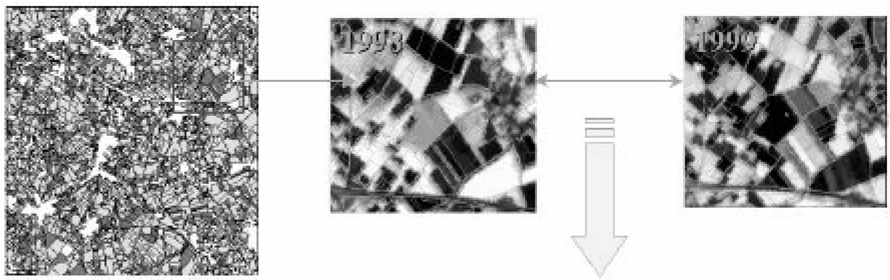


Figure 8 : Official yields of the National Institute for Statistics (NIS) vs. the image-based estimations (neural networks) for winter wheat and fodder maize (see table 2).

The validation results, presented in table 6, prove that the images of AVHRR and VGT do contain relevant information on the yield of the main crops, in spite of their low resolution. The R^2-values, which represent the fraction of the total variance explained by the image-based estimates, vary in function of the relative importance of the crops. The procedure works very well for winter wheat (R^2=59.8%) and somewhat less for sugar-beets (R^2=48.4%) and fodder maize (R^2=35.8%). The performance clearly decreases for the minor crops, especially for rape seed (R^2=6.8%).
However, the project uses remote sensing data as one source of information among other. The validation results of table 6 only relate to the accuracy of the image-based procedure. The final yield assessments of the B-CGMS is more reliable, because they are not only based on the remote sensing imagery but also on the outputs of the agromet-model and the technological trend function.
This work also demonstrated that the combined use of SPOT-VEGETATION and NOAA-AVHRR does not raise any problem. Linear unmixing of the compound signal of the 1km²-pixels can best be applied on the VEGETATION-images because of their high geometric precision. This important topic however requires further investigation, before it can be integrated in an operational yield forecasting scheme.

Crop Acreage Assessment

The European forecasting system set up a regional survey process at the European scale that estimates cultivated areas with a high-resolution imagery interpretation module. In Belgium, the acreage assessment module is replaced by information coming from the IACS (Integrated Administration and Control System) and providing land occupation for each crop. IACS collect farmer declarations to get crop subsidies from the Ministry of Agriculture. In their system, each agricultural parcel is available in numerical format for all the country. The system provides precise information of land occupation for each farmer requesting subsidies. The use of this source of information is one of the main originalities of the B-CGMS approach.



1998 \ 1999	Others	Sugar Beet	Cereals	Rape Seed	Fodder	Winter Wheat	Horticultural	Fallow	Fodder Maize	Winter Barley	Potatoes	Perm. Meadow
Others	64.4	3.7	3.2	0.0	0.6	10.9	0.8	0.8	5.7	0.2	3.2	6.4
Sugar Beet	6.4	2.9	7.7	0.0	0.4	58.1	1.2	2.9	11.3	0.4	8.4	0.3
Cereals	9.2	5.6	44.4	0.9	1.7	5.9	1.6	2.5	17.4	3.2	6.5	1.1
Rape Seed	1.0	1.1	6.9	0.7	0.1	81.3	0.0	2.8	2.9	1.3	1.0	0.9
Fodder	6.2	2.1	10.7	0.0	30.9	11.5	1.2	1.3	27.2	0.3	6.2	2.4
Winter Wheat	13.9	22.4	7.2	1.3	1.2	8.1	1.6	3.6	14.0	15.4	11.1	0.4
Horticultural	7.0	6.8	8.1	0.0	0.6	4.9	39.5	1.2	11.1	0.4	19.7	0.8
Fallow	4.7	4.4	4.4	0.2	1.8	16.0	0.3	57.1	7.3	0.5	2.5	0.8
Fodder Maize	3.9	4.6	9.1	0.0	1.5	15.4	1.2	1.2	56.7	0.4	6.0	0.9
Winter Barley	9.1	42.0	8.1	6.1	2.0	2.1	0.9	6.3	15.3	2.3	5.5	0.4
Potatoes	7.4	14.1	12.0	0.0	1.1	38.1	5.3	1.4	13.5	0.5	6.0	0.6
Perm. Meadow	2.8	0.2	0.3	0.0	0.1	0.2	0.1	0.0	0.7	0.0	0.2	95.5

Figure 9 : Elaboration of a transition matrix based on IACS land occupation in 1998 and 1999 (probabilities calculated for surface units).

From May onwards, the first declarations are progressively introduced in the IACS and the first acreage estimations for the different crops can be done at the end of May. Unfortunately, this sampling of declarations is not random (encoding by communes, agricultural circumscriptions,…). In order to reduce as much as possible the impact of this bad sampling, the information has been translated into a transition matrix, based on the change from year to year of the occupation of each parcel with a given crop (Cf. Figure 9). These matrixes give the probability for one parcel to change its occupation by an other one. They are set up on the basis of observations of the preceding campaign and are progressively updated during the new season with new data according to a statistical process using Markov chain properties.

Such approach gives an improved estimation of the acreage of the different crops during the campaign (from May to harvest) and is much faster than the methods developed at the European scale. It is also more precise than the European one and allows Belgium to predict not only the yield but also the production early in the campaign.

Statistical yield forecasting model

Final estimation and prediction of yield for the different agricultural regions and circumscriptions are obtained by combining the technological trend functions with the outputs of the agrometeorological model and the biomass indexes derived from satellite imagery.

The model can be written as:

$$Y = a + f_1(trend) + f_2(Agromet\ model) + f_3(biomass\ index) + \xi$$

where Y = predicted or estimated yield

f1, f2 and f3 are specific functions adjusted to the output of the different sub-models

ξ = error

The prediction quality of the different yield or biomass indicators can change considerably along the growing season. According to the period of the year, some data can be unusable or more simply are not available to make a forecasting. This means that some factors in these different functions should be used separately or complementary to the other ones. During all the growing period, factors or explanatory variables of the model are selected in order to minimise the prediction error, i.e. the difference between the observed values of yield of the NIS (National Institute of Statistics) and the predicted ones.

In order to calculate the different parameters of the forecasting model, the different functions that provide the indicator variables, i.e. the technological trends, the output of the agromet model and the remote sensing biomass indicators are simultaneously taken into account and validated to apply the hypothesis that weather conditions can modify or remove the technological trend impact. Validation is done on a set of data (years) different and independent of the one used for the calibration of the model.

Forecasting Results for 1998

Results are presented for the year 1998 as an example. The Belgian crop growth monitoring system is able to predict yield and acreage in an operational way and in real time for any period of time.

Agricultural acreage

Table 7 gives the assessment of the acreages in 1998 established with IACS data from 1997 and the matrix transition process. Comparison with data from the agricultural inventory shows a good correlation. The largest difference is observed with fodder maize. Changes of land occupation for the different crops are quite the same as the trends measured by NIS.

Crops	NIS 1997 (ha)	IACS 1997 (ha)	Difference in % with NIS	NIS 1998 (ha)	IACS 1998 (ha)	Difference in % with NIS	Difference 1997-1998 NIS	Difference 1997-1998 IACS
Fodder maize	185 251	178 022	-4,1	171 560	165 668	-3,6	-7,4	-6,9
Winter wheat	195 544	196 699	0,6	210 305	211 742	0,7	7,5	7,6
Winter Barley	43 292	44 152	1,9	46 090	47 526	3,0	6,5	7,6
Potatoes	55 510	52 927	-4,9	58 631	57 257	-2,4	5,6	8,2
Sugar beet	95 781	96 567	0,8	94 246	94 917	0,7	-1,6	-1,7
Rape seed	4 706	4 576	-2,9	5 592	5 403	-3,5	18,8	18,1

Table 7 : Comparison of the acreage assessment in 1998 with the agricultural inventory data of the 15th of may 1998 and IACS data from 1997.

Yield

The accuracy of the different estimations is evaluated by using a Jackknife procedure during the fitting process of the different models. In order to integrate remote sensing data in the comparison of the different models, only year 1995, 1996 and 1997 were used at the agricultural region and circumscription scale. 1998 is kept as a validation year. Table 8 presents yield assessment errors for a forecasting at the end of May 98. These results show an important improvement of the estimation if the agrometeorological model and the remote sensing biomass indicator are introduced in the model. It appears also that, for winter crops, prediction results are better at the end of May than at the harvest. Explanatory factors acting in the model change with crop and time of forecasting. Up to now, the system is unable to reduce the prediction error (when compared with the technological trend) for sugar beet and rape seed. A refined study on the remote biomass indicator along the summer period should give explanation of some observed deviations.

Model Type	Estimation error at harvest			Estimation error, 31 may 1998		
	Winter Wheat	Winter Barley	Rape seed	Winter Wheat	Winter Barley	Rape seed
Trend	8.2	6.5	3.0	8.2	6.5	3.0
Trend + Agromet. model	7.2	6.4	3.6	7.4	5.7	3.5
Trend + RS Biomass indicator	7.9	6.5	3.4	6.2	6.3	3.2
Trend + Agromet. model + RS Biomass indicator	7.1	6.3	3.8	6.0	5.7	3.7

Table 8.1: Yield estimation errors (100 kg) of winter crops with a forecasting at the end of May 1998.

Model Type	Estimation error, 31 may 1998			Estimation error at harvest		
	Maize	Sugar Beet	Potatoes	Maize	Sugar Beet	Potatoes
Trend	61.0	41.4	58.1	61.0	41.4	58.1
Trend + Agromet. model	61.7	40.5	53.7	-	-	-
Trend + RS Biomass indicator	49.1	41.8	59.4	-	-	-
Trend + Agromet. model + RS Biomass indicator	49.9	40.9	54.9	-	-	-

Table 8.2: Yield estimation errors (100 kg) of spring crops with a forecasting at the end of May 1998

The comparison of predicted values of winter wheat and winter barley at the end of may 98 with observed values measured at harvest is presented in figure 10. It clearly shows the ability of prediction of B-CGMS (R^2 = 69% and 85 % for winter wheat and winter barley respectively). Similar results were obtained for the other crops except for rape seed.

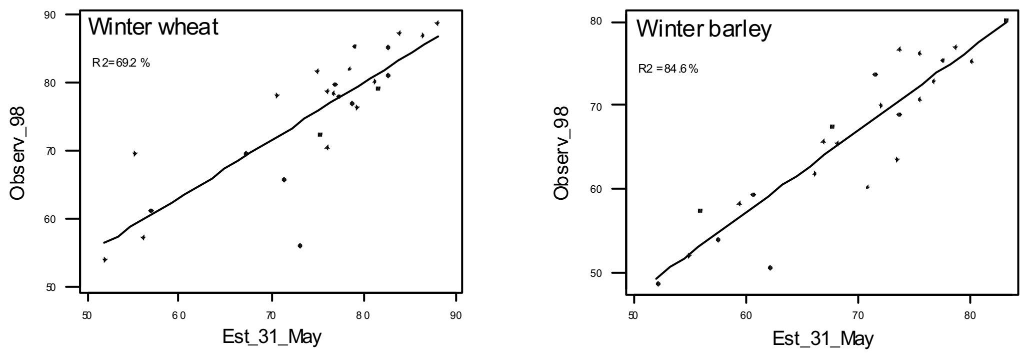


Figure 10: Predicted and observed winter wheat and winter barley

Conclusions

The main result of the project is the establishement of a nearly operational crop growth monitoring system adapted to the Belgian context. A check of operationality was organised with the publication of the first agrometeorological bulletin giving yield and production forecasts for the last decade of May 1998. It has been showed that the combination of remote sensing biomass indicators with the outputs of a spatialised agrometeorological model and the technological trend gives better yield predictions than the technological trend alone. This looks very promising for future research. However, a simulation model, even extremely precise, will never forecast the exact reality. The operational use of a yield prediction system will always encounter problems linked to uncertainties from input data accuracy, unavailability of some data (soil depth, soil water capacity,…) sometimes only during critical phases, spatial resolution of data and finally the limits of the model itself to approach reality. Finally, even if the model has been improved by its interactive interface (see http://b-cgms.cragx.fgov.be/) and should run easier for potential users, it must be kept in mind that the use of B-CGMS should always be inside the limits fixed by the complexity of the simulated phenomenon and that a human expertise is still very necessary to get the best of this type of tools.

PILOT PROJECT T4/42/067

FORECAST OF AVAILABLE FORAGE IN QUANTITY AND QUALITY FOR THE ESTABLISHMENT OF A FEEDING STRATEGY AT THE FARM AND REGIONAL SCALE

P. LECOMTE

CENTRE DE RECHERCHES AGRONOMIQUES DE GEMBLOUX (CRAGx)
Rue de Liroux 9
B – 5030 GEMBLOUX
BELGIUM

1. CONTEXT AND OBJECTIVES

To improve livestock farming systems sustainability, from an economical and environmental point of view, tools necessary to manage nutrients stocks must be developed. They must be able to estimate forage availability, in quantity and quality to adjust the complementation and, in this way, to reduce feeding costs that represent the greatest part of the proportional cost in livestock farming systems, and foodstuff wasting. Such maximisation of self-produced fodder crops valorisation in livestock farming systems will also increase product trace ability and differentiation and, in this way, the sustainability of these systems from a social point of view.

The use of dynamic model seems to be a promising tool to reach these objectives. Such models are based on the biomass formation through the photosynthetic activity of the plant under different environmental conditions (temperature, soil water content, photosynthetically active radiation…). Limitations of existing models are that their accuracy is correlated to their complexity. Some of their parameters being difficult to obtain in a continuous away on a great number of sites. The aim of this study is to validate an agro-meteorological model using some easily available parameters, for Grass Growth in quantity and quality, and to use remote sensing data to control and adjust output at regular intervals, on the one hand, and to integrate spatial heterogeneity, on the other hand. The accessibility of this tool will be obtained through its integration on an internet site.

2. DATA

Geographic study area: South Eastern part of Belgium

Satellite imagery used:

Images VGT-S10 (ten days synthesis MVC) from the 1st of April till the 30th of October, in 1998, 1999 and 2000. Satellite images for 1998 and 1999 come from the B-CGMS project (T4/42/23b), their co-ordinates are upper left lat 52.000, long. 2.000 and lower right lat 49.000, long. 7.000. The co-ordinates of images for the year 2000 are upper left lat 50.544, long. 3.319 and lower right lat 44.913, long 6.694.

Other data: Numerous filed data on grassland production in quantity and quality have been compiled or collected in order to calibrate and validate the agro-meteorological model, on the one hand, and the remote sensing observations, on the other hand.

3. METHODOLOGY

The accuracy of the grassland growth model in the area of interest was assessed in a feasibility phase. In the present work, we tried to validate the model, initially working at a punctual scale, on a wider geographical area by spatialisation of the input and

output data. We also added different modules to take nitrogen fertilisation into account and to predict forage quality.
To perform this validation step we followed grass growth, in quantity and quality, in 9 areas of 9 square kilometres with grassland coverage as high as possible. These areas were selected on the basis of soil coverage obtained from remote sensing observations (CORINE 1992) actualised with parcel occupation recorded through the SIGEC system and on the basis of their location in the different agricultural areas of interest. There field observations were also used to link remote sensing observations, and more especially Vegetation Index (NDVI – Normalised Difference Vegetation Index and SWVI – Short Wave Vegetation Index), to observed biomass.

4. OUTPUTS AND RESULTS

This study had allowed the development of a Grass Growth Model based on pedo-climatic data. It takes into account soil hydrological proprieties, thermal stress, and its impact on the delay before regrowth starting and on the speed of this regrowth, and nitrogen supply. A quality module had also been developed. Nevertheless, performances of this model on 2000 data were far from the one obtained following its cross validation on initial data set. So, model parameters must be adjust, through additional field observations, to integrate the diversity of the situation observed in the study area.
Remote sensing observations underlined the necessity to distinguish between meadows and grazed grasslands. Indeed, the mixture of grazed and cut grasslands, in a 1*1 km pixel, does not allow the direct translation of Vegetation Index differences in biomass production. It was then, currently, impossible to integrate remote sensing observations in the pedo-climatic model. To reach this target the proportion of grazed and cut grasslands must be defined in each pixel.
Definition that will also allow a better un-mixing of the proportion of the Vegetation Index is linked to the different vegetation components. Nevertheless, remote sensing observations could be used in relative ways. Firstly, to define the relative importance of forage stock constitution in the different agricultural areas. To do so, the definition of an adapted Vegetation Index threshold in function of the animal stocking rate had to be done in each agricultural area. Secondly, to identify grassland exploitation dynamic at the scale of the different agricultural areas, that is to say the periods of grazing, cutting or the periods of climatic stresses.

5. EXECUTION

Period: 12/01/1999-30/04/2001

Laboratory:

CENTRE DE RECHERCHES AGRONOMIQUES DE GEMBLOUX (CRAGx)
Rue de Liroux 9, B – 5030 Gembloux, Belgium
Phone: +32 61 23 10 10 Fax: +32 61 23 10 28
E-mail: lecomte@cragx.fgov.be

User partners :

AEDL Asbl
Rue de la Clef 41, B – 4650 Herve, Belgium
Phone: + 32 87 67 55 51 Fax: + 32 87 67 40 11
Contact person: L. Fabry

REQUASUD Asbl
Chemin de Liroux 9, B – 5030 Gembloux, Belgium
Phone: + 32 81 62 65 55 Fax: + 32 81 65 65 59
Contact person: D. Vrebos

6. RELATED DISCIPLINES

Agriculture
Environment

7. EXECUTIVE SUMMARY

Introduction

In order to improve livestock farming systems sustainability, from an economical and environmental point of view, tools necessary to manage nutrients stocks must be developed. Indeed, feeding costs are the greatest part of the proportional costs in these systems. Such tools must be able to estimate forage availability, in quantity and quality, to adjust foodstuff complementation and, in this way, to reduce nutrients wasting. Forage mainly composed of grass in the South Eastern part of Belgium where more than 75 % of agricultural land is covered by grasslands. Such maximisation of self-produced fodder crop valorisation in livestock farming systems will also increase product trace ability and differentiation and, so, system sustainability from a social point of view.

The use of dynamic model seems to be a promising tool to reach these objectives. Such models are based on the biomass formation through the photosynthetic activity of the plant under different environmental conditions (temperature, soil water content, photosynthetic active radiation, …). Limitations of existing models are that their accuracy is correlated to their complexity. Some of their parameters are difficult to obtain in a continuous way on a great number of sites. The aims of this study are to validate an agro-meteorological model, needing some easily available parameters, for Grass Growth in quantity and quality, and to use remote sensing data to control model outputs at regular intervals, on the one hand, and to integrate spatial heterogeneity, on the other hand. The accessibility of this tool was obtained through its integration on an internet site.

Modelling of grassland biomass accumulation in quantity and quality

The accuracy of the grassland growth model in the area of interest was assessed in a feasibility phase. In the present work, we tried to validate the model on a wider geographical area by spatialisation of the input and output data. We also added different modules allowing to integrate nitrogen fertilisation or to predict forage quality. To perform this validation step we followed grass growth, in quantity and quality, in 9 areas of 9 square kilometres with grassland coverage as high as possible. These areas were selected on the basis of soil coverage, obtained from remote sensing observations actualised with parcel occupation recorded through the IACS system, and on the basis of their location in the different agricultural areas of interest. Once these 9 areas selected, three meadow fields were followed, in each of them, during the 2000 season. In parallel, all farmer practices (fertilisation, cutting date, …) were recorded to be implemented in the Grass Growth model. As these observations had also to be used to calibrate remote sensing observations, days with low cloud contamination were chosen to perform sampling.

Before starting this validation step the model, initially working at a punctual scale, was spatialised to take meteorological and soil heterogeneity into account. So, simulations were performed on elementary mapping units (EMU) characterised by similar soil and meteorological conditions. These EMU are polygons geo-referenced (Belgian Lambert, Datum BD72). They were elaborated *via* a GIS on the basis of the meteorological grid, the soil map and the administrative limits in order to allow subsequent spatial aggregation, through the calculation of the weighted mean, in relation to the grassland proportion. In this way 4874 EMU were defined in the study area.

The data (temperature max. and min., vapour pressure, wind speed, rainfall, radiations) of the different meteorological stations were extrapolated, on a daily basis, to cover a grid with 5*5 km pixels. For the soil units, soil physical group, grouping soil mapping unit with similar hydrological proprieties and rotting depth, had been defined. All these data came from the project “Belgian-Crop Growth Monitoring System (B-CGMS 1998-2000 OSTC Project T4/42/23b)” and were integrated in a GIS, in parallel to the different modules of the grass growth model. Moreover, the 1st

version of the model worked with constant growing cycles length. This has been adapted to allow the definition of the starting and the ending date. In the same way, adaptations has been performed to take into account the residual biomass and to integrate a latency period, function of the biological age of the sward at cutting, before regrowth, after a cut or at the beginning of the season.
The updated version takes also into account the thermal stress, the water stress and the nitrogen nutrition impact. For the thermal impact, photosynthetic activity remains nil until a threshold. Then it starts to increase, in a linear way, till a second threshold from which it stays constant. As the photosynthetic response to temperature modification is not direct, a mean temperature, across last ten days, is used in this relation. These thermal units are also used to estimate the biological age of the sward. Water stress was defined from the ratio between the actual and the potential evapotranspiration. The actual evapotranspiration is defined from soil hydrologic parameters such as the available water reserve and the retention capacity. Nitrogen impact on sward growth was translated in a multiplicative coefficient acting on the daily growth. This coefficient is a linear function of the total amount of nitrogen available with a value of 0,533 without nitrogen fertilisation and a value of 1 with a fertilisation of 200 kg N/ha. The total amount of nitrogen being equal to the sum of the organic nitrogen brought through manure application, of the mineral fertiliser and of the input through nitrogen fixation by clover.
In order to integrate the prediction of grass quality in the model, a database covering more than 64 combinations of 'location * year * fertilisation level', with more than 900 data, was compiled. Grass quality is synthesised in two variables: the amount of protein that could be digested in the intestine (g/kg of Dry Matter (DM)) and the metabolisable energy content (VEM/kg of DM). The first had been predicted from the time of the year, the resting time before cutting and the yield observed. The determination coefficient (R^2) was of 0.64 in cross validation. It was associated to a standard error of 6 g/kg of DM, in validation. The modelling step retained, to predict the energy content, in spring, the cumulated temperature and the cumulated radiation and, in summer and autumn, the time of the year and the yield. Nevertheless, the determination coefficients observed for these relations were respectively of 0.56 and 0.39, with standard errors of respectively 35 and 30 VEM/kg of DM.
As the aim of the project wasn't to replace reference analysis, but to give an idea of stock quality to group more similar fields before to ask an analysis for these groups, we tested model accuracy to allocate each forage in the good group of protein or energy content. For protein, 79 % of the samples were well reallocated. For the energy, 80 and 71 % of the samples were correctly reallocated, in spring and in summer-autumn respectively.
Evaluation of the system so adapted was performed on the observations of the season 2000 recorded directly on farmer fields, under real farming practices. First of

all, of the 27 fields followed, we have draw aside all the grazing periods to focus the validation on hay or silage cycles. Then, after having implemented the model with the fertilisation practices of the farmer, the prediction root mean square error (PRMSE), in absolute and relative value, were calculated for the different agricultural areas and for the different parts of the season (first cycle in spring and other cycles in summer-autumn).

Even if the determination coefficient between the predicted and the observed biomass is equal to 0.77, the PRMSE, superior to 1 ton per hectare in most of cases, with a clear Site per Cycle interaction, is to high to allow the use of the model in its actual form. Model underestimates biomass value, this could be linked to an underestimation of nitrogen supplying through the mineralisation of soil organic matter. Adjustment of such internal parameters need more field observations to integrate agricultural area variability. Forage quality prediction leads to relative PRMSE of less than 15% that is far less than the 35 % observed for biomass. Nevertheless the PRMSE of 125 VEM observed for the energy content is to high to allow an accurate classification of the forage obtained.

Development of the user interface

Even if, in its current version, the grass growth model can't be diffused, the way to return it in an accessible form to the user had been explored, more especially throughout the design of an adapted interactive web-site (http://prairie.cragx.fgov.be). To do so, as main data are geo-referenced, the model, rewritten in Visual Basic to allow its compatibility with Microsoft Access, had been linked, in a dynamic way, to a GIS that acts as a data base management system and allows the return of the results under graphic, map or table forms. So, the fully automatic user interface allows to introduce simulation parameters (site, cutting date, fertilisation,…) before to obtained the evolution of forage quality and quantity under different graphic forms and/or spatial aggregations.

Remote sensing observation valorisation in grassland management

In order to study the possibilities to integrate remote sensing observations within the grass growth model, VGT-S10 images (resolution of 1 km * 1 km), have been obtained and analysed. They covered the period running from the beginning of April till the end of October, in 1998, 1999 and 2000. Assuming that atmospheric and geometric corrections applied to the images obtained were accurate, we homogenised their projection to allow their superposition to the grid used in the agro-meteorological model (Belgian Lambert Projection). Following this step, remote sensing reflectance had been filtered, through a temporal comparison, to reduce the negative impact of atmospheric perturbations and to interpolate missing values. This filtration had needed the definition of critical levels, representatives of cloud

reflectance or, in the opposite, of missing value. Then critical points had been deleted before to be linearly extrapolated from neighbour values. NDVI (Normalised Difference Vegetation Index) and the SWVI (Short-Wave Vegetation Index) were then calculated. The 1st one is widely used but is more sensitive to cloud contamination than the 2nd one that use mean infrared reflectance. In order to smooth rough vegetation indices variations, mobile mean, integration the target value and both its neighbours had been used.
Finally, to allow the superposition of the remote observations with the 5*5km grid used for the agro-meteorological model, these indices had been integrated in 25 square-kilometres macro-pixels. To do so, vegetation indices of each elementary pixel has been balanced in function of the grassland soil land-use proportion extracted from the "Corinne Land Use" cover. Four occupations classes have been used: 'grassland', 'forest', 'crop' and 'other' for each of the 478 macro-pixels.
After this phase of data pre-treatment, we have evaluated the possibilities to use remote sensing observations to predict grassland biomass in parallel to the agro-meteorological model, to estimate winter stock of forage and, finally, in the definition of grassland exploitation dynamic, mainly in the definition of cutting period. This was done from the pixel level to the agricultural region scale.
For the year 2000, at the scale of the observation sites, the analyses highlighted a relation between the observed biomass, all sites included, and the NDVI ($R^2 = 0.32$), on the one hand, or the SWVI ($R^2 = 0.46$), on the other hand. When the different sites were considered individually, determination coefficients were always superior to 0.5, for the SWVI, excepted for Froidchapelle where it was of 0.26. To integrate the approach on all the study area, we used, as reference values, the biomass estimated by the agro-meteorological model. As this model gives us the potential biomass produced under cutting regime and as the proportion of grassland exploited under grazing increase during the season, we could expect a greater discrepancy between remote sensing observations, reflecting the true agricultural practices, and biomass predicted by the model during the second part of the growing season. Indeed, from the data of Cattle Herd Breeders Association, we observed that proportion of grazed area increases quickly during the season, from 45% during the 1st cycle, to 66 % and up to 80 % of the grasslands during, respectively, the 2nd and 3rd growing cycles. So we concentrated this approach on the 1st cycle. It led to R^2 of 0.43 and 0.47 between model predicted biomass and, respectively, NDVI and SWVI vegetation coefficients. We confirmed the level of these relations in 98 and 99, for the different agricultural areas.Remote sensing data gives us information in space and time. In current crops we can use it to monitor growing stress. However, in grassland, following the numerous combinations of exploitation mode (grazing, cutting…) and their evolution during the season, such approach is more difficult. Indeed, each pixel of 1*1 kilometre includes more than one grassland. So it is difficult to define whether a

vegetation index decrease is due to a hydrologic or thermal stress during the vegetation growth, or to a cutting or grazing phase.
So, at this spatial resolution, even if we demonstrate the existence of a clear relationship between the evolution of grassland biomass and Vegetation Index obtained through remote sensing, it seems difficult to integrate these Vegetation Index directly into the agro-meteorological model to adjust predicted yields.
The possibilities to use remote sensing to predict forage stocks formation in animal farming system have then been explored. To do so, a NDVI threshold level has been defined. It corresponds to the biomass necessary to feed the herd under grazing. It has been fixed in Ardennes, where pedo-climatic conditions rarely led to hydrologic or thermal stress, following a cutting phase. Indeed, following such an event, the farmer will keep just enough grass to allow herd grazing till next regrowth. All value superior to this threshold will underlined possibilities to accumulate some forage stocks, while all value inferior to this threshold will underlined a production deficit, for example following an hydrologic stress, that will necessitate stocks consumption. If we observe the evolution of these excesses and deficits in space and time, we could clearly distinguish the 1st cut period. However the definition of the other cutting phases was less clear. This can be due to the definition of the threshold. Indeed, following its good and constant level of grass production, Ardennes area allows to maintain a high animal-stocking rate. So the fixed threshold could be overestimated for the other agricultural areas. This mean that such an approach needs to define a specific threshold for each agricultural area.
So, the definition of grassland exploitation dynamic through remote sensing had been explored further. When comparing the observations obtained on our 27 parcels of reference in 2000 and the Vegetation Index evolution, we could clearly defined the cutting period. To have an idea of biomass evolution dynamic a relative difference of NDVI ($RND_{(t)}$), in time, had also been calculated. High value underlined an increase in photosynthetic activity while negative value underlined a decrease of this activity following a stress or an exploitation of the grassland. A stagnation of this relative difference could be due to a grazing period. So study of RND(t) evolution could give an idea of grassland exploitation cycles (grazing, cutting, …) in the different agricultural areas with the impact of different climatic stresses when we put it in parallel to meteorological data.

Conclusions and perspectives

This study has allowed the development and the implementation of a Grass Growth Model based on pedo-climatic data. This model takes into account hydrological soil proprieties, thermal stress and its impact on the delay before regrowth starting or on the speed of this regrowth and nitrogen supply. A quality module had also been developed. Nevertheless, performances of this model on 2000 data were, from the quantitative point of view, far from the one obtained during its cross validation on initial data set. This underlines the necessity to adjust model parameters, by a close collaboration between modellers and field teams, to be able to integrate the diversity of the observed situations in the area of interest while focussing exclusively on meadows.

The necessity to distinguish between meadow and grazed grasslands was also highlighted in the analysis of remote sensing observations. Indeed, mixture of grazed and cut grasslands in a same pixel of 1*1 kilometre do not allow the direct translation of Vegetation Index differences in biomass production. So, it was, in this state of the art, impossible to integrate directly remote sensing observations at this spatial resolution into the pedo-climatic model. High-resolution imagery, optical or microwave, will offset low-resolution imagery. Various type of information can be extracted as the proportion of grazed and cut grasslands in each pixel at critical dates, this will also allow a better un-mixing of the proportion of the Vegetation Index linked to the different vegetation components within each pixel.

Nevertheless, remote sensing observations could be used in relative ways. Firstly, to define the relative importance of forage stock constitution in the different agricultural areas. To do so, the definition of an adapted Vegetation Index threshold in function of animal stocking rate had to be done in the different agricultural areas. Secondly, to identify grassland exploitation dynamic at the scale of the different agricultural areas, that is to say the periods of grazing, cutting or the periods of climatic stress.

PILOT PROJECT T4/10/068

DEVELOPMENT OF AN AUTOMATED INTERPRETATION TOOL OF SAR AND INSAR IMAGES FOR THE BELGIAN MINISTRY OF AGRICULTURE

P. DEFOURNY

UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL)
DEPARTMENT OF ENVIRONMENTAL SCIENCES AND LAND USE PLANNING - GEOMATICS
Place Croix du Sud 2 bte 16
B – 1348 LOUVAIN-LA-NEUVE
BELGIUM

1. CONTEXT AND OBJECTIVES

The objective is to assess the possibilities and the limitations of the use of SAR images (ERS and RADARSAT) in the currently operational control system developed by the Ministry of Agriculture - CTS in the framework of the Common Agricultural Policy.

This SAR study focuses on 4 specific issues related to this application:

- Can SAR images substitute the summer optical image, which is the main time constraint for the information delivery?
- Can SAR images increase the current accuracy obtained from the optical images?
- Can SAR images be useful for the Computer Assisted Photo Interpretation?
- When the information provided by SAR images can be delivered?

2. DATA

Geographic study area: Belgium

Satellite imagery used:

ERS-PRI
LANDSAT-ETM
SPOT-XS
RADARSAT-SGF
All the images were acquired in 2000.

Other data:

- Administration data
- Field data
- Meteorological data

3. METHODOLOGY

- The SAR data integration has to be done according to the current system specifications. Various classification tests have been completed using optical, SAR and optical-SAR images combinations. The maximum likelihood algorithm was used to classify the fields at parcel level and the spectral signatures were computed using all the declared fields (6571 parcels corresponding to 39 different crops).
- The accuracy assessments were made thanks to the crop type validated by field visits for 900 parcels. Both the remote sensing accuracy and the efficiency of the control system have been analysed.

- As SAR images have a different behaviour than optical images, a specific scheme for the Photo Interpretation of SAR images have been designed. It can be used in parallel with the classical photo interpretation system base on the use of optical images.

4. OUTPUTS AND RESULTS

A SAR images pre-processing chain has been adapted to be incorporated in the crop control system of the Belgian Ministry of Agriculture. The use of SAR images in addition to the available optical images increases the efficiency of the fraudulently declared parcels detection. The classification waterfall strategy developed in this project allows to increase the efficiency of the control for any remote sensing data. Indeed this is improved the control when achieved by optical images as well through the combination of optical and radar images. A computer-assisted photo interpretation method dedicated to the SAR data and adapted to the environment of the Ministry has been successfully proposed. All of these promising results lead the Ministry to implement the operational exploitation of radar images in the currently working system.

Of course the robustness of the proposed approach still needs to be documented through its applications over the years as the optical and radar remote sensing data set is actually different for every agricultural season. In this perspective, the Joint Research Centre (EU-JRC-Ispra) has proposed to provide more RADARSAT images to the Belgian Ministry for the coming year as follow-up of this pilot project presentation to all of the European actors at their annual meeting. Based on the results obtained for the year 2000, some conclusions can be translated in practical recommendations:

- The use of 3 to 5 SAR images with 2 or 3 optical images to increase the crops (an crop groups) discrimination in comparison with the control system based only on optical data;
- The use of the classification waterfall strategy to improve the control system efficiency based on both, optical data only and optical-SAR combination;
- The substitution of the last optical image by 3 RADARSAT images in order to reduce by more than 1.5 month the time delivery of the diagnostic and maintain the efficiency level thanks to the waterfall strategy;
- The use of SAR data for the photo interpretation of the suspected parcels using successive filtering techniques and the relative and local comparison protocol.

5. EXECUTION

Period: 12/01/1999-30/09/2001

Laboratory:

UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL)
Department of Environmental Sciences and Land Use Planning - Geomatics
Place Croix du Sud 2 bte 16, B – 1348 Louvain-la-Neuve, Belgium
Phone: +32 10 47 23 74 Fax: +32 10 47 88 98
E-mail: defourny@mila.ucl.ac.be
URL: http://www.agro.ucl.ac.be/biom/index_eng.html

User partner :

MINISTÈRE DES CLASSES MOYENNES ET DE L'AGRICULTURE – DG3
WTC3, Bd Simon Bolivar 30, B – 1000 Bruxelles, Belgium
Phone : + 32 2 208 32 11 Fax : + 32 2 208 38 10
Contact person : E. Dobbelaere, Directeur général

6. RELATED DISCIPLINES

Agriculture
Environment
Policy & legislation

FEASIBILITY STUDY T4/12/028

MANAGEMENT OF FORAGE RESOURCES AND FIRES IN EXTENSIVE CATTLE BREEDING IN NATURAL SAVANNAHS IN THE HUMID TROPICS

P. LECOMTE

CENTRE DE RECHERCHES AGRONOMIQUES DE GEMBLOUX (CRAGx)
Rue de Liroux 9
B – 5030 GEMBLOUX
BELGIUM

1. CONTEXT AND OBJECTIVES

The study has been realised in the framework of collaboration between a private partner, "Company Jules VAN LANCKER and scientific partners represented by the Agricultural Research Centre of Gembloux promoter of the study, and the Catholic University of Louvain Department of Geography. The project whose feasibility has been studied entered in the thematic axis " durable development of tropical countries ". It addresses all particularly to the theme " natural Resources " envisaged here under the angle of a durable management of spaces used for purposes of cattle breeding and the limitation of the natural course degradation in natural savannahs of the humid tropical zone. It concerns the feasibility of an approach integrating the satellite imagery to a Geographic Information System in view to characterise the evolution of the vegetation cover. To create a usable tool, it is indispensable to relate data provided by IS to terrain realities. The availability of these two factors in Africa over a period relatively long is quasi non-existent apart precisely in the particular case of the Kolo and Mushie ranches, property of the JVL and established since several decades in Congo. More specifically, the characterisation of the evolution of the vegetation cover has been posed in terms of impact of fires and animal carriage on the evolution of the vegetation of these ranches.

2. DATA

Geographic study area: Democratic Republic of Congo

Satellite imagery used:

NOAA AVHRR/2

HRV (SPOT 1-2-3)

HRVIR (SPOT 4)

VGT (SPOT 4)

Other data: Zootechnical and agrostological data's concerning two cattle ranches

3. METHODOLOGY

- Inventory of the existent data: geographical situation of test sites, inventory of satellite images, pre-treatment of the data's, inventory of terrain data. System integrating the Satellite Imagery and the Geographical Information GIS: diagram of an integrated management of the space and animals, identification of technical constraints, integration of the IS in the SIG, future improvements perspectives in IS for this type of activity
- Proposal concerning a pilot action: description of activities of the project, calendar of activities, costs of the project pilots

- Evaluation of the market: economic importance of a more dynamic management of savant's in Guinean zone, place of GIS and SI in the financing of development projects, cost/benefits approaches

4. OUTPUTS AND RESULTS

In look of the initial proposal, the information relative to fires of savannah will not be able to be directly integrated, due to problems of resolution in look of the burnt space size and due to the operational difficulty to obtain clear images in quasi real times. In the optic of a system aiming to quantify and control the degradation of the natural vegetation potential that does not hinder however in anything the general step. Following the inventory of the satellite Imagery available and descriptive and historical data of the two ranches, after having studied the different existent technical constraints, one can reasonably conclude to the interest and to the feasibility of a pilot action that would integrate the IS and data of management of a territory of breeding in view to characterise the evolution of the vegetation cover

In the course of the study it appeared that the recourse to the IS could contribute to provide 2 types of important information that classical terrain methods can not validly bring for great areas:

- The location of the degradation by IS at high spatial resolution SPOT in view of the distribution of the factor of degradation Fd adapted in a calculation of animal stocking rate
- The drawn to a detailed scale of an estimation of the available biomass (seasonal primary productivity Pi and factor of current utilisation Fu) by IS at high temporal resolution AVHRR recently launched VEGETATION satellite this step being driven so to the plan of the historical evolution of the indication of vegetation that on that its current state.

The study stress also evidence on the novelising interest that could have a pilot action conducted in partnership with an enterprise practising the cattle breeding in savannah and international consultancy in the area.

5. EXECUTION

Period : 23/12/1997-30/06/1998

Laboratory :

CENTRE DE RECHERCHES AGRONOMIQUES DE GEMBLOUX (CRAGX)

Rue de Liroux 9, B – 5030 Gembloux, Belgium

Phone: + 32 61 23 10 10   Fax: + 32 61 23 10 28

E-mail: lecomte@cragx.fgov.be

User partner :
CIE JULES VAN LANCKER SPRL
Rue des Drapiers 31-33, B – 1050 Bruxelles, Belgium
Phone: + 32 2 513 06 74

6. RELATED DISCIPLINE

Agriculture

FEASIBILITY STUDY T4/42/029

DEVELOPMENT OF A FORAGE PRODUCTION FORECASTING SYSTEM (QUANTITY AND QUALITY) IN SUPPORT OF A FOODSTRATEGY ON SCALE OF THE AGRICULTURAL REGION

P. LECOMTE [(1)]

R. OGER [(2)]

CENTRE DE RECHERCHES AGRONOMIQUES DE GEMBLOUX (CRAGX) [(1)]

Rue du Sermont 100

B – 6800 LIBRAMONT

BELGIUM

CENTRE DE RECHERCHES AGRONOMIQUES DE GEMBLOUX (CRAGX) [(2)]

Rue de Liroux 9

B – 5030 GEMBLOUX

BELGIUM

1. CONTEXT AND OBJECTIVES

Good farm management is only possible when forage availability and quality are known. In animal husbandry, the forage is mainly produced at the farm. Therefore, the estimate along time of forage stocks and quality is of prime importance to drive such farming system in an optimal economic way.

Dynamic models, describing the relationships between crop growth (yield), crop quality and environmental factors (solar irradiance, temperature, nutrient availability) have been set up. However these models often appear to fail when growing conditions are not optimal and don't take into account the important spatial variations across the region or subregion. A solution could to calibrate the model with information on the actual status of the crop during the season.

Information, such as the vegetation index (NDVI) could be provided by remote sensing and implemented in more general agrometeorological models to actualise and spatialise the prediction.

The aim of the study is to evaluate the feasibility of an integration of satellite imagery data and grass growth models at the level of region like Southeast Belgium.

2. DATA

Geographic study area: South Belgium

Satellite imagery used: NOAA AVHRR/2: Lat 50.80-49.50; lon 2.80- 6.50 for 1992, 1993, 1995 (free)

Couverture MARS92 (free)

Other data: Climatic data 1995 for Libramont and Shockeville

3. METHODOLOGY

- Describe the satellite data availability
- Isolate the proportion of the pixel NDVI due to the grasslands, and more specifically to the proportion of these grassland that will give hey or silage
- Define homogeneous growing zones for grass within the six Belgian areas cover mainly by grassland;
- Describe the remote sensing observations availability (vegetation index – NDVI – attributed to the grassland surfaces ; soil temperature, fraction of the radiation that is photosynthetically active - fAPAR),
- Trials on available of grass biomass prediction model will be performed by linking the observed yields, obtained from 1994 to 1997, in Libramont and Attert, to the following parameters: the remote sensing observations (vegetation index – NDVI – attributed to the grassland surfaces; soil temperature, fraction of the radiation

that is photosynthetically active - fAPAR) obtained 7, 14 and/or 21 days before the date of yield observation.

4. OUTPUTS AND RESULTS

Among the satellite products currently available on the market, we have researched these susceptible to present a recurrence and an operational character drawn to the scale of the project. It appears that only images with a low spatial resolution typically AVHRR or VEGETATION reply to these criteria. The use of this type of images is conditioned by the existence of prairie zones sufficiently vast and the detection on these zones of seasonal change.

We have put in evidence the existence in the Southeast of Belgium sufficiently zones of prairies that form a homogeneous structure drawn at the scale of the square km to justify the well-funded utilisation of images of low spatial resolution. We have equally shown that it will be necessary to use daily synthesis images of the VEGETATION or AVHRR type. These images have to be calibrated, and undergo atmospheric corrections and a masking of clouds. Even if results of NDVI measures during the course of a season undertaken in this work are not very convincing due to the quality of the image that were used, it appears possible to follow the evolution of vegetation of the prairies. We have equally seen that when data are not contaminated by clouds, it appears possible to describe of photosynthetic activity differences between regions and sub regions.

The agro meteorological model developed by OGER (1994), even if its development is not ended, offer already good result. The necessary elements for the constitution of a decision assistance system are present. A pilot action developed with partners of the agricultural world could help concretise the development of such system.

5. EXECUTION

Period: 23/12/1997-30/06/1998

Laboratory:

CENTRE DE RECHERCHES AGRONOMIQUES DE GEMBLOUX (CRAGX)

Rue de Liroux 9, B – 5030 Gembloux, Belgium

Phone: + 32 61 23 10 10   Fax: + 32 61 23 10 28

E-mail: lecomte@cragx.fgov.be

User partner:

ASSOCIATION PROVINCIALE DES ELEVEURS ET DÉTENTEURS DE BÉTAIL BOVIN DE LA PROVINCE DE LIÈGE

Rue de la Clef 41, B -4650 Herve, Belgium

Phone: +32 87 67 55 51   Fax: +32 87 67 40 11

6. RELATED DISCIPLINES

Weather and climate
Forest & natural vegetation
Agriculture
Environment

7. EXECUTIVE SUMMARY

In Southeastern part of Belgium more then 75 % of agricultural land is covered by grasslands. In order to improve management of livestock nutrients stocks, forage availability should be estimated with a good accuracy early in the season, in quantity as in quality. The use of dynamic model seems to be a promising way to reach this target (Bouman et *al*., 1996; Gustavsson, 1994; Gustavsson *et al*., 1995). Such models are based on the biomass formation through the photosynthetic activity of the plant under different environmental conditions (temperature, soil water content, photosynthetically active radiation,…). Limitations of existing models are that their accuracy is correlated to their complexity and to the number of parameters they integrate. Parameters are difficult to obtain in a continuous way. To reduce the complexity of such model and, in the same way, the number of parameters necessary to their running, it seems interesting to couple them to remote sensing data to control and adjust the model output at regular intervals (Barnes *et al.,* 1997; Delecolle *et al.,* 1991).

In the present work we analyse feasibility of such an approach, in mixed swards, on a regional scale, in the Southeastern part of Belgium. First, we test the accuracy of a model settled on permanent grassland communities. Then, existence of homogeneous area, of at least 1 km², covered with grassland, is determined in the different agricultural regions. Such areas are necessary for calibration of remote sensing observations. Thereafter, biomass was followed in these pixels through NDVI evolution to define whether remote sensing observations could give coherent estimation of these evolutions. Finally, information coupling system, between model prediction and remote sensing observation, through a SIG was proposed.

Model validation

The model used (Oger, 1994) is based on temperature, precipitation and solar radiation, on a daily basis. Water balance integrating soil characteristics, precipitation and evapotranspiration is also included.

The data on the dry matter (DM) accumulation and on the quality evolution were collected in three contrasted geographical regions (the Jurassic area - 974 mm, 8.3 °C (mean temperature), the Ardennes - 1084 mm, 7.5 °C and the Famenne - 818 mm, 8.1 °C). On these locations, the growth cycles were followed, bimonthly, during seventy days, with one new cycle being started each fourteen days. The first cycle was started the 1st of April. The sampling was closed at the end of November. The model was calibrated on data collected from 1968 till 1972, and from 1993 till 1994. Its validation was performed on data collected in 1995.

Results demonstrate that predictions of the model for the biomass evolution are close from field observations in Ardennes, with a deviation of maximum 10 % (figure 1). However this deviation increase to 23 % when observations on Jurassic area are taken into account.

Model accuracy differences observed between these two locations are explained by divergence in soil water balance, with the presence of a clayey marl soil in the second site. Such a soil could be rapidly saturated with water after heavy rains, now model takes into account water stress following its depletion, phenomenon well documented, not due to its excess. This underlines the interest to introduce remote sensing observation in order to adjust, regularly, the prediction of the model to such local heterogeneity.

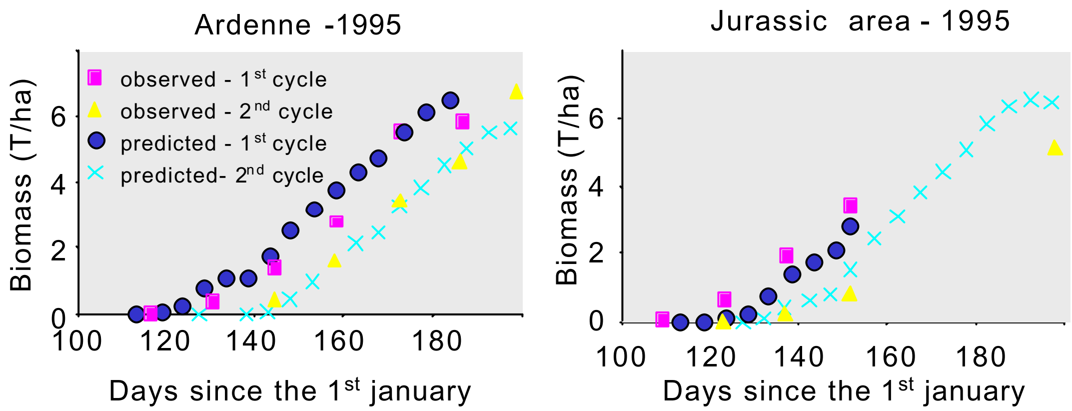


Figure 1 : Predicted versus observed values of the grassland biomass increase in Ardennes and in the Jurassic area in 1995.

Remote sensing data availability and existence of homogeneous area covered with grassland

In order to have sufficiently remote sensing data to readjust the prediction of the model, we choose to work with satellites that have a low spatial (1 km²) and a high temporal (one view per day) resolution, such as NOAA-AVHRR. In this way, homogeneous areas of more than 1 km², covered by grasslands, are necessary to calibrate remote sensing observation. The existence of such area was tested on the basis of the soil coverage edited by the program MARS92. The resolution grid of this coverage is 20 m.

First, a grassland/other coverage mask was settled. Then, a texture analysis has allowed to determine, within the grassland coverage, the area of high pixel homogeneity. A grid of 1 km² was then superimposed to define areas of interest.

These operations were performed with the CHIPS (Copenhagen Image Processing System, 1998) and Micro-Image (Olympus, 1997) softwares.
Numerous areas of high homogeneity in grassland coverage, areas of more than one square kilometre, had been isolated in the following agricultural regions (figure 2):

- Région herbagère Liégeoise,
- Haute Ardenne,
- Ardenne,
- Région Jurassique.

The only area in which grassland coverage homogeneity is low, in the Southeastern part of Belgium, is the Famenne not taken for extra-adjustment.

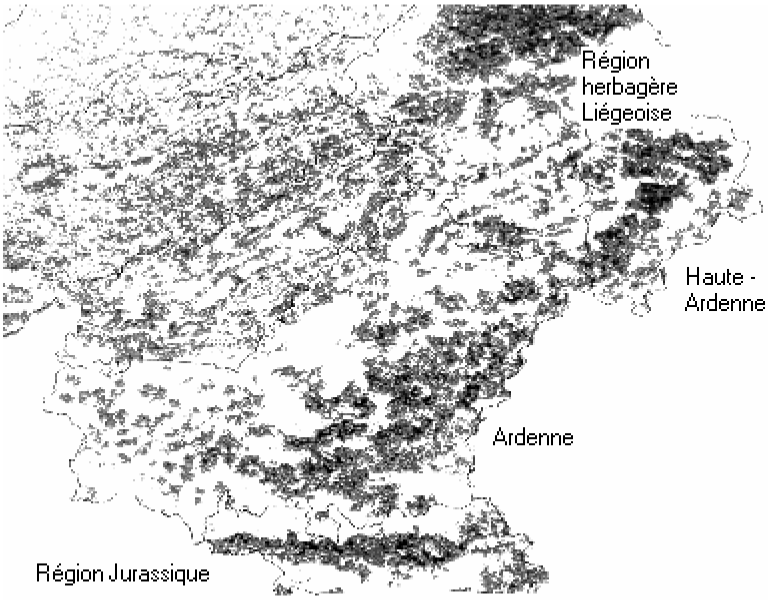


Figure 2: Areas covered with grassland in the South-Eastern part of Belgium are illustrated in grey. The blacker the zones are, the more homogeneous is their grassland coverage.

Coherence of NDVI evolution

In order to obtain a coherent evolution of NDVI during the season on grassland pixel a good calibration and correction (atmosphere, cloud, …) of remote sensing imagery must be performed. Following this step, significant differences were highlighted between area and sub-area, from biomass production and photosynthetic activity point of view.

Coupling model prediction and remote sensing observations

Figure 3 illustrates the organisation of the SIG necessary to couple model and remote sensing observations. The question remains about the better parameter to use to connect both these information: NDVI, LAI, …

Conclusions

In conclusion, the study underlines the possibilities to construct a decision support system, that will allow a better management of their fodder resources by the farmers, based on the integration in a SIG of agro-climatic model prediction adjusted through remote sensing observation.

However, to reach such a target, it will be necessary to take into account the impact of parameters such as nitrogen fertilisation and furniture through soil organic matter mineralisation into the model and to calibrate the relation existing between parameters obtained through remote sensing (NDVI, LAI, …) and grass quantity and quality observed in the field. This, respectively, to increase model accuracy and to allow to construct the bridge between model and remote sensing observations.

Finally, the decision support system interface had to be constructed and validated.

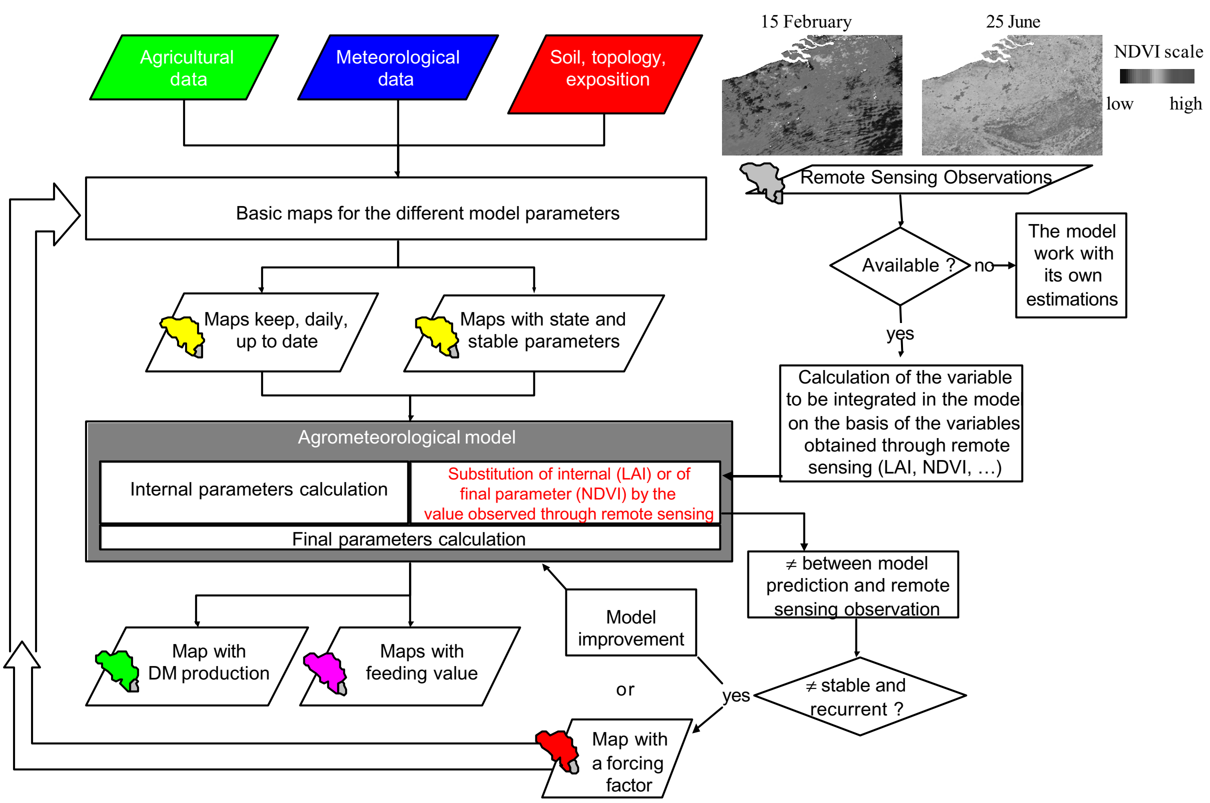


Figure 3: Organization of the junction between the dynamic model for growth and nutritional value of grassland and the remote sensing observation, this within a GIS allowing the dispatching of the data to the farmer.

FEASIBILITY STUDY T4/19/054

STUDY OF THE POTENTIAL FOR INTEGRATION OF SPOT VGT DATA IN EARLY WARNING SYSTEMS (FOOD SECURITY) IN THE SAHEL REGION

B. TYCHON

FONDATION UNIVERSITAIRE LUXEMBOURGEOISE (FUL)
UNITE EAU ET ENVIRONNEMENT
Avenue de Longwy 135
B – 6700 ARLON
BELGIUM

1. CONTEXT AND OBJECTIVES

The general objective of this feasibility study is to verify that VEGETATION instrument actually provides information of better quality than those from NOAA satellite specifically for the Sahelian region and within the scope of early warning, system on food and agriculture of FAO. FAO acquired a long experience in the field of satellite environmental monitoring for food crops and rangeland and they are definitely interested in improving their early warning system by studying the new possibilities given by the new instruments VEGETATION. This short study should also propose a structure that would provide technical, political and financial details for an efficient integration of VEGETATION data in the operational early warning system of FAO and would allow them to install the modified system in the different national and/or regional meteorological departments in Sahel region. This feasibility study should lead to a pilot project for the installation of the proposed new structure. The scientific main partner has a long experience in agrometeorology which is a major discipline in early warning system and he will get a contribution for JRC - Ispra for the Remote Sensing aspects.

2. DATA

Geographic study area: Sahelian Region (12W - 18N; 16E - 09N)

Satellite imagery used:

NOAA ARTEMIS

NOAA AVHRR

SPOT-4 VGT

3. EXECUTION

Period: 01/03/1999-31/08/1999

Laboratory:

FONDATION UNIVERSITAIRE LUXEMBOURGEOISE (FUL)

Unité Eau et Environnement

Avenue de Longwy 135, B – 6700 Arlon, Belgium

Phone: +32 63 23 08 29 Fax: +32 63 23 08 00

E-mail: tychon@ful.ac.be

URL: http://www.ful.ac.be/ful/Recherche/Surveillance/surveil.htm

User partner:

FAO

Via delle Terme di Carcalla, I – 00100 Roma, Italy

4. RELATED DISCIPLINE

Agriculture

5. EXECUTIVE SUMMARY

This communication was presented at the VEGETATION 2000 Symposium: Tychon B., Ozer O. and Toure S., 2000. Vegetation potentialities in food early warning systems in the Sahelian region. International symposium VEGETATION 2000, Belgirate, Italy, 3-6 April 2000.

Introduction and Objectives

Developing countries in the Sahelian region dedicate most of their activities to agriculture. A year with rainfall deficits or unevenly distributed rainfall during the rainy season often leads to food insecurity in this part of the world (Diop *et al*. 1996). This food status has to be foreseen early enough to allow decision-makers or financial backers to react fast enough to prevent or reduce the effects of potential famines. Among the available tools to foresee this type of disaster, the combined use of the low resolution NOAA-AVHRR sensor with the IR band of METEOSAT has served up to now in the global vegetation monitoring in Africa. This sensor association is presently used in routine by FAO inside its ARTEMIS Programme (FAO 1999). However, the AVHRR sensor has shown some limitations that did not always allow reaching the initial expectation of such an earth observation sensor. Some of these limits have been reduced even removed with VEGETATION sensor placed on SPOT 4 (SPOT-Image 1999).

The main objective of this study is to verify that VEGETATION instrument actually provides information of better quality than those derived from NOAA satellite specifically for the Sahelian region and within the scope of early warning system on food and agriculture of FAO.

Study area

The study area includes the central part of West African Sahel extending from western Mali to eastern Niger. In this area, two windows have been selected to compare the data derived from NOAA (AGRHYMET and FAO) and VEGETATION. These two windows were chosen in function of the ground based station density for which we do have estimated data of yields derived from the DHC_CP agrometeorological software (Bourneuf *et al*., 1998).

The location of the two windows is presented on figure 1. The first one (W1) covers an area about 170 000 km^2 and extends from the Malian northern Sahel to southern Burkina Faso (6°W-17°N; 4°W-10°N). The second one (W2) covers an area about

73 000 km^2 and only concerns the Sahelian belt of Niger (7°E-16°N ; 9°E-13°N).

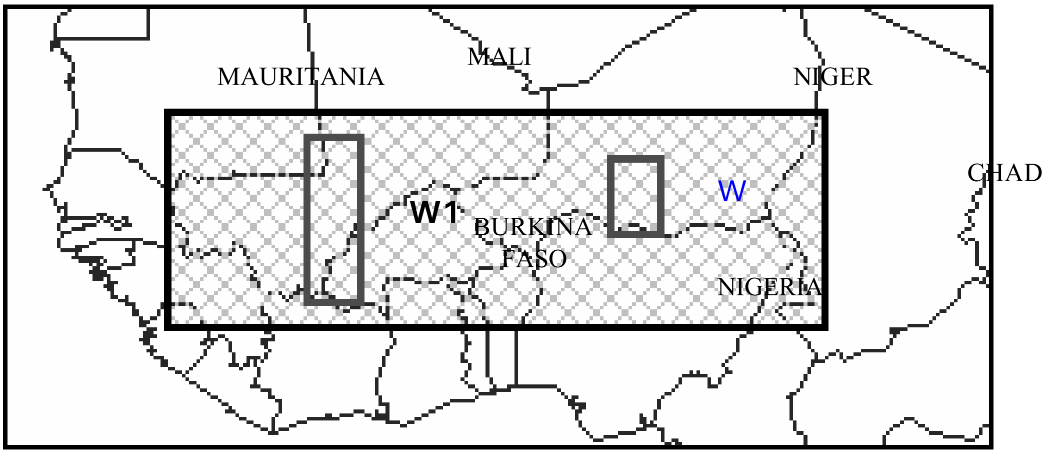


Figure 1: Location of the two windows (W1 et W2) selected for the study.

Methodology

Four criteria were selected to compare remote observations from the two satellites:

- The first criterion is based on the correlation between local yields of millet calculated with an agrometeorological model (DHC_CP) and the NDVI from NOAA and VGT. The NOAA image processing chain used in the AGRHYMET Centre has been developed by the USGS (J. C. Eidenshink *et al*. 2000).
- The second criterion checks the potentiality of spatial extrapolation of agrometeorological parameters. Here, the chosen criterion allows determining the start of the vegetation season with remote sensing based on a set of image series. Results from the two remote sources are compared with a map calculated with an agrometerological approach that fixes sowing date according to a given quantity of rainfall per 10-day period.
- A third criterion checked the saturation level of both sensors in regions with high vegetation density.
- Finally, pixel location was analysed inside a window crossed by the Niger River.

This study covers the 1998 rainy season (April to October).

Results

Yields correlation

Three vegetation indicators derived from the NDVI data of VEGETATION and NOAA have been used for the comparison with the estimated yields in the ground based station at the local scale.

These three vegetation indicators are:

1. The Length of the Growing Period (LGP).
2. The maximum value of NDVI observed between April and October.

3. An integration of the NDVI curve during the Growing Period.

$$\text{integ} = \int_{\substack{Début \\ Saison}}^{31.10} NDVI_t \, dt$$

The results obtained from these vegetation indicators to forecast the yield production are presented in table 1. In five cases out of six, the results obtained by VEGETATION are better than those derived from the NOAA data. This improvement is, in some cases, not negligible as it can reach 27%.

Once the results obtained by VEGETATION are compared to the ARTEMIS operational system developed and currently used in FAO, the improvements are of 38 and 30% (respectively for W1 and W2).

Window 1	Yields (kg.ha^{-1})	Window 2	Yields (kg.ha^{-1})
LGP-NOAA	R^2 = 0.66	LGP-NOAA	R^2 = 0.47
LGP-VEGETATION	R^2 = 0.69	LGP-VEGETATION	R^2 = 0.51
Difference in %	+ 5	Difference in %	+ 9
NDVI_M-NOAA	R^2 = 0.66	NDVI_M-NOAA	R^2 = 0.55
NDVI_M- VEGETATION	R^2 = 0.62	NDVI_M- VEGETATION	R^2 = 0.70
NDVI_M-FAO	R^2 = 0.45	NDVI_M-FAO	R^2 = 0.54
Difference in %[1]	- 6	Difference in %[1]	+ 27
Difference in %[2]	+ 38	Difference in %[2]	+ 30
NDVI_I-NOAA	R^2 = 0.68	NDVI_I-NOAA	R^2 = 0.62
NDVI_I- VEGETATION	R^2 = 0.70	NDVI_I- VEGETATION	R^2 = 0.64
Difference in %	+ 3	Difference in %	+ 3
N	77	N	46

Table 1: Comparison of the determination coefficients (R^2) linking the « Length of the Growing Period LGP » indicator, the «maximum value of NDVI-NDVI_M » indicator, the «integrated NDVI curve during the Growing Period-NDVI_I » indicator and the local ground based yields estimations. Difference in % = improvement (+) or reduction (-) of the yields forecast derived from the VEGETATION data in comparison with the NOAA[1] data and the ARTEMIS-FAO[2] data. N = number of points used to establish the relationship.

Starting date of the vegetation season

In Sahel, the starting date of the vegetation season can approximately be assimilated with the sowing date (Rasmussen 1992; Groten 1993). It is therefore possible to recover, by remote sensing, the likely periods for sowing over a huge area such as Sahel. To confront this approach with an agrometeorological method, which will be taken as a reference, the results of an agrometeorological indicator have been used. This indicator fixes the sowing date following a criteria established in the DHC_CP software: 10 mm of rainfall over a 10-day period. The results of the confrontation are presented at the figure 2 where the two remote sensing sources are compared with a map calculated with the agrometeorological approach.

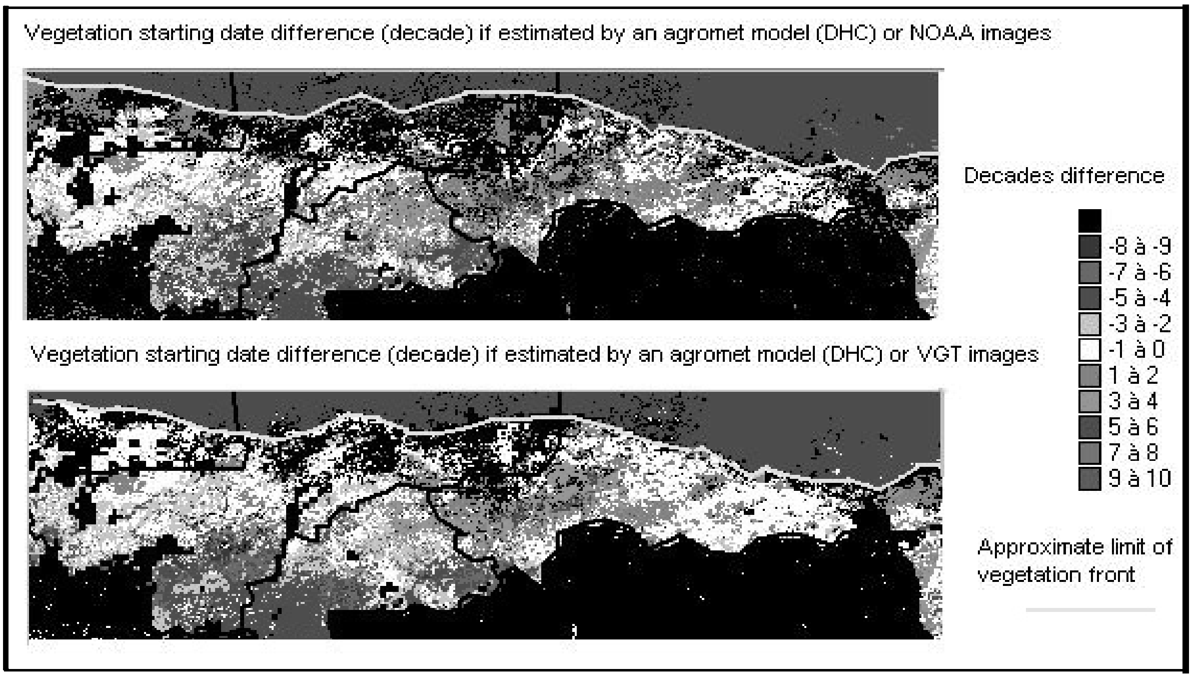


Figure 2: Comparison between the sowing dates estimated by remote sensing (NOAA and VEGETATION) and DHC_CP (agrometeorological model)

On figure 2, white and grey areas represent zones where a good correlation between both approaches can be considered. These zones cover a larger area with the results derived from the VEGETATION images. This shows the better capacities o f this sensor to detect the starting dates of the vegetation period. In this particular case, the use of remote sensing is particularly interesting. A good example is given on the area around the Niger River in Mali, which is highlighted by its red colour, underlining a 40 to 50 days diffe rence between the satellite data and the agrometerological approach. This ifference is clearly due to the fact that the pixel resolution is of 1 km for the remote sensing information compared to the 5 km pixel used in the agrometerological model. Such details are therefore lost in the model calculation. The red areas in southern Mali and Burkina Faso result from an artefact. As a matter of fact, the agrometerological model starts its simulations in May while satellite data are available since April. Therefore, as the vegetation starts growing in April in the Sudanese belt, all these red areas have not to be considered in the comparative analysis.
Another interesting point to notice is the presence of the green colour extending from central Burkina Faso to central Niger. This green colour indicates that the agrometerological model has derived a starting date of the vegetation season before it could be observed by remote sensing. This difference can be explained by the fact that early rainfalls exceeding 10 mm on a 10-day period have been followed by a dry spell. Therefore, the vegetation did not start its seasonal cycle at that date but several weeks afterwards as seen on the satellite data. This green area presents then a zone where fault starts have obviously been frequent.

Saturation levels in high density vegetation area

Figure 3 presents maximum NDVI value observed for the two sensors along a North-South transect in the first window. Whereas the agreement between the two sensor appears excellent between NDVI 0.2 and 0.35, a nearly systematic lower value is observed for NOAA between NDVI 0.35 and 0.4 followed by a faster increase of the AVHRR-NDVI between 0.4 and 0.6 that leads to a status where NOAA-NDVI is above VGT-NDVI around 0.6. Above 0.62, whereas VGT continue increasing, the AVHRR sensor seems to saturate. Along this 770 km transect, the NDVI data range is 17% larger for VGT than NOAA.

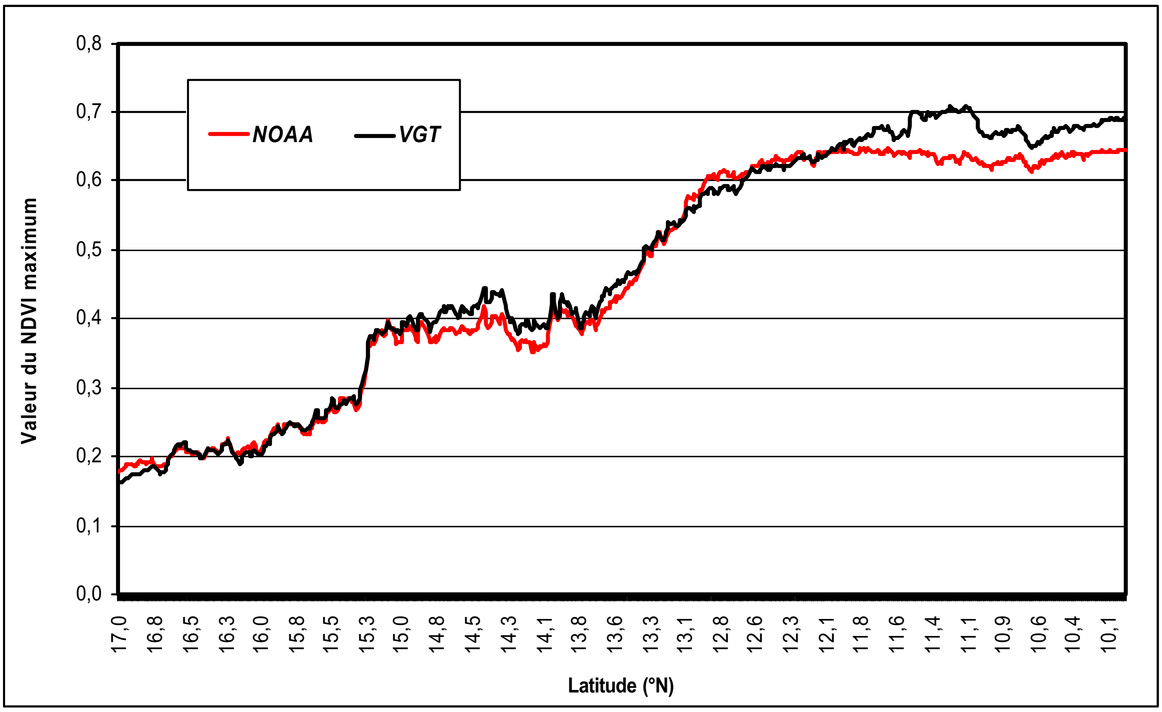
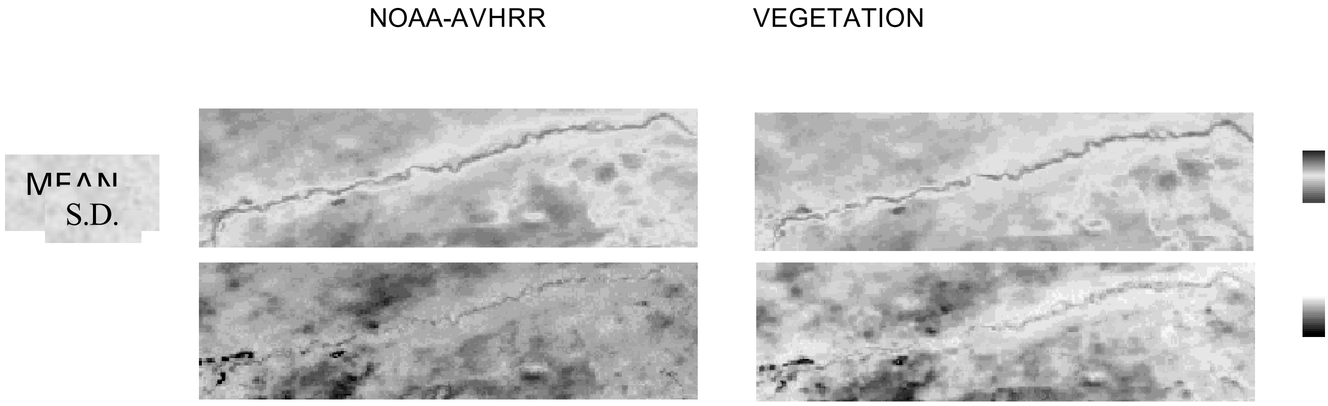


Figure 3: NDVI evolution along a north – south transect in window 1.

Pixel location accuracy

The area of the Niger River between Tombouctou and Gao was retained for a particular analysis of the pixel positioning. This region with very few vegetation allows an easy recovering of the river pixels. Figure 4 shows for the two sensors respectively the mean and the standard deviation of a set of 21 images from the first decade of April 1998 to the last decade of October 1998.

Figure 4: Pixel location around the Niger River



Mean values of the pixel time series provide equivalent images with the two sensors. Especially, the Niger River width does not appear significantly different (e.g. brown colour). Both NOAA and VGT give an estimated river width of about two to three pixels. On the other hand, the standard deviation image of the images series presents a systematic higher value for NOAA. A possible explanation of this scattering increase in the pixel series might be found in the change, with the different decades, of the geographical coordinates of a same area. However, if it was correct, pixels of the river with NOAA images should present a higher difference of standard deviation with the standard deviation of the neighbours pixels. This is not checked: the differences of standard deviation between river pixels and their direct neighbours' pixels are similar for the two sensors. This study of the pixel location accuracy should be improved but, at the present time, it does not underline a sensible advantage of VGT compared to NOAA.

Conclusions

The VEGETATION instrument demonstrated its higher capacities for vegetation monitoring in the Sahelian region within the scope of agricultural campaign monitoring and food early warning systems in comparison with the NOAA-AVHRR sensor presently used for this topic.

These potentialities should now be used to replace NOAA images in the different monitoring systems. Moreover, we think that VGT should be used for other applications than those presently run by NOAA. Especially, it should be necessary to look at the potentialities of the sensor in the monitoring of small areas (< 100 km²). It should also be worth improving the integration of remote sensing information inside agrometeorological models in order to valorise this new type of information in a quantitative way.

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CEO T4/F3/043

SABRES – SERVICES TO AGRIBUSINESS BY REMOTE SENSING

E. BREMS
V. SCHREURS

GEOGRAPHIC INFORMATION MANAGEMENT NV (GIM)
Researchpark Haasrode
Interleuvenlaan 5
B – 3001 HEVERLEE
BELGIUM

1. CONTEXT AND OBJECTIVES

The Service for Agribusiness by Remote Sensing (SABRES) project is developing and assessing practical methods of using very high-resolution satellite images (VHRSIs) combined with other spatial data within Farm Management Information Systems (FMIS). The very recent availability of 1 to 4 meter resolution images (IKONOS images available from February 2000 onwards) will revolutionise the use of satellite data for whole farm management and individual crop management, particularly precision farming. The SABRES project has been developing and testing prototype services that aim to deliver processed and interpreted information to farmers based on high-resolution satellite images.

2. DATA

Geographic study area: Belgium, France, Germany and United Kingdom

Satellite imagery used:

ETM+ (LANDSAT-7)
HRV (SPOT-1-2-3)
HRVIR (SPOT-4)
IKONOS (IKONOS)
LISS III (IRS-1-C)
PAN (IRS-1-C)
TM (LANDSAT-4-5)

3. METHODOLOGY

SABRES takes well-established methods of satellite remote sensing and applies them to data from VHR satellite sensors. Specially designed image products will be integrated into innovative, prototype farm management information systems (FMIS) developed from existing software products. In addition, an advanced component of the project delivers higher-level products to the FMIS (e.g. fertiliser and fungicide recommendation maps). SABRES focuses on VHRSIs and exploits the new capability offered for closely monitoring the development of crops during the growing season. This has not previously been possible from satellites and is therefore a completely novel application.

4. OUTPUTS AND RESULTS

VHRSIs provide a new and promising source for collecting information in agriculture. New techniques and experience have been developed in this project including different aspects of VHRSI processing and deriving value-added information, FMIS development and the development of a prototype Internet interface for ordering image products.

5. EXECUTION

Period: 21/12/1998-31/03/2001

Laboratory:

GEOGRAPHIC INFORMATION MANAGEMENT NV (GIM)

Researchpark Haasrode, Interleuvenlaan 5, B – 3001 Heverlee, Belgium

Phone: +32 16 40 30 39 Fax: +32 16 40 69 39

E-mail: vital@gim.be URL: http://www.gim.be

6. RELATED DISCIPLINES

Vegetation

Soil

7. EXECUTIVE SUMMARY

The Project

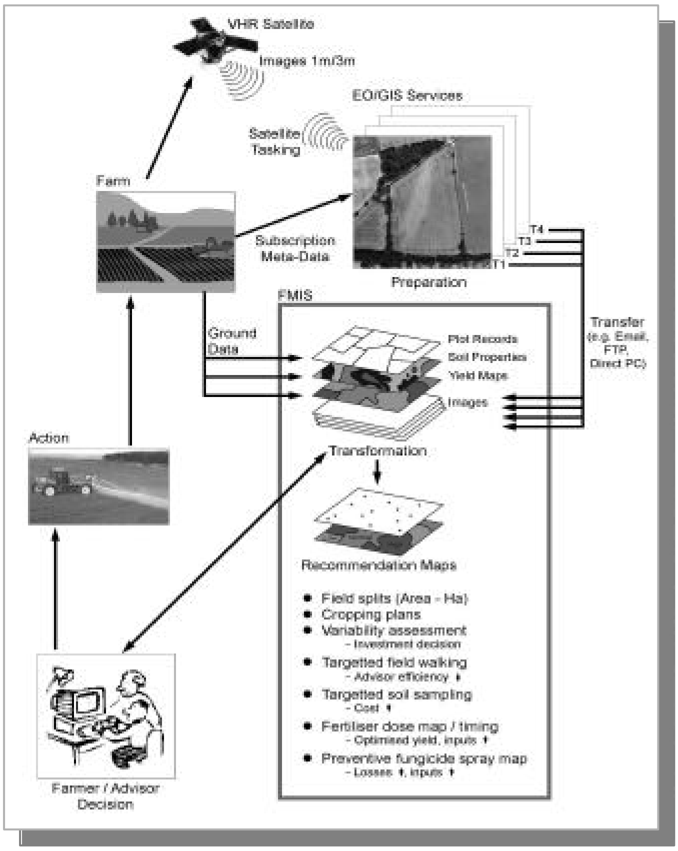
SABRES was initiated in September 1998 by the European Commission, with RSAC (UK), EFTAS (DE), GEOSYS (FR), GIM (BE), KUL (BE) and ADAS (UK) as partners. These partners worked closely with advisers and farmers in their respective countries.

Highlights

- Comprehensive examination of the requirements of farmers and agribusinesses in relation to EO data.
- Operational evaluation of the performance of image providers in meeting the needs of the value added retailers.
- Evaluation of the use of near real time satellite data in the crop management decision-making processes on farms.
- Feedback from users on the benefits to be derived from EO data.
- Development of algorithms relating satellite reflectance data to crop growth parameters, such as leaf area index.
- Assessment of Farm Management Information Systems (FMIS) for storing and analysing remotely sensed and ground collected spatial data.

- Development of a FMIS to integrate data and algorithms derived from satellite images to produce application maps for fertiliser and agrochemical inputs.
- Production of a prototype system for users to order and accept delivery of satellite images and derived data via the Internet.

Rationale



Schematic of the integration of EO services into the farm decision making process.
The availability of very high-resolution imagery (<5m) from the IKONOS satellite was seen as an opportunity to assess the value of these data for crop management.

This was particularly timely due to the increasing interest in yield mapping and the development of technology, which allows application equipment to continuously vary input rates within fields.

The SABRES rationale was based on the provision of field-scale information derived from satellite imagery, which could be linked with existing ground data to improve the crop input decisions taken by farmers and their advisers.

Emphasis was placed on capturing customer requirements over two growing seasons. The project also evaluated two particular aspects of very high-resolution satellites (<5m) for agricultural applications.

1. The value of the data collected.
2. The operational capability to deliver the data in near real time so that it can be used to influence inputs to the growing crop.

All partners involved agribusinesses and commercial farms in this process. Feedback from 1999, when other data had to be acquired due to the failure of IKONOS 1, and 2000 has been used in assessing the potential for future commercial services

Objectives

The project began in September 1998 and was completed in February 2001. It concentrated on combinable crops, and in particular cereals, due to their predominance on arable farms. The objectives were:

- To utilise VHRSIs as a new source for collecting information in agriculture, including monitoring crop status in time for remedial or preventive treatments to be applied using locally adjusted doses within fields.
- To take well established-methods of satellite remote sensing, apply them to data from new Very High Resolution (VHR) satellite sensors and integrate specially designed image products into innovative, prototype farm management information systems (FMIS) developed from existing software products.
- To deliver higher level products to the FMIS (e.g. fertiliser and pesticide recommendation maps) by application of existing techniques to a time series

of satellite images (obtained whilst the crop is growing) and in combination with ground data from conventional sources.

- To develop a subscription and distribution mechanism so that agri-business subscribers to the SABRES can receive pre-processed images and advanced products automatically from their EO/GIS service provider.
- To implement prototype software and metadata structures so that project customers can subscribe to SABRES, with details of the farm extent and services required, so that they can then receive high level image products for their farm(s) automatically over the Internet as soon as they are available.
- To obtain feedback from customers over the two growing seasons and to synthesise (technically, commercially and scientifically) the experience gained over the whole project to produce an exploitation plan.

Customer Requirements

Customer requirements were identified at the start of the project, as a foundation for the development of the data products and to allow an evaluation of the extent to which the requirements were met through feedback at the end of the 1999 and 2000 growing seasons. The requirements were prioritised by each of the partners with respect to their own country. They were split into categories, but the objectives of the project were primarily related to agriculture.

Agriculture – relating to crop management decisions at specific times of the year. In some cases the true requirement was to monitor on a weekly basis or even more frequently in the case of pest and disease incidence. These levels of service were outside the feasibility of this project but need to be taken into account when considering future commercial services. Practical rather than ideal levels of service were therefore specified in the requirements.

Geographic – the spatial resolution and accuracy of the images and derived products.

Estate Management and Conservation – farm woodlands and the assessment of land value and asset inventory.

Farm Management and Administration – the use of imagery to assist in the identification, storage and retrieval of land parcel and linear feature information within a farm management system.

Legislation, Regulation, Grants and Compensation – the use of images in drawing up farm plans that can be used for compliance purposes and in making grant applications and compensation claims.

IT and System Performance – the performance of the methods used to deliver imagery and derived data and the subsequent analysis within a farm management information system (FMIS).

Satellite images

From an evaluation of the customer requirements, it has been concluded that, for near real time crop management purposes, images will need to be provided at key times during the growing season. These will need to be matched to particular growth stages when major input decisions are being formulated and applied. Timing will vary according to cropping and location but will remain fairly independent of season. For example, taking cereals, 3 images will be required to assist with:

- Early nitrogen and herbicide applications – late February
- Second nitrogen and growth regulator applications – mid April
- Fungicides, growth regulator applications and weed mapping – May

It is a key requirement that images are supplied in the time windows requested as customers will naturally be reluctant to pay for information that is provided after input decisions have been made. There are two components to this, firstly acquisition of the images and secondly the time taken in delivery and processing. Acquisition of images has proved to be a serious constraint. The success rate for IKONOS varied from 100% for France to 0% for the UK. Overall only 45% of the ordered images were acquired and some of these were outside the requested time window.

VHRS systems, with their tilting capability and programming facility to improve the reliability of image acquisition, have only partially fulfilled their promise, even for very small study areas. SABRES demonstrated that satellite image providers have improved their delivery performance, and a delay of no more than 5 days from acquisition to delivery is achievable. Processing and data delivery by the value added retailer to the customer need take no more than two days, so that the total delay between acquisition and delivery to the customer should be no more than 7 days.

Crop management

Following the evaluation of satellite data on farms, the following crop management applications were identified and are listed in order of the current benefits in a commercial farming situation:

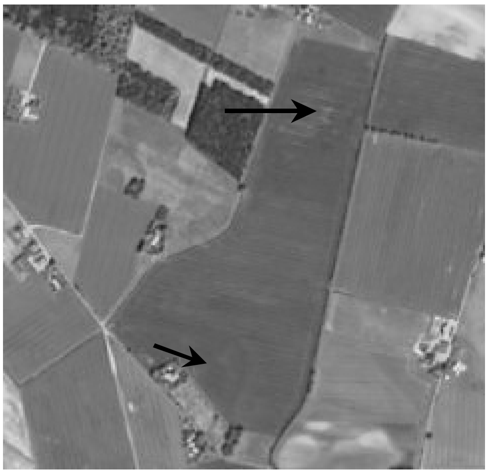
- Tactical field inspection – using imagery to target areas for further investigation in the field,
- Identification of management zones – improved soil mapping and delineation of areas justifying differential management,
- Weed mapping – mapping areas of weed for selective herbicide application,
- Nitrogen application regimes – monitoring plant canopy at different growth stages for determining overall levels of nitrogen application and for the production of nitrogen application maps (precision farming),

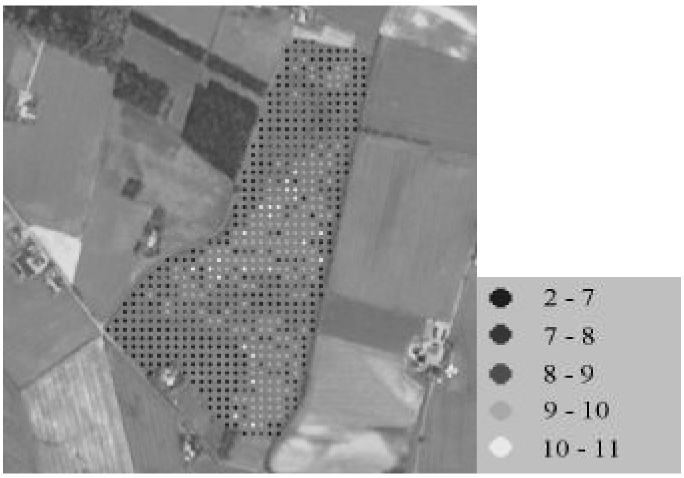
- Fungicide and growth regulator application strategy – as above but for fungicides and growth regulators,
- Disease/Pest monitoring and treatment – locating and mapping the incidence. Unlikely to be used as early warning but for monitoring the effectiveness of treatment and preventative measures in current and subsequent crops.

Field Inspection and Management Zones

Most progress has been made with these applications. Currently, decision making in crop management is largely based on farm experience, knowledge of soil types, soil sampling and analysis, and frequent crop inspection. Delineation of soil types is often imprecise and soil nutrient status is generalised, being based on random sampling, to establish average values for a whole field. Satellite imagery has been successfully used to improve the delineation of soil type boundaries and to identify areas showing consistent differences in crop performance that can be treated as separate management zones. Crop inspections rarely cover the whole field and the project has demonstrated the ability of satellite images to provide a synoptic view of growing crops, allowing agronomists and farmers to identify areas of poor growth requiring field inspection. This is likely to be an increasingly important application of satellite imagery as cost constraints are leading to individual agronomists and farmers being responsible for much larger areas of crops.

The IKONOS false colour image below shows how 4m-pixel resolution allows for the visual interpretation of crop vigour and the identification of poor growth zones. In this particular wheat field, poor areas were delineated as zones justifying extra nitrogen fertiliser treatment (arrowed). The superimposition of the yield map shows that this provided for improved growth and yield in the northern area, but not in the southern area where moisture availability proved to be the limiting factor.





Tonnes/ha

IKONOS MS image 14-05-00 ***Wheat field overlaid with yield map (t/ha).***

As IKONOS imagery was not available in the UK, lower spatial resolution imagery from SPOT and LANDSAT was used for evaluation on arable farms. Here, field sizes frequently exceeded 10hectares and SPOT XS material proved to be suitable for field inspection and management zone applications.

Application maps

A research element of the project has been to develop advanced thematic products, such as nitrogen fertiliser application maps, based on a combination of field information and satellite data. The challenge has been to develop models that can consistently and reliably correlate vegetation indices derived from satellite data with ground measurements. The use of Leaf Area Index to monitor canopy development has been shown to be an important factor for decision making on nitrogen and fungicide application strategies. The project has shown that vegetation indices calculated from IKONOS data (4m pixel) were more closely correlated with ground measurements than those from lower resolution satellite data (20m+ pixel) but there has been insufficient imagery within the period of the project to validate a reliable model.

Integration with Farm Management Information Systems

Another component of the project was to develop a Farm Management Information System (FMIS) that can combine data from different sources to produce advanced thematic products. The prototype system has been based on ArcView. It has been specifically designed to provide the basic functionality associated with other FMIS systems on the market, allowing for all parcel information to be entered spatially and associated with linked data in a database. A nitrogen application map is derived in the following three stages:

- Management zones are derived from soil maps (which may use satellite imagery to improve accuracy) and cropping history.
- Advised nitrogen requirement is calculated using soil analysis and yield data from previous years.
- Apparent nitrogen requirement is estimated from satellite imagery based on an estimation of crop biomass and the algorithm that has been developed within the project using reflectance data from all the visible and near infrared bands.

A comparison of the advised and apparent nitrogen is then made with input from the agronomist/farmer to produce a final nitrogen recommendation map. The degree of intervention by the agronomist/farmer is likely to decline as the algorithms are refined with additional data each year, and confidence in the system increases.

Access to Satellite Images and Data

Within the project a prototype subscription and distribution service has been implemented. This provides a simple centralised system where customers can register their farms and order images and products, with the appropriate value added retailer (VAR) being notified of the order and delivering to the customer through the system. The customer uses the first few pages of the web site to provide the spatial details of the area of interest using map co-ordinates or drawing a rectangle on a geoviewer. Once registered, a list of products is displayed which can be ordered for the whole area or an area within it. With the prototype, orders from the countries participating in SABRES are automatically routed to the VAR represented by the appropriate partner. The VAR then checks existing catalogues if an archive image is required and/or places an order with the relevant image provider to fulfil the order. Image processing and the production of products to the customer's specification are undertaken by the VAR and the customer is notified by email that the order is ready. Using a hyperlink connection on the email, the customer gains access to the distribution server, and downloads the order to a chosen directory on his own PC. Within the project, a commercially available FMIS adopted by one of the partners has been used to automatically check a directory for new images and successfully import them.

Exploitation

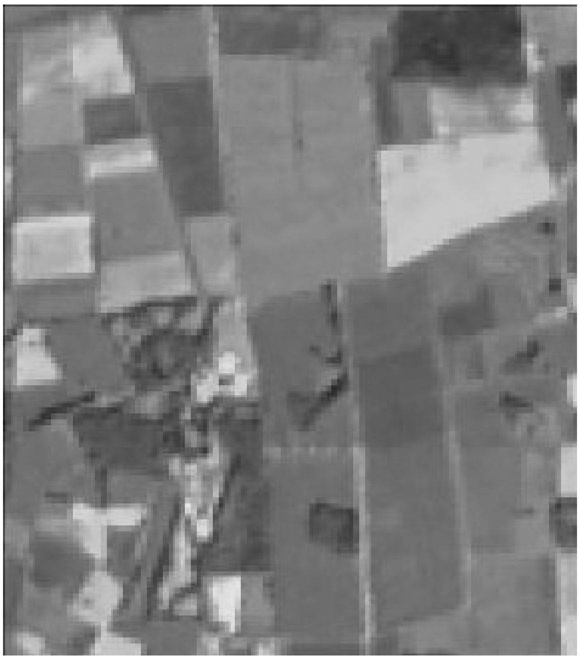
Precision farming technology has had a strong influence in raising awareness of yield variation within fields. However, low cereal prices, the cost of equipment and the lack of scientific knowledge on how to manage inputs in relation to site variability have all combined to dampen the original enthusiasm for the technique. Nevertheless there is still much interest in identifying areas within fields with differing production potential and understanding the reasons for this variability (precision agriculture). This suggests that farmers will adopt a lower technology approach, at least in the short term, and this has implications for the way in which the market for EO data can be exploited.

All partners will be exploiting the aspects of the results of the project, which reflect their own core skills and the market place in their own countries. The uncertainties regarding image acquisition dictate a pragmatic approach in relation to current system capability in an attempt to build a customer base for EO data that can be further exploited as more high-resolution satellites become operational. In the UK, a small number of zones with a high concentration of large arable farms, based on 60x60km SPOT scenes, will be selected. Consultants, agribusinesses and individual farmers will be offered a service, similar to that originally envisaged in SABRES, with both archive and near real time imagery. In order to simplify viewing and comparison of EO data, user-friendly software has been developed which offers flexibility in viewing images of fields at an individual farm level or over many farms in a zone. This will include a range of services from the VAR including consultancy support. In Germany, there is a demand for products that will assist in mapping cadastral boundaries and measuring field areas, and the main marketing effort will be in promoting the use of aerial photography. At the same time this medium and satellite imagery will be used to identify soil types and potential management zones. In France, the development work on the FMIS has resulted in a commercial product that is now being marketed and a web server for ordering and delivering images is being introduced. In Belgium, because of the very small arable farm market, the marketing effort is being concentrated on high value vegetable and root crops. Here the customers will be the large processor agribusinesses, where the FMIS and expertise developed within SABRES can be applied to the provision of crop intelligence over their production areas.

Conclusions

The project has demonstrated that operationally it is possible to deliver satellite images and products on farm within 7 days of the data acquisition. (This is a critical factor in meeting the objective to utilise near real time imagery for crop management). It has also shown that while the introduction of FMIS technology onto farms has been slower than originally envisaged, users can rapidly become familiar with hard copy satellite images and visually interpret them to derive information for crop management purposes. The importance of imagery in the early crop growth stages has been reinforced (Feb-May for combinable winter crops) as this is the time when there is the greatest potential for the derived information to influence crop husbandry. The credibility of future commercial services will be heavily dependent on image providers being able to provide consistent, reliable delivery of images.

Very-high resolution imagery has the potential to meet many of the customer requirements identified in the project and it is now technically possible to integrate images and products with other data sources on farm. The uncertainty associated with acquisition and the relatively high cost of imagery in the current economic environment are still barriers to the utilisation of satellite data. In terms of acquisition, as the number of VHR satellites increase, coupled with larger area scene coverage, as is proposed with SPOT 5 in 2002, then reliability and success rate should improve. Cost reduction could be realised through a more commercial attitude being taken by image providers for the purchase of part scenes, and by VARs concentrating their marketing efforts within geographic areas to achieve high levels of scene utilisation.



SPOT image 15-05 2000 (20m pixel resolution)   IKONOS image 14-05-2000 (4m pixel resolution)

The project has also demonstrated that a great deal of information on crop performance can be derived from 20m-resolution multispectral imagery, as can be seen from a comparison of the IKONOS and SPOT images above. These images were acquired on consecutive days and the differences in crop establishment and vigour can be identified, along with their extent, virtually as effectively on the 20m resolution as the 4m-resolution image. Nevertheless, users relate more enthusiastically to higher spatial resolution, because they have more confidence in the recognition of features when they appear to be more "focussed".

In marketing the applications for EO data at a farm level, it will be better for EO service providers to work through consultants, farmer co-operatives and other agribusinesses than individual farmers. These groups will be able to develop the necessary expertise to integrate satellite data into their advisory activities. In addition, individual advisers often have a close and trusting relationship with their farmer customers, making them an ideal conduit for introducing remote sensing techniques.

Publications

Blakeman, R.H., R. Bryson, P. Dampney. 2000. Assessing crop condition in real time using high-resolution satellite imagery. Remote Sensing in Agriculture. Aspects of Applied Biology 60, Association of Applied Biologists. 163-172.

François, O. and Killmayer, A., 1999. Operational services to agribusiness in France from yield and soil mapping to space imagery integration. Poster presented at the 2nd European Conference on Precision Agriculture, Odense, Denmark, 11-15 July, 1999.

Stuttard, M., Dampney, P., Büker, C., François, O., Brems, E., Vrindts, E. 1999. An assessment of Services to Agri-business by Remote Sensing (SABRES) - early results. Poster presented at the 2nd European Conference on Precision Agriculture, Odense, Denmark, 11-15 July, 1999.

Garcia Cidad, V., Vrindts, E., De Baerdemaeker, J. 2000. Use of Very High Resolution Images for Precision Farming: Recommendations on Nitrogen Fertilisation. To be published in the Proceedings of the EOS-SPIE Symposium on Remote Sensing, Barcelona 25-29 September 2000.

Garcia Cidad, V., 2001. Precision Farming, data acquisition and applications in GIS. http://www.europto.org/meetings/ers00/confs/4171 .

CHAPTER III

HYDROLOGY, GEOLOGY AND SOILS

RESEARCH CONTRACT T4/02/009

DEVELOPMENT OF ASSIMILATION SCHEMES FOR SOIL MOISTURE PROFILES USING REMOTELY SENSED DATA

F. DE TROCH
P. TROCH
R. HOEBEN

UNIVERSITEIT GENT (RUG)
LABORATORY OF WOOD AND WATER MANAGEMENT
Coupure Links 653
B – 9000 GENT
BELGIUM

1. CONTEXT AND OBJECTIVES

The moisture content and its vertical distribution (hereafter referred to as soil moisture profile) in the top meter of the soil is of critical importance in numerous hydrological, agricultural and meteorological processes. In order to make progress in our understanding of these processes (rainfall-runoff dynamics in catchments, crop water use during growing season, regional evapotranspiration, etc.) the need exists to develop new measurement techniques of the soil moisture profile. Recent advances in active microwave observations of the Earth's surface provide great potential to develop such new measurement techniques, since it is well known that the radar signal is affected by the surface soil moisture content. In this project we have focussed our attention on data assimilation schemes that allow to retrieve the moisture profile in the top meter of the soil from observations of the moisture content in the upper few centimetre of the profile. Such a data assimilation scheme combines infrequent surface soil moisture measurements with hydrological simulation models that propagate the measurements down in the profile. This technology will provide valuable information on soil moisture content over large areas, such as catchments, large irrigation perimeters and even whole regions.

2. DATA

Geographic study area: Zwalm catchment, East-Flanders, Belgium

Satellite imagery used: 13 ERS-2 SAR PRI images between 11/08/1997 and 05/10/1998.

Other data: Datasets from the EMSL non-vegetated terrain experiment, 6 RADARSAT SLC images between 04/08/1997 and 09/03/1998.

3. METHODOLOGY

- First, the accuracy of the estimation of surface soil moisture content from active microwave observations of bare soil surfaces was determined. For this, data from a laboratory experiment, held at the EMSL (Ispra, Italy) were used. We found that this accuracy is of the same order as many in situ measurement techniques (± 5 % vol).
- Next, a data assimilation scheme based on optimal state reconstruction technology was developed. For linear systems, state reconstruction can be achieved through Kalman filtering. The system equation used is based on the 1D Richards equation, which describes soil moisture fluxes in the unsaturated zone. The observation equation is based on the Integral Equation Model that simulates the interaction between an electromagnetic wave and a random rough bare soil

surface. To compute the soil moisture profile with the Kalman filter, both the system and observation equation have to be linearized.

- Finally this technique was validated in two steps. First synthetic time series of moisture profiles, radar observations and driving forces were generated, which allowed to assess the theoretical validity of the data assimilation scheme. Second, observed time series during the same laboratory experiment at EMSL allowed to validate the technique in near real world situations.

4. OUTPUTS AND RESULTS

- The laboratory experiment allowed us to establish the accuracy range of surface soil moisture estimation through active microwave observation of bare soil surfaces at about 5 % vol.
- A 1D data assimilation scheme to retrieve accurate soil moisture profile information from surface soil moisture measurements was developed.
- A sensitivity analysis resulted in the establishment of the accuracy range of soil moisture profile retrieval using infrequent and noisy data.
- We have shown for the first time that soil moisture profile retrieval is possible from measurements of the upper 5 cm of the soil.

5. EXECUTION

Period: 01/12/1996-30/11/1998

Laboratory:

UNIVERSITEIT GENT (RUG)
Laboratory of Wood and Water Management
Coupure Links 653, B – 9000 Gent, Belgium
Phone: + 32 9 264 61 39 Fax: + 32 9 264 62 36
E-mail: Rudi.Hoeben@rug.ac.be   URL: http://taoren.rug.ac.be/~rudi

6. RELATED DISCIPLINES

Weather & climate
Geology & soil
Hydrology & freshwater resources
Agriculture
Environment

RESEARCH CONTRACT T4/02/033

CATCHMENT SCALE ROOT ZONE SOIL MOISTURE CONTENT FROM SATELLITE RADAR OBSERVATIONS

F. DE TROCH

UNIVERISTEIT GENT (RUG)
LABORATORY FOR WOOD AND WATER MANAGEMENT
Coupure Links 653
B – 9000 GENT
BELGIUM

1. CONTEXT AND OBJECTIVES

For many agricultural and hydrologic applications, information on the soil moisture content in the top one-meter layer is required. Although conventional methods for soil moisture determination are accurate, they are time and labour consuming and impractical over large areas, such as catchments. Over large areas information on the surface soil moisture content can be acquired through the use of microwave remote sensing. The main objective of this research is to derive a robust algorithm, which retrieves root zone soil moisture information at the catchment's scale from radar imagery.

2. DATA

Geographic study area: Belgium

Satellite imagery used:

AMI-SAR (ERS)

SAR (RADARSAT)

3. METHODOLOGY

The procedure is based on 3-D hydrological modelling and an assimilation scheme based on the Kalman filter concept. Also the integration with geostatistical techniques will be investigated in order to characterise the scale and pattern of spatial correlation and cross-correlation of soil moisture and SAR-derived information. The possibilities of factorial kriging analysis on a time series of radar images for image filtering will be examined. In this geostatistical context, optimal interpolation of root zone soil moisture using ground truth samples and SAR-derived information as covariates will be validated. This soil moisture mapping will allow improved prediction of crop growth, floods, and catchment's scale evapotranspiration.

4. EXECUTION

Period : 15/12/1998-28/02/2001

Laboratory

UNIVERSITEIT GENT (RUG)

Laboratory for Wood and Water Management

Coupure Links 653, B – 9000 Gent, Belgium

Phone: +32 9 264 61 35 Fax: +32 9 264 62 36

E-mail: Francois.DeTroch@rug.ac.be URL: http://taoren.rug.ac.be/

5. RELATED DISCIPLINES

Geology & soil

Hydrology & freshwater resources

FEASIBILITY STUDY T4/DD/014

VALIDATION OF SAR INTERFEROMETRY TO JERS-1 AND RADARSAT IMAGES

C. JAMAR

UNIVERSITE DE LIEGE (ULG)
CENTRE SPATIAL DE LIÈGE (CSL)
Parc scientifique du Sart Tilman
Avenue du Pré-Aily, Bâtiment B29
B – 4031 ANGLEUR
BELGIUM

1. CONTEXT AND OBJECTIVES

The aim of this Project was to modify and validate the CSL interferometric SAR (InSAR) processor, developed under two previous TELSAT-3 study Contracts in the context of ERS-1/2 imagery, for the processing of JERS-1 (Japan) and RADARSAT (Canada) SAR images.

This Project was submitted as a Feasibility Study under the TELSAT-4 Programme. The User Partner (requesting the study) was Musée Royal de l'Afrique Centrale (MRAC), and the Scientific Partner (carrying out the study) was Centre Spatial de Liège (MRAC).

MRAC was interested in validating InSAR for JERS and RADARSAT images as part of its activities on the monitoring of volcanic risk over the Philippines (Mayon and Balusan volcanoes), for which specific characteristics of these two satellites (carrier frequency, polarisation, incidence angle, data availability) are more favourable than those of the ERS-1/2 system.

2. DATA

Geographic study area: The Philippines

Satellite imagery used: JERS-1and RADARSAT (SAR images). Purchased by UNESCO.

Other data: ancillary data (field observations, thematic maps, cartographic Digital Terrain Model) from the Scientific Partner.

3. METHODOLOGY

- Step 1: study of JERS-1 and RADARSAT imagery specificities and their incidences on the current CSL InSAR processor design.

- Step 2: modification of the current CSL InSAR processor following the results of Step 1 and validation on JERS-1 and RADARSAT datasets.

4. OUTPUTS AND RESULTS

The CSL InSAR processor was successfully validated for RADARSAT data.

All efforts deployed to obtain the required JERS-1 data (Single-Look Complex images) revealed unsuccessful.

5. EXECUTION

Period: 01/01/1997-30/06/1997

Laboratory:

UNIVERSITE DE LIEGE (ULG)
CENTRE SPATIAL DE LIEGE (CSL)
Parc scientifique du Sart-Tilman, Bâtiment B29, Avenue du Pré-Aily, B – 4031 Angleur, Belgium
Phone: +32 4 367 66 68 Fax: +32 4 367 56 13
E-mail: cjamar@ulg.ac.be URL: http://www.ulg.ac.be/cslulg/

User partner :

MUSÉE ROYAL DE L'AFRIQUE CENTRALE (MRAC)
Leuvensesteenweg 13, B – 3080 Tervuren, Belgium
Phone: + 32 2 769 52 11 Fax: + 32 2 769 56 38
E-mail: info@africamuseum.be

6. RELATED DISCIPLINES

Geology & soil
Hardware & software

7. EXECUTIVE SUMMARY

Introduction

High-resolution SAR images possess two information channels: the amplitude and the phase of the signal. Most of the applications are based on the sole amplitude. Interferometric techniques have demonstrated that unique and specific information may be retrieved from the phase channel, e.g. digital elevation models and terrain displacements. In the frame of the TELSAT-3 Belgian remote sensing Programme, CSL developed a complete SAR interferometric and differential interferometric processor that was demonstrated and validated on ERS-1/2 images.

The present document summarizes the results of a Feasibility Study carried out upon request by the Musée royal de l'Afrique Centrale (MRAC), who have a strong interest in exploiting SAR interferometric products for geological investigations in the Philippines. Due to the low availability of ERS-1/2 image data over this region of the world, it was decided to use both JERS-1 and RADARSAT images, requiring the appropriate modification and validation of the current CSL interferometric processor.

The presentation closely follows the work breakdown structure proposed for the study, i.e., first a theoretical investigation of the influence of specific sensor parameters on the interferometric processing, then the modification and validation of the ERS processor to handle JERS-1 and RADARSAT image pairs.

A theoretical study was first performed to identify and determine the influence of specific sensor parameters on the interferometric processing. Mainly, all the parameters that influence the coherence preservation were analysed. Special attention was given to the study of the Yaw Steering acquisition mode, used by ERS, but not implemented on JERS and RADARSAT platforms, and to its influence on coherence preservation.

Processor modification and validation

Persisting efforts to obtain single-Look Complex (SLC) JERS image pairs revealed unsuccessful either because we no longer received replies to our requests for information (NASDA) or because of difficulties in adapting the JERS SAR processor to SLC products (EURIMAGE). As a result, the CSL processor could not be validated for JERS.

The CSL processor was adapted to the specificities of RADARSAT following the conclusions of the theoretical studies.

Figure 1 shows one of the amplitude images for one partner of a RADARSAT pair (orbit 7187, 21 March 1997, 15.05°N and 120.36°E; orbit 6844, 25 February 1997, 15.03°N and 120.35°E). The corresponding interferogram shown on Figure 2 has a very poor signal-to-noise ratio as a result of considerable time decorrelation. The other image pair revealed still more decorrelated. Due to this time decorrelation, the interferometric processing did not allow us to produce DEMs and had to be stopped directly after interferogram and coherence map production. This is however sufficient, on a processing point of view, to consider that the CSL processor is now operational for handling RADARSAT image pairs

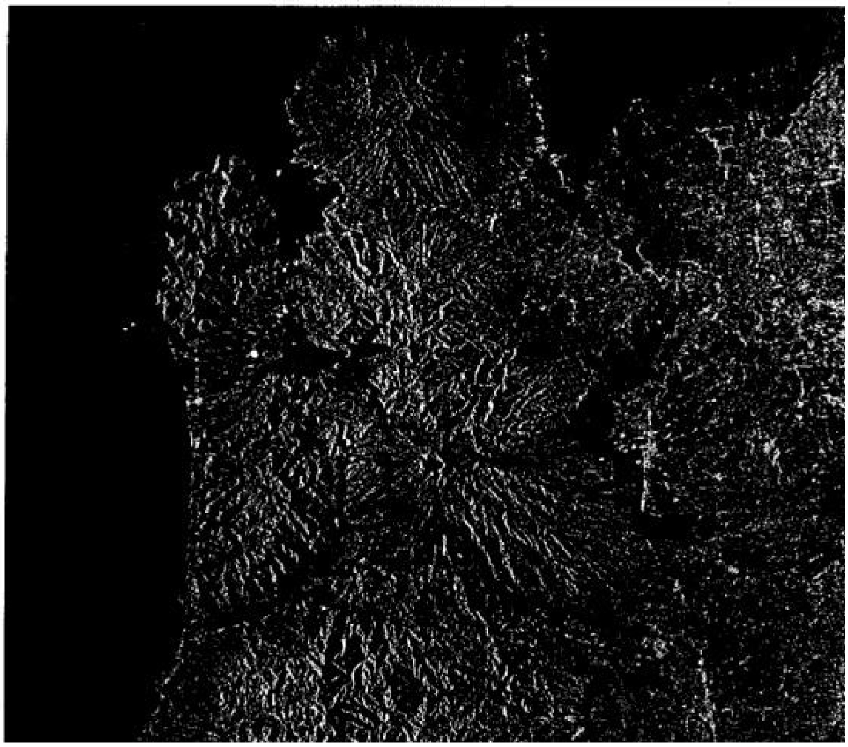


Figure 1

Figure 2

FEASIBILITY STUDY T4/12/027

DETECTION OF SOIL MOISTURE BY REMOTE SENSING AND PRONE KARST COLLAPSE AREAS (TOURNAISIS)

A. OZER

UNIVERSITE DE LIEGE (ULG)
DEPARTMENT OF PHYSICAL GEOGRAPHY
Allée du 6 Août 2
B – 4000 LIEGE
BELGIUM

1. CONTEXT AND OBJECTIVES

Karst collapses are important natural hazards for roads, houses, industries and water tables. More than 150 sink holes had been listed until today in the Tournaisis. Generally, they are cylindrical collapses with a maximum diameter of twenty meters and more than ten meters depth. The occurrence of those holes seems to be fortuitous. However, prone karst collapse areas are spatially well correlated with the location of joints in the Tournaisian limestone. It does not exist any signs to foresee the danger. Indeed, the quaternary deposits hide completely the inner soil movements, which will become sink holes.

The objective of this feasibility study consists in an attempt of demonstration that it is possible to explain some parts of the topsoil moisture distribution extracted from ERS SAR data by the natural fracturing of the Tournaisian limestone. If the correlation exist, it will be possible to derive hazards and risks maps for decision planner makers. Indeed, we need to solve a regional problem at reasonable cost. Microwave remote sensing is of interest for that scale. However, due to the small size of collapses, we need to find indirect information detectable with satellite radiometers and obviously related to our problem. We assume that topsoil moisture is the data which link up the remote sensing technique and the karst collapses.

2. DATA

Geographic study area:

Surroundings of the City of Tounai ("Tournaisis" area in the Province of Hainaut, Belgium).

Satellite imagery used

ERS scene	1998	May	18	10h41 am
ERS scene	1998	June	22	10h41 am
ERS scene	1998	July	27	10h41 am
SPOT scene	1998	August	07	10h56 am
ERS scene	1998	August	31	10h41 am
ERS scene	1998	October	05	10h41 am

Other data:

Geophysical data

Pedological data

Field samples for moisture

3. METHODOLOGY

In a remotely sensed image the perceived effects of soil water are modulated by surface roughness, degree and direction of slope, and the vegetation cover and structure. The areas of interest are roughly flat fields and thus remove parameters of degree and direction of slope. The two test zones are also homogeneous about soil affectation and thus have got equivalent roughness parameter. However, the main characteristic is that we possess two sets of geophysical data, which allow us to known the location of joints. In order to map soil moisture, we acquired five ERS2 SAR images and one SPOT HRV image. We worked with data takes during the relatively dry period from May to October. In this way, we were in the best conditions to remote the maximum contrast in topsoil moisture. The cartography of the moisture imply fields samples. The amount of moisture had been evaluated by laboratory analysis. The next step consist in the calibration of the remote values modulate by the roughness parameter of the surface. The latter is also measured in the field. The final step consist in the superimposition of the moisture and geophysical data in order to detect correlation.

4. OUTPUTS AND RESULTS

After discussions with the members of the team, we think that the basic ideas are relatively well founded for the parts where tertiary and quaternary deposits are relatively thin. Some problems had been encountered with ERS data. We think that the methodology should given accurate results with airborne SAR. Indeed, in that way, some parameters could be more controlled such as the date of the fly in order

1) To free from the bad weather conditions and the roughness of the surface (control the size of the vegetation over the test area);
2) To reduce the size of the pixels;
3) To increase the performance in the georeferencing step.

The cartography of the moisture depends on the roughness parameter. After the bad experience of that feasibility, it seems to be clear that a strong knowledge of the efficiency in the methodology of acquisition is the first factor to master. The prone karst collapse area detection is really worrying in the Tournaisis part because of increasing of pumping per year. At present, there is no state control about the relation between the occurrence of sink holes and the pumping of the water table. Only few scientists say about the problem or media when collapses had damaged infrastructures. The high complexity to forecast such a phenomenon should imply more research than presently.

5. EXECUTION

Period: 12/12/1997-31/12/1998

Laboratory:

UNIVERSITE DE LIEGE (ULG)

Department of Physical Geography

Laboratory of Geomorphology

Allée du 6 Août 2, Bâtiment B11, B – 4000 Liège, Belgium

Phone: + 32 4 366 54 56 Fax: + 32 4 366 57 22

E-mail: a.ozer@ulg.ac.be

User partners :

SERVICE DE GEOLOGIE FONDAMENTALE ET APPLIQUEE [SGFA] OF THE FACULTE POLYTECHNIQUE DE MONS

Rue de Houdain 9, B - 7000 Mons, Belgium

Phone: + 32 65 37 46 18 Fax: + 32 65 37 46 10

E-mail: Christian.Dupuis@fpms.ac.be

MINISTERE DE LA REGION WALLONNE, DIRECTION GENERALE DE L'AMENAGEMENT DU TERRITOIRE, DE L'URBANISME ET DU PATRIMOINE

Rue des Brigades d'Irlande 1, B – 5100 Namur, Belgium

Phone: + 32 81 33 21 11 Fax: + 32 81 33 21 10

6. RELATED DISCIPLINES

Geology & soil

Hydrology & freshwater resources

Environment

Natural hazards & disasters

Land planning & infrastructures

Cartography

7. EXECUTIVE SUMMARY

Introduction

Karst collapses are important natural hazards for roads, houses, industries and water tables. More than 150 sink holes had been listed until today in the Tournaisis. Generally, they are cylindrical collapses with a maximum diameter of 20 meters and more than 10 meters depth (O. Kaufmann *et al.*, 1997). The occurrence of those holes seems to be fortuitous. It does not exist any signs to foresee the danger.

Indeed, the quaternary deposits hide completely the inner soil movements, which will become sink holes.

The geological context of the Tournaisis is defined by carboniferous limestone (Tournaisian) covered by tertiary deposits of sand and clay from a few to more than 10 meters. All that deposits can be recovered by meters of quaternary silts. A geophysical study and a finding site, where present sink holes appeared, are leaded by the Sei, from Géologie Fondamentale et Appliquée (SGFA) of the Faculté Polytechnique de Mons. They allowed to clarify the geological environment where such hazards can occur. We know, at present, that prone karst collapse areas are spatialy well correlated with the location of joints in the Tournaisian limestone. However, the mapping of fractured rocks imply to carry out geophysical prospecting or drilling. Due to the high cost, they are only useful for local studies and not for a regional approach as need the country planning administration.

According to known data, the Laboratory of Geomorphology and Remote Sensing (LGT) of the Université de Liège proposed the hypothesis that part of the topsoil moisture could be explained by the presence of underlying joints. Indeed, those joints represent probably the main underground drainage framework. When joints are relatively important and the upper deposits not so thick, we can suppose that the moisture of the topsoil, just located above the joints, is more important than the moisture where joints do not exist in the underground. We assume that it is poszible to explain the most important moisture by the capillarity which allows the water to go back up.

Objective

The objective of this feasibility study consists in an attempt of demonstration that it is possible to explain some parts of the topsoil moisture distribution extracted from ERS Sar data by the natural fracturing of the Tournaisian limestone. If the correlation exist, it will be possible to derive hazards and risks maps for decision planner makers. Indeed, we need to solve a regional problem at reasonable cost. Microwave remote sensing is of interest for that scale. However, due to the small size of collapses, we need to find indirect information detectable with satellite radiometers and obviously related to our problem. We assume that topsoil moisture is the data, which link up the remote sensing technique and the karst collapse.
We have defined two test areas where demonstration is possible. They are calling respectively Gaurain – Ramecroix and Obigies and located in the surroundings of Tournai.

Methodology and problems encountered

In a remotely sensed image the perceived effects of soil water are modulated by surface roughness, degree and direction of slope, and the vegetation cover and structure (Wang *et al*.). The areas of interest are roughly flat fields and thus remove parameters of degree and direction of slope. The two test zones are also homogeneous about soil affectation and thus have got equivalent roughness parameter. However, the main characteristic is that SGFA possess two sets of geophysical data, which allow us to known the location of joints.

In order to map soil moisture, we acquired five ERS2 S, 4 R images and one SPOT HRV image. We worked with data taken during the relatively dry period from May to October. In this way, we were in the best conditions to remote the maximum contrast in topsoil moisture. We assume that it is possible to detect subtle variations of moisture at the scale we need by the use of ERS SAR images. This technical operation had been carried out by the Laboratory of Hydrology and Water Management (LGWM) of the University of Gent, which had already realised similar operation in the near past. The cartography of the moisture imply fields samples. Due to very bad weather conditions of spring and summer 1998, only two sets have been taken (August and October). The amount of moisture had been evaluated by laboratory analysis. The next step consists in the calibration of the remote values modulate by the roughness parameter of the surface. The latter is also measured in the field.

The next step to achieve the hazard and risk maps of the potential prone karst collapse areas consists in the super imposition of the geophysical data and the evaluated moisture repartition. However, unfortunately, the mapping of the moisture by LHWM had not given results expected due to the evaluation of the roughness parameter. In that way, all the methodology fell down.

The LGT investigated another approach, completely automatic, based upon the combination between the two first principal components (ACP analysis) of the SPOT image and the ERS SAR data. Indeed, this kind of operation had been previously and successfully used for flood studies in south of France and Bangladesh. Here is the reason we have acquired those visible data. The results we had obtained are not interpretable. The combined image has been superimpose with pedological data such has soil profile, natural drainage and texture and with data from atlas of the karst of Wallonia. No correlation had been found.

Finally, due to good contacts with Dominique Derauw and Christian Barbier from Centre Spatial de Liège, we had took a look about the opportunity to use differential interferometry in order to assess subsidence areas in the surrounding of Tournai. Some places of interest had been recognised but they spatially correspond to carries where walls are daily exploited. Secondly, due to residual noise, it's clearly impossible to detect karst collapse spots.

Conclusion

After discussions with the members of the team, we think that the basic ideas are relatively well founded for the parts where tertiary and quaternary deposits are relatively thin such as in Gaurain-Ramecroix.

Some problems had been encountered with ERS data. We think that the methodology should given accurate results with airborne SAR. Indeed, in that way, some parameters could be more controlled such as:

- The date of the view in order to free from the bad weather conditions and the roughness of the surface (control the size of the vegetation over the test area);The reduction of the size of the pixels;
- The performance in the georeferencing step.

The cartography of the moisture depends on the roughness parameter. After the bad experience of that feasibility, it seems to be clear that a strong knowledge of the efficiency in the methodology of acquisition is the first factor to master.

The prone karst collapse area detection is really worrying in the Tournaisis part because of increasing of pumping per year. At present, there is no state control about the relation between the occurrence of sink holes and the pumping of the water table. Only few scientists say about the problem or media when collapses had damaged infrastructures. The high complexity to forecast such a phenomenon should imply more research than presently. That's the reason we will continue to propose refine methodology in order to assess collapses.

FEASIBILITY STUDY T4/12/030

USE OF THE SATELLITE IMAGERY FOR THE FORECAST AND MANAGEMENT OF FLOOD DISCHARGE UPSTREAM OF THE POWER STATION OF COO IN ORDER TO REDUCE THE RISKS OF FLOODS IN THE OURTHE RIVER VALLEY

E. ESKENAZI

UNIVERSITE DE LIEGE (ULG)
LABORATORY OF HYDROLOGY AND HYDROGRAPHY
Quai Banning 6, Bâtiment C2
B – 4000 LIEGE
BELGIUM

1. CONTEXT AND OBJECTIVES

The valley of the Ourthe River worries the people in charge of the environment and rivers. Indeed, the repeated floods of these last years reinforce the idea of a policy integrating the management of the watershed areas. The construction of retention basins does not seem to satisfy everyone. It is thus necessary to turn to less draconian solutions for the environment. The site of the power station of Coo has a significant potential in the possibility of storing part of water of the Amblève during floods without major modifications of the environment. It seems significant to study this possibility of management in order to attenuate the risks of floods and help decision makers.

Therefore, the object of this feasibility study is to show the possibilities of using remote sensing in a mathematical model simulating the relationship between rainfall and runoff in the Amblève river in order to study the effects of different management and to prevent floods.

2. DATA

Geographic study area: Hydrographic basins of the Ourthe and Amblève Rivers - Belgium

Satellite imagery used: LANDSAT Thematic Mapper, 22/06/1996.

Other data: Digital Elevation Models - Hydrometeorological and water level data

3. METHODOLOGY

The model is based on rainfall-runoff calculations taking into account:

- Intensity and distribution in space and time of heavy rainfalls;
- Physiographic characteristics of the catchments;
- Land use modifications and initial moisture state;
- Projects of flood discharges retention.

The catchments characteristics are obtained through remote sensing, and then they are integrated after being properly adapted and completed into the flood risks prevision model.

4. OUTPUTS AND RESULTS

The application of such a tool allows to simulate and quantify the effects of any project at Coo on flood discharges in the Amblève and Ourthe valleys.

The developed approach seems promising and provides already good results. The hydrological model could however clearly be improved in a later phase by holding in better account the flood routing phenomena.
Moreover, it appears clearly that the hydrological model, which was presented in this study could be easily applied to other basins. The approach could be extended in order to be able to apply the model to any basin of the Région Wallonne.
This approach could highly interest the managers of hydrological basins and the decision-makers (Walloon Region - General Direction of the Natural resources and Environment DGRNE - Ministry for the Equipment and Transport MET).
The application of such a tool could allow an integrated management of any watershed and would constitute a decision-making aid as regards regional planning, flood prevention and better management of natural catastrophes...

5. EXECUTION

Period: 2/12/1997-30/06/1998

Laboratory:

UNIVERSITE DE LIEGE (ULG)
Laboratory of Hydrology and Hydrography
Quai Banning 6, Bâtiment C2, B – 4000 Liège, Belgium
Phone: +32 4 366 92 79 Fax: +32 4 366 91 99
E-mail: E.Eskenazi@ulg.ac.be

User partner :

CENTRALE HYDROELECTRIQUE DE COO - TROIS PONTS
Route du Lac, B – 4980 Trois Ponts, Belgium
Phone: + 32 80 89 28 11 Fax: + 32 80 89 28 09
E-mail: jeanpierre.germeau@electrabel.be

6. RELATED DISCIPLINE

Hydrology & freshwater resources

7. EXECUTIVE SUMMARY

Introduction

The valley of the Ourthe River worries the people in charge of the environment and the hydraulic channels. Indeed, the repeated floods of these last years reinforce the idea of a policy integrating the management of the catchment's areas. The construction of « shopping dams » does not seem to satisfy everyone. It is thus necessary to turn to less draconian solutions for the environment. The site of the power station of Coo has a significant potential as for the possibility of storing part of water of the Amblève River when a flood occurs without major modifications of the environment. It is thus significant to study in-depth this possibility of management of water in order to propose to the administration an interesting solution to attenuate the risks of floods.

Object of the present study

Paying attention to flood problems that touch the riverside residents of Amblève and Ourthe Rivers, the managers of the Coo hydroelectric power station plain to turn their installation to good account during extreme rainfalls by using the water volume of the station to stock flood.

The project consists in building a supply device of Amblève water into the lower station basin by gravity or pumping.

To justify such plan it is necessary to make a detailed hydrological study to evaluate the effective reduction of the flood risks in the Amblève and Ourthe valleys.

The goal of this feasibility study consists in showing the possibilities of exploiting the satellite data in order to use them in a mathematical model to simulate flood in the Amblève and Ourthe watersheds. The model is based on rainfall-runoff calculations taking into account:

- Intensity and distribution in space and time of the extreme rainfalls
- Physiographical and morphometric characteristics of the catchments
- Land use modifications and initial soil moisture conditions
- Projects of flood discharges retention.

The catchment characteristics are obtained through remote sensing, and then they are integrated after being properly adapted and completed into the flood risks provision model.

The application of such a tool makes it possible to quantify the effects of projects in the Coo power station on the flood discharges in the Amblève and Ourthe valleys. Furthermore, it can provide decision-makers with arguments to improve integrated management of those two hydrologic basins. This approach could also be easily transposable to other basins.

Descriptions of the achieved tasks

The following points were developed in this study:

a) Constitution of a topographic database specific to the basins of the Ourthe and Amblève Rivers and establishment of digital models of elevation giving the relief, the slopes and the exposures;
b) Interpretation of the satellite images in order to obtain information on land use at a precise date and establishment of thematic maps;
c) Preparation of the basic elements for the application of a simplified hydrological model being able to integrate the whole data in the basins of the Ourthe and Amblève Rivers and allowing to predict the effect of the rainy events on the hydrological mode and the flows of floods;
d) Calibration of the various parameters of the model allowing to compare the response of the basins with measurements observed at the various limnigraphic stations. (The concordance between the hydrograms calculated and observed is satisfactory except for the station of Nisramont, probably due to an active management of the dam in period of risings);
e) Evaluation of the impact of a device designed to chop of the flow peak at the power station of Coo Trois-Ponts and quantification of the reduction of the risks of floods downstream in the valleys of the Amblève and Ourthe Rivers.

Results and appreciations of the reduction of the risks of floods

An analysis of the flows on the Amblève and Ourthe basins was carried out from the rain of December 1991. The laws of the statistics show the exceptional character of this event, which presents a period of 10 years recurrence.

In this study, we simulated a storage tank at the power station of Coo - Trois-Ponts. Initially, we considered an unlimited volume of storage in order to quantify the necessary capacity of the tank so that an appreciable reduction of the flows could be observed downstream. In the second time, we limited the volume of storage to 13 million m³ capacity, which seems to be available at Coo - Trois-Ponts. In this case, a study of incidence on the flows downstream was carried out and showed a notable reduction of the flows on the Amblève River at its mouth with the Ourthe river (gage station of Martinrive).

The impact of storage of water in Coo is more limited on the Ourthe River (station of Sauheid). This is explained easily by the water contribution coming from the catchment's area of the Ourthe River above its junction with the Amblève Rriver.

Recommendations and highlighting of the future development prospects of the approach

The hydrological model, which was presented in this study could be easily applied to other basins. The approach could be generalized in order to be able to apply the model to a maximum of basins in the basin of the Meuse River.

This approach could highly interest the managers of the basins and the political leaders (Walloon Region - General Direction of the Natural Resources and Environment DGRNE - Ministry for the Equipment and Transport MET). The application of such a tool could allow them an integrated management of the basins and would constitute a decision-making aid in matters such as regional planning, management of natural disasters...

In order to lead to a better management of the basins, the hydrological model could also be improved:

- By better taking into account the propagation of the flows in the rivers;
- By integrating a module evaluating the infiltration better and allowing to simulate the melting of a possible layer of snow;
- By studying the influence of a modification of the land use and/or the road network using satellite images;
- By taking into account the flooded zones detected by remote sensing in the evaluation of the flows.

FEASIBILITY STUDY T4/67/044

SOIL SURFACE MOISTURE FROM SSM/I IMAGERY

J. VAN RENSBERGEN

VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK (VITO)
Boeretang 200
B – 2400 MOL
BELGIUM

1. CONTEXT AND OBJECTIVES

Global warming is expected to lead to an enhanced hydrological cycle with a greater number and intensity of both droughts and floods. Soil moisture, through its control on the surface energy and water budgets, exerts a strong influence on the entire hydrological cycle. Precise information regarding soil moisture status is of paramount importance for climate scientists, both for analysing surface-atmosphere feedback mechanisms, and for the validation of numerical simulations performed with regional climate models. At Vito, a methodology was developed to retrieve superficial soil moisture content from time series of Special Sensor Microwave/Imager (SSM/I) imagery.

2. DATA

Geographic study area: Europe and part of North Africa

Satellite imagery used: twice-daily global gridded (25 km resolution) SSM/I imagery, radiometrically and geometrically calibrated

Other data: daily precipitation from the NCDC Global Daily Summary

3. METHODOLOGY

Europe was extracted from the original global imagery, and the Polarisation Difference Temperature (PDT) was computed, defined as the vertically minus the horizontally polarised brightness temperature at 19 GHz. Further pre-processing included spatial averaging to reduce errors related to instrument noise and median filtering to remove outliers, and negative anomalies caused by rain bearing clouds. Using Fresnel's relations together with a theoretical model for the moisture-dependent soil dielectric constant, and also accounting for atmospheric and soil roughness effects, skin moisture content was computed for each pixel in the domain from time series of the PDT.

4. OUTPUTS AND RESULTS

The methodology was applied for Europe and North Africa for the period April to November 1990, producing daily maps of superficial (a few mm's) soil moisture content. One of the findings was that the methodology could only be successfully applied to a restricted part (21%) of the domain, mainly corresponding to those areas with sparse vegetation. Despite this limitation, the obtained moisture maps contain still sufficient information to be useful as a validation tool in regional climate modelling, especially since the areas where the method works well are generally those where bare soil evaporation constitutes an important component of the surface energy and water balance.

5. EXECUTION

Period : 01/06/1999-30/09/1999

Laboratory:

VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK (VITO)
Boeretang 200, B – 2400 Mol, Belgium
Phone: + 32 14 33 27 00   Fax: + 32 14 32 11 85
E-mail: kretzscj@vito.be URL : www.vito.be

User partner:

UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL)
Institut d'Astronomie et de Géophysique Georges Lemaître
Chemin du Cyclotron 2, B - 1348 Louvain-la-Neuve, Belgium
Phone: +32 10 47 32 97   Fax: +32 10 47 47 22

6. RELATED DISCIPLINES

Agriculture
Environment
Geology & soil
Radar Remote Sensing

7. EXECUTIVE SUMMARY

A methodology to obtain moisture content of the upper few millimetres of soil from SSM/I imagery is applied to a domain covering Europe, for the period April-November 1990. It is based on temporal changes of the SSM/I 19.35 GHz Polarisation Difference Temperature (PDT). The processing sequence employed to retrieve skin oil moisture is described in detail, the result being daily moisture maps. It is established that in large portions of the domain the method is not applicable, which is mainly due to the geometric variability of the SSM/I's field of view. In those parts of the domain where the method could be applied, representing 21.3% of the land pixels, the fractional error with respect to field capacity is estimated to range from 16 to 28%. Although no proper validation could be performed, comparison of daily moisture maps with precipitation during a heavy rainfall episode shows relatively good agreement. It is concluded that, although the retrieved moisture fields do not provide total coverage, they are useful as a validation tool in numerical climate

simulations. Furthermore, since the method appears to work best in sparsely vegetated areas, it is recommended that in the future the method should be implemented for semi-arid regions.

CHAPTER IV

OCEANS AND COASTS

RESEARCH CONTRACT T4/DD/004

THE MULTICOLOURED NORTH SEA

G. PICHOT
F. OVIDIO
K. RUDDICK
A.P. VASILKOV

THE MANAGEMENT UNIT OF THE NORTH SEA MATHEMATICAL MODELS (MUMM/BMM/UGMM)
Gulledelle 100
B – 1200 BRUXELLES
BELGIUM

1. CONTEXT AND OBJECTIVES

The main goals of the project are to take advantage of the information available from ocean colour remote sensing satellites, to calibrate them for the Belgian coastal waters, to use them in conjunction with biological models, and so to bring in elements of scientific answers to the debate presently held between riparian North Sea states about eutrophication problems, their geographical extension and the actions that have to be taken to monitor them.

2. DATA

Geographic study area: The Belgian Coastal zone and the surrounding waters of the Southern Bight of the North Sea.

Satellite imagery used: No imagery was purchased by the OSTC. AVHRR data was purchased by MUMM and SEAWIFS data was provided for research use by NASA.

Other data: Water samples collected on board of the Research Vessel *Belgica* were analysed for total suspended matter and chlorophyll concentration as well as for yellow substance absorption

3. METHODOLOGY

Obtaining quantitative information on chlorophyll and suspended sediments from satellite imagery is not an easy task; even if sensors are making better and better multispectral measurements, the signal that reaches them does not contain more than about 10% of marine-related information because of atmospheric effects. After geo-referencing an image, the first task to be performed is the rather crucial atmospheric correction, which extracts the marine signal at each wavelength. Then the image is fed to MU-COLOR, an analytical ocean colour model developed at MUMM. This region-specific, state-of-the-art model, combines all the available information and outputs quantitative maps of chlorophyll and suspended sediments.

4. OUTPUTS AND RESULTS

This project has lead to the development of an original atmospheric correction scheme for turbid coastal waters and of algorithms allowing to obtain quantitative data for chlorophyll and suspended matter concentrations for the Belgian coastal zone from the observations made by ocean colour sensors. Common features such as a turbidity maximum offshore of Oostende and at the mouth of the Scheldt Estuary can be for instance found in AVHRR reflectance imagery. While scientific research is still necessary to improve region- (and possibly season-) specific ocean colour models, the project has aroused the interest of potential end-users. Work in the following years will focus on the improvement of the algorithms, on the integrated use of data from a wide range of existing or planned (MODIS, MERIS) sensors, and on the development of higher-level applications, possibly combining imagery, in situ data and results of various mathematical models.

5. EXECUTION

Period: 01/12/1996-15/03/1999

Laboratory:

THE MANAGEMENT UNIT OF THE NORTH SEA MATHEMATICAL MODELS (MUMM/BMM/UGMM)

Gulledelle 100, B – 1200 Bruxelles, Belgium

Phone: +32 2 773 21 31   Fax: +32 2 770 69 72

E-mail: K.Ruddick@mumm.ac.be   URL: http://www.mumm.ac.be/

6. RELATED DISCIPLINES

Oceans & coasts

General Earth observation

RESEARCH CONTRACT T4/36/034

REGION-SPECIFIC OPTICAL REMOTE SENSING FOR COASTAL ZONE APPLICATIONS

G. PICHOT
K. RUDDICK

THE MANAGEMENT UNIT OF THE NORTH SEA MATHEMATICAL MODELS (MUMM/BMM/UGMM)
Gulledelle 100
B – 1200 BRUXELLES
BELGIUM

1. CONTEXT AND OBJECTIVES

The main goals of the project were:

- To improve the bio-optical algorithms used in MUMM's ocean colour models, using the latest theoretical developments and via a specific calibration based on measurement campaigns of optical properties and water quality parameters in the Belgian coastal zone
- To intensify the use of ocean colour products through enhancement of the image processing chain and use of new sensors
- To prepare end products and to present them to potential end-users.

2. DATA

Geographic study area: Southern Bight of the North Sea, Belgian coastal waters

Satellite imagery used: SPOT images

SPOT2HRV2 1991/01/18 11:04 UTC				**SPOT2HRV2 1992/05/20 11:20 UTC**		
	Latitude	Longitude			Latitude	Longitude
C1	51.637779	2.8283334		C1	51.658337	2.8150001
C2	51.501667	3.6675000		C2	51.470001	3.7741666
C3	51.120277	2.5816667		C3	51.149445	2.5241666
C4	50.986111	3.4125001		C4	50.963055	3.4741666

SPOT1HRV1 1992/09/26 10:57 UTC				**SPOT1HRV1 2000/06/07 11:11 UTC**		
	Latitude	Longitude			Latitude	Longitude
C1	51.635834	2.9077778		C1	51.807777	2.7638888
C2	51.506111	3.7466667		C2	51.652500	3.6366665
C3	51.116943	2.6708333		C3	51.294445	2.4947221
C4	50.988888	3.5008333		C4	51.140835	3.3583333

Other data:

Not provided by SSTC: numerous SEAWIFS images (see project web site)

3. METHODOLOGY

- MUMM's bio-optical model was improved using the latest theoretical advances from literature and through in domo research
- Standard NASA atmospheric correction of SEAWIFS imagery was improved to allow treatment of data above turbid coastal waters using theoretical work in optics.
- Spatial surveys of specific inherent optical properties (SIOPs) and water constituents were carried out to characterise Belgian coastal waters. Those measurements were then taken into account during the development of the bio-optical model.
- Validation of the Total Suspended Matter algorithm was carried out using in situ data.

4. OUTPUTS AND RESULTS

The fundamental research undertaken within this project has lead to the following achievements and conclusions:

- NASA's standard algorithm for the atmospheric correction of SEAWIFS data (Gordon and Wang, 1994) has been extended to turbid waters and has been distributed to researchers abroad via MUMM's web site.
- Algorithms allowing the computation of Total Suspended Matter (TSM) concentration maps from SEAWIFS and SPOT images have been developed
- Algorithms making use of the increased spectral resolution of upcoming sensors have been developed. Those algorithms should realistically improve the possibility of deriving chlorophyll-a concentration maps from satellite imagery of turbid waters.
- A combination of spectrophotometric and spectrofluorimetric methods were employed to characterise the absorption coefficients of phytoplankton, TSM and CDOM in Belgian coastal waters.

5. EXECUTION

Period : 15/12/1998-15/12/2000

Laboratory:

THE MANAGEMENT UNIT OF THE NORTH SEA MATHEMATICAL MODELS (MUMM/BMM/UGMM)

Gulledelle 100, B – 1200 Bruxelles, Belgium

Phone: +32 2 773 21 31 Fax: +32 2 770 69 72

E-mail: K.Ruddick@mumm.ac.be URL laboratory: http://www.mumm.ac.be/

URL project: http://www.mumm.ac.be/OceanColour/

6. RELATED DISCIPLINES

Oceans & coasts

Environment

General Earth observation

7. EXECUTIVE SUMMARY

The fundamental research undertaken within this project has lead to the following achievements and conclusions:

- NASA's standard algorithm for the atmospheric correction of SEAWIFS data (Gordon and Wang, 1994) has been extended to turbid waters and has been distributed to researchers abroad via MUMM's web site.
- Algorithms allowing the computation of total suspended Matter (TSM) concentration maps from SEAWIFS and SPOT images have been developed
- The current ocean colour sensors lack of spectral resolution in the red/NIR range make it impossible to derive Chl-a maps from available imagery. However, preparation has been made for upcoming sensors such as MERIS by concentrating on research comparing the reflectance at 670nm to the reflectance at other red or near-infrared bands and hence deducing absorption from chlorophyll-a at 670nm. This approach looks promising and new sensors are thus eagerly awaited.
- A combination of spectrophotometric and spectrofluorimetric methods were employed to characterise the absorption coefficients of phytoplankton, TSM and CDOM. *In situ* data was collected from the Research Vessel *Belgica* and laboratory experiments were also conducted to simulate the optical conditions along the Belgian coast. This data represents the largest available set of inherent optical properties measurements for Belgian waters and will be the main source of calibration data for chlorophyll-a algorithms.

PILOT PROJECT T4/03/065 (a-b-c-d)

ESTABLISHMENT AND APPLICATION OF A GEOGRAPHICAL INFORMATION SYSTEM, INCLUDING SPATIAL REMOTE SENSING APPLICATIONS, TO SUPPORT SUSTAINABLE MANAGEMENT OF COASTAL ZONE IN NORTH VIETNAM

L.HENS [(1)]

S. DAUTREBANDE [(2)]

A. OZER [(3)]

R. DE WULF [(4)]

VRIJE UNIVERSITEIT BRUSSEL (VUB) [(1)]
DEPARTMENT OF HUMAN ECOLOGY
Laarbeeklaan 103
B – 1090 BRUSSEL
BELGIUM

FACULTÉ DES SCIENCES AGRONOMIQUES DE GEMBLOUX (FUSAGX) [(2)]
UNIT OF AGRICLTURAL HYDRAULICS
Passage des Déportés 2
B – 5030 GEMBLOUX
BELGIUM

UNIVERSITE DE LIEGE (ULG) [(3)]
DEPARTMENT OF PHYSICAL GEOGRAPHY
Allée du 6 Août 2
B – 4000 LIEGE
BELGIUM

UNIVERSITEIT GENT (RUG) [(4)]
LABORATORY OF FOREST MANAGEMENT AND SPATIAL INFORMATION TECHNIQUES
Coupure Links 653
B – 9000 GENT
BELGIUM

1. CONTEXT AND OBJECTIVES

Different keys economic functions such as port and shipping activities, industry (cement, engineering, ship building, etc.), mining (construction materials, coal…), fishing, agriculture, forestry and tourism. Together with this economic development, the population increased and urbanisation expanded. On its turn, this development resulted in more services, land transport and building activities. This fact economic development has also adversely impacted the coastal and marine environment. Understanding these impacts is crucial to sustainable development.

This project is a pilot project that aims at evaluating the potential of different remote sensing and GIS techniques to study the land uses in the area of Ha Long Bay and Hai Phong. Moreover, the results were compared with the quantifiable aspects of the development plans for Quang Ninh and Hai Phong. The outcome of this comparison makes the results more useful for planners and policy makers.

2. DATA

Geographic study area : Hai Phong, Cat Ba, Cua Luc Bay (Northern Vietnam)

Satellite imagery used :

IKONOS

Type	Acquisition Date	Eastings 1	Northings1
MS-4m	April 2001	673940-707930	2310300-2298420

LANDSAT

Type	Acquisition Date	Path	Row
LANDSAT7	10/10/1999	126	46
LANDSAT7	31/12/2000	126	46

SPOT

Type	Acquisition Date	K	J
SPOT3 XS	28/12/1995	272	308
SPOT4 XI	14/09/2000	272	308
SPOT4 XI+P	05/11/2000	272	308

Other Data

Topographical maps

Map Name	Reference Number	Map Name	Reference Number
Quang Yen	6350 I	Cat Ba	6450 III

Do Son	6350 II	Ha Long	6450 IV
Cua Van Uc	6350 III	Cam Pha	6451 II
Hai Phong	6350 IV	Ba Sao	6451 III
Uong Bi	6351 II	LLE Cu Xu	6550 I
Dong Trieu	6351 III	Dao Tran Ban	6550 IV
Dao Van Canh	6450 I	Van Hoa	6551 III

1 Eastings and Northings in UTM-48n, WGS84

3. METHODOLOGY

- The data used in this project are based upon bathymetric maps of 1937, aerial photographs of 1952, topographic maps of 1952 and 1998, aerial photographs of 1993. 7 SPOT (1 to 4), 2 LANDSAT 7 and 1 IKONOS satellite images.
- All these data have different space and spectral resolutions. They were brought back to the same scale and were geo-coded.
- Thereafter these data were treated in various ways to establish a GIS and to obtain the different maps.
- To make these data more relevant for decision-makers.

4. OUTPUT AND RESULTS

The following maps were established:

- Change analysis based on NDVI differences (SPOT 1995-2000 images): Hai Phong/Quang Ninh region
- Land cover classification of IKONOS 2001: Hai Phong area part (a)
- Land cover classification of IKONOS 2001: Hai Phong area part (b)
- Land cover classification of LANDSAT 1999-2000: detailed study of Cat Ba
- Land cover classification of SPOT December 1995: Hai Phong/Quang Ninh region
- Land cover classification of SPOT November 2000 image : detailed study of Cat ba
- Land cover classification of SPOT November 2000 : Hai Phong/Quang Ninh region
- Land cover classification of SPOT September 2000 : Hai Phong/Quang Ninh region
- Coastline evolution : Cat Hai – West Cat Ba
- Coastline evolution : Do Son
- Coastline evolution : Hai Phong and Dinh Vu
- Soil and land use map : Bai Chai

- Soil and use map : Cam Pha
- Soil and use map : Do Son
- Main dykes
- Mapping of water bodies
- River flood mapping
- Salinity and water quality sampling SPOTs
- Sediment mapping by image subtraction between band 2 of SPOT 14/09/2000 and SPOT 5/11/2000
- Sediment mapping by image subtraction between band 2 of SPOT 24/12/1994 and SPOT 5/11/2000
- Tidal flood mapping based on SAR images: Halong area
- Tidal flood mapping based on SPOT images from 1994-1995: Halong area
- Tidal flood mapping based on SPOT images from 2000 : Halong area
- Digitised master plan for the Hai Phong area
- Districts and transportation in Hai Phong and Quang Ninh
- Facilities and historical sites in Hai Phong and Quang Ninh

All basic data are organised in a GIS.
The scientific data were interpreted in an environmental management and planning context.

5. EXECUTION

Period: 11/01/1999-31/10/2001

Laboratories:

FACULTE DES SCIENCES AGRONOMIQUES DE GEMBLOUX (FUSAGX)
Unit of Agricultural Hydraulics
Passage des Déportés 2, B – 5030 Gembloux, Belgium
Phone: +32 81 62 21 87 Fax: +32 81 62 21 8 1
E-mail: dautrebande.s@fsagx.ac.be

UNIVERSITÉ DE LIÈGE (ULG)
Geomorphology and Remote Sending Department
Allée du 6 Août 2, B – 4000 Liège, Belgium
Phone: + 32 4 366 54 56 Fax: + 32 4 366 57 22
E-mail: aozer@ulg.ac.be

UNIVERSITEIT GENT (RUG)
Laboratory of Forest Management and Spatial Information Techniques
Coupure Links 653, B – 9000 Gent, Belgium
Phone: + 32 9 264 61 10   Fax: + 32 9 264 62 36
E-mail: Robert.DeWulf@rug.ac.be

VRIJE UNIVERSITEIT BRUSSEL (VUB)
Human Ecology Department
Laarbeeklaan 103, B – 1090 Brussel, Belgium
Phone : + 32 2 477 49 47   Fax : +32 2 477 49 64
E-mail : lhens@vub.ac.be

User partners :

VIETNAM NATIONAL CENTRE FOR SCIENCE AND TECHNOLOGY
Director of Geographic Institute
Nghia Do – Tu Liem, Hanoi, Vietnam
Phone: + 84 4 858 72 85 Fax: + 84 4 836 11 92
Contact person: Prof. Le Duc An

HAI PHONG INSTITUTE OF OCEANOGRAPHY (HIO)
Marine Remote Sensing and GIS Department
246 Da Nang Street, Hai Phong, Vietnam
Phone: + 84 31 76 15 23   Fax: + 84 31 76 15 21
Contact person: Prof. Dr. Nguyen Chu Hoi

HANOI UNIVERSITY OF SCIENCE
92 Nguyen Trai Street, Hanoi, Vietnam
Phone: + 84 4 858 49 95 Fax: + 84 4 858 49 95
Contact person: Prof. Dr. Nguyen Van Mau, Rector

HAECON N.V.
Deinzesteenweg 110, B – 9031 Gent, Belgium
Phone: + 32 9 216 63 10   Fax: + 32 9 227 61 05
E-mail: cdm@haecon.be
Contact person: Christian P. De Meyer

SPACEBEL
Vandammestraat 5-7, B – 1560 Hoeilaart, Belgium
Phone: + 32 4 361 81 11   Fax: + 32 4 361 81 20
E-mail: eric.gontier@spacebel.be
Contact person: Eric gontier

6. RELATED DISCIPLINES

Forest & natural vegetation
Geology & soil
Hydrology & freshwater resources
Land planning & infrastructures
Natural hazards & disasters
Oceans & coasts
Transport & navigation
Urban & suburban

7. EXECUTIVE SUMMARY

Different key economic functions such as port an shipping activities, industry (cement, engineering, ship building, etc.), mining (construction materials, coal…), fishing, agriculture, forestry and tourism. Together with this economic development, the population increased and urbanisation expanded. On its turn, this development resulted in more services, land transport and building activities. This fast economic development has also adversely impacted the coastal and marine environment. Understanding these impacts is crucial to sustainable development.
This project is a pilot project that aims at evaluating the potential of different remote sensing and GIS techniques to study the land uses in the area of Ha Long Bay and Hai Phong. Moreover, the results were compared with the quantifiable aspects of the development plans for Quang Ninh and Hai Phong. The outcome of this comparison makes the results more useful for planners and policy makers.
The results consist of four packages of data. In each package maps were established, a contribution to the integrated GIS database was provided and a (set of) functional environmental quality parameter(s) were studied.

(a) Coastal dynamics and management of the Hai Phong – Cat Ba – Ha Long Bay areas

This part of the project entails the elaboration of dynamic and diachronic maps. The data allow to estimate the speed and the dimension of the erosion processes

affecting the shorelines. Urbanisation and the development of the industrial zones and the harbour of Hai Phong, and the coastline soil nature provide a base for coastal region land planning and risk prediction. Sedimentation in the estuaries allows to locate areas where dredging is necessary for the ship roads.

The following maps were established:

- Urban and industrial zones in the Hai Phong area: 1950-2001;
- Water limits in the Hai Phong area: 1951-1991-2000;
- Coastline evolution in Cat Hai and the west of Cat Ba: 1950-2001;
- Coastline evolution in Do Son, Hai Phong and Dinh Vu: 1950-2000;
- Zoning proposal for Cat Ba;
- Soil and land use map: Bai Chai;
- Soil and land use map: Cam Pha;
- Soil and land use map: Do Son.

The conclusions allowed differentiating among the different types of satellite images along the following lines:

- Satellite remote sensing can bring a lot to the coastal dynamic study but all depend of the scale chosen for the study;
- LANDSAT multispectral images are cheap and have 7 spectral bands, which make them indicated for classification applications. But the resolution of these images is only 30 meters. Consequently, one can only study large erosion or accumulation phenomena;
- SPOT images have only 3 (or 4) spectral bands and are more expensive, but the earning in precision is considerable (10 (in panchromatic) or 20 meters (in multispectral));
- IKONOS images seem to be the best of the satellites images with their 4 meters resolution (in multispectral). They are however expensive. This reduces considerably the application possibilities for many researchers;All remote sensing applications have to be completed by more conventional data as aerial pictures and fieldtrips.

(b) Water resources GIS for Quang Ninh and Hai Phong

This part of the project consists in designing the GIS database structure for water management and to list the corresponding required data and their characteristics. The available Vietnamese data were gathered, selected, structured and integrated in a coherent GIS. Relevant and objective information was extracted from the satellite images and integrated into the GIS.

This part of the project resulted in the following maps:

- Main dykes;
- Mapping of water bodies;
- River flood mapping from ERS SAR PRI images;
- Salinity and water quality sampling SPOTs;
- Sediment mapping by image subtraction between band 2 of SPOT 14/09/2000 and SPOT 5/11/2000;
- Sediment mapping by image subtraction between band 2 of SPOT 24/12/1994 and SPOT 5/11/2000;
- Tidal flood mapping based on SAR images: Ha Long area;
- Tidal flood mapping based on SPOT images from 1994-1995 and 2000 in Ha Long area;
- Meteorological database: stations, data and isolines.

General and specific recommendations concerning the completion of the GIS database were formulated. General recommendations concern: the quality of the data, the scale of mapping, the use of obsolete data and the format of the data. Specific recommendations for each of the maps are equally given.

(c) Land use changes

Land cover / land use maps were produced. When different land cover / land use classes were compared for SPOT- and LANDSAT-based classifications of the island of Cat Ba, comparable areas were found. The classification of the IKONOS image was difficult because of the high resolution, the poor spectral information and the lack of software tools suitable for classification of this kind of image. SPOT images were not suited for a quantitative approach, so a NDVI differencing approach was chosen. The resulting change map gives qualitative information on regeneration and degradation of the vegetation in the project area.

The following maps were produced:

- Area covered by the processed satellite images;
- Digital Elevation Models;
- Change analysis based on NDVI differences (SPOT 1995-2000 images): Hai Phong / Quang Ninh region;
- Land cover classification of IKONOS 2001: Hai Phong area part (a) and part (b);
- Land cover classification of SPOT November 2000 and LANDSAT 1999-2000: detailed study of Cat Ba;

- Land cover classification of SPOT December 1995 and SPOT September and November 2000: Hai Phong / Quang Ninh region.

(d) Management applications

Thematic maps on population density and tourism infrastructure have been established and were introduced into the GIS. Preliminary results on land cover and land cover changes are presented and discussed against earlier findings in the Ha Long City area. The comparison of these data reveals the following trends:

- A fast urbanisation in Hai Phong;
- Development of tourism is important for both areas, although there is more emphasis on tourism in Quang Ninh;
- In spite of the development of the new port area in Cua Luc Bay, harbour development happens on larger areas in Hai Phong;
- Transport facilities are planned to develop in combination with urbanisation, tourism and industrial development;
- The natural features in the study areas disappear faster in Quang Ninh than in Hai Phong. It should be noted however, that important natural areas in Hai Phong (such as Cat Ba) are not included in this study.

More detailed results focus on tidal areas and limestone ecosystems.
There is an undisputed potential for applicability of the primary data and secondary products generated within the framework of the project by different target groups, including: researchers, international co-operation projects, planners and private companies.
Apart from the scientific results this project also provided information on how to run and manage this type of projects in Vietnam and involving seven research groups. Different elements are important in this context. As far as the acquisition and the use of photographs is concerned:

- For relatively short-term projects as this one (18 months), it is advisable to rely on images that are available before the project starts. Finding e.g. suitable images during the rainy season is an extra risk factor if these photographs need to be taken during the project period;
- The three sets of images (SPOT, LANDSAT, IKONOS) have their own characteristics. They are only partially interchangeable;
- Real added value is less in a parallel use of the different photographs, but rather in the application of merging techniques.

The project could have made benefit of a more intense involvement of the Vietnamese partners. This was hampered by the delay in the implementation of the bilateral Belgian-Vietnamese collaboration programme.

The cost/benefit ratio will also increase if this project can be followed up. Particular areas of interest are:

- Application of remote sensing for coastal and marine resource management;
- Land suitability analysis for planning in coastal areas;
- Integrated Coastal Zone Management (ICZM) involving both the marine (including sea grass fields, coral reefs, coastal resources) and the land based aspects.

FEASIBILITY STUDY T4/DD/018

CONTRIBUTION OF SAR (RADARSAT) AND AVNIR (ADEOS) IMAGES TO THE STUDY OF BATHYMETRY AND WAVE FIELD IN THE BAY OF HAI PHONG (VIETNAM)

A. OZER

UNIVERSITE DE LIEGE (ULG)
DEPARTMENT OF PHYSICAL GEOGRAPHY
LABORATORY OF GEOMORPHOLOGY
Allée du 6 Août 2, Bâtiment 11
B – 4000 LIEGE 1
BELGIUM

1. CONTEXT AND OBJECTIVES

The main objective of the study consists to the process of radar images from ERS-1, ERS-2 and the Canadian satellite RADARSAT, in order to extract the swell plan and to study their anomalies. This information is necessary to explain the localisation of the eroded areas on the coastal zone. The radar images must also be used to validate the swell simulation model by comparison with the swell plan extracted from the radar images.

The second objective consists to complete the results obtained during the multitemporal comparison between the aerial photographs of 1952 and of 1993, by using the SPOT XS images and LANDSAT TM images. The documents will allow mapping the areas of erosion and the areas of sedimentation and to establish a relation with the swell plan obtain by simulation. A comparison with the tide currents will be also realised.

2. DATA

Geographic study area: The Bay of Haiphong in North Vietnam

Satellite imagery used:

ERS-1 PRI 24655-3195 (02/04/1996)
ERS-1 PRI 24655-3177 (02/04/1996)
ERS-2 PRI 4982-3195 (03/04/1996)
ERS-1 PRI 24154-3177 (27/02/1996)
ERS-1 PRI 24154-3195 (27/02/1996)

RADARSAT 5822 (15/12/1996)
RADARSAT 5865 (18/12/1996)
RADARSAT 8223 (01/06/1997)
RADARSAT 8266 (04/06/1997)

LANDSAT (16/06/1989)
LANDSAT (23/11/1989)
LANDSAT (01/12/1992)

SPOT XS (21/05/1988)
SPOT XS (31/08/1992)

SPOT XS (24/12/1994)
SPOT XS (07/12/1995)
SPOT XS (28/12/1995)

SPOT PAN (14/12/1989
SPOT PAN (07/10/1991)
SPOT PAN (21/10/1992)

Other data: Meteorological and marine data measured in situ coming from Haiphong: wind velocity, wind direction, waves, and tide for 27/02/96, 02/04/96, 03/04/96, 15/12/96 and 18/12/96.

3. METHODOLOGY

- Geometrical correction of each satellite image and of the aerial photos in UTM co-ordinates in order to carry out the overlay map.
- Speckle suppression of the radar images with a median filter 5X5.
- Directional filters to extracted the linear structures at the sea surface (swell).
- Overlay between each image and the bathymetry measured *in situ*.
- DTM realised with Arc Info in order to realise the swell simulation model.
- Mapping of the areas of sedimentation and erosion by overlaying the different images (multitemporal study). Overlaying of RADARSAT (15/12/1996) and SPOT XS (31/08/1992) images overlaid with the coast-lines in 1939 and in 1992.

4. OUTPUTS AND RESULTS

The first objective has not been reached, because no radar image were acquired during the specific meteo-marine conditions allowing the location of the swell plan. Only the radar image acquired on 04/06/1997 shows a front-line between two water bodies, that has different physical and chemical patterns. Therefore, the simulation model has not been validated during this study.
The map of erosion and sedimentation areas was carried out from the RADARSAT image acquired on 15/12/1996 and from the SPOT XS image acquired on 31/08/1992. This colour composition is used as the background of the map. Over this raster layer, we have put a vector layer that represents the coastline in 1939 (extracted from a topographical map) and the one in 1992 (extracted from aerial photos). Both coastlines were crossed using the Arc Info GIS software, in order to obtain the surface value for eroded and sediment areas.

The map of the areas of sedimentation and erosion shows that the sedimentation is often located along the channels and along the rivers. The areas of erosion are located on the coastal line. The phenomena of erosion seem to be due to the effects of the tide currents and to the swell that occur during very strong tempests. Most frequent swells that occur during the standard meteorological conditions breaks before to reach the coastline and, therefore, has almost no influence on the coastal zone evolution.

5. EXECUTION

Period: 01/05/1997-21/11/1997

Laboratory:

UNIVERSITE DE LIEGE (ULG)
Department of physical geography
Laboratory of geomorphology
Allée du 6 Août 2, Bâtiment 11, B – 4000 Liège, Belgium
Phone: + 32 4 366 54 46 Fax: + 32 4 366 57 22
E-mail: aozer@ulg.ac.be URL laboratory: www2.geo.ulg.ac.be
URL project: www2.geo.ulg.ac.be

User partner :

HAECON N.V.
Deinzesteenweg 110, B – 9031 Drongen, Belgium
Phone: + 32 9 216 63 63 Fax: + 32 9 227 61 05
E-mail: haecon@haecon.be URL: www.haecon.be

6. RELATED DISCIPLINES

Oceans & coasts
Environment
Natural hazards & disasters
Land planning & infrastructures
Urban & suburban
Cartography
Transport & navigation

7. EXECUTIVE SUMMARY

The main objective of the study consists of to process the radar images from ERS-1, ERS-2 and the Canadian satellite RADARSAT, in order to extract the swell plan and to study the anomalies. This information is necessary to explain the localisation of the eroded areas on the coastal zone. The radar images must also be used to validate the swell simulation model by comparison with the swell plan extracted from the radar images.

The second objective consists to complete the results obtained during the multitemporal comparison between the aerial photographs of 1952 and of 1993, by using the SPOT XS images and LANDSAT TM images. The documents will allow to map the areas of erosion and the areas of sedimentation and to establish a relation with the swell plan obtained by simulation. A comparison with the tide currents will be also realised.

The first objective has not been reached, because no radar image was acquired during the specific meteo-marine conditions permitting the detection of the swell plan. Only the radar image acquired on 04/06/1997 shows a front-line between two water bodies that have different physical and chemical patterns. Therefore, the simulation model has not been validated during this study.

For the second objective, a map of erosion and sedimentation areas was carried out from the RADARSAT image acquired on 15/12/1996 and from the SPOT Xs image acquired on 31/08/1992. This colour composition is used as the background of the map. Over this raster layer, we have put a vector layer that represents the coastline in 1939 (map) and the one in 1992 (aerial photos). Both coastline were crossed using the ARC-INFO GIS software, in order to obtained the surface values for eroded areas and for sediment areas.

The map of the areas of sedimentation and erosion shows that the sedimentation is often located along the channels and along the rivers. The areas of erosion are located on the coastline. The phenomena of erosion seem to be due to the effects of tide currents and due to the swell that occur during very strong tempests. Most frequent swells, that occur during the standard (d meteorological conditions, breaks before to reach the coastline and, therefore, has almost no influence on the coastal zone evolution.

Remote sensing techniques allow to carry out the study of the littoral zones evolution in tropical, on along (53 years) and (4 years) periods of time environment. The spatial resolution of the satellite images, that limits this kind of study in temperate environment, at least for the short periods, is not important in this case, because of the rate of the littoral evolution (up to 10 meters/year) is higher than the limit of the spatial resolution, after 4 or 5 years.

The ratios cost/efficacy established for all radar and optical images in this study, have demonstrated, that the SPOT XS images correspond to the best choice for the study of the sedimentary concentration and for the mapping of the coastal evolution. Nevertheless this mapping is even better when the SPOT image is combined with the radar image. The SPOT XS images produce lot of spectral information, because of the good spectral resolution and the radar images have a better spatial resolution (12.5 meters for ERS and RADARSAT instead of 20 meters for SPOT XS).

The radar images do not have supplied any information about the swell plans, because of the meteorological condition and/or because the orientation of the swell crests was parallel to the direction of the radar illumination. But we know, through the studies carried out in the Laboratory of Geomorphology and Remote Sensing and through the knowledge of the literature, that the RADAR SAR images have a great potential in the fields of the swell extraction.

The study of the ratio cost/efficacy between the ERS and RADARSAT images shows that, on one hand RADARSAT images are more expensive than the ERS images and that, on the other hand, they do not supply no more information than the ERS images for the study of the marine environment.

Nevertheless, the RADARSAT satellite presents the advantage to have the possibility to modify its incidence angle. It is an advantage for several applications because it allows its more images in a short time.

RADARSAT has the advantage, thank to the possibility to record the data on board, to be independent of the local spatial agencies, for example for the Bangkok antenna.

We would like to use the data from the Japanese satellite ADEOS (with the AVNIR sensor), but, because of a mechanical breakdown, this part of the study was cancelled.

FEASIBILITY STUDY T4/02/047

DETECTING ZOOPLANKTON STREAKS IN SALT LAKES USING HIGH RESOLUTION WATER SURFACE COLOUR PROCESSING

F. DE TROCH

UNIVERSITEIT GENT (RUG)
LABORATORY FOR WOOD AND WATER MANAGEMENT
Coupure Links 653
B – 9000 GENT
BELGIUM

1. CONTEXT AND OBJECTIVES

Knowledge about the distribution of zooplankton is a key factor in predicting accurately the population dynamics of commercially important fish species and in establishing the potential of sustainable aquaculture operations. Most related application developments have been concentrated on studying phytoplankton in the seas. The sea water colour processing has focused evidently on the greenish colour spectrum, generated by chlorophyll. Zooplankton, instead, is characterized by its general lack of chlorophyll and the more common reddish colour spectrum generated by carotenoid and affiliated compounds. Furthermore, these developments pertained to wide views of the oceans to study this biomass on a macroscale. We, instead, are interested on a derivative of the biomass on a mesoscale. This requires a resolution on the borderline of what most commercially available sensors provide. Also, most developments are geared towards monitoring more global changes within the time frame of several seasons. We are interested in detecting phenomena that are only relevant within a period of days as winds and currents disperse these clouds of organic material. A similar mode of operation is demonstrated by oil spill detection. The main objective of this study is to determine the technical feasibility of a detection system for zooplankton in lakes, based on present or near-future satellite sensors.

2. DATA

Geographic study area: Great Salt Lake, Utah, USA
Satellite imagery used: SPOT Xs, Proc. level: 1B, 09/10/1998, Path-Row: 548-268
Other data: "Ground truth" data provided by INVE Technologies nv.

3. METHODOLOGY

- First, a set of high-resolution images had to be collected. Due to the launching failure of the first commercial high-resolution sensor IKONOS, other sources of satellite imagery had to be found.
- Therefore, the availability of SPOT and LANDSAT images was studied in order to find some satellite data for the period over which ground truth data was collected.
- From the moment the satellite data was available, some of the existing methods to detect phytoplankton through satellite imagery were used in a slightly different way, accounting for the different spectral behaviour of the organic pigments of the zooplankton.
- Also, classical classification techniques, like principal components analysis and cluster analysis, were used on the images in order to find some evidence of the zooplankton streaks in the images.

4. OUTPUTS AND RESULTS

Only one multispectral SPOT image could be selected that was taken during the collection period of the ground truth data at the Great Salt Lake (USA). This image was used as an input for the different image processing techniques that had the potential possibility to distinguish between the zooplankton streaks and their neighbourhood. None of the presented methods could provide evidence of streaks in the image. Probably, the resolution of the used image wasn't high enough to create a good filter for the detection of the streaks. Further research is needed to investigate the spectral characteristics of the zooplankton. When these characteristics will be known there is a much higher possibility to find a good algorithm for the detection of the streaks in high-resolution imagery.

5. EXECUTION

Period: 01/09/1999-30/11/1999

Laboratory:

UNIVERSITEIT GENT (RUG)
Laboratory for Wood and Water Management
Coupure Links 653, B – 9000 Gent, Belgium
Phone: +32 9 264 61 35 Fax +32 9 264 62 36
E-mail: Francois.DeTroch@rug.ac.be URL : http://taoren.rug.ac.be/

User partner :

INVE TECHNOLOGIES
Oeverstraat 7, B – 9200 Dendermonde, Belgium
Phone: + 32 52 33 13 20 Fax: + 32 52 33 45 31

6. RELATED DISCIPLINES

Oceans & coasts
Agriculture
Environment
General Earth observation

7. EXECUTIVE SUMMARY

Knowledge about the distribution of zooplankton is a key factor in predicting accurately the population dynamics of commercially important fish species and in establishing the potential of sustainable aquaculture operations. Most related application developments have been concentrated on studying phytoplankton in the

seas. The sea water colour processing has focused evidently on the greenish colour spectrum, generated by chlorophyll. Zooplankton, instead, is characterized by its general lack of chlorophyll and the more common reddish colour spectrum generated by carotenoid and affiliated compounds.

Developments pertained to wide views of the oceans to study the phytoplankton biomass on a macroscale. We, instead, are interested on a derivative of the zooplankton biomass on a mesoscale. This requires a resolution on the borderline of what most commercially available sensors provide.

Most developments area geared towards monitoring more global changes within the time frame of several seasons. We are interest in detecting phenomena that are only relevant within a period of days as winds and currents disperse these clouds of organic material. A similar mode of operation is demonstrated by oil spill detection with radar remote sensing. The main objective of this study was to determine the technical feasibility of a detection system for zooplankton in lakes, based on present or near-future satellite sensors.

First, a set of high-resolution images had to be collected. Due to the launching failure of the first commercial high-resolution sensor IKONOS, other sources of satellite imagery had to be found. Therefore, the availability of SPOT and LANDSAT images was studied in order to find some satellite data for the period over which ground truth data was collected. Only one multispecral SPOT image could be selected that was taken during the collection period of the ground truth data at the Great Salt Lake (USA).

From the moment the satellite data was available, two sites were chosen on the image, a site where the presence of streaks at the time the image was taken was confirmed by INVE nv. And a second site where no streaks were found at that time. The detection of phytoplankton, using remote sensing, is based on the calculation of the chlorophyll content in a certain body of water and different models found in the literature describe how to determine the total amount of chlorophyll using the spectral characteristics of these pigments. Some of these existing models to detect phytoplankton through satellite imagery were used on the two selected areas in the SPOT image, accounting for the different spectral behaviour of the organic pigments of the zooplankton.

None of the used models could provide evidence for the presence of the zooplankton streaks. In both the test site and the steaks site, the same patterns became visible, what means that no streaks site, the same patterns became visible, what means that no streaks filter could be build based on the models for the phytoplankton detection. Taking into account the specific colour characteristics of the zooplankton streaks, it is thought that information from the low visible wavelengths could be important to distinguish between the streaks and their neighbourhood. This information isn't present in the SPOT image, which could explain the failure of the analysis. Using images of other satellite sensors that are more sensitive at lower wavelengths, like the high-resolution images of IKONOS, can give probably better results.

The ultimate goal of image classification is to find a specific class for every pixel of the image. Every class has his reflection and absorption characteristics and therefore multispectral images are used as an input for these kinds of techniques. Classic classification techniques, like principal component analysis, were used on the images in order to find some evidence of the zooplankton streaks in the images.
Except for the clear differences in response between water and land, no obvious patterns could be recognised in the principal components. Also, the cluster analysis couldn't detect the zooplankton streaks in the SPOT image. None of the presented methods could provide evidence of streaks in the image. Probably, the resolution of the used image wasn't high enough to create a good filter for the detection of the streaks. Further research is needed to investigate the spectral characteristics of the zooplankton. When these characteristics will be known there is a much higher possibility to find a good algorithm for the detection of the streaks in high-resolution imagery.

FEASIBILITY STUDY T4/36/052

OPTICAL REMOTE SENSING SUPPORT FOR A COASTAL ZONE ENVIRONMENTAL IMPACT STUDY

G.PICHOT

THE MANAGEMENT UNIT OF THE NORTH SEA MATHEMATICAL MODELS (MUMM/BMM/UGMM)
Gulledelle 100
B – 1200 BRUXELLES
BELGIUM

1. CONTEXT AND OBJECTIVES

ECOLAS is currently bidding for different EIA's related to port and offshore investment projects. One of the bids concerns the "Thai Offshore Base" (TOB) project, in the framework of which a port facility is to be constructed near the existing port of Songkhla on the Southeast coast of Thailand. This EIA is wide-ranging in scope, covering many potential pollution aspects. However, key elements relate to possible disruption and/or damage to the marine environment from suspended sediments dumped after dredging operations, and to possible changes in coastal and marine water movement. The necessary baseline information on the existing suspended sediment climate and on existing port discharges of waste water and subsequent transport in the coastal zone is lacking, suggesting an opening for the use of optical remote sensing. The specific objective of this project is to obtain, from optical remote sensing data, baseline environmental information on the suspended sediment climate (including location of high turbidity regions and rainfall-induced seasonal variability) and on the main characteristics of phytoplankton distribution and dynamics in the coastal zone affected by the port facility to be constructed at Songkhla. This information will be used in Ecolas' Environmental Impact Assessment.

The following tasks will be carried out to achieve the stated objectives:

- A summary will be made of the existing data (if any) relating to suspended particulate matter and chlorophyll distributions in the coastal zone of the port of Songkhla.
- A summary will be made of the potential sources of optical remote sensing data (e.g. LANDSAT, SPOT, SEAWIFS, AVHRR, etc.) with an appraisal of each sensor for the present application in terms of spatial, temporal and spectral coverage and resolution, data availability, etc.
- The selected imagery will be processed to give suspended matter and chlorophyll distributions.
- A scientific analysis will be made of the processed imagery, noting both remote sensing aspects that may affect the data quality as well as interpreting the imagery in terms of physical/biological processes
- The remote sensing imagery and accompanying scientific analysis will be incorporated into Ecolas' Environmental Impact Assessment.

2. DATA

Geographic study area: San Vicente Bay (Chile)

Satellite imagery used:

LANDSAT-5, LANDSAT-7

SPOT-3

Other data: Suspended matter data

3. EXECUTION

Period: 01/07/1999-31/12/1999

Laboratory:

THE MANAGEMENT UNIT OF THE NORTH SEA MATHEMATICAL MODELS (MUMM/BMM/UGMM)

Gulledelle 100, B – 1200 Bruxelles, Belgium

Phone: +32 2 773 21 22 Fax: +32 2 770 69 72

E-mail: G.Pichot@mumm.ac.be URL: http://www.mumm.ac.be/

User partner:

ECOLAS

Lange Nieuwstraat 43, B – 2000 Antwerpen, Belgium

Phone: +32 3 233 07 03 Fax: +32 3 233 81 20

4. RELATED DISCIPLINE

Oceans & coasts

5. EXECUTIVE SUMMARY

The objective of this project was to obtain baseline environmental information on the distribution of sediments in the waters of San Vicente Bay (Chile). This information was wanted by Ecolas in the framework of an Environmental Impact Study (EIS) of this region. For the purposes of this TELSAT feasibility study the "client" is considered to be Ecolas. However, the final end-user is the Chilean regional authority for environmental inspection, CONAMA, who have commissioned the EIS to Ecolas. The EIS being carried out by Ecolas covers water pollution issues with emphasis on the pollution of sediments and the water. The purpose of the TELSAT feasibility study is to add a remote sensing component to their study and to evaluate the cost-effectiveness of this method.

San Vicente Bay is located near the towns of Talcahuano and Concepcion. The Bay has an area of about 17km², with water depths increasing to 50m near the opening to the South Pacific. The bay is heavily industrialised with important fish-processing, steel and petrochemical factories which discharge wastewater directly into the sea via a number of outlet pipes. The Bay is used by ships, which remain at anchor to offload at the fish-processing factory. A raw sewage outlet for the town of Talcahuano also discharges into the North of the Bay. At the Southern coast of the bay is a sandy beach once suitable for tourism but now largely disaffected because of pollution. However, efforts are underway to rehabilitate the bay for tourism and fishing.

Ecolas' main requirement was to assess the degree of contamination of sediments and to estimate the total volume of polluted sediments that are to be removed. In this respect remote sensing should provide a map showing zones of distinct sediment types/concentrations, thus enabling extrapolation from a few in situ measurements to the whole of the bay area.

Method

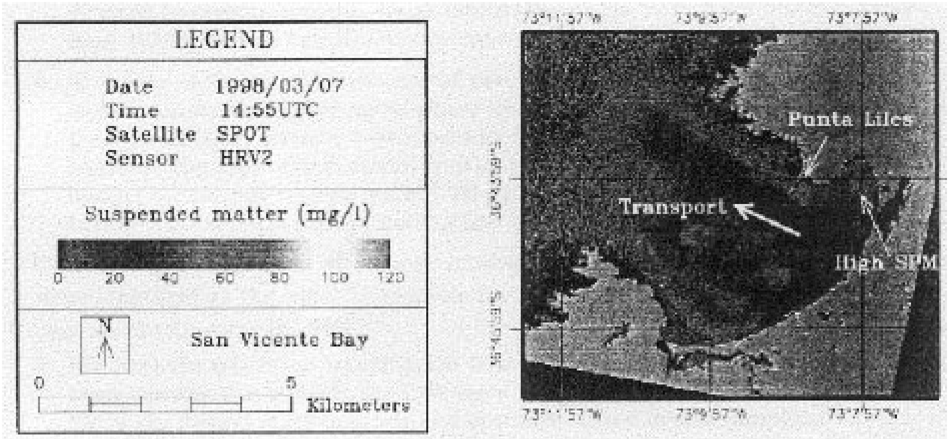
The remote sensing activities can be decomposed into three distinct phases: selection of imagery, image processing and interpretation.

The selection and ordering of imagery in this study was strongly constrained by the small size of the Bay, which reduced the set of suitable sensors to those of the SPOT and LANDSAT families.

Image processing was performed using the Environment for Visualizing Images software (E\VI 3.2a). Image data are georeferenced, cropped, radiometrically calibrated, atmospherically corrected and converted to suspended matter units by use of a hydro-optical model. Problems were encountered with sensor noise (striping, banding, etc.) for the LANDSAT images, which required interactive Fourier transform noise removal techniques. Both false colour top-of-atmosphere images and suspended matter maps have been presented for the one SPOT image and the three LANDSAT images.

Results

Of the four images processed, the SPOT-derived suspended matter map (see figure below) is considered to be the best duality. The area of high-suspended matter in the North-East corner of the bay can be clearly identified and corresponds to *in situ* measurements. This is also found in the better LANDSAT images. The plume-like structure of the suspended matter field around the Punta Liles with lower concentrations to the West of this headland suggesting transport of suspended matter out to sea. Other features visible in the top-of-atmosphere images were noted as of potential interest in other environmental impact studies and gave an indication of the possibilities of optical remote sensing.



Suspended matter concentration derived from the SPOT image of 7th March 1998

The general impression of Ecolas was that this imagery was interesting in giving a new, synoptic view of suspended matter within the bay. Of particular interest was the transport of suspended matter from the North-East corner of the bay out to sea past the Punta Liles headland, implied by the SPOT image and the LANDSAT image of 7th February 1987. On the critical side it was noted that the imagery falls short of answering the most crucial questions for this EIS and does not provide a comprehensive statement of transport of suspended matter nor of the total volume of bottom sediments to be dredged. However, for other present or future studies which Ecolas is involved in remote sensing may become cost-effective.
LANDSAT images were of poor quality for this application because at the low signal levels typical of water bodies the sensor noise becomes very significant.

The basic image processing methodology, including atmospheric correction, is generic and can easily be applied to other regions. The main variations that can be expected concern availability of imagery (ground station coverage) and the choice of sensors (particularly relating to spatial resolution required).

Future application of optical remote sensing to coastal zone EIS

The costs and benefits of remote sensing have been analysed in detail. The cost of image processing software and the need for specialist knowledge prohibit development of an in-house remote sensing capability within Ecolas at least in the foreseeable future. Moreover the cost of imagery and of subcontractor manpower required for image processing and interpretation renders the technique expensive with typical total costs amounting to a few 100 KBF for even the simplest studies. Thus, the technique seems best adapted to the very largest international EIS. Considering the cost of remote sensing two contexts have been identified where this could be a cost-effective technique:

- Using an estimate of 2.5% as the project component, which could typically be devoted to remote sensing, large international EIS with total budgets exceeding 100MBF would be sufficient to cover typical remote sensing costs.

- At a very different scale the use of very basic remote sensing products such as low-resolution top-of-atmosphere images, photographic products or even quick looks is an attractive proposition when bidding for an EIS contract because of the high promotional impact of such imagery. In such a case the budget would not usually exceed 10 KBF for remote sensing and a very fast turnaround is required (typically a few weeks).

Considering the benefits of remote sensing products the following conditions were identified as the most favourable for the cost-effective use of remote sensing within EIS-type projects:

- For projects where no information is available from primary references, remote sensing can provide the first view of a region and is particularly valuable at the project start to guide and optimise future *in situ* sampling.

- For projects with large horizontal extent (*e.g.* greater than 15km) the use of much cheaper low-resolution imagery improves the cost-effectiveness of remote sensing.

- If the EIS covers both marine and terrestrial environmental issues then an economy of scale can be achieved regarding the cost of imagery provided remote sensing expertise in both marine and terrestrial remote sensing is available.

This feasibility study has prepared the way for future self-supporting use of remote sensing techniques in the context of coastal zone environmental impact studies.

FEASIBILITY STUDY T4/02/053

STUDY OF SEDIMENT PLUMES IN LARGE DELTA SYSTEMS USING FIELD MEASUREMENTS AND SATELLITE DATA

M. DE DAPPER

UNIVERSITEIT GENT (RUG)
DEPARTMENT OF GEOGRAPHY
Krijgslaan 281 Gebouw S8/A1
B – 9000 GENT
BELGIUM

1. CONTEXT AND OBJECTIVES

This study focuses on the detection of sediment plumes and sediment contents brought down by large rivers. The knowledge of the main currents and the amount of sediment is important with regard to the development of deltas and consequently with regard to the navigability of the rivers. The condition of sediment plumes is traditionally examined through direct measurements from a ship. These observations are point tied along the ship's course. This traditional approach doesn't offer a survey of the total condition of the sediment plumes. To come to such an overall picture the observation grid has to be refined in the conventional way, implying that the costs will sharply increase. Due to the synoptic capacity, the use of remote sensing documents could offer a solution. However the question rises to what extent these data can be used to determine the sediment contents and sediment plumes. This question is asked by the companies HAECON N.V. and DEME N.V./Dredging International, for the case of the outlet of the Rio de la Plata (Argentina and Uruguay). Both companies are co-operating to elaborate a project of dredging-works to keep the ship's course in the Rio de la Plata open and to control the influence of the dredging-operations on the environment.

With regard to the theme of this research satellite images with information on the visual reflected light will be needed. This study aims a multiscale approach:

- First of all a *detailed* interpretation has to be set up by means of relatively fine resolution images; this interpretation is a tool for the following up of the dredging-works in the channel. For that it is necessary to correlate the field data with the digital values of the visual bands of the LANDSAT TM images. This will be done in two periods: one during high discharge of the Rio de la Plata, another during low discharge. The compiled correlations allow to carry out the image classification for both periods. As the branches of the Rio de la Plata reach a maximum depth of about 9-m, the digitised bathymetrical maps will be used to improve the image classification processes.
- A second approach is situated on a *regional* level and will happen by means of medium resolution images (RESURS-01) in order to study the environmental effects of dredging-works on the different water catchments at the Rio de la Plata. To obtain an interpretation of the RESURS-01 image a correlation between the RESURS-01 bands and the similar bands of the LANDSAT TM will be compiled.
- A third approach is situated on a *global* level and wants to observe the course of the sediment plumes in the Atlantic Ocean. For that purpose rough resolution images of the SEAWIFS sensor will be used. A comparison will be made between former achieved results and the SEAWIFS images.
  In a last step an error analysis will be made showing to what extent the satellite images and the proposed method give an accurate view on the situation of the suspension material in the Rio de la Plata. At the same time an analysis will be

made of costs and benefits comparing the conventional field measure methods and the use of remote sensing methods.

2. DATA

Geographic study area: Rio de la Plata (Argentina)
Satellite imagery used:
LANDSAT 5 TM
LANDSAT 7 ETM
RESURS-01 SK
SEAWIFS
Other data:
Nautical maps
Topographic maps

3. METHODOLOGY

- Digitising bathymetrical maps of the Rio de la Plata and adjoining part of the Atlantic Ocean in order to make a Digital Elevation Model of the study area.
- Processing of the satellite images used in order to: Georeference the SEAWIFS - image to the LANDSAT 7 ETM+ image using topographical maps and the RESURS-01 SK image as an intermediate Make different colour composites Produce classifications using 'Density Slicing' based on relative sediment loads Develop a filter to detect man-made channels.

4. OUTPUTS AND RESULTS

- Digital Elevation Models for the Rio de la Plata and adjoining part of the Atlantic Ocean and for a detailed part (LANDSAT 7 ETM+ scene) of the Rio de la Plata (resolution: 30m).
- Colour composites of the LANDSAT 7 ETM+ and SEAWIFS data.
- Classification of the LANDSAT 7 ETM+ image based on 'Density Slicing' indication the sediment plumes.

Based on these results it can be concluded that it is possible to detect patterns of sediment transport in large delta systems used remote sensing techniques. The LANDSAT 7 ETM+ sensor can be used to make a detailed study, while the SEAWIFS gives the opportunity to have a synoptic view of the Rio de la Plata and adjoining part of the Atlantic Ocean. Also a model can be developed to detect the 'cross points' of the sediment plumes over the man-made channels. This model can be used to optimise the dredging activities. Deliverables: Digital Elevation Model of the Rio de la Plata, classified image based on relative sediment loads, 3D views.

5. EXECUTION

Period: 01/06/1999-30/06/2000

Laboratory:

UNIVERSITEIT GENT (RUG)
Department of Geography
Krijgslaan 281 Gebouw S8/A1, B – 9000 Gent, Belgium
Phone: +32 9 264 46 90 Fax: +32 9 264 49 85
E-mail: Morgan.DeDapper@rug.ac.be
URL http://www.admin.rug.ac.be/RUGphone?P_vakgr=WE12V

User partner :

HAECON N.V.
Deinzesteenweg 110, B – 9031 Drongen, Belgium
Phone: + 32 9 216 63 63 Fax: + 32 9 227 61 05
E-mail: haecon@haecon.be URL: www.haecon.be

6. RELATED DISCIPLINES

Oceans & coasts
Hydrology & freshwater resources
General Earth observation

7. EXECUTIVE SUMMARY

The aim of the study is to investigate whether it is possible to use remote sensing techniques to detect sediment plumes or to determine sediment concentrations in large river systems. More specifically the Rio de la Plata (Argentina – Uruguay) is under consideration.

Because the sediment loads are in suspension, it is necessary to use passive remote sensors, since this spectral range, especially the blue light, is less absorbed by the water. Therefore 2 sensors are used, namely the LANDSAT 7 ETM+ - and the SEAWIFS – sensor. These two sensors record on two different scales and resolutions: The LANDSAT 7 ETM+ - image has a spatial resolution of 30 m while SEAWIFS has a spatial resolution of 1100 m. A detailed study on a part of the Rio de la Plata (near Buenos Aires (Argentina) and Colonia de Sacramento (Uruguay)) will be executed based on the LANDSAT 7 ETM+ - images. A synoptic approach can be realized using the SEAWIFS – data. The SEAWIFS can also be used to detect sediment plumes in the adjoining part of the Atlantic Ocean.

Because the difference in resolution between these two sensors is very large, it is necessary to introduce a third sensor that operates on a medium scale. The RESURS SK – sensor, with a spatial resolution of 160 m, is appropriate for that goal. By means of these images it is possible to link both other images geometrically.

The Rio de la Plata is very shallow (a medium depth of 5 m) and large amounts of sediment are supplied by the Rio Uruguay and the Rio Parana. Therefore dredging is necessary to clear the man-made channels. Because this dredging brings sediment in suspension, it is also important to know in which way this 'secondary' sediment is transported in the system. To estimate the amount and importance of this sediment, it is useful to make a comparison between the situation when dredging activities are carried out and the situation after the dredging activities are ended.

To quantify the detected sediment concentrations, it is necessary to link this information with data acquired by field survey. This data exists and is provided by HAECON NV. Besides it is necessary to detect to which depth the visual light can penetrate into the water. In this way it becomes possible to determine to which extend the bottom of the Rio contributes to the reflection of the water. To eliminate this factor a bathymetrical model must be created. Based on this quantification, the LANDSAT 7 ETM+ - images can be classified. The resulting image should show patterns of sediment transport in the Rio de la Plata. It is also necessary to investigate this both for the period of high and low run off in the Rio Parana and Rio Uruguay.

A last aim is to study whether the quantified spectral values of the LANDSAT 7 ETM+ can be extrapolated to the SEAWIFS – images. In this way it is possible to come to a classified, synoptic image of the entire Rio de la Plata and adjoining part of the Atlantic Ocean. Also for this aim, the RESURS SK – image should be used to link both other images.

To attain these objectives following GIS – data has been created:

- A Digital Elevation Model for the entire Rio de la Plata and adjoining part of the Atlantic Ocean with a spatial resolution of 500 m. Specifically for the study area (area covered by the scene of the used LANDSAT 7 ETM+ - image (path/row: 225/084)) the resolution is upgraded to 30 m. In that way it is possible to compare pixel wise the DN-values of the satellite-image with the values of the DEM. On these DEM's it is obvious that the Rio de la Plata is very shallow. Even the continental shelf is less than 100 m deep and is extended to several hundredths of kilometres into the ocean. It is also demonstrated that the Rio de la Plata is dominated by bars such as the Banco Ortiz and Banco Inglès. Remarkable are the relative deep, natural channels in the northeastern part of the Rio de la Plata.

The dredged channels are partly constructed using these natural ‘depths’. These DEM’s can be used to support the interpretation of the remote sensing data.

- Based on the LANDSAT 7 ETM+ - image (path/row: 225/084) acquired on January 19th, 2000 following images are produced:
  - A true (TCC) and a conventional false (FCC) colour composite. Several patterns of sediment transport can be detected on these colour composites. Besides, small vessels and parts of the dredged channels can be noticed. Remarkable is the contact zone between the water supplied by the Rio Uruguay and the Rio Parana. It can be noticed that in January, the Rio Uruguay has a larger sediment load than the Rio Uruguay. On these colour composites, especially on the FCC, also the spoil-grounds of the dredgers can be delimited. In combination with the thermal data from the LANDSAT7 ETM+ - sensor, the difference between the river water and the saltier water in the estuary can be detected.
  - A classified image based on the principle of ‘Density Slicing’. This ‘Density slicing’ uses relative sediment loads but it is still appropriate to distinguish different patterns of sediment transport.
  - An image showing the man-made channels in the Rio de la Plata. This image is produced by using a Y-directional filter on the blue band. By using such a filter linear elements are put into contrast. In this way the man-made channels are automatically detected.
- Based on two SEAWIFS – images (respectively taken on August 26th, 1999 and January 19th, 2000) following images are produced:
  - A colour composite (combination of bands 6 (red), 2 (blue) and 1 (blue)) of the image taken on August 26th, 1999. This combination has been chosen based on the Optimal Index Factor (OIF). This factor calculates the optimal combination of three spectral bands so the abundance is minimal.
  - A colour composite (combination of bands 3 (blue), 2 (blue) and 1 (blue)) of the image acquired on January 19th, 2000. This combination has also been chosen based on the OIF.
  - A colour composite (combination of bands 8 (infrared), 6 (red) and 5 (green)) of both the image taken on August 26th, 1999 and the image taken on January 19th, 2000, in order to compare them with the conventional colour composite of the LANDSAT7 ETM+ - image.

    When both colour composites are compared, the difference in sediment transport between winter and summer can be noticed. Also the way in which the sediment is transported and diluted by the ocean currents can be measured.

    It can be concluded that it is possible to detect sediment plumes in large delta systems based on remote sensing and more specifically using the visual range of LANDSAT 7 ETM+ - and SEAWIFS – data. The LANDSAT 7 ETM+ - sensor offers the opportunity to examine the area in detail, while SEAWIFS gives a more synoptic view of the area. When these digital data can be quantified by correlating it to a more extended data set collected in the field, a quantified classification can be made. This is, though, not so evident. An important problem is the difficulty to find a cloudless image over the area. This is a particular problem in winter and especially for the SEAWIFS. Besides, a large number of field data is necessary to be statistical relevant and a field campaign is very expensive. As a consequence the available data are inappropriate to make a quantified classification. But based on the 'Density Slicing'-technique it is possible to come to a relative classification that gives an indication of the patterns of transport in the Rio de la Plata. It is also possible to develop a model to detect the 'cross points' of the sediment plumes over the man-made channels. This is very important to optimise the dredging schedule. In that way it becomes possible to predict where and when dredging is the most necessary in the Rio de la Plata. Besides, spoil-grounds in the Rio de la Plata are detected. Based on remote sensing the evolution of these spoil-grounds can be surveyed. This is necessary to estimate the influence of this secondary sediment on the sedimentation of the man-made channels. For shipping these spoil-grounds can form obstacles that are not indicated on the nautical maps.

CHAPTER V

WEATHER AND CLIMATE

TECHNICO-ECONOMICAL FEASIBILITY OF THE COMMERCIALISATION OF AN INSTRUMENT (C-FIX) FOR THE CALCULATION OF THE NET CARBON EXCHANGE WITH THE ATMOSPHERE IN THE FRAME OF THE FRAMEWORK CONVENTION ON CLIMATE CHANGE (FCCC)

J. VAN RENSBERGEN

VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK (VITO)
Boeretang 200
B – 2400 MOL
BELGIUM

1. CONTEXT AND OBJECTIVES

The instrument constitutes an improvement of the methodology for evaluating the impact of changes in land use (e.g. deforestation), on the net carbon exchange between atmosphere and vegetation.

The main advantage of the proposed approach is that real time earth observation will be used rather than statistical data, which often are outdated and unreliable (especially important for developing countries).

The objectives are:

- Evaluation of the economical feasibility of a product which will calculate the net carbon exchange based on earth observation data and ecosystem models.
- Determination of the technical and operational requirements of to the potential users of this product.
- Definition and budgeting of the technical stages to scale up the prototype towards a product.

2. METHODOLOGY

- Product description and demonstration
- Identification of target groups
- International organisations (FAO, UNESCO, World Bank, ABOS, NGO's...)
- Countries that have ratified the Framework Convention on Climate Change (FCCC)
- Market research: data collection
- Development of a questionnaire
- Data collection
- Analysis of economical feasibility and market potential
- Determination of formal technical and operational standards
- Definition and budgeting of the technical stages to scale up from prototype to product
- Final evaluation and reporting.

3. EXECUTION

Period: 15/12/1996-30/06/1997

Laboratory:

VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK (VITO)
Boeretang 200, B – 2400 Mol, Belgium
Phone : + 32 14 33 68 00 Fax : + 32 14 32 27 95
E-mail : vrensbej@vito.be   URL : www.vito.be

User partner :

HORIZON CENTRE
Leuvensesteenweg 510 bus 45, B – 1930 Zaventem, Belgium
Phone : + 32 2 773 73 72   Fax : + 32 2 773 79 10

4. RELATED DISCIPLINES

Weather & Climate
Atmosphere
Forest & National Vegetation
Economical Issues

5. EXECUTIVE SUMMARY

In the framework of the impulse programme Global Change (1991-1996), VITO has developed a methodology to find the net carbon exchange between biosphere and atmosphere using yearly multitemporal observations of the NOAA-AVHRR sensor. From these observations, fractions of absorbed photosynthetic active radiation (fAPAR), phenological classification, and data integration in ecosystem models is performed. The NOAA-AVHRR images may be replaced by SPOT-VEGETATION information, available from mid 1998 onwards.

For countries that do not dispose of adequate quantitative data on changes in land use, deforestation and forest fires, this method offers a real, reliable and cost effective way to monitor the evolution, and to report on the net carbon exchange with the atmosphere (in the form of CO_2). Countries that dispose of elaborate statistical information, can use the methodology as an additional and completely independent verification. The application of the methodology becomes a recurrent activity (annual to tri-annual) in the framework of the commitment to report to the Climate Convention.

The objectives of the study are to investigate the economic feasibility of the commercialisation of the methodology in the form of a product, to determine the formal requirements imposed on the product by the different user groups, and to find the technical stages to turn the prototype into a product that conforms with the user requirements.

On the basis of inquiries, interviews, and literature reviews, the market potential of the C-Fix product has been determined. Two fields of application have been identified, each drawing on a clear market interest.

1. The use of C-Fix as an instrument for the calculation of the carbon budget (Climate Convention) draws on a market at three levels
    - The national level, parties to the Convention, which rely for their commitments to the Climate Convention on statistics and which find in C-Fix a useful alternative
    - The regional level, where groups of countries, helped by international organisations or not, act as an intermediary to the Climate Convention
    - The scientific level, where carbon budgets play a crucial role in global modelling of climate systems

2. C-Fix for the analysis of the damage to vegetation

The analysis of the impact of climatological anomalies (e.g. late frost, long period of drought), and environmental pollution (ozone damage, acidification, heavy metal pollution) is a second field of application.

From the feasibility study the specific operational requirements are determined to estimate the market potential. The specific requirements of the product are:

- Centralised processing (sale of finished products instead of software licenses)
- Net carbon budget of vegetation calculated on a yearly basis
- Specific processing towards productivity of vegetation on a daily basis (or ten-day composite SPOT-VGT images)
- The option to deliver results per country and/or region has to be open, as well as the possibility to aggregate data (region, continent, world)
- Central and global archive
- Delivery of information in a GIS environment (for further analysis by the customer) and/or direct assistance to the customer.

The study evaluated the technical stages to arrive at a centralised and automated C-Fix application and budgeted the investment and development costs in the following way :

Hardware	4.779 kBEF
Software	1.262 kBEF
Development	5.119 kBEF
Total	**11.160 kBEF**

Concerning the operational costs, the cost of global meteorological data (temperature and solar radiation) remains unknown. This element is subject to further technical and economical analysis.

CHAPTER VI

NATURAL HAZARDS AND DISASTERS, HUMANITARIAN AID

PILOT PROJECT T4/11/022

DEVELOPMENT OF A DECISION TOOL BASED UPON THE USE OF REMOTE SENSING AND GIS FOR THE SITE PLANNING AND THE MANAGEMENT OF REFUGEES CAMPS TAKING INTO ACCOUNT THE ENVIRONMENT

E. WOLFF

UNIVERSITE LIBRE DE BRUXELLES (ULB)
INSTITUT DE GESTION DE L'ENVIRONNEMENT ET D'AMÉNAGEMENT DU TERRITOIRE (IGEAT)
Boulevard du Triomphe - CP 246
B – 1050 BRUXELLES
BELGIUM

1. CONTEXT AND OBJECTIVES

The objectives of this project were threefold:

- To compile and to organise into a GIS small scale geographic data
- To develop a spatial decision tool to support site planning and the management of refugees camps
- To set up a robust computer configuration dedicated to ground surveys, using the developed decision tool and the small scale geographic data

2. DATA

Geographic study area: Goma, Democratic Republic of Congo, Africa

Satellite imagery used:

- SPOT: 20/01/1994-24/06/1995-13/07/1996
- LANDSAT TM: 07/08/1987

Other data: Classifications derived from low-resolution data (AVHRR) : USGS and TREES classifications.

3. METHODOLOGY

Scientific literature and a rapid survey among organisations involved in the assistance to displaced people ended to define and rank relevant and geographic criteria to locate refugees' camps. Instead of overlaying criteria within a GIS, a multi-criteria and multi-objective technique was used; it avoids to threshold continuous variables and ensures a better definition of the adequacy of any area to “accueillir” refugees' camps. The user may choose relevant criteria and define them as factors (a continuous criterion that increases the adequacy of the decision, i.e. the distance to be walked by displaced people) or constraints (a binary criterion that limits the decision, i.e. not within the protected areas). The relative importance of the factors are then ranked two by two by the users in order to define weights of their linear combination. Before applying the suitability “formula”, all factors are standardised between 0 and 255.

The method is based mainly on the use of small-scale geographic data that were collected for free on the Web. Data were collected over the world, Africa and central Africa. They were described within a meta-database. High-resolution remote sensing was used over the test site of Goma in order to measure the small scale data quality, to improve these data, and test the impact of improved data on site selection.

4. OUTPUTS AND RESULTS

Two scenarios have been tested: an emergency situation and a non-emergency one where environmental criteria may be taken into account. Both of them give a map of adequacy of areas to select site for refugees' camps. These maps leads the user to concentrate the site selection over some more suitable areas, but does not locate an adequate site.

- The method was applied over several zones centred on Goma: An area of 150 by 150 km was used to set up the method
- The Great lakes region (300 by 400 km) was used in order to demonstrate its applicability over a wide region of the world facing conflicts
- A small area (40 by 40 km) for which high resolution data were available

Adequacy maps were confronted to the ground experience of our partner in Goma. Emergency sites location are quite well modelled. In the environmental scenario, actual camps located in non-suitable areas were indeed facing environmental problems such as water supply, high impact on protected areas, their relocation wasn't possible for security reasons. Comparison with the situation around Goma had the only objective of validating the tool under development.

Precise site location and site management were not studied thoroughly within this project; conclusions of a previous feasibility study on the use of remote sensing for refugees camps management and mapping stated that interpreted space maps of high and very high resolution remote sensing data are adequate documents to be use by humanitarian organisations.

The private company associated to this study has developed a spatial tool for ground survey. It allows to view spatial data (i.e. vectors and images), to add vector data (i.e. roads, camps, …), to collect ground data using a GPS organised into a database.

5. EXECUTION

Period: 15/12/1997-30/06/1990

Laboratory:

UNIVERSITE LIBRE DE BRUXELLES (ULB)

Institut de Gestion de l'Environnement et d'Aménagement du Territoire (IGEAT)

Boulevard du Triomphe - CP 246, B – 1050 Bruxelles, Belgium

Phone: +32 2 650 50 76 Fax: +32 2 650 50 92

E-mail: ewolff@ulb.ac.be URL: www.ulb.ac.be/igeat/igeat/ige5.htm

User partner :
I-MAGE Consult
Rue de Gembloux 122, B – 5002 Saint-Servais, Belgium
Phone: + 32 81 47 02 84   Fax: + 32 81 47 02 85
E-mail: info@I-mage.be   URL : www.i-mage.com
Contact person: Bruno Henquin

6. RELATED DISCIPLINES

Geographic Information Systems
Humanitarian

PILOT PROJECT T4/20/060

PLANNING, ASSISTANCE AND RESEARCH ACTIVITIES FOR MINING CLEARANCE, BASED ON IMAGES FROM THE SATELLITE (PARADIS)

M. ACHEROY [(1)]
H. DECLEIR [(2)]

ECOLE ROYALE MILITAIRE (ERM) [(1)]
SIGNAL AND IMAGE CENTRE
Avenue de la Renaissance 30
B – 1000 BRUXELLES
BELGIUM

VRIJE UNIVERSITEIT BRUSSEL (VUB) [(2)]
CENTRE FOR CARTOGRAPHY AND GIS
DEPARTMENT OF GEOGRAPHY
Pleinlaan 2
B – 1050 BRUSSEL
BELGIUM

1. CONTEXT AND OBJECTIVES

The aim of the PARADIS project is to build a planning method and a software prototype to help the Bomb Disposal Unit of the Belgian Army in managing humanitarian mining clearance campaigns. The latter involves the following tasks: collect general data at mission announcement, perform a Field Survey to roughly locate minefields, plan campaigns, go back on the field to obtain precise minefield and unexploded ordnance (UXOs) locations, clear the minefields and remove UXOs, and finally evaluate the quality of the work.

In this framework, the objective of the project is to build a planning method and two software packages. The planning method involves three main actors: a mining clearance organisation, an image interpretation team and a scientific team typically including a geographer and an image processing specialist. The first software package consists of management tools integrated in a common GIS platform, working from the country scale to the field scale, in order to ease the use of remote sensing images and geographic database for humanitarian mining clearance campaigns. The second software package consists of a pool of Image Processing tools aiming at facilitating the work of image analysts by extracting objects of interest in a humanitarian mining clearance context on high and very high resolution satellite images and on scanned maps.

2. DATA

Geographic study area: Mozambique (Tete province) and Laos (Champassak province)

Satellite imagery used:

IKONOS (15°34'S 32°46'E,15°39'S,32°52'E), SPOT (kj 140-382), RADARSAT Fine Beam Path (260A F4N) and Map image, LANDSAT MMS (path 180, row 71).

Other satellite data: LANDSAT TM, SPOT, IKONOS

Other data: Various geographic data, suspected minefield and UXO locations

3. METHODOLOGY

In order to position the new system, a review of existing GIS tools has been made. This review revealed the lack of a method oriented towards the tasks to be completed by bomb disposal experts. The analysis of the end-user's needs and of existing tools resulted in the construction of the PARADIS interface around IMSMA, a UN-standard database for humanitarian mining clearance, and ArcView, a standard GIS package. Starting from the needs at each step of a humanitarian mining clearance mission, a working method has been elaborated over a Test Site in Mozambique, in collaboration with NPA, a NGO specialised in humanitarian mining clearance activities. The functions to be implemented in the interface and their working scale have been identified. The usefulness of remote sensing data and their required processing have been studied. In the case of a new mission, the purchase and interpretation of satellite images have to be done by professionals. The image interpretation unit of the Belgian Ministry of Defence (SGR-IM) was foreseen to handle this task in an operational mode. The data flow between the various actors (end-users, image interpretation and a scientific team) has then been established. Objects of interest in satellite images and scanned maps have been identified and Image Processing tools aiming at their extraction implemented in order to speed up image interpreter's work. The whole procedure involving SGR-IM has been tested on a very different test site in Laos, simulating a new mining clearance campaign.

4. OUTPUTS AND RESULTS

Tables and documents synthesise the elaboration of the planning method and of the GIS software prototype. The table of user needs lists the required information, its spatial nature, possible sources, appropriate scale, and provides some comments. Another table conveys the system design, describing the expected functions and working scales. A graph describes, in operational mode, the data flow between concerned actors. A humanitarian mining clearance legend is proposed in accord with IMSMA.

A software package working at four scales embedded in a GIS, compatible with IMSMA and the Belgian UXO Lao database has been produced. The Country Scale (1:1 000 000) is fed by the Digital Chart of the World, topographic maps, meteorological data and maps of refugees. The Region Scale (1:250 000 to 1:50 000) contains satellite images (SPOT, LANDSAT TM, RADARSAT), topographic maps and information from field survey. The Field Scale (1:10 000 to 1:1 500) contains aerial photos, very high-resolution satellite images (IKONOS), statistics and sketches. The Advancement Scale (1:500) is added in order to produce a detailed description of each minefield.

The SIC Graphical User Interface has been extended with interactive tools for supervised classification, for launching programs and visualising results. A pool of programs divided in several classes (pre-processing, processing and post-processing) has been set up. Several Image Processing methods have been designed, implemented and published (two conferences papers, one workshop).

The PARADIS method has been presented at a workshop, a conference and to the IMSMA management team. The main conclusion is that RS Data, especially high and very high-resolution data, are very useful in this context.

5. EXECUTION

Period: 01/06/1999-30/09/2001

Laboratory:

ECOLE ROYALE MILITAIRE (ERM)
Signal and Image Centre
Avenue de la Renaissance 30, B – 1000 Bruxelles, Belgium
Phone: +32 2 737 64 70   Fax: +32 2 737 64 72
E-mail: acheroy@elec.rma.ac.be   URL: http://www.rma.ac.be/

VRIJE UNIVERSITEIT BRUSSEL (VUB)
Centre for Cartography and GIS
Department of Geography
Pleinlaan 2, B – 1050 Brussel, Belgium
Phone: +32 2 629 33 83   Fax: +32 2 629 33 78
E-mail: hdecleir@vub.ac.be

End User:

MINISTERE DE LA DEFENSE NATIONALE, SERVICE D'ENLEVEMENT ET DESTRUCTION D'ENGINS EXPLOSIFS (SEDEE-DOVO)

Quartier Meerdaalbos, Naamsesteenweg 100, B - 3050 Oud-Heverlee, Belgium

Other Project Partners:

Norwegian People Aid (NPA), Ministry of Defence, General Intelligence and Security Service, Intelligence Service Section Imagery (SGR-IM)

6. RELATED DISCIPLINES

Risk management
Geographic Information Systems
Human dimensions
Hardware & software

7. EXECUTIVE SUMMARY

Introduction and overview

Millions of mines are infesting over seventy countries on all continents. The whole industrial, economical and social life of a country can be disrupted by a mine infection. Indeed, mines still maim or kill decades after they were laid, injuring the young generation, reducing the farming capabilities, disorganising the transportation system, preventing the use of some drinkable water points thus causing the appearance or re-appearance of diseases, etc.

The United Nations have defined standards in order to clarify the tasks involved in humanitarian de-mining activities. A survey has three specific functions or levels: information gathering of a suspected mine or UXO area (level one), a detailed topographical survey including area reduction and marking (level two) and the completion survey (level three). These procedures should be present in the method to elaborate.

Our early dream was to build an intelligent system, that is, a system based on blackboard architecture, linked to a Geographical Information System (GIS) installed on a portable. This system would enable the user to have access to a global scale (country scale) and a local scale (region scale) where he would view satellite images and extract some useful information at run time, thanks to Image Processing routines called by the backboard.

Another objective was to identify minefields indicators, that is, on satellite images, identify areas were minefields are located, based on visual hints. For example, one could imagine that having a sequence of images taken over a given area, showing at some early time a cultivated field that is not cultivated anymore at a later time, could be a hint for the presence of mines. The same reasoning would hold for abandoned roads.

The early dream was soon followed by an early deception. After a first mission in Mozambique, it turned out that no minefield indicator could be found. Actually, this is not completely true: one could be seen on the SPOT image. Indeed, the Songo minefield, characterised by different texture and colour, could be seen. However, this field is an atypical minefield and everybody knows about its presence; therefore, first, the hint is not of a great help and second, it cannot be generalised. The Songo minefield is a 30-km long minefield encircling the Cahora Bassa dam where mines have been led for more than 30 years. This minefield is heavily mined (more than 22 000 mines have already been removed by NPA) and therefore serves as a “training area” for bomb disposal experts when they experienced some work on a minefield almost empty of mine. Moreover, the idea that abandoned field could be a hint for the presence of mine couldn't be generalised in these countries where the practice of land fallow holds. As far as road are concerned, their abandon is not necessarily the consequence of mines neither (track in poor state, broken bridge, disused ferry, etc.).

As a consequence of the absence of minefield indicators, the Image Processing work would be limited to the extraction of objects of interest for the bomb disposal experts, such as roads, rivers, land cover, buildings, etc.

The team also soon realised that building on a PC, an intelligent system that would on the SPOT perform semi-automatic image analysis, was not what the users needed. Indeed, a mission should be prepared far in advance before sending the bomb disposal experts on the field. On the other hand, additional tools for reporting minefield clearance evolution were foreseen.

The modified plan of work has been divided in four phases: a starting phase, a designing phase, an implementation phase and a validation phase. The starting phase aimed at reinforcing the background in Humanitarian mining clearance, in learning about Mozambique where the Test case had been chosen, in making contacts in the humanitarian mining clearance world and in establishing a state of the art study about existing GIS for humanitarian mining clearance.
During the designing phase, the tasks involved in a humanitarian mining clearance mission have been listed and the information needs for each of these tasks addressed. A Working method on two Test sites in Mozambique has been established. In parallel, the design of image processing tools and of an environment allowing the extraction of object of interest in the context of humanitarian mining clearance was set up.
The implementation phase concern both the prototype GIS interface and the image-processing module. As far as the latter is concerned, the SIC/RMA Graphical User Interface (GUI) has been extended, and specific image processing tools developed. For the GIS interface, the necessary scales to perform the identified tasks have been identified. Then, the functions to be found in the interface according to the mission schedule have been implemented.
The validation phase concerns the validation of the proposed method and of the interface in an operational mode. It implies to establish the data flow at a given mission and test the whole method on another site.

End User presentation

The Belgian Armed Forces Bomb Disposal Unit, also known as SEDEE – DOVO, is responsible to defuse or render safe and destroy all munitions found on the Belgian territory. This means munitions from World War 1 and 2 and munitions or improvised devices used by terrorists or crooks.
Apart from giving direct support to Belgian unit when deployed abroad, the unit is also contributing directly in humanitarian mining clearance all over the world. At the moment, the unit has teams of technical advisors deployed in Laos and Cambodia.
During humanitarian mining clearance a lot of problems are encountered. One of the major problems is the lack of adequate maps or mapping tools, making planning very difficult. An integrated tool for planning is needed.

Starting phase

During the starting phase, the background in Humanitarian mining clearance has been reinforced by reading UN documents, reports of EU projects, web pages, participating to workshops, discussing with photo-interprets, and paying visit to several labs: JRC, ITC, Geneva International Centre for Humanitarian Mining clearance (GICHD).

At the GICHD, a better insight of IMSMA, a UN-standard database for humanitarian mining clearance activities, was gained and a starting point for what would become "the table of user needs" was obtained from Paddy Blagden, technical director of the GICHD. The later table lists the Remote sensing data useful for humanitarian mining clearance activities. The contact with the Centre was kept during the whole project.
A state of the art study about existing GIS for humanitarian mining clearance has been done. Efforts have been made to obtain two of them: IMSMA and Minedemon. This study revealed the lack of a method oriented by the tasks to be completed by bomb disposal experts.

Designing phase

Identification of spatial data needs

Starting from the identification of the user needs for each task of a mining clearance mission, we built up a table listing the required information, its spatial nature, possible sources, appropriate scale, and added comments. A short version of this table has been presented at the JRC, in ISPRA, at the workshop "Towards Harmonised Information Systems for Mine Action in South Eastern Europe".

First Mission in Mozambique

In order to prepare the mission in Mozambique, all data have been collected and images interpreted. Note that only high-resolution data were available at that time.
The first mission in Mozambique had the objective to test the use of high resolution images for mining clearance activities and check their interpretation made by the geographer at the SIC.
Globally, the project aroused interest; identified scales and needs seemed to be shared by the mining clearance community.
The first finding concerns the usefulness of high-resolution images as substitute for regional maps. These images may really be used up to 1 : 50 000 scale. They are detailing or updating standard mapping coverage at 1 : 250 000 scale. But in order to be fully useful, the geometric correction of high-resolution data should be improved. Corrections that were achieved with 1 : 250 000 maps are not precise enough to locate GPS points measurements. So, if no more accurate maps exist, either it is needed to take GPS points to correct the image before being used by bomb disposal experts, or the system should include a tool to adjust the georefencing of the image according the GPS measures of visible control points.

Organisation of a campaign

The general planning method proposed involves three main actors: a mining clearance organisation, an image interpretation team and an image processing team.

The first and most important actor is the team of bomb disposal experts, role played by the SEDEE-DOVO in the PARADIS project.
The image interpretation team has been found in the Defence itself in the General Intelligence and Security Service, Section Imagery (SGR-IM). It should be emphasised that this role accepted by SGR-IM could be given to a well-chosen subcontractor in the case of non-Belgian mission.
Extracting information from satellite images and scanned maps could be a tedious work if a lot of images are to be analysed or if images are large so that semi-automatic feature extraction could be a precious help for image interpreters. This work is not mandatory, but it will speed up the interpreter's work. This task is assigned to the image processing team. In an operational mode, the SIC will still offer this work to SGR-IM, as it part of the SIC mission.
The procedure of data collection proceeds as follows. At the mission announcement, the mining clearance team contacts the interpretation team (SGR/IM) in order to identify the regions and the best season for acquiring satellite data over the areas of interest, and to purchase them. This team is also responsible for collecting maps and performing the georeferencing of the satellite images. The images are then sent to the signal processing team (SIC) for automatic analysis: extraction of the hydrographic and road networks, identification of water areas, and image classification. This information will be used to facilitate the image analysis which aim is to produce the vectorial overlays made of roads, inhabited and cultivated areas, infrastructures, etc., again performed by the interpretation team (SGR/IM). The latter team will also produce colour composite images using all bands, and black and white images displaying the panchromatic data. On the other hand, the bomb disposal expert team (SEDEE-DOVO) fills the IMSMA database with the field survey.
When all these data have been collected, they are introduced in the prototype described in the "PARADIS Interface".

Software packages

PARADIS Interface

We have identified the tasks to be performed in the interface, according to the schedule of a mission and to the identification of data needs described previously. A table describing all the functions to be implemented in the interface and their working scale has been identified.
Thus, a software package working at four scales embedded in an ArcView platform, compatible with IMSMA and the Belgian UXO Lao database has been produced.
The global scale or Country Scale (1:1 000 000) does not involve satellite images; its input is made of DCW (Digital Chart of the World), topographic maps, meteorological data and maps of refugees. At this scale, the user can combine information such as administrative limits, roads, relief, hydrographic network, inhabited areas and local

names, climate zones, soil types, refugees, airports, mine clearance centres location and responsibility areas.

The Region Scale (1 : 250 000 to 1 : 50 000) contains satellite images (SPOT, LANDSAT TM, ERS and RADARSAT, etc.), topographic maps and information from field survey. Based on these data, the user can see practical roads and bridges, village extensions, hydrographic network, hospitals, military buildings, accident localisation, campaign schedule, minefield locations and land cover. This overlay information comes from image interpretation and from the IMSMA database. At this scale, the mining clearance staff has the tools to plan its campaigns and organise its team according to priorities, regional constraints and logistic facilities.

The Field Scale (1 : 10 000 to 1 : 1 500) contains aerial photos, very high-resolution satellite images (IKONOS), statistics and sketches. Very accurate maps of the suspected areas and cleared minefields are available as overlay. An Advancement Scale (1 : 500) is added in order to produce a detailed description of each minefield.

The design of the prototype has been presented at the ISPRS2000 conference in Amsterdam. A summary of the design is provided by a one double face page document illustrating the system for the Laos and Mozambique test sites.

Image Processing

The image interpretation could be a tedious work, especially if images are large or numerous. The idea was thus to design tools to extract objects of interest such as water areas, rivers, roads, etc. Moreover, the interpreters lack of tools for a good visualisation; for example, on a 11-bit IKONOS image, the user will not be able to see features in the shadowed areas if no special treatment is performed. Therefore, a pre-processing tool was implemented to solve this problem. On the other hand, the interpreters often have digital maps that they wish to vectorise. We thus considered the development of vectorisation tools for scanned maps.

As in operational mode, the images would be sent to the SIC and considering that some tests on the setting of program parameters should be performed most probably by a unique scientist, all useful programs were organised in a pool divided in several classes: pre-processing, processing and post-processing. The SIC Graphical User Interface (GUI) has thus been extended with interactive tools for launching programs and visualising results. Moreover, the GUI scatterogram was extended in order to serve as a supervised classification tool.

Several new Image Processing methods have been designed, implemented and published. A new method for thin ridge extraction has been designed and presented at the VI 2001 Vision Interface Annual Conference, in Ottawa. A fuzzy clustering method and the fusion of several ridge detectors applied to an IKONOS image have also been presented at the workshop on “Very High Resolution Images” held in Brussels in June 2001. The fuzzy clustering method has also been presented at 4th

World Multiconference on Systemics, Cybernetics and Informatics in Orlando, and a classification method was accepted as journal paper in Pattern Recognition Letters.
Specific filters for highlighting edges and ridges from SAR images have been developed. Combined with the ridge extraction tool developed at the SIC, it enabled to extract edges and ridges from the RADARSAT images. The method described in a PhD thesis has also been published for a conference.
As far as post-processing tools are concerned, a Markov method has been implemented in order to obtain better classification; polygonal approximation algorithms have been coded, and a line fusion algorithm mixing the results of some edge or ridge detectors has been proposed.

Evaluation phase

The evaluation concerns the method, the use of Remote Sensing data, the PARADIS interface and the use of image processing tools.

Method

In order to evaluate the method, it was necessary to simulate a new mission on a new Test Site, so that the participation of the "interpretation team" could be tested. Therefore, new images had to be purchased. The Test site had been chosen in Laos, where the SEDEE-DOVO was active.
The PARADIS team managed to obtain funds from the "Secrétariat pour la Coopération au Développement" in order to buy satellite images and to send two persons on the field. SPOT images were available as archive, and luckily, UXO LAO, partner of the SEDEE-DOVO in Laos, could lend us an IKONOS image if we could assess the use of Very High Resolution images for humanitarian mining clearance activities.
The participation of SGR-IM was fantastic, the time schedule satisfied, and the products up to the end-user expectation.

Use of Remote Sensing data

For the IKONOS image, the image interpretation made by the SGR-IM was good for punctual and linear elements such as houses, trees, roads, rivers, etc. The land cover interpretation seemed firstly more difficult to use (due to the complexity of the land use in that region; for example the mixing of coffee plants and bushes), secondly less useful on the ground. In fact, we were very impressed by the ability of the local population (both bomb disposal experts and villagers) to use, read and work with the raw image. They just had the feeling to see an aerial photo! For that reason, the accuracy of the panchromatic images seems predominant to the spectral information contained in the multi-spectral images. They also preferred to work with the raw image instead of the interpreted one because the colours of the interpretation hide the reality of the image. To confirm the ability to work with the image, we asked bomb disposal experts to delineate on the field an area that we selected on the image (and conversely, to draw on the image a "cleared area" on the field), and that job was done without hesitation. The IKONOS images might also be used in the future by the survey and the roving teams to locate the UXOs (instead of drawing schematic maps or to accompany the team to the right place). This assessment is different for the SPOT image. Due to its lower resolution and to its false colours, it is much more difficult to read it, and the interpretation realised by the SGR-IM was very helpful for the bomb disposal experts. They could use it as a map, associating each colour or symbol to an object or an affectation. A villager met during our work also had almost no difficulties to read the interpreted image. He could guide us along the paths of his village showing us our position on the document.

PARADIS Interface

The PARADIS interface was not finished at that time, so that only part of it could be tested. However, its philosophy has been explained to other end-users, and very much appreciated. The presentations made to various people have sparked off great interest and encouragement. They all showed their willingness to use it later, because among others it simplifies the representation of the clearance areas and it optimises (both easiness and speed) the encoding of data in IMSMA.

Furthermore we noted that specific tools (such as the grid-clearance, the automatic integration of GPS measurements and the shifting of the scanned maps) might improve the bomb disposal experts' work both for the everyday job and for the planning process at the office.

A last mission in Mozambique took place in September 2001. It aimed at presenting results of the projects to our local partner, the non-governmental organisation, Norwegian People Aid and to confirm the use of very high-resolution data. As far as Remote sensing data are concerned, the visual interpretation of very high resolution images is of good quality and is useful for non experts, but some errors might occurs and should be corrected either on the ground or by sending some feedback to interpreters. Interpretation of land use changes is of course interesting for a regional management and may be of some interest for planning mining clearance activities but they should not be considered in simplistic terms as being mine indicators.

Use of Image Processing tools

SGR-IM showed much interested in tools aiming at extracting various themes from scanned maps (extracting roads, rivers, etc.) and more specifically the extraction of contour lines. Though there are tools for modifying the image colormap in the SGR-IM environment, the local histogram equalisation output was appreciated. Besides, SGR-IM is interested in the extraction of image objects such as roads and river parts, in the case they have to interpret a large zone, even if many false alarms are present. They appreciated the simplification introduced by the ridge detection, that is, extracting the middle axis rather then the two borders; they never met such kind of tool in their environment. As far as the classification is concerned, they are less enthusiasts, as they hardly use this kind of tool. However, if a further process extracts relevant objects like the contours of well-identified regions, the classification tool would then present some interest for them.

Conclusions and further perspectives

As a general conclusion, we may say that PARADIS was a successful project, thanks to a motivated multi-disciplinary team and especially thanks to the very motivated and co-operative end-users.

To be more precise, the conclusions of the PARADIS project are listed:

- The project has demonstrated the benefits of using remote sensing data in humanitarian mining clearance.
- The team has set up an operational method that has been evaluated during three field missions, two in Mozambique and one in Laos, where the end-user is working.
- The operational method implies several units of the Belgian Defense. Collaboration between these units has been set up and tested, simulating a new humanitarian mining clearance mission.
- An interface answering the user needs has been produced.
- Various Image Processing methods have been designed and tested. Their use as helping tools for image interpreters has been evaluated.

As far as the future of the project is concerned, the following points should be mentioned:

- The project has been presented to the IMSMA manager and the Geneva International Centre for Humanitarian Mining clearance (GICHD). They showed much interest in the project and would be ready to initiate a new project with the team, so that the ideas and method developed could be used and distributed with a future version of IMSMA.
- End-users showed early their interest in PARADIS (“If there is one God, we wish to work with you”, heard in ISPRA, March 2000). More seriously, end-users in Mozambique (NPA) and in Laos (UXO Lao) were very enthusiastic about the project (“It is the first time we see a product really useful for bomb disposal experts”, heard in Laos, June 2001) and would be very much interested in a follow up.

FEASIBILITY STUDY T4/12/025
FEASIBILITY STUDY T4/12/026

ENVIRONMENTAL RISK MAPPING IN THE WADI MUJIB CANYON (JORDAN), BASED ON RUSSIAN STEREOSCOPIC TK-350 SATELLITE IMAGES

M. DE DAPPER [(1)]
A. OZER [(2)]

UNIVERSITEIT GENT (RUG) [(1)] (T4/02/25)
DEPARTMENT OF GEOGRAPHY
Krijgslaan 281 Gebouw S8/A1
B – 9000 GENT
BELGIUM

UNIVERSITE DE LIEGE (ULG) [(2)] (T4/12/26)
DEPARTMENT OF PHYSICAL GEOGRAPHY
LABORATORY OF GEOMORPHOLOGY
Allée du 6 Août 2, Bâtiment B11
B – 4000 LIEGE
BELGIUM

1. CONTEXT AND OBJECTIVES

The project is meant to build up a basic scenario for geomorphological mapping based on Russian stereoscopic high resolution TK-350 satellite images, which gives basic information for the preparation of a geo-archaeological map and for risk mapping concerning slope (in)stability. This scenario has to be applicable to arid and semi-arid regions, and it must possible to extent it to the Mediterranean areas. The basic scenario is built up for the canyon of the Wadi Mujib (Jordan). In this area the construction of a dam is planned for the near future. This will lead to a archaeological rescue campaign and specific problems of slope (in)stability. From archaeological viewpoint (use partner: 'Belgian Excavations in Jordan at Lehun, Prof. Dr. D. Homès-Frédéricq, KMKG) there is the need for research of the evaluation of the high-resolution images in pre-studies concerning localising of possible sites in arid and semi-arid regions. For such regions stereoscopic aerial photographs are often not available. The Russian high-resolution TK-350 images could be a possible solution for this problem. On the other hand there is the need (use partner: Engineering Consultants « Verdeyen & Moenaert », Ir. P. D'Haene, VM) for research of the surplus value of the input of stereoscopic high-resolution images in a Geographical Information System for a geomorphological/geological (neotectonism) pre-study by the construction of great infrastructure works, above all dams, in arid and semi-arid regions.

2. DATA

Geographic study area: Wadi Mujib canyon, Jordan

Satellite imagery used:

Russian stereoscopic and high resolution TK-350 satellite images (20/05/1992)

(15/336-2, 1156, 101)

(15/336-2, 1158, 101)

Other data: topographical, geological and archaeological maps

3. METHODOLOGY

- Building up of the basic scenario for geomorphological mapping using TK-350 images with enlarged scale of 1:100,000 (total study area) and of 1:50,000 (test zone).
- Field work in the test zone (7-17 October 1998): geomorphological and neotectonical survey.
- Preparation of a GIS in ILWIS, ARC/INFO and ERDAS IMAGINE with basic information layers or factors that will be used for the building up of the basic

scenario for geo-archaeological mapping and of the basic scenario for slope (in)stability mapping.

- Building up of the basic scenario for slope (in)stability mapping on the basis of the geomorphological map prepared by using the TK-350 images in addition of different weighted influencing factor layers.
- Building up of the basic scenario for geo-archaeological mapping on the basis of the geomorphological map prepared by using the TK-350 images in addition of different influencing factor layers.
- Application of the basic scenarios on the environmental risk and impact of future infrastructure.

4. OUTPUTS AND RESULTS

The combination of the geomorphological interpretation of TK-350 images to become a landslide map with a short controlling field survey, gives the necessary, qualitative basic information to build up a model of landslide risk mapping. Even if time or money prevent the execution of field survey, the quality of the basic information gained by the use of TK-350 products should be satisfying: in the case study of the Wadi Mujib canyon the geomorphological map (with indications of landslide presence) corresponded good with the field observations done afterwards. Archaeological excavations in the future will be based on the indications of probability on the geo-archaeological maps. In general the map on 1:50,000 contain usable and detailed information for planning the rescue campaign in the frame of the construction of the dam. Both customers (KMKG and VM) were very satisfied with the holistic approach of this feasibility study and the attained quality of results. According to the customers' opinion the use of TK-350 satellite images for environmental risk studies can be a good solution if aerial photographs are not available or the costs for a flight to obtain the necessary photos are estimated to be to high. The key advantage is the 100% security that, for almost every region in the world, stereoscopic TK-350 images are available. A second chief advantage is the timesaving concerning the easy image restitution of the TK-350 images when integrating them into a GIS. However, in some cases, the limited or maximum scale for enlarging (1:50,000) can be a disadvantage.
Deliverables (analogue and digital; 1:100,000 and 1:50,000): DEM, lithological map, tectonical map, geomorphological map, geo-archaeological map, landslide risk map, 3D-views.

5. EXECUTION

Period: 19/12/1997-31/12/1998

Laboratories:

UNIVERSITEIT GENT (RUG)
Department of Geography
Krijgslaan 281 Gebouw S8/A1, B – 9000 Gent, Belgium
Phone: + 32 9 264 46 90 Fax: + 32 9 264 49 85
E-mail: morgan.dedapper@rug.ac.be

UNIVERSITE DE LIEGE (ULG)
Department of Physical Geography
Laboratory of Geomorphology
Allée du 6 Août 2, Bâtiment B11, B – 4000 Liège, Belgium
Phone: + 32 4 366 54 56 Fax: + 32 4 366 57 22
E-mail: aozer@ulg.ac.be

User partners :

KMKG
Jubelpark 10, B - 1040 Brussel, Belgium
Phone: + 32 2 741 72 11 Fax: + 32 2 733 77 35
Contact person: Prof. Dr. D. Homès-Frédéricq

ENGINEERING CONSULTANTS VERDEYEN & MOENAERT
Kerselarenlaan 15, B - 1030 Brussel, Belgium
Phone: + 32 2 743 12 80 Fax: + 32 2 743 12 89
Contact person: Ir. Pierre D'Haene

6. RELATED DISCIPLINES

Geology & soil
Environment
Natural hazards & disasters
Land planning & infrastructures
Cartography
General Earth observation (remote sensing)

7. EXECUTIVE SUMMARY

Introduction

This summary presents the researches of the laboratories of Physical Geography and Geomorphology at the University of Gent and the University of Liege concerning the evaluation of the value of Russian stereoscopic TK-350 satellite images for geomorphological mapping in the frame of environmental risk mapping. A case study was done for the Wadi Mujib canyon (Jordan).

Customer need

In many semi-arid and arid regions of the world aerial photographs are not available. However such documents are necessary for studies in geomorphology (as slope instability) in the frame of future risk prediction for planned infrastructure. In this way Russian stereoscopic and high resolution TK-350 satellite images could be a solution and advisable for consultant agencies as VM.

The study area selected for this research was the Wadi Mujib canyon in Jordan. Since 1977 KMKG (B.C.E.J., Prof. Dr. D. HOMES-FREDERICQ) has performed archaeological excavations on the site of Lehun, situated at the rim of the plateau in front of the canyon. Until now the excavations have been very successful (findings from the Palaeolithic till the Ottoman period) and together with a lot of archaeological observations in the canyon valley the archaeological evidence in the whole area is incontestable. As the construction of a dam in the canyon (near Lehun) is planned for the near future, a lot of up till now undetected sites or artefacts will be lost due to the flood of the storage lake. With this in mind KMKG needs a reference map showing the most probable locations of undetected sites to perform new archaeological excavations as fast and as efficiently as possible.

Methodology and results

a. Study of literature concerning:

- Geo-archaeological research in arid and semi-arid regions;
- Problems of slope (in)stability by the construction of infrastructure;
- Applicability of GIS and remote sensing for these matters.

b. Building up of the basic scenario for geomorphological mapping using TK-350 images with enlarged scale of 1:100,000 (total study area) and of 1:50,000 (test zone). The legend is based on the legend worked out by the Department of Geography of the University of Zaragoza (Spain, Dir.: Prof Dr. J.L. PENA MONNE) (Cartografia geomorfológica básica y aplicada. J.L. PENA MONNE (ed.), Longrono: Geomorfa Ediciones, 1997, 227 p.). After controlling of the geomorphological maps during the fieldwork the interpretation of the utility of the

TK-350 images for geomorphological mapping in (semi-)arid regions could be made.

c. Field work in the test zone (7-17 October 1998): control of the geomorphological map (scale 1:50,000) on the field. Observation of the tectonic features: lineaments, faults, fractures, flexures.

d. Preparation of a GIS in ILWIS, ARC/INFO and ERDAS IMAGINE with basic information layers or factors that will be used for the building up of the basic scenario for geoarchaeological mapping and of the basic scenario for slope (in)stability mapping. As the basic scenarios must be prepared for two different scales, the GIS contains different layers built up using different map sources but containing similar information (1:100,000: pixel size 50*50m, 1:50,000 pixel size 10*10m): DEM, Lithological map,Tectonical map, TK-350 images (stereopair) (for both scales pixel size 10*10m), Geomorphological map.

e. Building up of the basic scenario for slope (in)stability mapping on the basis of the geomorphological map prepared by using the TK-350 images. The statistical model results in a landslide risk map (for both scales) by the addition of weight factors influencing the slope (in)stability. The importance of each factor is depending on the statistical relation of it with the occurring landslides in the area (detected on the TK-350 images). The factors are: slope degree, lithology, distance to fault and distance to Wadi.

f. Building up of the basic scenario for geo-archaeological mapping on the basis of the geomorphological map prepared by using the TK-350 images. The heuristic model results in a map representing the probability for locations of up till now undetected archaeological evidence by the addition of factors having an attractive influence on Man looking for the best site location. Each factor would have its own influence perhaps changing in the history depending on the specific natural and cultural conditions of each time period. The factors are: slope degree, slope aspect, distance to Wadi, distance to water source or travertine, presence of terrace remnant, presence of fertile soil or alluvium, distance to the ancient King's Highway and distance to the escarpment plateau-canyon.

g. Application of the basic scenarios on the environmental risk and impact of future infrastructure: Jordan has planned the construction of a dam in the Wadi Mujib canyon near the new King's Highway bridge: in this way Jordan hopes to collect fresh water for irrigation and to supply the ground water (LOY W. (1994)). However, the vulnerability of the environment to slope degradation caused by landslides and triggered by earthquakes, high variability and high intensity of scarce winter rainfall, absence of vegetation, lithology ... forms a real treat for a rapid slowdown of the storage lake capacity. On the other hand a lot of up till now undetected archaeological evidence should disappear due to inundation. Using the resulting risk maps of the models e and f, it is possible to make a first simulation of the future impacts of the dam by overlay with the boundaries of the future storage lake resulting from different dam heights (10m, 20m, 30m, 40m, 50m).

Deliverables

Analogue and digital formats of DEM, Geomorphological map (1:100,000; 1:50,000), Geo-archaeological map(1:100,000; 1:50,000), Landslide risk map (1:100,000; 1:50,000).

Customer opinion

Both customers (KMKG and VM) were very satisfied with the holistic approach of this feasibility study and the attained quality of results. According to the customers' opinion the use of TK-350 satellite images for environmental risk studies can be a good solution if aerial photographs are not available or the costs for a flight to obtain the necessary photos are estimated to be to high. The key advantage is the 100% security that, for almost every region in the world, stereoscopic TK-350 images are available. A second chief advantage is the time-saving concerning the easy image restitution of the TK-350 images when integrating them into a GIS, However, in some cases, the limited or maximum scale for enlarging (1:50,000) can be a disadvantage.

Costs / Benefits

The price of one TK-350 stereopair with 60% overlap in the form of film-positives (first copy) is 6300 $ and in the form of film-negatives (second copy) is 6700$. This price is relatively low taking into account that the data are recent, the covered area is 200*300km (so: 0.105$ / km²) and the ground resolutions is 10m.

Delivery time

The delivery of the Russian TK-350 satellite images can be made yet within 30 days upon receiving by the Supplier of the copy of the contract signed by the Customer. The products are delivered by Federal Express (or other express mail if required). The TK-350 images are available for almost every region in the world.

Image processing
Costs should not only be counted based upon the real price of the product, but upon the processing time too: put the case that the same geographical data (the same study area, of the same date ...) is available on aerial photographs of 1:50,000 and on TK-350 images and put that the price /km² for each of both is about the same. Then it should be advisable to use the TK-350 images because the image restitution is much easier and can be done more quickly due to the large extension of the covered area of and the reference cross marks upon both egatives.

Mapping capacities
The degree of detail reached for geomorphological mapping on the TK-350 images is very satisfying, certainly at 1:50,000.

Conclusions
According to the principal objective of this feasibility study we can conclude that the utility of the Russian TK-350 satellite images is satisfactory high in two ways: their value for geomorphological mapping in the frame of environmental risk mapping on the one side, but on the other, their competitive value in comparison with aerial photographs in the frame of costs, delivery time, image processing, mapping capacities...

A chief advantage of using the TK-350 images and integrating them into a GIS is the easy image processing and photogrammetric restitution due to the large covered area and the presence of reference cross marks upon the negatives: in this way when integrating the resulting geomorphological maps into the GIS they can easily be georeferenced to the digital TK-350 images.

The possibility to detect basic features of local geology as macroscopic deformation and identification of lineaments / faults on the TK-350 images
(1: 50,000) is another key advantage.

In the framework of a future pilot project it should be advisable to study the utility of the TK-350 images for the production of DEMs and DEM-derived maps (slope degree, slope aspect).

FEASIBILITY STUDY T4/03/055

CHANGE DETECTION IN SATELLITE IMAGE SEQUENCES FOR MINEFIELD DELINEATION

F. CORNELIS

VRIJE UNIVERSITEIT BRUSSEL (VUB)
ELECTRONICS AND INFORMATION PROCESSING DEPARTMENT
Pleinlaan 2
B – 1050 BRUSSEL
BELGIUM

1. CONTEXT AND OBJECTIVES

The objective of the current feasibility study was to investigate the potential use of change detection in satellite image sequences for the delineation of minefields in two mined areas of Mozambique: Mameme and Songo. A second objective was to see whether existing databases contain sufficient and reliable satellite image data to investigate existing minefields constructed in the past. The context of the study was the European project REG/661-97/2, a Pilot Project on the use of airborne minefield detection in Angola and the PARADIS project on the use of GIS system for mining clearance campaigns.

2. DATA

Geographic study area: Songo, Mameme (Mozambique)

Satellite imagery used: The LANDSAT TM, LANDSAT MSS and SPOT images used in the study were made available by RMA; ITC and Satellus.

Other data: Historical data of the minefields was made available by RMA and a manual delineation of the Songo minefield was made available by ITC.

3. METHODOLOGY

- The change detection methodology applied in the study (for both the Songo and Mameme area) consists of two processing steps. For each change detection experiment, the source image is first rectified with respect to the reference image to convert the image data file co-ordinates to a common co-ordinate system. In the second step, a difference operator is applied to the reference image and the rectified source image.
- The rectification experiments were done with ERDAS Imagine software at the VUB department of Geography.
- Three types of difference operators were applied for the Songo area: a modulus difference operator, an absolute difference operator and a difference operator based on histogram biasing. For the Mameme region, only modulus difference analysis was considered.
- The resulting change detection maps were compared - for Songo - with the manual delineated map obtained after local fieldwork by ITC.

4. OUTPUTS AND RESULTS

The output of the project includes apart from rectified LANDSAT TM, LANDSAT MSS and SPOT images, 8 change detection maps: 4 modulus change maps TM840903-TM920909, TM840903-TM950902, TM950902-SPOT990828, MSS7208-MSS7908, 3 absolute change maps TM840903-TM920909 R, G, B and 1 biased change map TM840903-TM92090. Different arguments are given to motivate our conclusion that the interpretation of radiance differences of local changes in the change detection maps is extremely difficult. The analysis of local structural characteristics of the changes is not possible due to the typical dimension of the minefield with respect to the resolution of the available image data. These results will be discussed with the user partner of the project, Handicap International, during a workshop at the VUB and will be made available for the PARADIS project of RMA.

5. EXECUTION

Period : 01/04/1999-30/02/2000

Laboratory :

VRIJE UNIVERSITEIT BRUSSEL (VUB)

Electronics and Information Processing Department

Pleinlaan 2, B – 1050 Brussel, Belgium

Phone: + 32 2 629 28 31 Fax: + 32 2 629 28 83

E-mail: jpcornel@etro.vub.ac.be

User partner :

HANDICAP INTERNATIONAL

Rue de Spa 67, B – 1000 Bruxelles, Belgium

Phone: + 32 2 230 60 30 Fax: + 32 2 280 16 01

6. RELATED DISCIPLINES

Social & cultural activities

General Earth observation

Data/service policy

7. EXECUTIVE SUMMARY

The current feasibility study investigated the potential use of change detection in available satellite image sequences for minefield delineation in two mined test areas of Mozambique; Songo and Mameme. Two types of satellite data, i.e. LANDSAT and SPOT images, were retrieved from different data bases for these areas by satellus

(Sweden) in the context of the European Pilot project REG/661-97/2 (Pilot Project on airborne minefield detection in Angola) and have been made available for the current study by ITC (Netherlands), RMA (Belgium) and Satellus.

The analysis of the available satellite image data with respect to the historical facts of the Tete province in Mozambique (information source: RMA) let us conclude that three change detection experiments for the Songo area were relevant for the study: change detection between LANDSAT TM 1984 (reference image) and LANDSAT TM 1992 (source image) to analyse potential changes due to the war, change detection between LANDSAT TM 1984 and LANDSAT TM 1995 to investigate the “natural” changes (outside the war period) together with the changes due to the war and change detection between LANDSAT TM 1995 and SPOT 1999 to investigate the “natural” changes outside the war period.

The three original visible channels and the corresponding histograms of the LANDSAT TM 1984, 1992 and 1995 images have a very low contrast. A more detailed analysis of the histograms indicated however that the full dynamic range of the sensors is covered. The provider of the images, Satellus, could not give an explanation for these imaging properties of the LANDSAT TM sensors. This problem is not observed in the SPOT 1999 image.

The change detection methodology applied in the study (for both the Songo and Mameme area) consists of two processing steps. For each change detection experiment, the source image is first rectified with respect to the reference image to convert the image data files co-ordinates to a common co-ordinate system. In the second step, a difference operator is applied to the reference image and the rectified source image.

Due to the low contrast of the LANDSAT TM images, the ground control points needed for the rectification of the source images were selected on the enhanced source and reference images (obtained after histogram equalisation). For each rectification, 40 ground control points (GCP’s) were selected. Individual RMS errors (i.e. for each GCP) and a global (total) RMS error smaller than 1 were achieved, which guarantees a rectification on sub-pixel level. A sub-pixel accuracy of the rectification was mandatory because the Songo minefield (the region of interest) covers a stroke of only one pixel width in a SPOT image (information source: ITC). The final rectification of the (original) source images with respect to the reference image was performed using a 3rd order polynomial. Experiments with a 1st, 2nd, 3rd and 4th order polynomial indicated that a 3rd order polynomial was sufficient to rectify the images.

Three types of difference operators were applied to the rectified source and reference images: a modulus difference operator, an absolute difference operator and a difference operator based on histogram biasing.

The histograms of the difference images illustrate that the detected changes for the modulus difference operator are concentrated in a very narrow band of the available grey value range ([0-255]). This means that the corresponding modulus difference images have an extremely low contrast, which makes them inappropriate for visual interpretation. A visual inspection of the obtained changes is only possible after image enhancement of the individual channels of the difference images. Different problems make the interpretation of these enhanced change detection maps extremely difficult, if not impossible. We recall that the region of interest (the Songo minefield) covers a stroke of only 1 pixel width. A rectification of the manual delineated Songo minefield with respect to the obtained change detection maps was unfortunately not possible because ITC could not supply a digital version of the manual delineation. A scanned colour print cannot be used for that purpose because the radiance values of individual pixels are completely lost during the printing process. The manual delineation shows however that the radiance values (and their variance) of the changes outside the region of interest in the LANDSAT TM 1984-1992 and LANDSAT TM 1984-1995 are indistinguishable from those within the minefields region.
The original (higher) resolution of the SPOT 1999 image is lost after rectification with LANDSAT TM 1995 and therefore does not have any contribution for visual interpretation of the detected changes outside the war period.
After comparison of the histograms of the SPOT 1999-LANDSAT TM 1995 difference image and the histograms of both the LANDSAT TM-LANDSAT TM 1984-1992 and 1984-1995 difference images, we must conclude that the different spectral properties of the LANDSAT TM and SPOT sensors makes the interpretation of detected changes in SPOT-LANDSAT change detection maps even more difficult and does not allow to make a comparison with the changes detected between two LANDSAT TM images. As a consequence, we could not make a comparison of the detected changes in the Songo minefield during the war period with “natural” changes occurred after the war.
The absolute difference operator applied for change detection in the LANDSAT TM 1984 and 1992 images results in three RGB colour images representing the absolute tendency of changes between respectively the red, green and blue channels of LANDSAT TM 1984 and 1992. Although these absolute difference images contain more information about the changes during the war period for the global 1984 LANDSAT scene compared to the modulus difference image of the same period, no specific changes could be detected in the Songo minefield area that were not observed outside this area.
To get rid of the histogram shifts between the LANDSAT TM 1984 and 1992 images, a change detection methodology based on histogram biasing was developed. The basic assumption for the construction of the corresponding difference operator was

that the radiance values of water (the lake of the Songo area) should be stable in time. The histogram biases were derived from the radiance distributions obtained after segmentation of the lake in both images. The resulting difference image obtained after correcting the original LANDSAT images for the histogram bias reveals, together with the histograms, again a very low contrast. After comparing the enhanced histogram biased difference image with the modulus difference images of the same period, we had to conclude that even with this biased difference operator, no specific changes can be observed in the Songo minefield area.

The historical facts and the ground truth of the Mameme area are less clear and understood compared to the Songo area. Moreover, the change detection experiments for the Songo area showed that changes between SPOT and LANDSAT TM images (after rectification) do not give relevant information for minefield delineation due to the difference in spectral behaviour of the corresponding sensors. This observation is also true for LANDSAT MSS. For these reasons and also due to the dates and types of available satellite data of the region, we had to conclude that for the Mameme region, only the change detection experiment between LANDSAT MSS 1972-LANDSAT MSS 1979 was relevant for the study.

The histograms of the three original visible channels of LANDSAT MSS 1972 and LANDSAT MSS 1979 illustrate an even lower contrast of the LANDSAT MSS image data for the Mameme area compared to the LANDSAT TM imagery of Songo. Details of the histograms indicate that the full dynamic range of the sensors is also covered for LANDSAT MSS. These imaging properties of the LANDSAT MSS sensors remain also unexplained until now.

A sub-pixel rectification of LANDSAT MSS 1979 with respect to LANDSAT MSS 1972 was achieved with 20 GCP's.

The histograms of the LANDSAT MSS 1972-1979 difference image, obtained after applying a modulus difference operator indicate again, as for the LANDSAT TM change detection experiments for the Songo region, a very low contrast of the detected changes. The visual analysis of changes was also only possible after image enhancement of the obtained difference image.

The lack of a geo-referenced map of the Mameme minefield prevents a critical analysis of potential differences in changes between the minefield and the surroundings however, even in the enhanced difference image. Moreover, the observed distribution of changes over the complete LANDSAT TM scene, together with the resolution of the LANDSAT MSS images (80 m) prevents the localisation of a region of interest, indicating that the changes do not reveal critical parameters that are relevant for minefield delineation.

The typical dimension of minefield like Songo and Mameme with respect to the resolution of the available satellite image sequences from existing databases does not allow a structural analysis of observed radiance values in change detection maps.

As a result of this study, it is our believe that the local radiance values of changes in LANDSAT MSS, LANDSAT TM and changes in SPOT and LANDSAT imagery do not contain meaningful information for minefield delineation.
The potential contribution of sequences of Very High Resolution (VHR) imagery (e.g. IKONOS) for minefield delineation remains uncertain and was even not considered in the current study, because only IKONOS imagery of the post-war period would have been available for the considered regions in Mozambique. It is our conviction that a future study on the use of VHR image sequences for minefield delineation in real conflict regions should consider the satellite monitoring of a (potential) conflict region before, during and after the conflict and should not rely on existing databases.

FEASIBILITY STUDY T4/12/056

ASSESSMENT OF THE CRITICAL PARAMETERS DETERMINING THE VULNERABILITY OF DAMS IN VIETNAM BY MAKING USE OF RADAR SATELLITE DATA

C. JAMAR

UNIVERSITE DE LIEGE (ULG)
CENTRE SPATIAL DE LIÈGE (CSL)
Parc scientifique du Sart Tilman
Avenue du Pré-Aily, Bâtiment B29
B – 4031 ANGLEUR
BELGIUM

1. CONTEXT AND OBJECTIVES

In the northern region of Vietnam, near Hanoi, many earthrn dams built one hundred years ago retain the flood water from the Red River during the period from end of July to end of August. Local Authorities as well as the residents are then in permanent alert state because of the real fear of dam failure. As a consequence, it is convenient to know if remote sensing brings some information in this thematic considering the large area and the number of dams to monitor.

The goal of the present study consists in establishing the potential use of satellite remote sensing notably with radar imagery and its interferometric derived products in order to identify earthern dams vulnerability in northern region of Vietnam.

2. DATA

Geographic study area: Vietnam, Hanoi

Dams of the Duong River (Tributary of the Red River)

Satellite imagery used:

SPOT 2 panchromatic 01/05/1999
SPOT 4 multispectral 26/09/1999
ERS 1 (SLC) 17/03/1996
ERS 2 (PRI et SLC) 18/03/1996
ERS 2 (PRI et SLC) 09/09/1996
(RADARSAT 03/08/1996)
(RADARSAT 01/12/1996)

Other data:

General description of the local context
General description of the flood protection policy

3. METHODOLOGY

The lack of field information leads us to a first objective consisting in the dams' location, then in the evaluation of satellite imagery to the establishment of dams' characteristics.

Pre-processing of the images: calibration, elaboration of interferometric images; flipping, subset, coregistration and filtering of the images.

Location of dams, water bodies and irrigation channels:

- Image processing: images combination and principal component analysis, classification.
- Results evaluation and comparison.

Study of the dams' structures:

- Extraction of the backscattering coefficient (σ°) corresponding to the dams and comparative evaluation in terms of dams superficial moisture.
- Extraction of the average dams interferometric coherence.

4. OUTPUT AND RESULTS

- The SPOT Xi image and the combinations SPOT-ERS PRI allow the identification of dams, water bodies and irrigation channels. The combination between a couple of RADARSAT images and their normalised difference image leads to a satisfactory result too.
- The dams' vulnerability seems identifiable on the classified SPOT Xi and SPORT-ERS combination according to the existence of both water bodies outside of the dams and dams discontinuity.
- The ERS PRI images allow putting in evidence the superficial moisture changes in the dams between the two acquisition dates. However, we have to report a potential PRI calibration problem.
- The use of the interferometric DEM's that were put at our disposal does not seem decisive for the dams' location and for their morphology identification.
- The use of one-day interferometric coherence opens some perspectives since a small coherence value could indicate a significant change in the dams' surface between the two dates.
- A field campaign together with an extensive image acquisition appears to be necessary in order to validate and to extent our observations.

5. EXECUTION

Period : 01/04/1999-30/04/2000

Laboratory :

UNIVERSITE DE LIEGE (ULG)
Centre spatial de Liège (CSL)
Parc scientifique du Sart Tilman, Av. du Pré-Aily, Bâtiment B29, B – 4031 Angleur, Belgium
Phone: + 32 4 366 55 86 Fax: + 32 4 367 56 13
E-mail: cjamar@ulg.ac.be

User partner:
SPACEBEL
Rue des Chasseurs Ardennais, B - 4031 Angleur, Belgium
Phone : + 32 4 361 81 11   Fax: + 32 4 361 81 20
E-mail: info@spacebel.be

6. RELATED DISCIPLINE

Humanitarian, natural hazards and disasters

CHAPTER VII

CARTOGRAPHY AND GEOGRAPHICAL INFORMATION SYSTEMS (GIS)

RESEARCH CONTRACT T4/11/007

SUPPORT TO LAND COVER RECOGNITION AND INTERPRETATION (ARIOS – PHASE 1)

E. WOLFF [(1)]
P. VAN HAM [(2)]

UNIVERSITE LIBRE DE BRUXELLES (ULB) [(1)]
INSTITUT DE GESTION DE L'ENVIRONNEMENT ET D'AMÉNAGEMENT DU TERRITOIRE (IGEAT)
Boulevard du Triomphe - CP 246
B – 1050 BRUXELLES
BELGIUM

UNIVERSITE LIBRE DE BRUXELLES (ULB) [(2)]
SYSTEMES LOGIQUES ET NUMERIQUES (SLN)
Boulevard du Triomphe – CP 165/57
B – 1050 BRUXELLES
BELGIUM

1. CONTEXT AND OBJECTIVES

This research project aims to improve techniques of remote sensing image processing for land cover mapping and their integration into a geographic information system. The quality and the updating of these inventories are to be the basis of a sustainable and efficient land management. The purpose is to develop a method improving the recognition and the interpretation of land cover, in order to improve the use of spatial information and ancillary data during the interpretation of multi-sensors and multi-sources data, to preserve classification rules, and to stock the expertise resulting from the interpretation in order to use it again (updating or more detailed inventory on a larger scale). Two kinds of numerical classification are developed: During this first phase, classifications by pixel are computed. The aim was to show the importance of the integration of textural and contextual information during the classification. In the same way, the artefacts created by the use of this kind of spatial information are suppressed thanks to the use of a multiple classifier. In spite of the introduction of the texture and the context as well as the use of a complex classifier, the « salt-and-pepper » effect persists. Some post - classification filters will be used to generalise the picture, to increase the level of abstraction of this classification and so to come closer of the visual interpretation CORINE Land Cover. During the second phase (see ARIOS – phase 1 - T4/11/41), the accuracy of the classification were improved with the use of objects. The images are segmented in regions while using techniques of border detection. New features of texture and context were computed. When regions are obtained and the selected discriminative features computed, the objects are classified on basis of different kind of classifiers. The degree of abstraction and the level of generalisation will come closer of the interpretation visual.

2. DATA

Geographic study area : Belgium : Mons, (Southwest), Nivelles (Northeast), Fontaine l'Evêque (Southeast) and Soignies (Northeast)
Satellite imagery used : HRV (SPOT-1-2-3), TM (LANDSAT-4-5)

3. METHODOLOGY

The test-site was chosen for its varied landscape: urban, industrial and rural. It is located in Belgium, between 3°54’ to 4°22’ East and 50°22’ to 50°41’ North and includes the cities of Mons and La-Louvière. Satellite imagery from the OSTC used listed below. An image used in the CORINE Land cover project was also used (LANDSAT TM 199- floating – 01/05/1990). The other data used are the following: visual land cover interpretation (CORINE Land Cover), digital elevation model level 2 and Tele-Atlas data (roads networks, motorways networks, water bodies, railways networks, inhabited areas). Different classification methods have been tested, which can be divided in two groups: firstly unique classifiers and secondly the combination of classifiers. These classifiers were applied over the 7 spectral bands of TM, textural attributes and exogenous data. Results have been compared to the reference image CORINE Land Cover for testing areas; then a confusion matrix is produced and the kappa overall accuracy coefficient has been calculated. The first group of techniques includes maximum likelihood, stepwise discriminate analysis and tree decision classifier. The second group of techniques concerns the combination of classifiers. The idea is that the classifiers either gives the good class, or if they mistaken, they mistake each in another way. Classifications are combined by using a majority vote.

4. OUTPUTS AND RESULTS

The first group of techniques tested gives the following results: the advantage to use a tree decision classifier is that it can manage a lot of attributes (this is a necessity because of the relevant size of the window vary according to the land cover class) and of several types at the same time (nominal, ordinal and cardinal). The classification based on spectral attributes obtained with the tree decision give almost similar accuracy that the maximum likelihood analysis. The addition of textural and contextual variables improves very considerably the accuracy. For the tree decision classification, the kappa accuracy coefficient is 0,65 for a few textural variables, 0,72 for a lot textural variables and 0,76 with contextual variables. This result is improved (K = 0,84) when the problematic classes, as “dump sites”, “ transitional woodland-shrub ”, “Sport and leisure facilities”, have been removed. The second group of techniques (combination of classifier) leads to a very high accuracy, higher than the one of each of the classifiers taken alone (K = 0,88), but the classified image shows very strong artefacts at the objects boundaries. The problem is that the definition of training and validation areas are too “pure”; therefore the system does not learn to recognise these boundaries and they are not taken into account for the validation (the accuracy is therefore overestimated). To solve this problem, training and validation areas have been choosing at random within the interpreted images derived from the CORINE Land Cover database. The classified image is much closer to CORINE Land Cover data even though the kappa coefficient is a bit lower (K = 0,77)

5. EXECUTION

Period: 01/12/1996-31/06/1999

Laboratories:

UNIVERSITE LIBRE DE BRUXELLES (ULB)
Institut de Gestion de l'Environnement et d'Aménagement du Territoire (IGEAT)
Boulevard du Triomphe - CP 246, B – 1050 Bruxelles, Belgium
Phone: + 32 2 650 50 76 Fax: + 32 2 650 50 92
E-mail: ewolff@ulb.ac.be URL: www.ulb.ac.be/igeat/igeat/ige5.htm

UNIVERSITE LIBRE DE BRUXELLES (ULB)
Systèmes logiques et numériques (SLN)
Av. Franklin Roosevelt 50 – CP 165/57, B – 1050 Bruxelles , Belgium
Phone: + 32 2 650 26 93 Fax: + 32 2 650 22 98
E-mail: pavaha@ulb.ac.be URL: www.ulb.ac.be/polytech/sln

6. RELATED DISCIPLINES

Cartography
General Earth observation
Space science
Image Processing

7. EXECUTIVE SUMMARY

The first objective of this project was to improve the digital classification in order to update a land cover inventory. The aim is to develop a method to assist land cover interpretation with a better use of the spatial information and the exogenous data. The main objectives are to adapt and to use a tree decision classifier (C4.5) and to test the introduction of spatial attribute (texture, structure) and exogenous attribute (roads, hydrology, relief, …) into the classification process.

A module has been developed to generate relevant spatial information and introduce it into the classification process. It generates texture image for a great number of attributes and variable window sizes.

The test-site has chosen for its varied landscape: urban, industrial and rural. It is located in Belgium, between 3°54’ to 4°22’ East and 50°22’ to 50°41’ North and includes the cities of Mons and La-Louvière.

Different classification methods have been tested, which can be divided in two groups: firstly unique classifiers and secondly the combination of classifiers. These classifiers were applied over the 7 spectral bands of TM, textural attributes and exogenous data. Results have been compared to the reference image CORINE Land Cover for testing areas; then a confusion matrix is produced and the kappa overall accuracy coefficient has been calculated. The first analyse have been compared with the maximum likelihood.

The first group of techniques includes maximum likelihood, stepwise discriminate analysis and tree decision classifier. The advantage to use a tree decision classifier is that it can manage a lot of attributes (this is a necessity because of the relevant size of the window vary according to the land cover class) and of several types at the same time (nominal, ordinal and cardinal). The classification based on spectral attributes obtained with the tree decision give almost similar accuracy that the maximum likelihood analysis. The addition of textural and contextual variables improves very considerably the accuracy. For the tree decision classification, the kappa accuracy coefficient is 0,65 for a few textural variables, 0,72 for a lot textural variables and 0,76 with contextual variables. This result is improved

(K = 0,84) when the problematic classes, as “dump sites”, “ transitional woodland-shrub ”, “Sport and leisure facilities”, have been removed. The second group of techniques concerns the combination of classifiers. The idea is that the classifiers either gives the good class, or if they mistaken, they mistake each in another way. Classifications are combined by using a majority vote. It leads to a very high accuracy, higher than the one of each of the classifiers taken alone (K = 0,88), but the classified image shows very strong artefacts at the objects boundaries. The problem is that the definition of training and validation areas are too “pure”; therefore the system does not learn to recognise these boundaries and they are not taken into account for the validation (the accuracy is therefore overestimated). To solve this problem, training and validation areas have been choosing at random within the interpreted images derived from the CORINE Land Cover database. The classified image is much closer to CORINE Land Cover data even though the kappa coefficient is a bit lower (K = 0,77).

Within this first phase, all classifications were applied on pixels; during the next phase, we’ll work on the classification of regions. This will increase the generalisation level of the results and hopefully get them closer to a land cover visual interpretation.

RESEARCH CONTRACT T4/12/038

INSAR BASELINE COMBINATION FOR TOPOGRAPHICAL PHASE REFERENCE GENERATION

C. JAMAR

UNIVERSITE DE LIEGE (ULG)
CENTRE SPATIAL DE LIÈGE (CSL)
Parc scientifique du Sart Tilman
Avenue du Pré-Aily, Bâtiment B29
B – 4031 ANGLEUR
BELGIUM

1. CONTEXT AND OBJECTIVES

Synthetic Aperture Radar Interferometry (InSAR) is a technique that allows generating Digital Elevation Models (DEM) using the phase information contained in a pair of co-registered SAR scenes. SAR interferograms may contain topographical fringes, but also fringes due to optical path variation between SAR acquisitions known as differential fringes. DInSAR aims to retrieve the topographic component in interferograms in order to measure the differential component and infer very fine displacement measurements. Therefore a topographic phase reference is needed in order to be subtracted from the interferogram and to generate the differential one. This topographic phase reference may be obtained either from an external DEM or from another SAR pair known as free from any differential phase component. The current project entitled "Baseline combination for topographical phase reference generation" aims to develop and implement a method, known as baseline combination, for producing high quality InSAR topographic references to be used in DInSAR studies. Baseline combination simply makes use of several SAR pairs in order to increase the signal to noise ratio. The Sar interferogram allows achieving a better height standard deviation in the resulting DEM. Moreover, it is expected that this combination process allows averaging the independent atmospheric components.

2. DATA

Geographic study area: Brussels, Belgium - Izmit, Turkey

Satellite imagery used: ERS1 & ERS2 SLC data

Brussels: Frame-1017; Track 015 (5 image pairs from December 1993 till March 1994)

Other data:

External DEM from NGI

Meteorological data from RMI

Meteorological images from EUMETSAT

3. METHODOLOGY

- To validate the method, two Belgian test sites were chosen: Brussels, using three-day repeating cycle ERS1 images and Liege using Tandem pairs. A theoretical study of the method with expected achievable accuracy was performed as well as an extensive simulation of expected artefacts over Belgium for the candidate acquisition dates. Analyse of meteorological data as well as simulated artefacts guided our choice of the best image pairs to be selected for an optimal reference DEM generation. Base line combination was tested and resulting DEMs were compared with reference one. Numerous possible combinations were performed to test all aspect of the method.

- In the course of this project, the 17th of August 1999, an important earthquake of magnitude 7.6 occurred along the north Anatolian fault in the area of Izmit (Turkey). In agreement with ESA and the Belgian Federal Office of Scientific, Technical and Cultural Affairs (OSTC), we decided to use the Izmit area as a test site in the frame of the current project in replacement of the Liege test site previously proposed.

4. OUTPUTS AND RESULTS

Baseline combination has been implemented successfully. Some aspects of the technique were badly evaluated especially the fact that only unwrapped phases can be averaged. But, we successfully overcome the encountered difficulties and developed a method to unwrapped interferograms jointly and iteratively. This phase unwrapping procedure allowed us to unwrapped interferograms much efficiently than classically. A specific tool was implemented to evaluate directly the phase noise in an interferogram and/or in an unwrapped phase surface. This tool allow us to evaluate beforehand the height and phase accuracy we can expect from an InSAR processing. Baseline combination revealed to have two aspects. The first one consists in using the technique to lower the fringe rate as far as possible in order to put atmospheric artefacts in evidence. Useful information can be obtained this way to evaluate and locate much more accurately the importance of such artefacts. The second aspect of baseline combination consists in using it by averaging unwrapped phase to lower the phase standard deviation of the combined phase surface. Such combination allows us to obtain more accurate DEMs than those obtained using a single interferogram. Phase standard deviation lowering appears to be more important when using "low quality" interferograms than when combining good ones. Even when combining low quality phase surfaces with good one, one can expect phase noise reduction. Apart from the phase noise reduction, baseline combination offers also the advantage of averaging the artefacts that might be present in each combined one. Finally, the combined InSAR DEM appears to be accurate enough to put in evidence some events like high buildings. Therefore, we consider that the objectives of the present study were successfully achieved.

5. EXECUTION

Period: 15/12/1998-15/12/2000

Laboratory:

UNIVERSITE DE LIEGE (ULG)
Centre Spatial de Liège (CSL)
Parc scientifique du Sart Tilman, Avenue du Pré-Aily, Bâtiment B29,
B – 4031 Angleur, Belgium
Phone: +32 4 367 66 68 Fax: +32 4 367 56 13
E-mail: cjamar@ulg.ac.be URL: http://www.ulg.ac.be/cslulg/

6. RELATED DISCIPLINES

Atmosphere
Geology & soil
Natural hazards & disasters
Land planning & infrastructures
Urban & suburban
Cartography
Hardware & software

7. EXECUTIVE SUMMARY

Synthetic Aperture Radar Interferometry (InSAR) is a technique that allows generating Digital Elevation Models (DEM) using the phase information contained in a pair of co-registered SAR scenes. Coherent phase terms in a pair of SAR images allow to generate interferogram containing fringes due to orbital parameters, topography, optical path variations and intrinsic phase response of plot of scatter. Optical path variations can be induced even by true displacement of the observed scatterograms along the line of sight or by changes of atmospheric refraction index between the acquisitions under concern (known as atmospheric artefacts). Fringes issued from optical path variation are named differential fringes.

With a good knowledge of the orbital parameters, mainly the baseline components, orbital fringes can be adequately removed. If differential fringes may be neglected, a DEM of the scene may be generated provided the coherence between used SAR scene is conveniently preserved. If differential fringes are present, topographic and differential components can only be separated if one of the two is known. In differential interferometry, the aim is to measure the differential fringe component to detect local displacements along the line of sight. Therefore a topographic phase reference is needed in order to be subtracted from the interferogram and to generate the differential one. This topographic phase reference may be obtained either from an

external DEM or from another SAR pair known as free from any differential phase component.

The current project entitled "Baseline combination for topographical phase reference generation" aims to develop and implement a method, known as baseline combination, for producing high quality InSAR topographic references to be used in DInSAR studies. Baseline combination simply makes use of several SAR pairs in order to increase the signal to noise ratio. The SAR interferograms are combined, i.e. added or subtracted, in such a way that the resulting interferogram allows achieving a better height standard deviation in the resulting DEM.
Moreover, it is expected that this combination process allows averaging the independent atmospheric components.

The main objectives of this study are:

- Have a better knowledge of atmospheric artefacts in order to optimise image pair selection and reference DEM generation.
- Verify the ability to reduce these artefacts by averaging.
- Study the ability to simulate the expected artefacts using meteorological data.
- Analyse the altimetry accuracy gain offered using baseline combination.

In the course of this project, baseline combination process was developed, implemented and validated. A theoretical study of the method with expected achievable accuracy was performed as well as an extensive simulation of expected artifacts over Belgium for the candidate acquisition dates. Analysis of meteorological data as well as simulated artifacts guided our choice of the best image pairs to be selected for an optimal reference DEM generation. Initially, two test sites were chosen for validation: Brussels, using three-day repeating cycle ERS 1 images and Liege using Tandem pairs.
But, in the course of this project, the 17th of August 1999, an important earthquake of magnitude 7.6 occurred along the north Anatolian fault in the area of Izmit (Turkey). In agreement with ESA and the Belgian Federal Office of Scientific, Technical and Cultural Affairs (OSTC), we decided to use the Izmit area as a test site in the frame of the current project in replacement of the Liege test site previously proposed to perform a complete DInSAR study of this event. In particular, coherence-tracking measurements were successfully performed to measure on-ground azimuth displacements. The results of this separate study were subject matter of a separate report and were presented at the ERSENVISAT Symposium, Gothenburg in October 2000.
The Brussels test site was extensively used to implement and validate the method. Numerous interferograms and interferogram combinations were made to analyse the

efficiency of the method in words of phase standard deviation gain with respect to pair characteristics. The ability of baseline combination to be used as a tool for atmospheric artefact analysis was demonstrated successfully.

A specific tool was implemented to evaluate directly the phase noise in an interferogram and/or in an unwrapped phase surface. This tool allows evaluating beforehand the height and phase accuracy we can expect from an InSAR processing.

Baseline combination implies having several interferometric SAR pairs. Therefore, a joint iterative phase unwrapping has been efficiently implemented in order to take full advantage of this pair multiplicity. This joint phase unwrapping process allows us to obtain unwrapped phases better than those that can be independently generated.

Baseline combination has been implemented successfully. Some aspects of the technique were badly evaluated especially the fact that only unwrapped phases can be averaged. But, we successfully overcome the encountered difficulties and developed a method to unwrapped interferograms jointly and iteratively. This phase unwrapping procedure allowed us to unwrapped interferograms much efficiently than classically.

Baseline combination revealed to have two aspects. The first one consists in using the technique to lower the fringe rate as far as possible in order to put atmospheric artefacts in evidence. Useful information can be obtained this way to evaluate and locate much more accurately the importance of such artefacts.

The second aspect of baseline combination consist in using it by averaging unwrapped phase to lower the phase standard deviation of the combined phase surface. Such combination allows obtaining more accurate DEMs than those obtained using a single interferogram. Phase standard deviation lowering appears to be more important when using "low quality" interferograms than when combining good ones. Even when combining low quality phase surfaces with good one, one can expect phase noise reduction.

Apart from the phase noise reduction, baseline combination offers also the advantage of averaging the artefacts that might be present in each combined one.

Finally, the combined InSAR DEM appears to be accurate enough to put in evidence some events like high buildings.

Therefore, we consider that the objectives of the present study were successfully achieved.

RESEARCH CONTRACT T4/11/041

ASSISTED LAND COVER RECOGNITION AND INTERPRETATION (ARIOS - PHASE 2)

E. WOLFF

UNIVERSITE LIBRE DE BRUXELLES (ULB)
INSTITUT DE GESTION DE L'ENVIRONNEMENT ET D'AMÉNAGEMENT DU TERRITOIRE (IGEAT)
Boulevard du Triomphe – CP 246
B - 1050 BRUXELLES
BELGIUM

1. CONTEXT AND OBJECTIVES

The research project was motivated by the gap existing between the performance visual interpretation and the poor results of numerous classification techniques. This gap was explained by the lack of integration of textural, structural and contextual information during the classification process. Therefore, the general objective of this research was to improve the image processing techniques of satellite images for the land cover mapping by introducing textural, structural and contextual information into the classification process in order to get closer to the result of a visual interpretation.

2. DATA

Geographic study area : Area of Mons and La Louvière

in Lambert co-ordinates :

- Upper left corner : 118993 m,151001 m
- Lower right corner : 149018 m,120976 m

in geographic co-ordinates:

- Upper left corner : 3°54'E, 50°41'N
- Lower right corner : 4°22'E, 50°22'N

Satellite imagery used :

- SPOT XS, scene 247-41, level 1B, 17/05/98
- SPOT P, scene 247-41, level 1B, 17/05/98
- SPOT XS, scene 247-42, level 1B, 11/09/2000

Other data :

- CORINE Land Cover
- Digital elevation model , level 2
- Tele-Atlas database : roads and motorways networks, water bodies, railways networks, inhabited areas

3. METHODOLOGY

Firstly, textural and contextual information were integrated into a per pixel classification approach. Several classifiers (decision tree C4.5, nearest neighbour) were tested and compared by using the same training and validation set of pixels. Results were compared to a visual interpretation of land cover (CORINE Land Cover). Classifier were combined by using a multiple classifier system, named BAGFS that combines bootstrap aggregating with multiple feature subsets. Some post - classification filters were used to generalise the classified image, to increase its generalisation level and to get closer of the visual interpretation CORINE Land Cover.

Secondly, two methods of per region classification were investigated with success: on one hand several routines were programmed by the SLN team, on the other hand new software was acquired in February 2001 (E-COGNITION) and tested. Both are segmenting a multi-spectral satellite image and classifying it efficiently, but the former is based on a segmentation method using contour extraction and the latter on a region growing method. New features of texture and context were computed. Then, regions are classified on the basis of several classifiers. The classified image has a generalisation level, which get closer to the interpretation visual.

4. OUTPUTS AND RESULTS

Two methods of per region classification were investigated with success: on one hand several routines were programmed by the SLN team, on the other hand new software was acquired in February 2001 (E-COGNITION) and tested. Both are segmenting a multi-spectral satellite image and classifying it efficiently, but the former is based on a segmentation method using contour extraction and the latter on a region growing method. New attributes have been tested for the interpretation of land cover. Several classification techniques were used. Classification method was adapted to the low number of training regions. This per region classification approach is really rich and promising, even though not all features and options were explored and tested. Indeed, on very high-resolution images, size of the objects to be classified is often larger than the pixel size. It is in that particular context that we believe per region classifiers are the most promising.

5. EXECUTION

Period: 15/12/1998-31/07/2001

Laboratory:

UNIVERSITÉ LIBRE DE BRUXELLES (ULB)
Institut de Gestion de l'Environnement et d'Aménagement du Territoire (IGEAT)
Bd du Triomphe - CP 246, B - 1050 Bruxelles, Belgium
Phone: + 32 2 650 50 76 Fax: + 32 2 650 50 92
E-mail: ewolff@ulb.ac.be URL: www.ulb.ac.be/igeat/igeat/ige5.htm

6. RELATED DISCIPLINE

Land planning & infrastructures
Urban & suburban
Cartography
Hardware & software

7. EXECUTIVE SUMMARY

The general objective of this research was to improve the image processing techniques of satellite images for the land cover mapping by introducing textural, structural and contextual information into the classification process in order to get closer to the result of a visual interpretation.

The area of Moons and La Louvière in Belgium was selected for its large diversity of urban landscapes. SPOT and LANDSAT TM data were acquired and processed. The reference data was the CORINE Land Cover data set which is basically.

Results and methods of the first phase of the project, dealing with per pixel classifier, were synthesised and positioned regarding to the scientific and technical literature. From this review, several conclusions can be drawn: even though texture, structure and context are integrated into the classification process, only land cover classes can be efficiently classified, land use classes not.

While most of the studies are dealing with agricultural or forest classes, which are relatively easy to classify, our research focuses on urban and periurban classes, which are of course more complicated to identify. Moreover, the obtained accuracy is very good compared to others studies.

Developed methods, i.e. decision tree classifier and multiple classifier system, are new methods in remote sensing; few or no article are dealing with them.

Unlike most classification results, the generalisation level of the classified image is really close to the visual interpretation.

Although the first stage of this research was focused on per pixel classification, the second one dealt with per region classification. The specific objective was to improve the generalisation of a classified image but also to reduce the dimension of the classification problem by diminishing the number of object to classify.

A deep bibliographic review was achieved on segmentation and led to the conclusion that among the numerous methods, none led to a consensus. Two groups of method can be distinguished: contour extraction and region growing methods.

Two methods of per region classification were investigated with success: on one hand several routines were programmed by the SLN team, on the other hand new software was acquired in February 2001 (E-COGNITION) and tested. Both are segmenting a multi-spectral satellite image and classifying it efficiently, but the former is based on a segmentation method using contour extraction and the latter on a region growing method.

The method underlying the development routines is very close to the per pixel classification method; training regions are selected and used to initiate the classification process. Results are assessed with a validation set of regions.

The E/COGNITION software is based on a much more interactive and visual approach. Training regions are selected visually, in an interactive manner according to the classification results. During the classification process, they are not (re)classed since the interpreter assigns them a class during the training. Therefore, regions difficult to classify may be interpreted visually. The classified image is thus part of the supervision process of the interpreter. The assessment is achieved visually by the interpreter without any formal procedure.

Consequently, a detailed comparison of results becomes tricky not only because segmentation methods differ but also because classification protocols are not identical from the training and the validation point of view; accuracy can not be compared and no conclusions can be drawn on relative classifier efficiencies.

Although per region classifications are diminishing the size of the classification problem, the drawback is that the classifier algorithm does not always have enough regions to be properly trained. This is the case either when a class is not much extended in the image, or when they are constituted of few and large regions. In those cases, the training may be too specific and not properly extended to a new region to classify. Therefore, it appears to be more efficient to selected training regions interactively according to the difficulties of classification for each class.

This per region classification approach is really rich and promising, even though not all features and options were explored and tested. In the framework of this research study, per region classifier was applied on high-resolution remote sensing data. In another feasibility study dealing with the mapping and the monitoring of green urban areas, per region classifier was tested on very high-resolution remote sensing data. Results were really encouraging. Indeed, on these very high-resolution images, size of the objects to be classified is often larger than the pixel size. It is in that particular context that we believe per region classifiers are the most promising.

RESEARCH CONTRACT T4/02/042

AUTOMATIC SPATIAL MATCHING OF MULTISENSOR DATA

I. BRUYLAND

UNIVERSITEIT GENT (RUG)
DEPARTMENT FOR TELECOMMUNICATIONS AND INFORMATION PROCESSING
St Pietersnieuwstraat 41
B – 9000 GENT
BELGIUM

1. CONTEXT AND OBJECTIVES

In this project, we have investigated the automation of the spatial registration process of multisensor images. The innovation with respect to the state-of-the-art was the use of "control objects" to guide registration. Control objects are objects that are visible in images of different type whose characteristic properties can be used to map the images onto each other, even if their appearance differs across the images (e.g. due to scale, partial cloud cover).

Standard registration techniques offer little perspective for the automation of multisensor registration. The non-linear differences in pixel intensity due to sensor type and ground resolution, plus the multiscaling aspect result in the fact that such a dataset will not satisfy the assumptions for the use of correlation or Fourier techniques. Point based techniques are in this case the only feasible alternative. These techniques are mainly based on manual interpretation, which results in slow processing time. These are critical factors for monitoring and warning systems.

This project aims at the extension of the concept "control points" to a more general concept of "control objects". This concept groups points (e.g. landmarks), curves (e.g. coastlines, rivers) and areas (e.g. areas with homogeneous vegetation, urban areas). The goal of this extension is to use the shape and structural features of the object in the registration process.

2. DATA

Geographic study area: Greece
Satellite imagery used: Vegetation SPOT-4, LANDSAT TM, RESURS-01, SEAWIFS
Other data: Vector data

3. METHODOLOGY

The corresponding control objects in the different images have to be aligned based on structural features. Such techniques are being developed for industrial inspection, like defect classification based on variance in shape, chain codes or Fourier descriptors are generally used for the characterisation of the contour of the object, followed by the definition of similarity measures, which guide the alignment process and quantify variances between contours. Also structural, model based techniques are applied, where robust contour features (e.g. based on curvature) are extracted for structural matching. Multisensor registration in remote sensing specifically demands robustness against occlusion (e.g. clouds), sensor specific noise (e.g. radar speckle) and resolution scale.

4. OUTPUTS AND RESULTS

A prototype system has been developed based on scale-invariant shape description and matching techniques, which is able to find correspondences between vector descriptions of object contours. These descriptions can come from a GIS database (e.g. a river or coastline represented by a polyline) or can be extracted from images (e.g. a coastline represented as a chain of pixels). Given these descriptions the system finds correspondences between similar parts. These correspondences can then be used to calculate the transformation between the image or between the image and the GIS database. The system has been tested and shows robustness for shape deformations due to affine transformations, partial cover and image noise. This makes the system suited for registering images with different spatial resolution (e.g. LANDSAT TM and RESURS). The feasibility of automatic registration of low and high resolution and of images and GIS-data was experimentally verified. The quality of registration depends on the spatial distribution of the control objects over the images. In order to guarantee an even distribution over large areas, different types of objects need to be extracted from the image (e.g. coastlines, rivers, boundaries of areas like cities, forests and fields). In this project we concentrated on coastlines but the system easily extends to other objects.

One task within the project was reserved on finding new ways to improve existing techniques that are traditionally used within monitoring. This resulted in the following case studies:

- Refinement of medium resolution images;
- Supporting system requirements for monitoring;
- Shape analysis for the characterisation of changes.

5. EXECUTION

Period: 15/12/98 - 15/12/2000

Laboratory:

UNIVERSITEIT GENT (RUG)

Department of Telecommunications and Information Processing

St Pietersnieuwstraat 41, B – 9000 Gent, Belgium

Phone: +32 9 264 34 12   Fax: +32 9 264 42 95

E-mail: ib@telin.rug.ac.be

6. RELATED DISCIPLINES

Information & communication technology

Hardware & software

7. EXECUTIVE SUMMARY

This project aims at the interpretation of multisensor information within monitoring and warning systems. The diversity of sensors that observe the earth all give a unique picture of a certain phenomenon, as well in ground resolution as in the spectral range of the imagery. One sensor by itself is inadequate to give a complete interpretation of the observed scene. Having data available from complementary sensors permits a more accurate and detailed analysis.

One of the main factors, which hinder the widespread use of multisensor analysis, is the spatial registration of several sensor images within a common geometric framework. Today's techniques are still based on manual identification of ground control points and are therefore very labour intensive. Especially in applications like monitoring, the time spent on processing and the amount of data are critical, and automating the registration process is certainly of importance. Automation however is not evident when using multisensor data. Ground control points can differ strongly when seen on images with different ground resolution. Conventional points (e.g. crossroads) that are being used in high-resolution images may not be visible on low-resolution images. On the other hand, possible ground control points (e.g. a cape) in a low-resolution image can have a different appearance in a high-resolution image.

The theme of this project aims at the automation of the registration process, by extension of the ground control point to the concept of "**ground control object**". This concept groups points (e.g. landmarks), curves (e.g. coastline, rivers) and areas (e.g. urban areas). The goal of this extension is to ease the registration process by exploiting the spatial information couple with an object, namely the point co-ordinates, together with the shape and the structural features of the object. For example, not only a cape but also the characteristic shape of the entire coastline can be used to guide the registration process. This permits to compensate for:

1. The sensor ground resolution, by the characterisation of the scaling effect, hereby modelling the evolution of a structure over several ground resolutions, and
2. The spectral characteristic, by using structural features instead of intensity based (and therefore sensor specific) features.

Within the project, we studied the development of a prototype system based on multisensor data for identification of stress situations and disturbances. It corresponds to the theme of section E.2 "Transsectoral support – Development of monitoring and warning systems". The development of this system examined two important aspects:

1. Automation of the registration process, which forms an important bottleneck for the operational usage of multisensor data due to the real-time limitations, quality control and cost of manpower. This is especially important for monitoring applications where daily processing of new data is a central issue.

2. Exploitation of the potential of multisensor analysis for monitoring, whereby optimal use will be made of the availability of complementary sensors, as well in scale as in spectral range.

RESEARCH CONTRACT T4/37/066

METHODOLOGICAL CONTRIBUTION TO THE INTERPRETATION OF VEGETATION DATA FOR FRAGMENTED LANDSCAPES WITH BROKEN RELIEF. OPERATIONAL IMPLEMENTATION OVER THE CENTRE-EASTERN AFRICA

P. DEFOURNY [(1)]
J. LAVREAU [(2)]

UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL) [(1)]
DEPARTMENT OF ENVIRONMENTAL SCIENCES AND LAND USE PLANNING
Place Croix du Sud 2 bte 16
B – 1348 LOUVAIN-LA-NEUVE
BELGIUM

MUSÉE ROYAL DE L'AFRIQUE CENTRALE (MRAC) [(2)]
Steenweg op Leuven, 13
B-3080 TERVUREN
BELGIUM

1. CONTEXT AND OBJECTIVES

The general and operational objective consists to produce a land cover map of the great lakes area, in the framework of the Global Land Cover 2000 program (Joint Research Centre, European union) and to particularly pay attention to the impact of the topography on the signal interpretation.

Four specific objectives:

- Document the impact of the topographic effects on the reflectance measurement and on the NDVI for the interpretation of a temporal series of daily VEGETATION data
- Propose some recommendations on the data process in order to avoid the possible topographic effects
- Analyse the interest of a methodology of data fusion to valorise the altitude information, the geomorphology and the other sources of information as radar mosaics.
- Produce a land cover map over the studied area with the adapted methodology.

2. DATA

Geographic study area: Latitude 4°N-14°S and longitude 25°E-35°E (2.257.920 Km²)

Satellite imagery used:

366 Daily SPOT VEGETATION images (S1 format) of 2000 year provided in the framework of Global Land Cover 2000

Other data:

- Digital Elevation Model covering all the studied area, 1km spatial resolution (GTOPO 30)
- Digital Elevation Model covering the Lac Albert area, 100 m spatial resolution
- A complete mosaic of LANDSAT images covering the entire studied area.
- Cartographic documents : Trees map (1997), Carte de la végétation du Congo belge et du Rwanda-Burundi (R.Devred, 1953), "La végétation de l’Afrique" (F. White, 1983)

3. METHODOLOGY

- Research of the extreme observation and illumination conditions over one year, for the studied area and simulation of these conditions with a digital elevation model
- Spatial and temporal analysis of the topographic effects on VEGEATION data
- Study of the evolution of the incident energy according to the slope for extreme illumination configurations
- Study of the impact of the spatial resolution of the sensor on the perception of the topographic effects
- Validation of a compositing methodology adapted to the specificity of the studied area and realisation of annual and seasonal composites.
- Elaboration of an automatic mapping methodology taking into account the specificity of the study area and of the VEGETATION data. This two stage methodology takes advantage of both the spectral and the temporal information.

4. OUTPUTS AND RESULTS

- Method to document the topographic effects on the signal recorded by low spatial resolution sensors as VEGETATION.
- An operational and automatic methodology of cartography providing of rapid and consistent updates of cartographic documents for the equatorial areas.
- A land-cover map of the Great Lakes and African rift area (2.257.920 Km²). This map includes 17 classes labelled with the FAO Land Cover Classification System (LCSS). It has been presented for the Global Land Cover 2000 program in March 2002.
- An analysis of different compositing methodologies and identification of the best candidate to answer to the needs and to the constraints of the studied area.

5. EXECUTION

Period: 12 months: from March 2001 to March 2002

Laboratories:

UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL)
Department of Environmental Sciences and Land Use Planning
Place Croix du Sud 12 bte 16, B – 1348 Louvain-la-Neuve, Belgium
Phone: + 32 10 47 23 74 Fax: + 32 10 47 81 92
E-mail: defourny@mila.ucl.ac.be URL: www.agro.ucl.ac.be/enge/

MUSEE ROYAL DE L'AFRIQUE CENTRALE (MRAC)
Steenweg op Leuven 13, B – 3080 Tervuren, Belgium
Phone: + 32 2 769 54 55 Fax: +32 2 759 56 38
E-mail: jlavreau@africamuseum.be

User partner :

TRACTEBEL ENGINEERING
Avenue Ariane 7, B – 1200 Bruxelles, Belgium
Phone: + 32 2 773 75 11 Fax: + 32 2 773 79 80
E-mail: engineering@tractebel.com URL: www.engineering.tractebel.com

6. RELATED DISCIPLINES

Forest & natural vegetation
Cartography
General Earth Observation
Space science

7. EXECUTIVE SUMMARY

The land cover mapping of tropical areas constitutes a major stake for the national authorities as well as for the international organisations and the scientific community. Unfortunately, the quality, the availability and the update of the cartographic documents vary according to the accessibility conditions of the territories and the politic stability.

The remote sensing data allow staging with these problems. Indeed, they provide a frequent synoptic view of large area in many wavelengths.

Projects as TREES have exploited this information to provide a contemporary map of equatorial forests.

Unfortunately, up to now, no automatic and operational methodology based on high temporal resolution data is available for the equatorial forests. This results probably

from the numerous constraints related to these regions. Our study attempts to achieve this objective. The study area covers the region of the Great Lakes and of the African rift (2.257.920 Km² , 4°N-14°S/25°E35°E).
The particularities of this area are the high frequency of cloud cover, the large gaps between two adjacent acquisitions tracks and the presence of a broken relief. These particularities considerably reduce the number of usable data. It's thus a very difficult area to interpret for optic remote sensing.
On the other side, let us quote:

- An important gradient of the vegetation as it covers the equatorial forest, the miombo, the savannah, and the bare sols of Tanzania...
- An inversion of seasonality on both sides of the equator
- A fragmented landscape according to the spatial resolution of the sensor

Those particularities are constraints that are important to take in consideration for the elaboration of an automatic methodology of cartography alflowing guaranteeing the spatial consistency of the produced document and presenting a sufficient sensibility to describe the different land cover types.
Today, the improvements brought to the composing strategies allow the elaboration of automatic methodologies exploiting both the spectral and temporal potentialities of the sensor. Consequently, our study consists to elaborate this type of methodology in order to realise and to objectively update the cartographic documents. To achieve the objective fixed by the study, we realised 2 stages.
The first stage of the research consists of a study of the topographic effects on the signal. As mentioned above, the relief is a major constraint of the studied area. However, if the effects of the topography are well documented for high and medium spatial resolution sensors, there is no study describing those effects for low spatial resolution sensors as VEGETATION.
However, three effects can potentially influence the signal. First, there are radiometric effects coming from a reduction or an increasing of the incident solar energy because of the slope. Second, the 5-days cycle of the viewing angle combined with the large viewing angles (55°) could produce a masked area for the observation and an alternation of observation of the eastern slope (-55°), the western slope (+55°), even both (nadir view). Third, there are geometrical distortions bounded to the parallax associated to the topography.
This last effect is known and corrected by orthorectification in the framework of the standard pre-processing chain of VEGETATION images. In this study, we focused on the two first effects (radiometric and shadows).
The simulations and the analysis realised in this study highlighted the fact that the shadows effects and the masked areas for the observation are marginal for the altitude and the resolution (1 km) that concern us.

The major effect of the topography consists of a variation of the illumination intensity bounded to the variation of the relative position sun-sensor along the time. However, from one day to another, this variation is very low and doesn't provoke major differences of illumination between several consecutive acquisitions. It is perfectly established that the relative position of the surface compared to the sun has a considerable influence on the quantity of received incident energy and thus on the surface reflectance. This effect is perfectly visible on high-resolution images (LANDSAT, SPOT HRV...) but absent on low-resolution images (SPOT VEGETATION, NOAA AVHRR). We demonstrated so the existence of an adequacy between the observation scale and the manifestation of the topographic effects on the signal. The good perception of the relief on a high-resolution image is coming from the dimension of the pixel that is lower than the dimension of the structuring elements of the relief. The observation resolution constitutes a determinant element to take in consideration. With a VEGETATION image, the spatial resolution is too weak to highlight the impact of the relief on the signal.

These conclusions are bounded to the low latitude areas where the solar inclination is limited to the hour of acquisition of the image. The approaches developed by this study could be valorised for the study of the topographic effects clearly observed at higher latitudes.

The temporal analysis highlighted that the intensity of the BRDF effect is not bounded to the topographic component. The reflectance variations coming from the variations of the acquisition geometry are similar to the variations encountered in plane areas (maximum 100%).

Let us note however that the near-infrared band is the more sensitive to the BRDF effects before the middle infrared and the visible bands. The more important reflectance variations are bounded to the relative position sun-sensor (backward or forward). The zenith observation angle provokes some variations too but they are relatively weak (40%).

The study of the topographic effects has been the occasion to evaluate the importance of the other constraints of the studied area. It has thus allowed establishing that the major constraints are the spatial and temporal variations of the atmospheric perturbations and the inversion of the seasonality on both sides of the equator. The last one provokes a problem of spatial consistency of the cartographic product.

The second stage of this research consists of elaborating a methodology of automatic cartography according to the several constraints identified in the first stage. To achieve this objective, we proceeded first to the pre-processing of the data.

Two methodologies of composing have been identified and evaluated according to the objective of cartography. This first stage is very important for the classification because it will determine the quality of the final cartographic product. The Mean

composing strategy (Vancutsem et al., 2002) has been identified as the most pertinent strategy according to the objective. It provides a great spatial consistency to the composite and allows the utilisation of all the spectral information, what was only possible with non-composted data before.
Based on the potentialities of the composites and on the constraints of the studied area we developed an operational and automatic methodology, which allows the realisation of rapid objective, and consistent updates of the product. The originality of the approach consists of exploiting both the spectral and temporal information of the surface and not only the temporal behaviour of a vegetation index as usual. The use of all the available information allows a more powerful discrimination of the different types of land cover compared to the use of a vegetation index as the NDVI or the NDWI. This methodology provides thus a spectral and phonological reality to the identified classes.
The produced cartographic document presents a large spatial consistency, a good identification of the thin structures (gallery forest, rivers...) and a satisfying identification of the different types of land cover. The final map is composed of 17 classes of land cover labelled with the prescriptions of the Land Cover Classification System of the FAO (LCSS) as required by the Global Land Cover 2000 Program.
Because of the numerous constraints encountered in the studied area (cloud cover, relief, vegetation gradient, inversion of seasonality), we consider that the proposed methodology could be applied to other territories and other conditions.
This methodologic tool could be very interesting as well in the framework of the change detection as for the ecosystem management and the understanding of the world ecological processes.

PILOT PROJECT T4/02/070

BASIC AND THEMATIC CARTOGRAPHY ON BASIS OF HIGH AND VERY HIGH RESOLUTION MULTITEMPORAL SATELLITE IMAGES FOR THE KIVU AREA (CONGO)

P. DE MAEYER

UNIVERSITEIT GENT (RUG)
DEPARTMENT OF GEOGRAPHY
Krijgslaan 281 Gebouw S8
B – 9000 GENT
BELGIUM

1. CONTEXT AND OBJECTIVES

1) This study investigates in how far a basic planimetric map for the eastern Congolese region Kivu, can be created by combining recent *high resolution* satellite imagery with the available obsolete cartographic documents, historical geodetic surveys and other available cartographic documents.

To produce a satellite map, the geometric reference system of the satellite map has to be defined by a sufficient number of ground control points. These points must be clearly identifiable on the image as well as be co-ordinated in a geodetic network. This is one of the main technical problems in a satellite image map production.

2) The main purpose of the second part of the study is to show potential uses of *very high-resolution* image in a city of an African country. As for many of the Third-World cities, Bukavu grew up during the last decades and available topographical information on Bukavu dates from the middle of the twentieth century. This lack of updated information can be fulfilling by an appropriate use of the IKONOS image recorder on the 14th February 2001.

2. DATA

Geographic study area: the co-ordinates of the study area are UL : 1°S-26°E/LR : 4°S-29°E. The study area is in the Kivu region of Congo

Satellite imagery used:

LANDSAT MSS 1970 13 images cost: 200US$ /image (126000BEF)

LM2186061007507190|12/03/1975| 5 | 1 | X |S01 36 00|E028 53 00|2200020097| OK

LM2186062007507190|12/03/1975| 8 | 5 | X |S03 02 00|E028 32 00|2200020098| OK

LM2186063007505390|22/02/1975| 8 | 1 | X |S04 23 00|E028 11 00|2200020708| OK

LM1186064007318090|29/06/1973| 8 | 1 | X |S05 40 42|E027 39 08|1200241810| OK LM2187061007505490|23/02/1975| 8 | 5 | X |S01 28 00|E027 27 00|2200020250| OK1

LM1187061007225990|15/09/1972| 8 | 4 | X |S01 32 32|E027 23 41|1200040694| OK2

LM1187062007225990|15/09/1972| 8 | 2 | X |S02 59 17|E027 03 24|1200040695| OK

LM1187063007225990|15/09/1972| 8 | 1 | X |S04 25 56|E026 43 07|1200040696| OK

LM1187064007312790|07/05/1973| 8 | 1 | X |S05 40 10|E026 09 17|1200210045| OK1

LM1187064007225990|15/09/1972| 8 | 1 | X |S05 52 26|E026 22 47|1200040697|
OK2
LM2188063007521790|05/08/1975| 5 | 1 | X |S04 17 00|E025 20 00|2200130148|
OK
LM2188064007518190|30/06/1975| 8 | 0 | X |S05 50 00|E024 53 00|2200110164|
OK1
LM1188064007226090|16/09/1972| 8 | 5 | N |S05 52 25|E024 56 13|1200040759|
OK2

LANDSAT ETM+ 2000-2001 cost: 625US$/image (108 750BEF)

Date	Centre Point	Path	Row	Cloud Cover
17 Sep 1999	-4.34 Lat, 28.74 Lon;	173	63	2
05 May 2000	-1.45 Lat, 27.78 Lon;	174	61	2
02 Nov 1999	-1.45 Lat, 26.23 Lon;	175	61	4
30 Aug 1999	-4.34 Lat, 25.62 Lon;	175	63	0

Complementary images were put at the disposal of the project by the user partner
IKONOS image 4000US$/image and 1 XS image, zone Bukavu (11x11km)
(4000US$) (348 000BEF)

Other data:

National Geographic Institute (1956), Province of Kivu, Territorial Organisation
Aerial photographs (1959), from : maps catalogue available at Royal Museum for Central Africa.

3. METHODOLOGY

See 7. Executive summary

4. OUTPUTS AND RESULTS

The produced satellite image maps are on a scale of 1: 200.000. The used projection is the Universal Transverse Mercator with the Clarke 1880 ellipsoid.

Produced cartographic data:

- Base maps 1/200.000 based on most recent LANDSAT ETM + images
- Thematic maps 1/200.000 based on classified LANDSAT ETM+ images and land cover change detection based on ETM+, TM and MSS images

- Thematic maps and urban analyses of the city of Bukavu based on very high resolution IKONOS images

The maps were completed with essential topographical information (based on the information of older maps and surveys) and border and marginal information. This data exist in different digital formats.

5. EXECUTION

Period: 01/07/1999-30/11/2001

Laboratory:

UNIVERSITEIT GENT (RUG)
Department of Geography
Krijgslaan 281 Gebouw S8, B – 9000 Gent, Belgium
Phone: +32 9 264 46 88 Fax: +32 9 264 49 85
E-mail: philippe.demaeyer@rug.ac.be

User partner:

MUSÉE ROYAL DE L'AFRIQUE CENTRALE (MRAC)
Leuvensesteenweg 13, B - 3080 Tervuren, Belgium
Phone: + 32 2 769 52 11 Fax: + 32 2 769 56 38
E-mail: info@africamuseum.be

6. RELATED DISCIPLINES

Cartography
Solid Earth resources
Forest & natural vegetation
Natural hazards & disasters
Urban & suburban
General Earth observation
Space science

7. EXECUTIVE SUMMARY

Great parts of developing countries are characterised by the lack of reliable up-to-date planimetric information. The available maps of these areas are mainly produced in small scale, are mostly obsolete and offer only poor information.
Some studies and projects concerning these regions require reliable and detailed maps to fulfil basic orientation and information needs. For the production of this

reliable basic information, up-to-date field data has to be collected trough topographic surveys. These surveys however aren't always possible because of inaccessibility of the region due to political circumstances or natural disasters. Most of these tropical regions are, under the pressure of several factors, subject to rapid politic, socio-economic and environmental changes. For the monitoring of these changes, no reliable planimetric and thematic base exists.

Satellite image data of these inaccessible regions contain plenty of recent information that can be used for mapping purposes. One image gives a complete spatial inventory of an area on a specific moment. The temporal analysis of satellite images provides an assessment of human encroachment and land cover changes.

A satellite map is a cartographic document based on satellite images combined with additional available information and interpretation of the satellite images. There is a big difference between the visual presentation of satellite base maps and the standard topographical maps. The cartographic information on the maps is originating from available conventional sources, such as maps and field data, or is originating from image interpretation. Based on the category of cartographic information on the map the maps can be divided into three types:

- General, basic or topographic satellite maps *are composed with a satellite image as background and vector information layers,*
- Thematic maps have a *background that consists of an interpreted satellite image,*
- Subject oriented maps *are composed by using and interpreting very high-resolution images.*

The objective of this pilot project is to produce:

- Base maps 1/200.000 based on most recent LANDSAT ETM + images
- Thematic maps 1/200.000 based on classified LANDSAT ETM+ images and land cover change detection based on ETM+, TM and MSS images
- Thematic maps and urban analyses of the city of Bukavu based on very high resolution IKONOS images

The used projection is the Universal Uransverse Mercator with the Clarke 1880 ellipsoid.

The study area

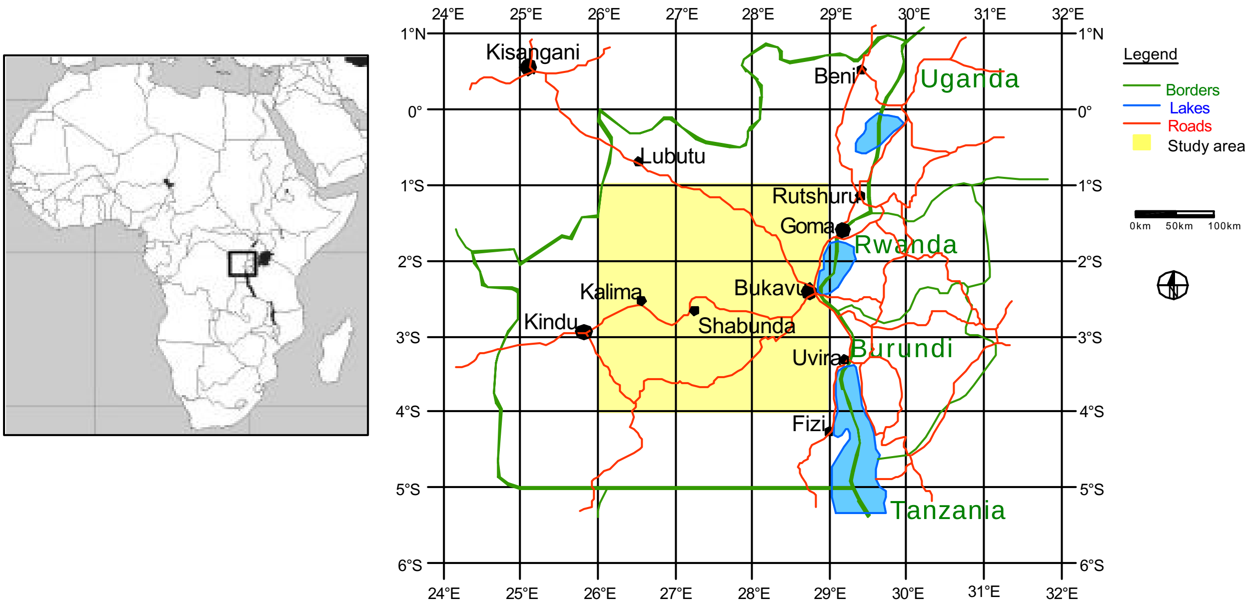
Although densely populated, rich in mineral commodities and agricultural products, the Kivu region (D.R. Congo) has remained less known than other regions, at least from a scientific point of view.

General knowledge has been hampered by several factors:

- Although favourable to agriculture and settlement, the relief, climate and penetrability has been the cause of the absence of airborne photography and basic geodesy, resulting in turn in lack of regular cartography. To day no detailed map of kivu is available;
- The complexity of the socio-cultural network. For centuries, the region of kivu has been situated in the migration corridor with several ethnical, social and cultural communities. These communities are furthermore strongly influenced by the vicinity of other countries and the political events which are manifesting there;
- A complex geology. The region is indeed situated at the crossing of orogenies ranging from the Archaean to the late Precambrian, i.e. a unique geological record. To day, the geology is still a matter of continental-scale interpretation;
- A mineral fortune exploitation by a large number of small companies and individuals, most time without interest for the geologic context.

For the reorganisation of the infrastructure and for the benefit of humanitarian operations, a basic cartography is useful for several non-governmental organisations, certainly when further interpretation according to their needs is possible.

Figure 1: The study area in the Kivu province of D.R.Congo



The study region (Figure1) is an area with a clear need for cartographic products but where a complete terrestrial inventory is out of the question because of political reasons. Only remote sensing can help to realise this inventory for the production of a basic cartography by offering up-to-date information through high-resolution imagery.

Satellite maps based on high resolution images

The production of satellite maps contains three main activities, which are: image processing and interpretation, map composition and continue quality control.

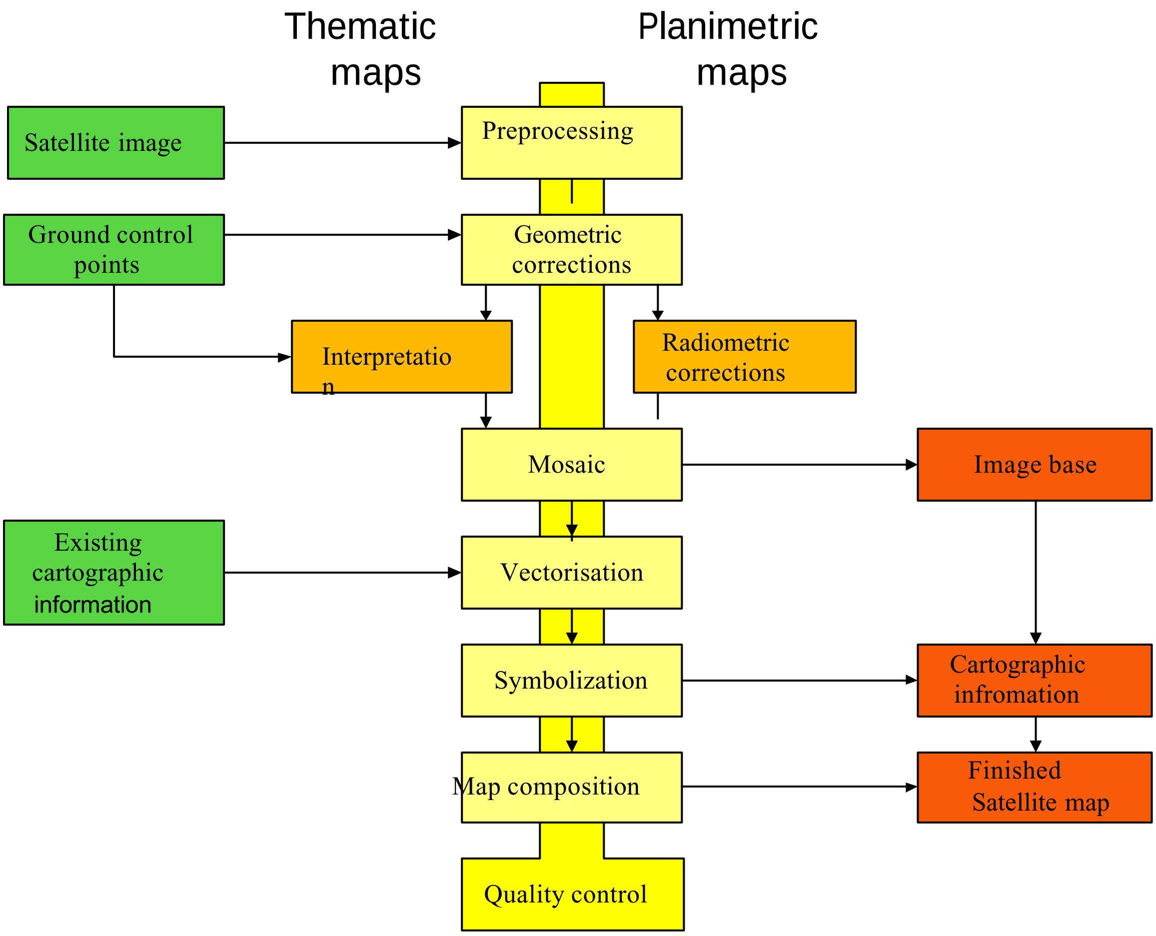


Figure 2: General Production line for planimetric and thematic image maps

Image processing

Satellite images, used for the production of maps, don't have the characteristics of a cartographic document. The production process has to be followed to become a finished map.

For the phases of pre-processing, mosaicking and radiometrical enhancement standard techniques were used.

- *Geometric corrections*

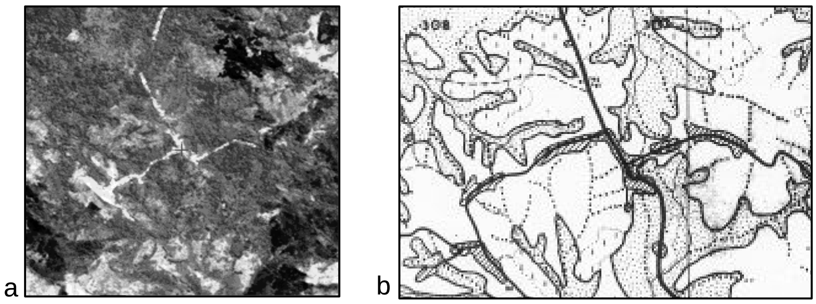
  For the production of satellite image maps several scenes have to be geometrically rectified to fit the co-ordinate system of the map. At first, the geometric reference system of a map has to be defined by a sufficient number of ground control points. Using a transformation model calculated with a least

squares regression analysis of the control points, a geometric corrected image is produced.
The ground control points must be spatial small and clearly identifiable in the image data as well as be co-ordinated in a geodetic network. By positioning more ground control points than necessary, the correctness of the transformation parameters can be evaluated though the calculated Root Mean Square Error (RMSE). On the basis of the RMSE and the residual errors of the ground control points, the accuracy of the geometrical correction can be defined. For the satellite images of Kivu we have put in front a maximum RMSE of 4 pixels (0,57mm on the map, 114m on the ground).
The accuracy of the georeferencing depends of:

- Good identifiable ground control points;
- The quality of the data sources from which the ground control points are extracted;
- The accuracy of positioning the ground control points.

The way of positioning the ground control points depends on the documents they were extracted from. Ground control points extracted from existing reliable maps can be positioned using the classic working method (example in Figure 4). The feature of the road crossing is recognisable on the image so that it can be used as a ground control point.
Disposing of reliable maps and a good quality of image data, this working method is rather easy.

Figure 3: Comparison of the image features (a) and the map information (b).



The positioning of ground control points, extracted from the geodetic surveys, is not as evident as seen in Figure 3. This needs a more interpretative working method because the signals of the survey points aren't visible on the image.
'Le Canevas Planimétrique du Kivu-Maniema' was surveyed with a triangulation. This indicates that the survey points are mutually visible and therefore mostly situated on high relief features. The survey directions and

points are visualised on an overview on 1 / 1 000 000. For two areas, there are also an overview on 1 / 300 000 and 1 / 250 000. Because these overviews have a very pore topographical background (Figure 4 a), it is very difficult or even impossible to position the survey points on the image.
Some maps of the area, like the 'Cartes de Territoire' (Figure 4 b) also indicate the survey points. By comparing these maps with the features on the image, the survey points can be located (Figure 4 c) and be given the exact co-ordinates, read from the co-ordinate list in the survey report.

The possibility of positioning a survey point on the image within the accepted error margin depends on the relief. Survey points on a rounded hilltop or located in an area with a high density of hilltops can't be positioned with enough certainty.

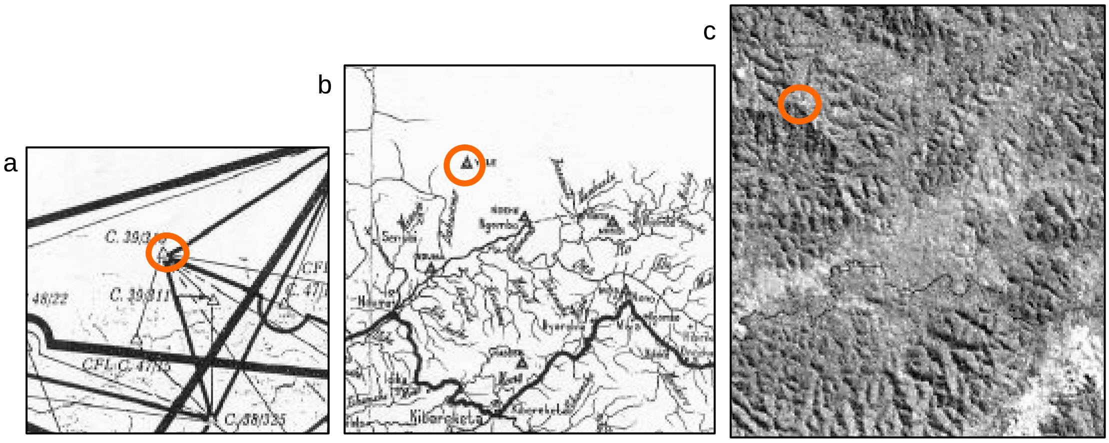


Figure 4 : Position of a ground control point on an overview of 'Le Canevas Planimétrique du Kivu-Maniema' (a), on 'La Carte de Territoire de Punia (b) and on the image (c).

Using this working method, we have found ground control points for a large area of the region. The central area and the western part of the study area can't be georeferenced using the existing documents. These areas are similar to those areas of 'Le Canevas Planimétrique du Kivu-Maniema where no survey points exist.

We notice that only a very small part of the maps in the inventory can be used for the direct extraction of ground control points. This is mainly caused by a pore geometrical accuracy of most maps.

For the areas that were corrected, the used ground control points have a RMS error smaller than 2-pixel units (57 m).

Classification

The basemaps are also produced with an interpreted background. The available LANDSAT TM and ETM+ images were classified using 10 different classes; dense vegetation, secondary vegetation, bare soil, agriculture, savannah, swamps, clouds, shadow, water, culture.

The images are classified using the supervised maximum likelihood method. Of each class a few image pixels are sampled. After the classification a Sieve filter is used.

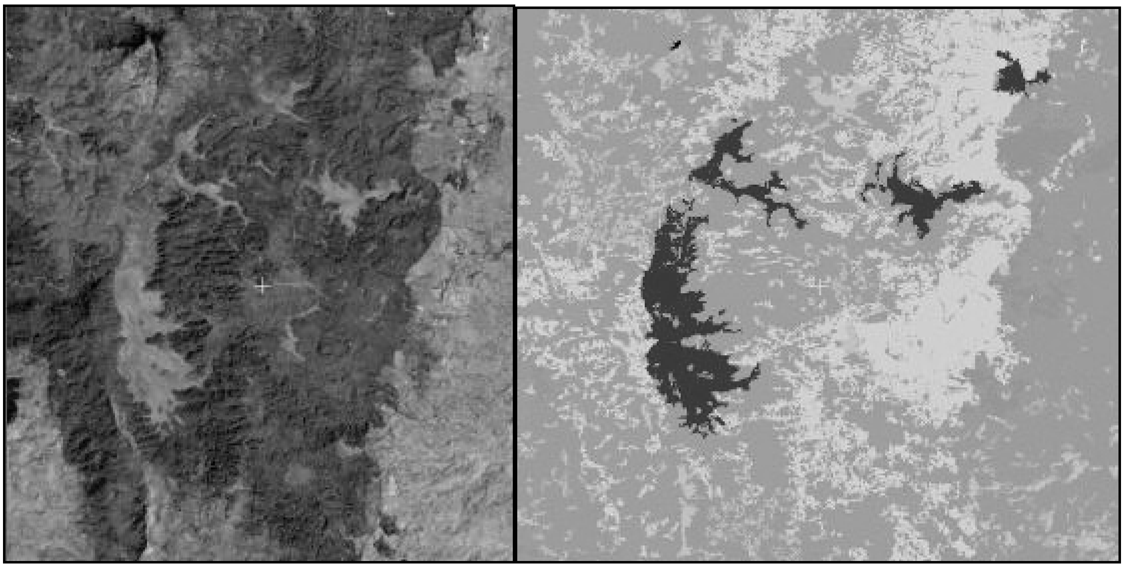


Figure 5: **land sat ETM+ true colour image and interpreted image layer**

The result is an interpreted layer that can be used as background image for the produced cartographic information layers.

Map composition

The result of the geometrical and radiometrical processing is a rectified, mosaicked and enhanced set of image data for a map sheet. However in addition to the image itself a map requires graphical elements such as lines, letters, numbers, etc. representing and depicting topographical features. These elements must be superimposed on the image. Also border and margin information is added for positioning and interpretation of the map sheet. The margin information consists mainly of the standard information (legend, scale, north, etc.), but contains also a part that gives information about the used images and existing documents and for the interpretation of the image data.

The additional topographic information locates important topographical elements that are limited visible on the image. The density and the graphical presentation of the elements in combination with the image background have to form a harmonious entity, in a way that the overprint remains legible and the image data is conserved as much as possible.

To endeavour a harmonious entity, three aspects were taken in account when information was added:

- The amount of information;
- The overprint of topographical information on a satellite image map is only used for accentuating specific elements or as help for interpretation. There it is different from a standard topographical map. The potential amount of information that can be added depends in our case mainly on the available information found on the existing maps. For some areas a selection has to be made, for other areas only limited information is available;
- The positioning of the information (the indication of point, line and surface elements). The positioning of the topographical information occurs by visual interpretation of the image data for roads and rivers. The place names and position of villages is extracted from the existing cartographic documents;
- The symbolisation of the elements (the graphical presentation of the different topographical elements on the satellite image). During the symbolisation of the topographical elements on the satellite image, we are confronted with some typical difficulties. The assignment of the size, shape, pattern and colour of the symbols has to happen in such a manner that they are clearly legible on the map but cover as little the image data as possible.

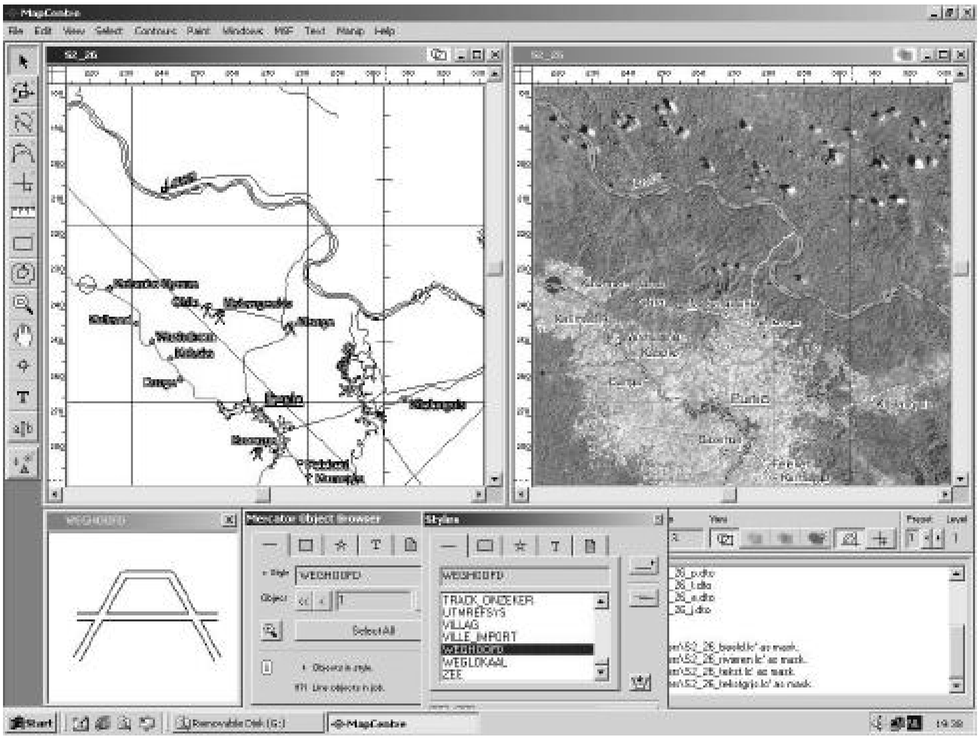


Figure 6: Symbolisation of the interpreted cartographic information

Quality control

During the production of image maps a continuous quality control is necessary. This is done by a continuous follow up by experts. The results were also checked by extern organisations like Wildlife Conservation Society – New York, The Africa Museum – Tervuren and GTZ research results – Germany. The place names and location of villages were checked by local contacts. They checked the produced maps on the field.

Thematic base maps based on very high resolution images

The main purpose of this thematic study is to show potential uses of very high-resolution image in a city of a developing country. As for many of the cities in developing countries, Bukavu has expanded enormously during the last decades. The available topographical information on Bukavu dates from the middle of the twentieth century and hasn't been updated since. This lack of updated information can be fulfilling by an appropriate use of the IKONOS image recorded on the 14th February 2001.

DEM is mandatory for image registration and urban analyses. First a DEM was created using aerial photographs dating from 1959 and a set of ground control points. The ground control points were selected on topographical maps of 1957. Because of the lack of good ground control points the quality of this DEM was not good enough for geographical research and the orthorectification of the images. By classifying and digitising the contour lines of the topographical maps we created a new DEM. This

was done on a semi automatic way. A grid DEM was interpolated using the digital contours together with the digitised ridges, valleys and additional control points.
The range between the minimum and maximum altitudes observed is more than 500 meters with a horizontal displacement of less than 5 kilometres. Furthermore, the inclination angle is more than 28 degrees. In this case orthorectification is mandatory for correcting relief displacements. Nevertheless, the lack of good Ground Control Points on the old topographic maps explains the remaining global RMSE of 10 meters.
For making easier image interpretation, multispectral (4m) and panchromatic (1m) images are fused together by means of the LMVM algorithm developed at the Labororatoire SURFACES.

Depending of the object, the Computer Assisted Image Interpretation (CAII) uses or does not use the near infrared information (true or false colour composite).
For a more detailed interpretation about the city morphology we draped the 1m multispectral-merged image over the 1m resolution DEM grid.

Figure 7: Build-up areas, red (1954), pink (2001)

This information could be used to simulate a three dimensional flight over the city of Bukavu.
This was done with the PCI Geomatica software.

The Built-up Area Index (BAI) computed on the urban mask obtained by CAII and classification of the vegetation, is compared with the middle of the previous century situation interpreted from topographic maps. The present BAI higher values and in the same time the centre of the city are clearly shifted to the south direction. Statistical analyses are also done on built-up versus slope data.
The lack of good GCP points (no differential GPS measures available and very old topographic maps) and the use of DEM (DSM is not available) produce orthorectification not precise enough for topographical features extraction. Nevertheless the Bukavu growth factor for half century is evolved to more than double. New constructions are located on steeper slopes. This last fact is key information when one knows the frequency of landslide developments. More features could be extracted from IKONOS image if good GPS measurements would be done and if contact with city authorities would be established. Some practical study like the search for better localisation for new Bukavu extensions could be done.

Conclusions

The survey does not cover the complete Kivu region, just like the usable maps, it is rather impossible to georeference all the images with the same accuracy without field work. To become a complete coverage of basic satellite image maps of the Kivu, the ground survey of new ground control points is desired.

The analogue as well as the digital version of the satellite image maps can be used for further thematic studies of the area. Because no other reliable maps of the study area exist, we can name the satellite image maps basic maps of the area. These maps contain some added topographical elements as well as a huge amount of diverse information of the study area.

The realisation of satellite images is a good alternative to become up-to-date basic maps of areas that are difficult to access and don't have a recent cartography. The number of maps that can be finished without carrying out field surveys, together with their geometrical accuracy depends totally of the characteristics of the available documentation for the area.

PILOT PROJECT T4/02/072

INFORMATION DRIVEN REGISTRATION OF VERY HIGH RESOLUTION IMAGERY FOR THE UPDATE OF ROAD DATABASES

I. BRUYLAND

UNIVERSITEIT GENT (RUG)
DEPARTMENT OF TELECOMMUNICATION AND INFORMATION PROCESSING
St Pietersnieuwstraat 41
B – 9000 GENT
BELGIUM

1. CONTEXT AND OBJECTIVES

As the role of spatial information becomes more important (e.g. decision making and management for government bodies and companies, geomarketing, car navigation) pressure is put on the industry to produce detailed and up-to-date digital maps. Computer vision and object recognition can play an important role to improve the production of these maps, which is very time-consuming and price-absorbing. One issue is the problem of making different data sets geometrically consistent. This is essential for a coherent use of data sets supplied by different data producers. The coming of more detailed spatial databases (on geometry, attribute and feature level) increases the problem of making the data sets consistent. The need for these high accuracy products is predicted for future markets (e.g. advanced driver assistance in car navigation, land management, etc.) and the availability of high resolution source material (e.g. IKONOS 1m resolution satellite imagery) makes computer vision technology accessible. This technology is useful not only to upgrade the database but also to detect and remedy areas with spatial quality problems in order to ultimately end up with a homogeneous European database.

2. DATA

Geographic study area: City of Gent (Belgium)
Satellite imagery used: IKONOS P-1m
Other data: road vector database

3. METHODOLOGY

In this project we investigated the possibilities of information driven registration in the context of road databases as defined by Tele Atlas. Two main problems were investigated:

a. How accurately can roads be extracted from VHR satellite images and what information is useful for registration and quality control?

Line detection based on polynome interpolation was used to determine pixels belonging to road structures in the image. We analysed its performance and introduced several optimisations to give better results. In the end, detection of crossroads was introduced.

b. Given the detection of roads, how can registration be performed and optimised?

Crossroads were found to be stable registration objects. The problem can then be represented as finding the correspondence between two sets of points. Graph matching techniques were employed which make use of the spatial relations between points to find correspondences. This makes the correspondence technique less vulnerable for crossroads, which are detected in the right location but whose detected shape does not fully correspond its counterpart in the database.

4. OUTPUTS AND RESULTS

Line detection proved to be a powerful technique for detection of roads, not only in fields as is often shown in the literature, but also in suburban and industrial zones. The technique is very generic and useful for a variety of sensors (satellite/aerial, visual/SAR). The detection is not perfect however. For registration more stable objects were needed than the road fragments that were detected. Crossroads proved to be a good choice. Detection was adequate and more important the number of false detection could be kept low.

Based on the detection of crossroads, a correspondence between the image and the database was found using graph matching techniques. The main factor here was a good definition of the constraints, which define the desired solution. A good definition of constraints allows for a good performance of the system. The transformation that is found is a morphing transformation, where each point has a counterpart and local transformation of image patches can be performed. This is very flexible and allows for local deformations to exist. By putting bounds on the allowed transformation, outliers can be detected. This is of high importance for quality control where inconsistencies should be detected.

The results were presented to Tele Atlas and the technology was found to be useful to be considered for integration within their production environment.

5. EXECUTION

Period: 01/07/1999-31/01/2002

Laboratory:

UNIVERSITEIT GENT (RUG)

Department of Telecommunication and Information Processing

St Pietersnieuwstraat 41, B – 9000 Gent, Belgium

Phone: +32 9 264 34 12 Fax: +32 9 264 42 95

E-mail: ib@telin.rug.ac.be URL: http://telin.rug.ac.be/index.html

User partner:
TELE ATLAS
Moutstraat 132, B – 9000 Gent, Belgium
Phone: +32 9 244 88 11 Fax: +32 9 222 74 12

6. RELATED DISCIPLINES

Cartography
Hardware & software
Information & communication technology

7. EXECUTIVE SUMMARY

Project description

As the role of spatial information becomes more important (e.g. decision making and management for government bodies and companies, geomarketing, car navigation) pressure is put on the industry to produce detailed and up-to-date digital maps. Object recognition can play an important role to improve the production of these maps, which is very time-consuming and price-absorbing.
One issue is the problem of making different data sets geometrically consistent. This is essential for a coherent use of data sets supplied by different data producers. The coming of more detailed spatial databases (on geometry, attribute and feature level) increases the problem of making the data sets consistent. The need for these high accuracy products is predicted for future markets (e.g. advanced driver assistance in car navigation, land management, etc.) and the availability of high resolution source material (e.g. IKONOS 1m resolution satellite imagery) makes this technology accessible. This technology is useful not only to upgrade the database but also to detect and remedy areas with spatial quality problems in order to ultimately end up with a homogeneous European database.
Tele Atlas is a European company with HQ in Gent which is the market leader in the production of digital road maps in a wide variety of applications all over Europe. The company is faced with the problem of upgrading its current European databases to a higher accuracy. Current techniques can't support this in a cost-effective way due to the necessary manpower. Automated registration of high resolution imagery to the existing databases can form an essential tool to support a wider use of spatial information. In addition to this desired resolution upgrade does Tele Atlas need to ensure continuous updating of its database to reinforce its leading position.
This project addresses this problem and aims at the introduction of advanced object recognition for assisting the spatial registration of high resolution imagery to a road vector database. A system will be developed that allows images to be automatically

registered, based on prior knowledge of the road network in the database and on road fragments extracted from the images. Important is the use of prior knowledge of the road network. Automatic extraction of roads from aerial or satellite imagery is a hard problem for which it is difficult to guarantee consistent recognition performance over a large dataset. However, given an existing road vector database, even inconsistent and incomplete, the use of this information gives the problem a new focus, to a point where a solution becomes feasible.

A system that makes efficient use of this information consists out of two processes, namely a low-level process that performs extraction of road fragments from the image and a high-level process that matches these fragments to the existing road network. These two processes are linked by a control structure that handles the information flow in both directions, i.e. updating the correspondence between image and road network based on road fragments (bottom-up), as well as refining the search for road fragments in the image based on evidence from the road network (top-down).

Accomplished tasks

WPI - Data collection

The dataset for the area under investigation is put together in WP 1. This dataset consisted of an IKONOS image above Gent. The image content and quality was analysed for its use for road extraction and the upgrading and quality control of the existing road vector database. A number of test areas were set up, illustrating difficulties at different levels (suburbs, industrial zones, express roads). This allowed an evaluation of the system. Ground truth information was acquired over these areas in the form of the corresponding road network as defined within the database of Tele Atlas. This defined the desired output.

Aside from the main focus, a number of other datasets were briefly tested to see if the developed algorithms were not too sensor specific. More specifically a SAR image and several aerial photos above the US were examined. The choice of these images was suggested by Tele Atlas who has a specific interest in this data.

WP2 - Extraction of road fragments from VHR imagery

Accurate feature detection is a very important task in early vision and is vital for many visual tasks. Extraction of roads is performed using edge and region information, with added constraints on radiometric and geometric features. Based on these generic road models, fragments of the road network are extracted from the image and are used to initialise the interpretation step (cf. WP3). Robustness, accuracy and a reasonable recognition rate are essential for a good performance of the interpretation system. In this work package, we examined techniques, which extracts road parts, based on a generic road model, which is adapted to VHR satellite imagery.

Obviously, an important part of the work was spent on this work package. Line detection based on polynome interpolation was used to determine pixels belonging to road structures in the image. This technique has been extensively studied in the literature but almost always on ideal situations (i.e. a road bordered by homogeneous regions like fields). The focus is mainly on detecting roads very accurately within subpixel accuracy. The examples and results shown in the literature are usually very good but stop at urban areas where structures appear next to the roads. Our experiments were conducted from a more practical viewpoint. We were interested to see how far we could take the algorithm and what performance could realistically be expected for large scale applications. Line detection proved to be quite a powerful technique, which generates a rich description of the image content (image gradient and curvature, orientation). By setting appropriate thresholds on gradient and curvature this gives a binary image of potential line pixels. Using a "thinning" operator, the regions of line pixels can be reduced to lines of single pixel width. The orientation information can then be used to link the pixel, which shows a similar orientation into the same pixel chain (cf. Fi-. la).

In addition to "nice" roads, suburbs and industrial zones also belong to the class of regions for which road detection seems feasible. An important feature, which in our experiments proved useful to distinguish road lines from noisy structures, was the length of the detected line. This feature was not useful in inner cities where the roads can be short or can carry a lot of extra detail (cars, trees, shadow) which results in a high amount of fragmentation in the road network. In this respect, not so much line detection but the vectorisation proves to be a critical part (i.e. thinning and pixel chaining). These parts of the process chain can still be much improved and should help to further distinguish roads from noisy structures.

The road network that can realistically be detected in a first stage is not of sufficient quality to be useful for registration with a road vector layer. The main difficulty is the difference in representation between what can be detected from the image and the vectors that are present in the database. This hinders the correspondence problem considerably. A much more robust registration object was necessary. We found crossroads to be good candidates since in its abstract form it can be represented as a point object both in the image and in the database. The road network as is detected however fails in the vicinity of crossroads since the line model does not hold anymore. We implemented a simple region growing scheme which extends the initial road fragments, with regions which show a similar grey value. For roads, which are adequately detected this proved to be sufficient in many cases to bridge the bad SPOTs at crossroads. Detection of crossroads was then performed on the vector representation of the detected network by selecting the points, which have three or more neighbours. Such a simple scheme is of course not fool proof. A cheap and efficient verification to filter out false alarms is to check if in the vicinity of a hypothetical crossroad a flat SPOT exists. Crossroads are seen by the line detector as a flat region. By simply applying different thresholds on the gradient and the curvature, which have already been calculated for the detection of lines, we can detect the flat SPOTs and verify our crossroads. Fig.1b shows an example of crossroad detection (boxes are possible crossroads, crosses are positive crossroads).

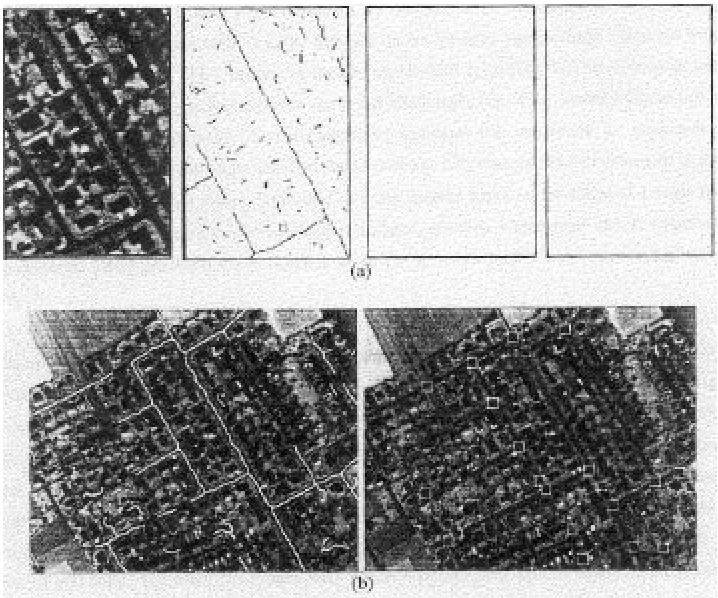


Figure 1: Results from (a) line detection and (b) detection of crossroads

The performance of the crossroad detector relies heavily on the initial road network that is detected. We performed a few tests on regions of 1 km². By varying the minimal line length we examined the number of positive and false positive crossroads versus the total number of crossroads which are present in the database for the corresponding region. Depending on the type of road that is present, we measured a correct detection of 5% to 20% of the total number of crossroads. The number of false detection ran from 0% to 10%.

WP3 - Information-driven registration

The problem of road extraction is a difficult one due to occlusion, shadow and variability in shape and radiometric properties. This is especially true for urban zones where these problems are more pronounced than in rural areas. Due to the complexity of the problem, extraction of roads cannot be performed in a single pass. The road fragments that are extracted in early vision need to be grouped into a consistent road network using "global" information, in addition to the "local" generic road model that is used. Global information provides the context to build a road network. It can be made up out of several components:

- road network logic (e.g. cars on the roads, houses next to roads, no gaps);an existing road network that needs to be updated;
- additional GIS layers that add constraints (e.g. parks, ho uses)
- user interaction

Part of the road network logic was already used in building up the initial detection (e.g. the line structure, flat SPOTs for crossroads, no gaps, similar grey values etc.). The second source of information that is exploited in this work package is the existing road network in the database. In the previous work package crossroads were found to be stable registration objects. The problem can then be represented as finding the correspondence between two sets of points. Graph matching techniques were employed which make use of the spatial relations between points to find correspondences. This makes the correspondence technique less vulnerable for crossroads which are detected in the right location but whose detected shape does not fully correspond its counterpart in the database (defects can occur due to image noise). So instead of using features based on the shape of a single crossroad to guide matching, we use geometric relations (angle, distance) between a crossroad and its neighbours to find correspondences. These are much stable features given the detection quality, which we can realistically expect from line detection.
Our experiments were focused on determining the performance of the matching system under varying noise conditions. Noise is introduced on the spatial location of the crossroad, which is caused by image noise or inconsistencies between the image and the database. Next to spatial noise, spurious points are also present due to false detection of crossroads. Given the performance of crossroad detection in the previous work package, the problem can be posed as finding, a small subset within a larger set of points. Our first experiments were performed using a relaxation labelling scheme. This technique was round to give a good performance for large datasets (order of 100-200 points) within reasonable processing time (approx 3 min for sets of 100 points on a Pentium III 500 MHz, 128 Mb). The figures were initially measured for similar datasets having approximately the same number of points. For a 100/100 correspondence (i.e. finding a correspondence for 100 points in a second dataset of 100 points) we can expect a correct correspondence ratio of 70% under average spatial noise conditions.

The performance however degraded considerably when we moved on to datasets, which differ in size. For a 10/50 correspondence we round an average performance of only 30% correct correspondences, whereas a 10/10 correspondence is almost always solved perfectly. On further investigation, the problem was found to be when the number of points in the second set increases, the number of possible solutions

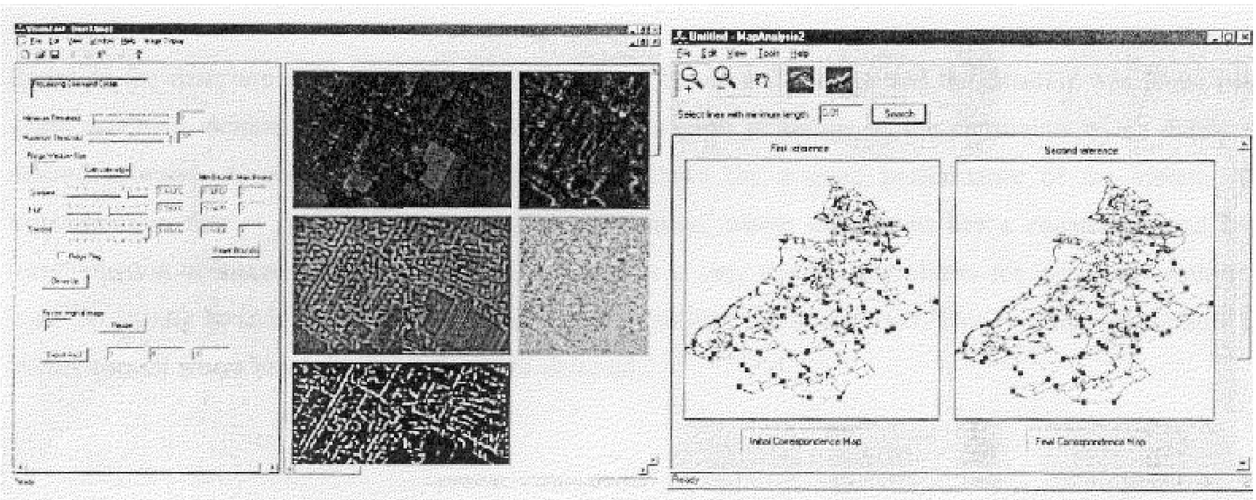
which are consistent with the imposed constraints increases also. This means that there are several possible optimal solutions for the correspondence technique to choose from and in an unbiased system the choice that is made will not necessarily be the solution which we like to see. The solution is to increase the number constraints in the system or to make them stricter, thereby making the desired solution more unique. In our case, the constraint which defines our solution is given by the difference in angle between pairs of points. If the difference becomes too large, the constraint is violated. Initially the margin was taken to be ± 45°. Subsequently reducing this margin increases the performance considerably. For a margin of ± 5°, the correct correspondences were 85%, false correspondences 10%.
In this context, we should note that the underlying transformation model at the moment is a morphing transformation, i.e. each point has its counterpart in the second dataset and after triangulation local transformation of image patches can be performed. This is much more flexible than imposing a parametric transformation model (e.g. an affine transformation) as it allows local deformations to exist. The downside is that it's much harder to detect outliers since the model is so flexible. To get a good performance, one should analyse the deformations that the application should allow and find a combination of constraints, which optimally define the solution. This can be a combination of the graph matching scheme as is explained and a parametric transformation model to filter out gross errors.
Next to relaxation labelling, other correspondence techniques were investigated, namely search trees and genetic algorithms. The first were round to be too memory intensive and were useful only for small datasets. Genetic algorithms were investigated because they are a global optimalisation scheme, which are less vulnerable for getting trapped in sub-optimal solutions. The mean performance was round to be good but unpredictable, in the sense that sometimes it remains stuck at very bad solutions. The main reason for this performance is that genetic algorithms which evolve "solution strings" in a population, need to have some coherence between the individual elements of the string, so that pairs of the solution string, form meaningful building, blocks which can be exchanged to "build" better solutions. In our case the only meaningful building block was just a single element (i.e. a single correspondence pair of points) which is not sufficient to guarantee an optimal solution using genetic algorithms.

WP4 - Software development

The research code that was developed for our experiments at TELIIN, were rewritten and integrated in two stand-alone windows applications. One application is used as a demonstrator for line detection. An image can be imported and the user can set different parameters for line detection. To see the inner workings of the detection, images like gradient and curvature are visualised within the workspace. By interactively modifying the parameters, the user can quickly investigate the quality of detection that can be possible.

The second application implements the graph matching techniques for registration. It makes use of MapObjects from ESRI to import and visualise a GIS layer in ESRI-shape format. The nodes of a road network that belong to roads of a user defined minimal length can be selected. Given two such datasets, the correspondences between these nodes can then be calculated using relaxation labelling. The output can be exported to a text file for further processing.

These applications are meant for educational purposes for Tele Atlas to become more familiar with the



techniques. The source code is delivered with the applications if further development is needed.

Conclusion

In this project we investigated the possibilities of information driven registration in the context of road databases as defined by Tele Atlas. Two main problems were investigated:

1. How accurately can roads be extracted from VHR satellite images and what information is useful for registration and quality control?
2. Given the detection of roads, how can registration be performed and optimised?

Line detection proved to be a powerful technique for detection of roads, not only in fields as is often shown in the literature, but also in suburban and industrial zones. The technique is very generic and useful for a variety of sensors (satellite/aerial, visual/SAR). The detection is not perfect however. For registration more stable objects were needed than the road fragments that were detected. Crossroads proved to be a good choice. Detection was adequate and more important the number of false detection could be kept low.

Based on the detection of crossroads, a correspondence between the image and the database was found using graph matching techniques. The main factor here was a good definition of the constraints, which define the desired solution. A good definition of constraints allows for a good performance of the system. The transformation that is found is a morphing transformation, where each point has a counterpart and local transformation of image patches can be performed. This is very flexible and allows for local deformations to exist. By putting bounds on the allowed transformation, outliers can be detected. This is of high importance for quality control where inconsistencies should be detected.

FEASIBILITY STUDY T4/12/049

POTENTIALS OF VERY HIGH RESOLUTION REMOTELY SENSED IMAGERY FOR THE ELABORATION AND THE UPDATE OF "LARGE SCALE DIGITAL MAPPING"

J.-P. DONNAY

UNIVERSITE DE LIEGE (ULG)
DEPARTMENT OF GEOMATICS
Laboratoire SURFACES
Allée du 6 Août 17, Bâtiment B5, Sart Tilman
B – 4000 LIEGE
BELGIUM

1. CONTEXT AND OBJECTIVES

The A.L.E. company (Association Liégeoise d'Électricité - user partner) requires large scale maps for its daily activities relating to the power supply and the management of the power network in the region of Liege.

Digital maps cover one square kilometre on the field and are georeferenced to the Belgian Lambert 72 system. Paper maps can be drawn from digital data at different scales, from 1/500 to1/2 000. The most important objects in the maps concern various kinds of buildings, and the quality assessment relies upon several measures and indices such as: the rate of correctly identified objects, planimetric accuracy thresholds and a completeness index. It is obvious that field surveys and photogrammetric restitution are necessary to fit the accuracy requirements of the digital map. However the updating process only resorts to these costly techniques after that significant changes have been identified by aerial photo interpretation.

The aim of this feasibility study is to assess the potentials of very high resolution (VHR) remotely sensed imagery (~1 m) to correctly identify and locate the different kinds of buildings . The project will make use of CAPI -like techniques applied upon geometrically corrected satellite images. The geometric correction process is of first importance for planimetric accuracy, so this topic will be carefully examined in the first stage of the project. It is expected to fusion panchromatic and multispectral data (from the same sensor/satellite) to generate colour composites if they could improve interpretation. Genuine fusion algorithm developed by SURFACES would be used for this task. The three major quality indices defined in the terms of reference, concerning identification, accuracy and completeness, will be used too to check the quality of the satellite image analysis. Reference data constituted by existing digital maps covering selected regions of interest will be provided by the user partner. The capability of satellite image to be an aerial photo surrogate to detect and to locate changes of the built-up area would be considered as the main positive result. Moreover, according to the obtained values of the quality indices, satellite image analysis could be integrated in the assessment process of the field / photogrammetric works, for all or some categories of buildings. The consequences of the introduction of satellite remote sensing techniques in the elaboration (updating / assessment) of the digital maps will be considered, notably in terms of time and costs.

2. DATA

Geographic study area: Fléron and Beyne-Heusay (Walloon Region, Belgium)

Satellite imagery used:

- KOSMOS (KVR-1000)
- IKONOS

Other data:

Vector data

Orthophotographs (1:50 000, 1995, National Geographic Institute)

3. METHODOLOGY

- Collect of the reference data
- Correction and geo-registration
- Overlaying of the vector and raster data
- Contrast stretching
- Interpretation of the images
- Change detection and validation
- Accuracy assessment (confusion matrix)

4. EXECUTION

Period : 01/10/1999-31/01/2000

Laboratory:

UNIVERSITE DE LIEGE (ULG)

Department of Geomatics

Laboratoire SURFACES

Allée du 6 Août 17, Bâtiment B5, Sart Tilman, B – 4000 Liège, Belgium

Phone : +32 4 366 54 24   Fax : +32 4 366 56 93

E-mail : donnay@geo.ulg.ac.be URL : http://www.geo.ulg.ac.be/Surfaces/

User partner :

A.L.E (Association Liégeoise d'Electricité)

Rue Louvrex 95, B - 4000 Liège 1, Belgium

Phone : + 32 4 220 12 11   Fax : + 32 4 220 12 00

5. RELATED DISCIPLINE

Cartography and GIS

6. EXECUTIVE SUMMARY

The aim of this feasibility study was to assess the potentials of very high resolution imagery to perform the update of digital large scale maps. The user partner is the "Association Liégeoise d'Electricité" (A.L.E.). The update of maps implies the detection of changes and new objects in order to direct the topographic survey

towards the new elements. The study was restricted to buildings and roads, the main objects, which may change.

Several products were tested. It was showed that the images coming from the KOSMOS satellite, and the ortho-photographs from the National Geographic Institute cannot be used to perform the update of the building changes. The resolution of the first product is not sufficient and the radiometric quality of the second product is too weak, although the announced spatial resolution is 1 m. The IKONOS images were processed and interpreted without being able to validate the results. It is thus not possible to assert that this kind of images can be used to update the digital maps. However, the analysis of an ortho-photograph and a KOSMOS image showed the importance of two parameters: (1) the spatial resolution, and (2) the radiometric quality of the images. Thus, it is supposed that the announced spatial resolution of the IKONOS satellite will not be small enough to detect changes if the radiometric resolution is too weak.

Moreover, the detection of new buildings and new frontages could be made possible if:

- The panchromatic and multispectral images are merged;
- The geometric and radiometric corrections are performed as accurately as possible;

These conditions can be easily satisfied. Furthermore, the information related to the planning permissions could be used to validate the detected changes.

Thus, it seems that the potentials of very high resolution imagery are still limited for updating large scale maps. Today, the interpretation of aerial photographs (IGNB, PPNC) seems to be the most operational method to update maps and to detect changes in a univocal and accurate way.

FEASIBILITY STUDY T4/12/051

CARTOGRAPHY OF MICROCLIMATIC ZONES USING A DTM OBTAINED VIA RADAR IMAGERY (ERS)

A. OZER

UNIVERSITE DE LIEGE (ULG)
DEPARTMENT OF PHYSICAL GEOGRAPHY
LABORATORY OF GEOMORPHOLOGY
Allée du 6 Août 2, Bâtiment B11
B – 4000 LIEGE
BELGIUM

1. CONTEXT AND OBJECTIVES

Digital elevation models (DEMs) usually come from digitising contours or SPOT data from topographic maps, which are then transformed with an algorithm. This approach presents several problems, including errors in data acquisition, simplification of the original data, artefacts, etc. The time required to build these models implies very high costs in human resources, when the surface is large and accuracy important. Over the past years, the “Centre Spatial de Liège” (CSL) has developed techniques based upon SAR interferometry to build high precision DEMs. This approach offers three advantages. First, it allows covering patches of 100x100 kilometres. Secondly, the accuracy of the elevation value ranges from 5 to 15 metres. Thirdly, this technique could be applied throughout the world with the same efficacy.

This feasibility study compares the efficacy of two DEMs in the study of location of human settlements with regard to sunlight. The first one is a “classic” DEM derived from contours. The second was generated by interferometric techniques. If the interpretation efficiency and analysis prove to be the same, it would then be more attractive to use the interferometric approach, as it saves lots of time, and thus money. Furthermore, this approach could provide precise information at both regional and local scales.

Sunlight data comes from a program which «highlights» DEMs. The light source simulates the trajectory of the sun in the sky. Due to the symmetry of the movement, (ascending trajectory from 21/03 to 21/09 and descending from 21/09 to 21/03), we only need to compute for a half-year.

The aim of the cartography (inside a geographical information system) consists in the delineation of the “cold” areas, because of the obvious link between sunlight and heat. Due to the very complex interaction of sunlight and the atmosphere, it is quite difficult to precisely define the mean annual temperature of an area without continuous local measurements. However, we can try to solve this problem by using human sensitivity. We postulate that people prefer to live in “warm” areas, or where there is a lot of sunlight. So, if we possess the precise location of houses in past centuries, we will be able to define the relatively warm and cold areas. It should then be possible to provide assistance to planners in defining areas where people can build houses, carry out activities or adapt types of vegetation to increase productivity.

2. DATA

Geographic study area: District of Sprimont, Walloon Region, Belgium.

Satellite imagery used:

Images SLC SAR ERS

Image 1 ERS1 Track 301 Frame 999 Orbit 24838 14/04/1996 21:43

Image 2 ERS2 Track 301 Frame 999 Orbit 5165 15/04/1996 21:43

Other data: DEMs generated from contours

3. METHODOLOGY

The methodology comprises ten steps: defining the problems to be solved; delineation of a test area; building a "classic" DEM; building an interferometric DEM; creating a program which highlights DEMs; georeferencement of the interferometric DEM; acquisition and georeferencement of the thematic data; classification of the light data; analysis themes in the framework of sunlight; comparison of the analyses of the two models.

The test area is the district of Sprimont (natural region of Condroz). This choice was derived from former studies. The topography is like corrugated iron with the axis oriented from east to west. From an environmental viewpoint, the alternation of geological layers gives the area a homogeneous character. The "classic" DEM was built from the digitising of contours from four 1/10000 maps. It took three weeks full-time to achieve the results. The interferometric DEMs are built in the CSL. Under various ESA and Belgian government contracts, the CSL has developed a SAR interferometry (InSAR) and differential interferometry (DInSAR) processor. InSAR and DInSAR processing requires several steps, some of which are shared by the two techniques. One of the more difficult problems to be solved consists in the classification of the DEM derived from radar images. The non-existence of a program that express data to define geographic canvas implies the use of ground control points selected both in the radar image of intensity and over the corresponding topographic map.

A very good copy of the old maps of Ferraris (1770-77) was edited in 1965 at the scale of 1/25000 in order to more easily compare with a standard map of NGI at that time. The red colour code is used for houses. Thus, it is quite easy to scan and extract the pixels that define human settlements. Since the landscape does not change much, classifying the data was also simple. It was thus possible to find some similar points in both current and old maps. Today, the "plans de secteur" (country management maps) define areas where it is possible to settle. They contain old villages that are the cores of present-day, more extended, urban areas. These are characterised by a shape stretched along the main roads. At the beginning of the 1970's, such areas were defined from a speculative point of view. Environmental characteristics were not integrated in the final decision. Consequently, some areas where nobody would live were integrated in the urban tissue.

4. OUTPUTS AND RESULTS

At first glance, the statistical parameters are quite similar in the "classic" and interferometric cases. The colour map of sunlight data, in equal interval classes, gives us the same impression. The extreme values are symmetrically disposed for both images. One of the main differences in the histograms comes from the central

part for the “classic” models where a few values are over-represented. Analysis of this data shows that the most important value in the histogram of the “classic” model (13.9% of the total) represents flat areas. The reason it does not exist in the histogram of the interferometric DEM is that they are very few totally flat pixels
The comparison between the houses of the Ferraris maps (1770-77), present urban areas of “plan de secteur” and the light data must be analysed attentively and in detail. In all, we analysed 14 hamlets and villages in the district of Sprimont. We analysed the presence (high = 1point; low = ½ point) of classes of sunlight inside building areas for two kinds of DEMs (“classic” and interferometric) and for two periods (1770-77 and 1970-80).
We observed in all periods and in all models that the mean and the upper mean are best represented. It is only for the «classic» model, during the recent period, that we can find equivalence between lower and upper means. The difference between the lower and the upper mean is always greater for the interferometric model than the “classic” one.
If we are only interested in statistical parameters we conclude that houses, in the case of the old maps, and the urban area, in the “plan de secteur”, must be considered as samples that reflect the global distribution of sunlight. However, the sample represents human settlements and small variations can be explained by human behaviour. In both cases, the pattern of houses reflects the distribution of the more highlighted areas in a very small environment.
The statistical parameters of the global distribution of sunlight for houses give no information about the way the houses are distributed in the field. It might be possible to mathematically describe the relative organisation of the houses. However, the human brain does that more easily than an algorithm.
The differences between “classic” and “Insar” sunlight files can be explained by the nature of the topographic surface. The «classics» DEMs are generated from a complex interpolation of elevation data digitised from contour maps. The Insar DEM represents the retrodiffusion surface of incident wave. Consequently, land use influences the shape of the topographic surface. This is also the case for the “classic” model, but for other reasons. Topographic maps are designed, first, for military use. Therefore, in urban areas for example, the most important information is the relative position of houses, roads and factories. Thus, contours do not appear. Similarly, for extraction zones, the main lines are drawn in order to give the most important feature of the extraction area rather than the correct position of the elevation value through the contour lines. When a “classic” DEM is built, this pool of data is often compensated by the imagination of the person responsible for the digitalisation. In our case study, several quarries were erased!
Twenty percent of urban and career areas, 23% of woods (broad-leaved trees and firs) and 57% of meadows composes the test area. For the meadows, the

topographies are the same, except where farms exist. For the woods, the results are roughly similar. For urban areas and quarries, the differences are greater, but it depends on the place. At present, we have not extracted a rule, which allow us to predict places where we can forecast differences. From a statistical point of view, it is thus obvious that the correlation between parameters is near 0.7: good correlation with meadows, plus a small part from wooded areas.
The realisation of a light map for the whole Walloon region could be useful for the evaluation of the correlation between agricultural and forest productivity for different kinds of species and light data; in the framework of sewer planning: definition of the best location for purifying stations which use photosynthetic bacteria; realisation of an epidemiological study in order to check if there exists a relation between number of persons suffering from nervous breakdowns and the location of poorly-lit houses. Comparison between the location of poorly-lit areas and the thermal profile of motorways.

Elements of comparison	"classic" model	Interferometric model
Cost	One full-time person for 3 weeks for a surface of 15kmx15km.	100kmx100km for less than one week.
Areas	Where there exist topographic maps.	Theoretically, all over the world.
Referencement	The same as the map projection.	At present, the best accuracy is one or two pixels.
Accuracy	The z data come from contours. The surface varies with the algorithm. The users define the size of the pixel.	The z value varies from 5 to 15 metres. The surfaces correspond to plan of retrodiffusion. The best pixel size is 20 metres.
Data quality	No data in the urban and careers areas.	Approximately the same as "classic" model. Variation in relation with land uses.

5. EXECUTION

Period: 01/05/1999-31/12/1999

Laboratory:

UNIVERSITÉ DE LIÈGE (ULG)
Department of Physical Geography
Laboratory of Geomorphology
Allée du 6 Août 2, Bâtiment B11, B - 4000 Liège , Belgium
Phone: +32 4 366 54 46 Fax: +32 4 366 57 22
E-mail: aozer@ulg.ac.be

User partners:

MINISTÈRE DE LA RÉGION WALLONNE. Direction générale des ressources naturelles et de l'environnement (D.G.R.N.E.), division de la nature et des forêts (D.N.F.)
Avenue Prince de Liège 15, B – 5100 Namur, Belgium
Phone: + 32 81 33 50 50 Fax: + 32 81 33 51 22

MINISTÈRE DE LA RÉGION WALLONNE
Direction de l'Aménagement et du Génie Forestier
Direction Générale de l'Aménagement du Territoire, de l'urbanisme et du Patrimoine (D.G.A.T.L.P.)
Rue des Brigades d'Irlande 1, B – 5100 Namur, Belgium
Phone: + 32 81 33 21 11 Fax: + 32 81 33 21 10

6. RELATED DISCIPLINES

Interferometry
Cartography
Country planning
Human behaviour

7. EXECUTIVE SUMMARY

This summary was presented at Fringe'99, the second ESA International Workshop on ERS SAR interferometry:
D. Closson, Y. Cornet, A. Ozer, H. Hansen, D. Derauw, Ch. Barbier, 1999. Cartography of Microclimatic Zones Using InSAR DTM. Fringe'99 : Second ESA international workshop on ERS SAR interferometry. Advancing ERS SAR interferometry from Applications towards Operations, 10-12 November 1999, Centre Spatial de Liège, Belgium.

Introduction

Digital elevation models (DEMs) are usually derived from digitising contours from topographic maps, which are then transformed with an algorithm. This approach presents several problems, including errors in data digitising, simplification of the original data, artefacts, etc. The time required to build these models implies very high costs in human resources, when the surface is large and accuracy important. Over the past years, the “Centre Spatial de Liège” (CSL/Belgium) has developed techniques based upon SAR interferometry (InSAR) to build high precision DEMs. This approach offers three advantages. First, it allows covering patches of 100x100 kilometres. Secondly, the accuracy of the elevation value ranges from 5 to 15 metres. Thirdly, this technique could be applied throughout the world with nearly the same efficiency.

This feasibility study compares the efficiency of two DEMs in the study of human settlement locations with regard to sunlight conditions. The first one is a “classic” DEM derived from contours. The second was generated by interferometric techniques. If the interpretation efficiency and analysis prove to be the same, it would then be more attractive to use the interferometric approach, as it saves lots of time, and thus money. Furthermore, this approach could provide precise information at both regional and local levels.

Sunlight data comes from a program which «highlights» DEMs. The light source simulates the sun's trajectory in the sky. Due to the movement symmetry, (ascending trajectory from 21/12 to 21/06 and descending from 21/06 to 21/12), we only need to compute for a half-year.

The aim of the cartography (inside a geographical information system) consists in the delineation of the “cold” areas, because of the obvious link between sunlight and heat. Due to the very complex interaction of sunlight and the atmosphere, it is quite difficult to precisely define the mean annual temperature of an area without continuous local measurements. However, we can try to solve this problem by using human sensitivity. We postulate that people prefer to live in “warm” areas, or where there is a lot of sunlight. So, if we know the precise location of houses in past centuries, we will be able to define the relatively warm and cold areas. It should then be possible to provide assistance to planners in defining areas where people should build houses, carry out activities or adapt vegetation types in order to increase productivity.

Method

The methodology comprises ten steps: defining the problems to be solved; delineation of a test area; building a "classic" DEM; building an interferometric DEM; creating a program which highlights DEMs; geocoding of the interferometric DEM;

thematic data acquisition and geocoding ; sunlight data classification; analysis themes in the framework of sunlight; comparison of the analyses of the two models.

Before the 20th century the housing location was in equilibrium between the needs for water (no distribution), food (no markets), wood (no petrol) and work (over 90% in agriculture). So, the best location was one near water (rivers, springs, etc.), a forest and that received a lot of sunlight. Ninety percent of the population lived in the countryside and therefore was well aware of such environmental parameters. Today, however, nearly the whole population lead an urban existence. The break with environmental factors is nearly total. In Belgium, less than 2% of the active population works in agriculture. If technologies allow us to cast off physical constraints, it is still true that humid areas or those, which lack sunshine, are not attractive for human settlements. In practice, planners should not allow building in such places. If we follow this line of reasoning, a study of this phenomenon should show us that people have always wanted to live in places close to springs and in sunny areas. For this demonstration, we used old, high-quality maps that present the landscape, as it was 200 years ago. These maps realised by the Earl Ferraris (1770-77) were at a scale close to 1/11000. It is very clear that this cartography is an extremely important document, as it allows us to see former landscapes where our ancestors lived. The environmental factors can be appreciated through the pedologic maps where data was collected at the 1/5000 scale and published at the 1/20000 scale. Why did the inhabitants decide to live in the places they did ? We'll surely never be able to ask them. So, the search for an objective reason or parameter therefore becomes necessary. For vegetation, light is an important factor, as it allows growth. Clearly, vegetation growth does not depend solely on light. Water and soil are also of prime importance. However, we believe that the superimposition of two sets of data (light and tree growth) could be interesting, especially with additional analyses by forest planners.

The test area is the district of Sprimont (a natural region in the Condroz). This choice was derived from former studies. The topography is similar to corrugated iron with the axis oriented from east to west. From an environmental viewpoint, the alternation of geological layers gives the area a homogeneous character.

The classic DEM was built from the digitising of contours from 1/10000 maps. It took three weeks full-time to achieve the results. The interferometric DEM was built at CSL [3]. Under various ESA and Belgian government contracts, CSL has developed a SAR (Synthetic Aperture Radar) interferometry (InSAR) and a differential interferometry (DInSAR) processor. The CSL processor includes functionality to transform any InSAR product from radar geometry to cartographic projection e.g. on reference ellipsoid WGS 84. These final products are terrain-corrected geocoded products.

One of the most difficult problems to be solved consists in controlling the geocoding in the InSAR DTM. Ground Control Points (GCP's) must be selected in both the SAR image and topographic maps to control the correct geocoding of the InSAR DTM. Due to the poor legibility of radar images, the accuracy of this approach is not better than two pixels in the SAR image. In the best case one pixel precision can be achieved. This is probably one of the most important steps because it determines the quality of the comparison. The validation is quantitative (RMS) and qualitative (classification of intensity superimposed with topographic maps in a GIS). We noticed an obvious link between some bright pixels in the SAR image and the presence of houses isolated in meadows.

The algorithm [1,2,5] that computes the energy received by a parcel of land comprises three main steps. The equations are written in a local axis system. The axes are oriented along N-S and E-W directions. Several approximations were made: the program assumes a transparent atmosphere and shadows are not taken into account. Nor do we consider the parcel's altitude. The first step is the computation of the slope magnitude and orientation of the parcels. The pixel slope is computed by considering a square vignette of nine pixels centred on the pixel. We fit the 9 pixels area by a 2nd order surface. The desired slope is the value of the first order derivative computed at the centre of the vignette. By this we determine the normal of the pixel:

$$Nx = \sin(p) * \sin(g) \quad (1)$$

$$Ny = \sin(p) * \cos(g) \quad (2)$$

$$Nz = \cos(p) \quad (3)$$

where p is the slope magnitude and g the slope orientation. The second step is the computation of the Sun’s position in the local axes system. The position of the Sun is given by:

$$Sx = \cos(h) * \sin(a) \quad (4)$$

$$Sy = \cos(h) * \cos(a) \quad (5)$$

$$Sz = \sin(h) \quad (6)$$

where h is the altitude and a the azimuth of the Sun.

Altitude and azimuth can be computed easily by applying spherical trigonometry:

$$\sin(h) = \sin(\varphi)\sin(\delta) + \cos(\delta)\cos(\varphi)\cos(ts) \quad (7)$$

$$\cos(a) = \frac{\sin(\delta) - \sin(\varphi)\sin(h)}{\cos(\varphi)\cos(h)} \quad (8)$$

where *f* and *d* are respectively the latitude of the considered pixel and the declination of the Sun. *ts* is the the hour angle. The third step is the computation of the energy. The angle between the normal of the pixel and the line that joins the pixel to the Sun is:

$$\cos(\Theta) = Nx.Sx + Ny.Sy + Nz.Sz \quad (9)$$

We should note the time-dependency of some variables Sx(t), Sy(t), Sz(t) and thus cos(q(t)). The energy received by the pixel is computed by integrating the product of the solar constant and cos(q(t)) over the considered period.

$$En_{period}(J/m^2) = \sum_{\forall day \in period} \int_{day} E_0 \cos(\Theta(t))dt \qquad (10)$$

An appropriated change of variable allows us to realise the integration with ts, the hour angle, as integrating variable.

$$ts = ar\cos(-tg(\delta)tg(\varphi)) \qquad (11)$$

Note that the declination varies continuously with time. For each day we only consider its value at 0H UTC. The algorithm uses the Simpson method for the integration [6].

An excellent copy of the old Ferraris maps (1770-77) was edited in 1965 at a scale of 1/25000. This scale was used to compare data more easily with the standard NGI map of that time. The red colour code was used for houses. Thus, it is quite easy to scan and extract the pixels that define human settlements. The geocoding of this old map was also simple, as the landscape has not changed a lot. So it was possible to find some similar points on current and old maps.

Another source for housing data is the pedologic maps. The nature of this document implies that information relative to houses is confined to a particular class (OB for building areas). The limits give us a view of the built up areas at the end of the 1950s. From 1970, planners defined and designated the areas where people could live. These limits were defined from a purely speculative approach and thus integrated all sorts of areas including humid, cold ones as well as areas with high agricultural productivity. Thirty years later, it is possible to evaluate the damage caused by this speculative approach and provide solutions to planners.

Results

Lighted DEM' s

At first glance, the statistical parameters are quite similar in the "classic" and interferometric cases. The colour map of sunlight data, in equal interval classes, offers the same impression. The extreme values are symmetrically disposed for both images. As mentioned above, due to the particular topography shape similar to corrugated iron and oriented east west, it is easy to define the global behaviour of the data:

- The first three classes, from 0 to 75, define extremely poor sunlight areas (and thus heat). They are steep slopes turned towards the north. They are geographically symmetric and/or similar to the last five classes, from 151 to 255, which are turned towards the south.
- The fourth class corresponds to gentle slopes turned towards the north. It is equivalent to the sixth class, that is, gentle slopes turned towards the south.

- The fifth class presents the summit curvature, which is a flat area.

One of the main differences between these histograms comes from the central part for the classic model where a few values are over-represented. Analysis of this data shows that the most important value in the histogram of the "classic" model (13.9% of the total) represents flat areas. The reason it does not appear in the InSAR histogram is that they are very few completely flat pixels. This is also a very good argument to demonstrate that the interferometric model is better than classic one because it’s closer to reality in the field.

Relationship between human settlements and sunlight over the last two centuries

Today, the «plans de secteur» (land management maps) define areas where it is possible to settle. They show the old villages that are the cores of present-day, more extended, urban areas. These are characterised by an octopus-shaped configuration that stretches along the main roads. At the beginning of the 1970’s, such areas were defined from a speculative point of view and environmental characteristics were not taken into account in the final decision. Consequently, some areas where nobody should have lived were integrated in the urban tissue.

Since then, geological hazards, such as floods and rock falls have induced damages that recall the importance of considering natural constraints in land planning. Consequently, if we are able to localise the best places for sunlight conditions, places that people chose in past centuries, we will also be able to define urban areas of the «plans de secteur» that are not really attractive, either for building or to live in.

The comparison between the houses on the Ferraris maps (1770-77), present urban areas on the «plan de secteur» and the light data must be analysed attentively and in detail. First, we need to consider one or two pixels of error in the location of each piece of data. Secondly, we use the convention that the true location of the microclimatic limit passes, at best, roughly through the limit of the patch of same class. Let's analyse some cases:

Fraiture: This village is settled near the top of a hill. Our interpretation is that the precise location seems to be just below the curvature change, where the slope and thus the amount of light received increases, making a significant difference in living conditions. More towards the bottom, the values of the slopes are too high to build there. Note that the housing locations are stretched east to west, along this curvature change.

Today the «plan de secteur» integrates parts above and below the extended old building area without taking into consideration either that area's origin or the location of the old village.

Lillé: This interesting hamlet is located on the northward flank of a hill. It is composed of two groups of houses. We postulate that northward flanks are not interesting because of the lesser amount of light they receive. Nevertheless, the location of the northern patches of houses is very interesting. It's situated just over a flat area that receives more light than the surrounding zones facing north. The study of the southern patches of houses on the Ferraris map was not so evident due to an error in location on the original document. The comparison with a current map allowed us to correct this error. We observe the same results as in the northern patches. Today the urban area also includes very poorly lighted areas, especially near the southern patch of houses. We observe a kind of gap between two cold areas integrated in the plan de secteur and the southern patch of houses is located precisely within that gap.

Presseux: Like Lillé, this village is located on the northward flank of a hill. The most interesting observation is that housing patches are stretched from Southeast to Northeast. This is exactly the place and the direction of a small area that receives more light than the immediate surroundings. Today the "plan de secteur" includes all the really poorly lighted areas.

Dolembreux: Maybe the exception. It is the only place in all of Sprimont completely located inside a poorly lighted area. This example gives us proof that there are no simple rules providing an explanation for the

In all, we analysed 14 hamlets and villages in the district of Sprimont. The conclusions of our interpretation on this small sampling are as follows:
We analysed the presence of classes of sunlight inside building areas for two kinds of DEMs (classic and interferometric) and for two periods (1770-77 and 1970-80).
We observe that in all periods and in all models the mean and upper means (class 5 and class 6) are best represented. It is only for the classic model, during the recent period, that we can find equivalence between the lower and upper means. The difference between the lower and the upper mean is always greater for the interferometric model than for the classic one.
If we are only interested in statistical parameters we conclude that houses, in the case of the old maps, and the urban areas in the plan de secteur, must be considered as samples that reflect global sunlight distribution. However, the sample represents human settlements and small variations can be explained by human behaviour. In both Lillé and Presseux, the housing pattern reflects the distribution of the sunnier areas in a very restricted environment.
The statistical parameters of global sunlight distribution for houses give no information about the way that houses are distributed in the field. It might be possible

to mathematically describe the relative organisation of houses. However, the human brain does that easier than an algorithm...

Conclusions

About geocoding

Our InSAR data were projected in UTM co-ordinates with a poor accuracy of a few kilometres, which is the accuracy in the location of the four corners of the SAR image. This is not accurate enough for the themes we had hoped to discuss. In order to use sunlight data inside a GIS, we solved the problem of geocoding by using ground control points. However, the lack of legibility of the SAR image allows a precision of one or two pixels, which means 40 to 80 meters in our case.

When geometric correction parameters are defined, we apply the transformation to the InSAR DEM. The test area's limited dimensions allows this kind of approach, because the amount of work entailed is acceptable in a feasibility study. However, in a real-life operational situation, a more efficient approach to geocoding would be required (i.e., an efficient geometric correction program). Future research will focus on this very important point. Research is currently underway at the CSL to improve geocoding precision by using the external global DEM to project the SAR images and/or computed DEMs.

Sunlight data

The differences between "classic" and InSAR sunlight files can be explained by the nature of the topographic surface. The "classic" DEMs are generated from a complex interpolation of elevation data digitised from contour maps. The InSAR DEM represents the retrodiffusion surface of incident waves. Consequently, land use influences the topographic surface shape. This is also the case for the "classic" model, but for other reasons. Topographic maps are first designed for military use. Therefore, in urban areas, for example, the most important information is the relative position of houses, roads and factories. Thus, contours do not appear. Similarly, for extraction zones, the main lines are drawn in order to give the most important features of the extraction area rather than the correct position of the elevation value through the contour lines. When a "classic" DEM is built, this lack of data is often compensated by the imagination of the person responsible for the digitalisation. In our case study, several quarries were even erased!

The test area is composed of: 20 percent, urban and quarry areas; 23% wooded areas (broad-leaved trees and firs) and 57%, meadows. For the meadows, topographies are the same, except where farms exist and the results are roughly similar for the wooded areas. For urban areas and quarries, the differences are greater, but it depends on the place. At present, we have not extracted a rule that would allow us to predict places where we can forecast differences. From a statistical

point of view, it is thus obvious that the correlation between parameters is near 0.7: good correlation with meadows, plus a small part from wooded
areas.

Application Opportunities

The realisation of a light map for the whole Walloon region could be useful for all of the following: to evaluate the correlation between agricultural and forest productivity for different species and light data; within the framework of sewer planning: definition of the best location for purifying stations using photosynthetic bacteria; realisation of an epidemiological study to check if a relation exists between the number of persons suffering from nervous depression and the location of poorly lighted houses; comparison between the location of poorly-lighted areas and the thermal profile of motorways.

Acknowledgements

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CHAPTER VIII

LAND PLANNING AND INFRASTRUCTURE, URBAN AND SUBURBAN ENVIRONMENT

RESEARCH CONTRACT T4/02/008

ADAPTIVE MODEL-BASED CHANGE DETECTION IN TEMPORAL SAR SATELLITE IMAGE SEQUENCES

J. D'HAEYER

UNIVERSITEIT GENT (RUG)
DEPARTMENT TELECOMMUNICATION AND DATA PROCESSING
St Pietersnieuwstraat 41
B – 9000 GENT
BELGIUM

1. CONTEXT AND OBJECTIVES

The project aims at the development of more advanced techniques for change detection by making use of semantic information in the form of reference images. Instead of detecting the changes at the level of the individual pixels it is intended to detect changes at higher semantic level by using model based segmentation techniques.

Methods for the automatic construction of the models of the context will be developed.

The research will focus on monitoring using temporal SAR-satellite imagery. The specific speckle noise is problematic for change detection methods based on image differences. Segmentation methods that exploit textural homogeneity will be studied.

2. DATA

Geographic study area: Brussels, Leuven and Mechelen in Flemisch Brabant (Belgium)

Satellite imagery used:

ERS 1 : January, April, August, November 1993

ERS 2 : January, April, August, November 1997

Other data: Weather data from Royal Meteorological Institue of Belgium

3. EXECUTION

Period: 01/12/1996-30/11/1998

Laboratory:

UNIVERSITEIT GENT (RUG)

Department Telecommunication and Data Processing

St Pietersnieuwstraat 41, B – 9000 Gent, Belgium

Phone: +32 9 264 34 14   Fax: +32 9 264 42 95

E-mail: Johan.DHaeyer@rug.ac.be

URL: http://www.ftw.rug.ac.be/vakgroepen/default.htm

4. RELATED DISCIPLINES

Urban & suburban

General Earth observation

5. EXECUTIVE SUMMARY

The localisation and identification of significant changes in image sequences is an important task within the exploitation of satellite image data for monitoring purposes. With the growing availability of high resolution satellite imagery, the need for sophisticated automatic or semi-automatic aids for data processing is significant.

The available change detection methods in temporal image sequences use difference images and as a result are highly sensitive to registration errors as well as photometric or radiometric conditions. Even if techniques would be developed for the elimination of all the differences due to image creation, there would still be differences of which the significance can only measured by image processing specialists, familiar with the observed scene.

This project studies the development of more advances techniques for the detection of changes in image sequences, where semantic information in the form of reference images will be used. Instead of detecting changes on the level of the individual pixels, we propose to detect changes on a higher semantic level by using **model based techniques**. Within this paradigm, the detection process is guided by the use of image models describing expected changes. This allows the filtering of irrelevant image noise and results in a detection scheme, which is more robust.

The research will focus on monitoring using **Synthetic Aperture Radar** (SAR) imagery. While still relatively unexplored compared to the more popular optical and infrared sensors, SAR offers distinct advantages (day/night imaging, independence of weather conditions) which in monitoring applications are of special interest. The challenge lies in identifying the information content of radar, which could be efficiently and reliably used. Within this project, one thematic application has been explored, which showed promising results, namely the detection and monitoring of **urban areas**. This applications is of high interest in the current market and the advent of the high-resolution sensors (3-10 m spatial resolution) has made this theme accessible using space imagery. Compared to traditional aerial photography, which up to now has been the preferred observation tool for this application, space imagery offers standardised products on a timely basis. The integration of automated analysis techniques and space imagery then allows an objective, uniform tool, reducing human (i.e. variable) interpretation in the detection phase to a minimum.

PILOT PROJECT T4/12/024
FEASIBILITY STUDY T4/12/048

USE OF SATELLITE DATA FOR THE DECENNIAL UPDATE OF THE DIVISION IN STATISTICAL SECTORS OF THE KINGDOM (T4/12/024)

ASSESSMENT OF THE CONTRIBUTION OF THE MIR SPECTRAL BAND OF SPOT 4 FOR THE MAPPING OF LANDCOVER : APPLICATION TO THE DELINEATION OF BUILT AREAS (T4/12/048)

J.-P. DONNAY

UNIVERSITE DE LIEGE (ULG)
DEPARTMENT OF GEOMATICS
Laboratoire SURFACES
Allée du 6 Août 17, Bâtiment B5, Sart Tilman
B – 4000 LIEGE
BELGIUM

1. CONTEXT AND OBJECTIVES

1.1 T4/12/024

The Belgian National Institute of Statistics (NIS) has decided to adjust its basic census districts or statistical sectors for the 2001 census of population and housing. Indeed, many statistical sectors and agglomerations boundaries do not fit anymore because of urban growth and rural settlement development. The last updating took place with the 1981 census. It was a long and lasting job performed by traditional way based on aerial photo interpretation. The NIS wants to take advantage of new technologies to accelerate the process and make it more objective. NIS has decided to use a methodology developed by Laboratory SURFACES and using an image processing system with SPOT satellite images and GIS software.

1.2 T4/12/048

The INS (Institut National de Statistique) and other governmental or regional administrations which have a heavy need in ground occupation data for economic or land planning and management purposes more and more rely on remotely sensed image data to acquire the necessary information. With the launch in early 1998 of the SPOT 4 satellite, SPOT Image not only ensures continuity in the acquisition of its traditional image data but also provides an improvement of its multispectral image products by adding a new 20 metre resolution mid infrared (MIR) channel to the previous three channels. The principal objective of this feasibility study is to test the general quality of these new four band multispectral images of SPOT 4 and to find out how the new MIR channel contributes to an improved image classification of land cover, with a special aim at the delineation of built areas. The new MIR channel is highly sensitive to soil and leaf moisture, making it especially useful for improving analysis of vegetation cover and soil cover types. The aim of this study is to analyse how this channel also contributes to the improvement of the discrimination of other features especially in urban areas. The general methodology which will be used in this study is to compare the results of three-band versus four-band analysis of the new SPOT 4 image over some test areas, which have already been the object of previous studies and for which other ancillary data are available, in order to be able to effective improvement bound to the new channel.

2. DATA

Geographic study area: The whole Belgium.

Satellite imagery used :

A selection of 59 SPOT images from the two multispectral covers of 1995 and from the panchromatic cover of 1996.

Other data:

- Vector polygons of statistical sectors and associated database with evolution of population (1981 to 1997);
- A selection of NGI orthophotoplan (Black and White – 1 m geometric resolution);
- NGI Topographic maps;
- Vector polygons of the recent communal boundaries.

3. METHODOLOGY

The different procedures used by the method are:

- Geometrical correction of the SPOT images;
- Merging of multispectral and panchromatic images;
- Tracing of the built area map by classification;
- Delimitation of built areas and construction of a Boolean mask; dilatation followed by erosion procedure (morphological closing) in order to regroup built areas closer than 100 meters from each other;
- Detection in rural sectors of all built nucleus from 3.0 to 9.9 ha, from 10.0 to 19.9 ha and 20.0 ha and more;
- Selection of relevant high resolution digital orthophotoplans;
- Creation of new statistical sectors by heads-up digitising on top of the selected orthophotoplans;
- Trial to delimit the boundaries of urban agglomerations over 9 ha, according to 200 meter EUROSTAT distance criteria.

4. OUTPUTS AND RESULTS

The main products and results delivered by the laboratory SURFACES are:

- A digital cartography with built areas appeared in dispersed settlements sectors;
- A selection of relevant orthophotoplans;
- A digital cartography with a trial of urban agglomeration boundaries determined according to 200 meters EUROSTAT criteria;
- A trained staff.

These deliverables help the NIS to finalise the statistical area partition, to determine its content in terms of street sections and buildings for the 2001 census.

5. EXECUTION

Period: 15/12/1997-31/12/1999 (T4/12/024)
01/01/2000-12/02/2000 (T4/12/048)

Laboratory:

UNIVERSITE DE LIEGE (ULG)
Department of Geomatics
Laboratoire SURFACES
Allée du 6 Août 17, Bâtiment B5, Sart Tilman, B – 4000 Liège, Belgium
Phone: +32 4 366 54 24 Fax: +32 4 366 56 93
E-mail: donnay@geo.ulg.ac.be
URL project: http://www.geo.ulg.ac.be/binard/INS_web_En.htm

User partner:

INSTITUT NATIONAL DE STATISTIQUES (INS)
Rue de Louvain 44, B – 1000 Bruxelles, Belgium
Phone: + 32 2 548 63 65 Fax: + 32 2 548 63 66
URL: http://statbel.fgov.be/

6. RELATED DISCIPLINES

Land planning & infrastructures
Urban & suburban
Cartography
Economic issues
Agriculture

7. EXECUTIVE SUMMARY

Introduction

To meet the recommendations of international institutes, the needs of local authorities and to guarantee the historic follow-up after the fusion of communities, Statistics Belgium has taken the initiative to divide the communal territory into statistical sectors. They are also used as a basis for the population census per judicial district.

The latest division into statistical sectors dates from 1981 and is no longer adapted to the present boundaries of the agglomerations. Therefore Statistics Belgium has decided to update the boundaries of the sectors and in the mean time to automate their processing, to redefine the boundaries of the principal Belgian agglomerations in accordance with the EUROSTAT criteria and to develop a geographical information system with a view to the census of 2001. The defining of the boundaries of the principal agglomerations and the development of a geographical information system is in agreement with the programme 1998-2002 of EUROSTAT.

Statistics Belgium wants to use modern techniques such as remote sensing and image processing to improve the impartiality and speed of the activities. Ideally, each new census should be accompanied by an update of the division into statistical sectors. Furthermore this first usage of spatial remote sensing data by Statistics Belgium must be considered as an innovative step that, within Statistics Belgium, undoubtedly will initiate other applications of high resolution (HR) and very high resolution (VHR) data.

Thanks to the production procedure set up during this pilot project, rural zones with new habitat nuclei could be detected on HR satellite images. Then the statistical sectors were updated at Statistics Belgium through computer-assisted photo-interpretation (C.A.P.I.) on the orthophotomaps of the IGN (Institut géographique national) due to delays in the various spatial programmes that use VHR sensors.

Finally, a first delimiting of the large morphological agglomerations in accordance with criteria close to those of EUROSTAT has been carried out. An estimate of the cost of the pilot project has been made for the laboratory SURFACES as well as for Statistics Belgium.

Data used

- In the framework of this project multispectral SPOT coverage of 1995 and panchromatic SPOT coverage of 1996 were used. The total size of the files containing 59 images amounts to about 2 gigabytes ;
- The Walloon Region and the Flemish Region have provided the project with the files containing the boundaries of statistical sectors of 1981. The database that is linked to each of the 19 374 sectors has been enlarged with the figures of the population evolution from 1981 until 1997 ;
- The orthophotomaps of IGN have been produced using aerial photographs at 1/40 000. The complete coverage of Belgium at a sampling interval of 5 m, as well as a limited number of orthophotomaps at full resolution (1m) were used;
- Scanned images (black and white) of topographic maps at 1/10 000 are used as a base map for the vector information of the statistical sectors.
- The most recent municipal boundaries will be used for the situation of 2001.

Methodology

The different steps that led to the update of the statistical sectors in the rural zones are mentioned hereafter.

- Geometric corrections were made in two steps: firstly, the panchromatic is corrected according to the orthophotomaps (5 m spatial resolution) of the IGN, secondly, the multispectral is rectified in accordance with the panchromatic. As the area to be treated is fairly large and there is no digital elevation model available in the framework of this project, a simple first order correction model was applied to the images. The nearest-neighbour resampling algorithm was used in order to preserve the spectral information. In general, the mean quadratic error is lower than the size of the pixel (10 m for the panchromatic and 20 m for the multispectral) except for certain images in Upper Belgium where the dynamic of the relief is too important to observe this criterion.

- Panchromatic and multispectral data have to be merged for the photo-interpretation of automatic classifications. The merging method used in this project, equalises local means and variances. It was developed in the laboratory.

- Belgium was divided into 22 work zones such as to cover the whole of each sector by identical satellite data (no changing of the image in the middle of a sector).

- Successive « automatic » classifications followed by an interpretation, were produced adding refinement for the « strategic » classes and for the « sensitive » sectors. Although the classification was especially produced to detect habitat nuclei, the following 6 keys were used: stretches of water, cultivation and waste land, woods, pasture, built-up, non classified. The interpretation of the results of the « successive » classifications is facilitated by the colouring of the intermediary results. The final classification is transformed into a simple built-on mask.

- A generalisation of the built-up layer is obtained through a morphological closing procedure on a window of 100 m diameter (an extension followed by an erosion) which makes it possible to fill in most discontinuities of less than 100 m observed in the built-on mask. This generalisation makes it possible to apply the Statistics Belgium criterion of built-on continuity, necessary to detect the nuclei.

- The built-up nuclei, to be detected in the framework of this pilot project, have to meet the following criteria: be located on a dispersed habitat sector (code 8 or 9) ; have a surface of more than 3 ha. The following typology was used to evaluate the importance of the need to update: type 1 (3 to 10 ha) ; type 2 (10 to 20 ha) and type 3 (more than 20 ha). Next, the vector files to delimit the nuclei are sent to Statistics Belgium. Furthermore, they are accompanied by synthetic tables with in particular the total surface of the different types of nuclei for each of the sectors and for each of the orthophotomaps of the IGN. After analysis of the data, Statistics Belgium proceeds with the ordering of orthophotomaps to divide the new sectors through C.A.P.I.. The new sectors always correspond with a partition of existing sectors. A new type of coding has been set up to identify these sectors.

- The sectors digitalised at Statistics Belgium, will be digitally reproduced on the IGN base map at 1/10 000. A new overlay was developed for the map of the statistical sectors.
- Two first drafts to delimit the urban agglomerations for EUROSTAT using the thresholds of 100 or 200 m were made. Respectively 38 and 22 agglomerations could be distinguished. These boundaries could not be refined in the framework of this pilot project.

Contribution of the SPOT 4 MIR band (T4/12/048)

The pilot study focused on the estimate of gain obtained by adding the MIR band to the procedure of extracting habitat nuclei while updating the decennial division in statistical sectors. Two classifications were made according to the methodology used in the pilot project: one on the 3 channels B1, B2, B3 (XS1, XS2,XS3), another one on the 4 channels B1, B2, B3 et B4 (Xi) of the same SPOT image.

The fourth band adds nothing spectacular, it is used though for a sensitive matter, namely to decrease the confusion between waste land and built-on areas. This results in a considerable gain of time when using the Statistics Belgium methodology to detect built-up nuclei. Indeed, on the one hand, fewer nuclei have to be verified and, on the other hand, nuclei that were mistakenly detected starting from four bands are often situated alongside highways. Their elimination was thus highly facilitated.

Financial evaluation

The cost of the methodology « satellite images combined with orthophotomaps » comes very close to that of the methodology « whole orthophotomap». But, the first method is far less tedious and makes it moreover possible to obtain the habitat nuclei of the whole territory of Belgium as well as the agglomerations' limits in accordance with the distance criteria of 100 m. By means of some supplementary operations, the agglomerations can also be determined in accordance with a random distance criterion.

Conclusion

From an operational point of view, the pilot project has provided Statistics Belgium with the basic products necessary to update the boundaries of the statistical sectors:

- The list of IGN orthophotomaps corresponding with sectors that have to be verified first, namely sectors with a rural character where built-up nuclei have been detected;
- The file in *ARCView* format with the boundaries of built-on surfaces located in thinly settled sectors.

In addition the project has provided:

- 23 new statistical sectors for the Charleroi zone;
- A file in *ARCView* format with a first approximation of the agglomerations' boundaries on the country level in accordance with the Eurostat criteria. This file could be refined (suppression of communication lines, etc.) if EUROSTAT agreed to contribute to the financing of such a project;
- The training in techniques of remote sensing and GIS of the personnel of Statistics Belgium that is responsible for the division in statistical sectors;
- A methodology which, contrary to the one used in the past, enables a semi-automated processing of the division in sectors;
- A methodological remark in the final report of the project;
- SPOT XS and panchromatic images with geometric corrections and divisions according to the work zones, registered onto CD-ROM at the disposal of Statistics Belgium;
- The new presentation models of the maps with statistical sectors;
- An estimate of the purchase price and processing of the data.

The 22 treated work zones cover the 30 513 km² of Belgium of which 24 916 km² in so-called dispersed habitat sectors. The 7 467 nuclei can be divided into 3 673 sectors prone to a revision out of 6 692 so-called dispersed habitat sectors. The total surface of withheld nuclei amounts to 713 km² (Table 1). Most nuclei (5 677) belong to type 1 and occupy a surface that is slightly larger than that of the 640 nuclei of type 3 (respectively 289 and 266 km²). The 1 150 nuclei of type 2 cover 158 km². Thanks to the databases linked with vector files and to the different lists received, Statistics Belgium interprets the orthophotomaps to create new sectors.

	Type 1 (3 - 10 ha)	Type 2 (10 - 20 ha)	Type 3 (20 ha and more)	Total
Number of nuclei	5 677	1 150	640	7 467
Surface (in km²)	289	158	266	713

Table 1 : Built-up nuclei detected in the dispersed habitat sectors**.**

Setting up the method and standardising the exchanged files has taken more time than planned. Statistics Belgium is satisfied with the result and has reached the production phase. Working restrictions have determined the choice of the classification to obtain the built-on layer as well as the simple geometric image correction methods. Very specialised research is not always directly applicable to large zones or to images of varying quality. The reverse of this approach is that the produced images can only be used for this precise application. This is why this classification cannot be used for other purposes than those for which it has been developed. It was only meant for Statistics Belgium to be applied on the orthophotomaps that form a substitute of the ground truth.

PILOT PROJECT T4/DD/059 (a-b)

USE OF VERY HIGH-RESOLUTION DATA FOR THE INVENTORY OF (UN)BUILT AREAS : AN INTEGRATED METHODOLOGY INCLUDING QUALITY CONTROL, FOR FLANDERS' LAND PLANNING AND MANAGEMENT POLICY

H. DECLEIR [(1)]
J.-P. DONNAY [(2)]

VRIJE UNIVERSITEIT BRUSSEL (VUB) [(1)]
CENTRE FOR CARTOGRAPHY AND GIS
DEPARTMENT OF GEOGRAPHY
Pleinlaan 2
B – 1050 BRUSSEL
BELGIUM

UNIVERSITE DE LIEGE (ULG) [(2)]
DEPARTMENT OF GEOMATICS
LABORATOIRE SURFACES
Allée du 6 août 17, Bâtiment B5, Sart Tilman
B – 4000 LIEGE
BELGIUM

1. CONTEXT AND OBJECTIVES

The project makes use of very high resolution (VHR) satellite data and of the digital geographical data owned by OC GIS Vlaanderen. This proposal aims at in depth generation of thematic geo-information while at the same time transferring technical know how. More specifically the objectives can be summarised as follows:

- The construction of a thematic map of the built up area in selected study areas using VHR satellite imagery. This map will result from manual as well as semi-automatic image classification procedures. An analysis of errors will be performed for the semi-automatic classification and a validation will be made by comparison with the results of the manual method of photo-interpretation;
- The linking of these data to individual cadastral parcels using GIS operations as an alternative to the current procedure of inventorying the build-up parcels in residential areas applied by the individual communities;
- Extracting information from the images that is useful to the thematic partners e.g. the density of buildings and scale related properties in urban areas.

This project has as a further specific goal the promotion of the use of satellite remote sensing data in regional and local governmental planning departments.

2. DATA

Geographic study area: Cities (Gent, Hasselt) of Flanders (Belgium)

Satellite imagery used:

City of Gent : IKONOS – April 28th 2000

City of Hasselt : IKONOS – May 9th 2000

Other data:

- Gent:
  - Vector data of houses and parcels (from Vlaamse Landmaatschappij – VLM)
  - High resolution aerial photography (March 2000)

- Hasselt:
  - Black and white orthophotoplans from the National Geographic Institute (NGI).

3. METHODOLOGY

- Development of an accurate built-in map using the panchromatic IKONOS images based on Computer Aided Image Interpretation (CAII). These interpretations were made with the additional help of the fused multi-spectral images and orthoplans when necessary.
- Development of a built-up map using automatic classification algorithms, i.e. Maximum Likelihood and Neural Network classification algorithms. These procedures used the multi-spectral IKONOS images. The feasibility of textural information (Haralick contrast, Moran's I) was tested for use in the classification process. The CAII maps were used to train and validate the automatic classifications.
- Development of GIS procedures to make an inventory of built and unbuilt cadastral parcels based on CAII.
- Development of GIS procedures to give an indication of morphological characteristics of housing on CAII. Error and accuracy analysis.

4. OUTPUTS AND RESULTS

Note: Hasselt means Hasselt study area & Gent means Gent study area

- Visually interpreted IKONOS images for the Hasselt and Gent
- Automatic classified IKONOS images for Gent and partially for Hasselt
- Inventory of un-built parcels for Hasselt
- Map of the Built-up Area Index (BAI) for Hasselt
- 1 proceeding paper, 1 project poster, interim and final project report
- Organisation of a workshop, compilation and distribution of a CD-ROM with workshop presentations
- Software in Java and C for the execution of the tasks

5. EXECUTION

Period: 01/01/2000-30/06/2001

Laboratory:

VRIJE UNIVERSITEIT BRUSSEL (VUB)
Centre for Cartography and GIS
Department of Geography
Pleinlaan 2, B – 1050 Brussel, Belgium
Phone: +32 2 629 33 82   Fax: +32 2 629 33 78
E-mail: hdecleir@vub.ac.be
URL: http://www.vub.ac.be/DGGF/ccg/welcome.html

User partner:
VLM
Gulden Vlieslaan 72, B – 1060 Brussel, Belgium
Phone: +32 2 543 72 00   Fax: +32 543 76 35

6. RELATED DISCIPLINES

Land planning & infrastructures
Urban & suburban

7. EXECUTIVE SUMMARY

Introduction

In the 70's, the rather low spatial resolution of the LANDSAT Multispectral Scanner (MSS) sensor prevented the development of urban applications with remote sensing from space. In the 80's the appearance of the LANDSAT Thematic Mapper (TM) and SPOT's "Haute résolution dans le Visible" (HRV) sensors allowed a preliminary development of urban remote sensing applications from space. However, the insufficient spatial resolution of TM and the low spectral resolution of HRV also limited these applications of land use classifications in urban and suburban areas. Indeed, it is precisely in these areas that one observes the highest radiometric variations. This is due among other things to the small size and the substantial diversity of the urban objects which generates a radiometric contamination between neighbouring pixels which in turn makes object identification very difficult. Researchers have put their hopes in Very High Resolution (VHR) images. It has taken a long time for these images to become available due to numerous technical difficulties and launch failures. While waiting for VHR images to become commercially available, numerous studies on simulated data were carried out. They have resulted in the reuse of photointerpretation methods through the development of "Computer Aided Image Interpretation" (CAII) techniques. Since the successful launch of Space Imaging's satellite IKONOS-2 on September 24, 1999, and more specifically since the beginning of the image marketing in January 2000, VHR images were gradually put at the disposal of researchers.

This pilot study tried to visually interpret IKONOS-2 images over a Hasselt and Gent study area. These interpretations serve as a basis for training and validating automated classification procedures. The latter was investigated as a time consuming alternative for the costly visual interpretation. Further, we have developed some GIS procedures to automatically make an inventory of built and unbuilt parcels and to automatically give an indication of the spatial distribution of building densities in the study areas.

Computer Aided image Interpretation (CAII)

The ordering of VHR images had to take the following parameters into account :

- Maximum allowable cloud over;
- Maximum allowable observation angle (related to the horizontal accuracy);
- Window of acquisition time (interval in days and/or season);
- Geometrical accuracy : depending on the necessary precision for the application at hand, or on the importance of the available budget, the horizontal accuracy of the panchromatic images can be varied from ± 50m to ± 2m.

The CAII was realised with 5 urban land cover classes (buil-tup, water, roads & parkings, railways and unbuilt) although only the unbuilt class was necessary. The fusion of the panchromatic (1m) and multi-spectral (4m) images in a true colour phase colour infrared image was an sustainable help in the execution of the visual interpretation. These images were obtained with the Local Mean and Variance Matching algorithm (LMVM). The interpretation of the panchromatic IKONOS imagery, with additional information of the fused images and often the orthophotoplan, was digitised on the computer screen. The data were – at the same scale – simultaneously visualised on the computer screen, so that in case of doubt, the fused image or the orthophotoplan could aid in the interpretation.

The problems associated with the interpretation are very closely related to those of aerial photointerpretation : shadows, slant effects, radiometric variations due to the solar aspect and the spectral signature that is characteristic of constituent materials but not of the object's actual use (e.g. asphalt road and roofing felt).

It is important to notice that the unbuilt mask does not correspond to the actual vacant plots for new constructions. It also reflects too narrow plots of land, plots with too strong a slope, easily flooded zones, etc…

Automatic Classification

Because the CAII method is time consuming, part of this project aimed to obtain the built-up mask by automatic classification techniques. Several approaches were tested, taking the spectrally heterogeneous nature of urban areas into account.

We tested per pixel classifications using both Maximum Likelihood and Neural Network classifiers. This resulted in a methodology based mainly on in house developed software. The results of the visual interpretation were used to train and validate the classifiers. The same five classes : built-up, roads & parking, water, railroads, and un-built were used.

Taking the very high resolution of the IKONOS images into account we also tested whether adding texture to the classification would improve results. We adopted a moving window approach to calculate textural measures that were meant to be

added as neo-channels into the classification (Haralick Contrast, and Moran's I). A primary statistical analysis of the resulting neo channels showed that these texture measures, calculated with a moving window, did not increase class separation.
The accuracy of the per pixel classifications for both study areas were 56-58% for all five classes. When we added some classes together to obtain a mask of un-built areas, the accuracy was about 80% for Hasselt, and 90% for Gent. This is reasonable, but not yet sufficient for practical purposes. Especially the results obtained by the textural measures were disappointing. Future research has to be conducted to improve the method by which the textural measures are implemented. Further, no significant differences were detected in the performance of the Maximum Likelihood or Neural network classifiers.

Inventory of morphological characteristics of housing

To represent the morphological characteristics of housing, the Builtup Area Index (BAI) was implemented. This index indicates building density by taking the ratio of the built-up area by a certain reference area. We used two kinds of reference areas. The first uses a fixed window size (100 x 100 pixels) (raster approach), while the second uses the delineation of the cadastral parcels (vectorial approach), which is variable. With both methodologies, the BAI was calculated on the Computer Aided Image Interpretation (CAII) of the Hasselt study area. Further, a comparison was performed based on the available cadastral building information. Therefore, the BAI map based on the cadastral information was subtracted from the BAI map that was derived from the CAII. This resulted in a map with error contour lines. The error analysis led us to conclude that the error in BAI was higher in the city centre. For the raster approach 90% of the area has an error lower than 10%, while for the vectorial approach 75% of the area is lower that 10%. The average errors were 0% for the raster approach and –13% (underestimation) for the vectorial approach.

Inventory of (un)built parcels

The possibility to identify built or unbuilt cadastral parcels based on the interpreted or classified VHR satellite image was important objective of this project. The inventory was derived from the vectorial BAI, which was the subject of the former paragraph. A parcel was identified as unbuilt, when the BAI was 0%, the other parcels were referred to as built. An accuracy assessment of the inventory gave an overall accuracy of 84%. Although the overall accuracy of the inventory in not quite bad it is not sufficient for an operational application.

Dissemination of results

Various activities ware undertaken to disseminate the project results :

- Attendance of workshops (oral and poster presentations, proceedings)
- Organisation of the workshop on current and future use of VHR satellite imagery in Belgium, 29th June 2001, Brussels.

PILOT PROJECT T4/10/069

INTEGRATION OF IKONOS DATA WITH EXISTING DATA SOURCES TO MONITOR LOCAL IMPACTS OF RAPID HUMAN DISTURBANCES AND NATURAL HAZARDS

E. LAMBIN

UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL)
DEPARTMENT OF GEOLOGY AND GEOGRAPHY
LABORATORY OF REMOTE SENSING AND LAND USE CHANGES
Place Louis Pasteur 3, Bâtiment Mercator
B – 1348 LOUVAIN-LA-NEUVE
BELGIUM

1. CONTEXT AND OBJECTIVES

The purpose was to compare IKONOS data with various other data sources, for the updating of topographical maps, to produce a vegetation map, which can serve as input in hydrological models, and to map expansion of rural settlements and urbanisation. A further purpose was to present a methodology to integrate multi-source remote sensing data into a consistent time series of land cover maps in order to carry out change detection.

2. DATA

Geographic study area: the Kavango river of Namibia

Satellite imagery used:

IKONOS April 2001 – Divundu area

LANDSAT TM7 March 2001

Other data:

- Aerial photographs of the Kavango river:
  - 800 images acquired in October 1998
  - 800 images acquired in April 1999
- Orthoimages obtained with the compliments of the Surveyor General of Namibia. The images were captured in 1996.

3. METHODOLOGY

- All data taken into account in this project were first analysed according to the needs of the updating of topographical maps at scale 1:50.000 and 1:250.000, as it is currently done by the Directorate of Survey and Mapping of Namibia.
- IKONOS data were used in a multi-sensor approach to map rural settlements in Northern Namibia and to detect changes in settlement patterns over a 5-year period.
- We conducted a vegetation and land cover classification on the floodplain and surrounding area of the Kavango River in Namibia.
- We developed a method to increase the comparability between land cover maps coming from panchromatic aerial photographs, multispectral remote sensing data and/or historical land cover maps by harmonising their levels of thematic content and spatial details.

4. EXECUTION

Period: 01/07/1999-30/11/2001

Laboratory:

UNIVERSITE CATHOLIQUE DE LOUVAIN (UCL)
Department of Geology and Geography
Laboratory of Remote Sensing and Land Use Changes
Place Louis Pasteur 3, Bâtiment Mercator, B – 1348 Louvain-la-Neuve, Belgium
Phone: +32 10 47 44 77 (or 28.73) Fax: +32 10 47 28 77
E-mail: lambin@geog.ucl.ac.be URL: http://ftp.geog.ucl.ac.be/TDAR/Ftdar.html

User partner:

NADAR
Place de la Belle Maison 15, B – 4570 Marchin, Belgium
Phone: +32 85 25 41 53

5. RELATED DISCIPLINES

Hydrology & freshwater resources
Agriculture
Environment
Land planning & infrastructures
Cartography

6. EXECUTIVE SUMMARY

This pilot study was conducted in Northern Namibia. The purpose was to compare IKONOS data with various other data sources, for the updating of topographical maps, to produce a vegetation map, which can serve as input in hydrological models, and to map expansion of rural settlements and urbanisation. All data taken into account in this project were first analysed according to the needs of the updating of topographical maps at scale 1:50.000 and 1:250.000, as it currently done by the Directorate of Survey and Mapping of Namibia. IKONOS data have mapping capabilities comparable to the colour aerial photographs used in this study, but have the disadvantage of being much more expensive and less suitable for studies covering large areas. IKONOS data were used in a multi-sensor approach to map rural settlements in Northern Namibia and to detect changes in settlement patterns over a 5-year period. Integration of IKONOS data with high-resolution aerial photographs in a time series analysis allows us to monitor rural settlements and even detect settlement changes linked to the establishment of temporal dwellings. A spatial resolution of 1m, with the fusion of panchromatic and multispectral

information of the IKONOS data proved indispensable for the detection of the smaller family units. We conducted a vegetation and land cover classification on the floodplain and surrounding area of the Kavango River in Namibia. Both IKONOS and colour aerial photographs allowed for the mapping of riverine vegetation, which could not be recognised on the lower-resolution imagery. The automatic classification of satellite images clearly is a big advantage compared to the manual interpretation of aerial photographs. A further objective was to present a methodology to integrate multi-source remote sensing data into a consistent time series of land cover maps in order to carry out change detection. We developed a method to increase the compatibility between land cover maps coming from panchromatic aerial photographs, multispectral remote sensing data and/or historical land cover maps by harmonising their levels of thematic content and spatial details. Finally, a cost comparison was done to investigate the added value of each image type used in the study and to present optimal solutions for governmental departments in developing countries.

Fluctuations in the quality of remote sensing data can be very high. The potential for interpretation of these data has a direct incidence on the cost (good data will require less field work). For a mapping institution, it is much easier to impose data quality norms (and to control their application) when they order aerial photography. Satellite imagery will be provided in multiple scenes, many having variable acquisition date and quality. The mapping institution has practically no control over the quality, and can be contractually forced to pay for data having actually a low potential for mapping. This risk will seldom be taken by these institutions.

PILOT PROJECT T4/12/071

INTEGRATION OF VERY HIGH-RESOLUTION SATELLITE IMAGERY WITHIN THE CARTOGRAPHIC CHAIN OF THE WALLOON REGION: CHANGE DETECTION ON NUMERIC ORTHOPHOTO MAPS

J.-P. DONNAY

UNIVERSITE DE LIEGE (ULG)
DEPARTMENT OF GEOMATICS
LABORATORY SURFACES
Allée du 6 Août 17, Bâtiment B5, Sart Tilman
B – 4000 LIEGE
BELGIUM

1. CONTEXT AND OBJECTIVES

Some authorities (DGPL) of the Walloon Region (Belgium) are involved in the realisation of a complete regional coverage (16,844 km2) of natural colour ortho-photomaps to be used at large scales (up to 1:4000). These are made of very high resolution digital ortho-rectified aerial photos presented as raster files. Those raster files are grouped by corresponding administrative boundaries and distributed to the local authorities in order to be used for various land and urban planning purposes. One goal of the DGPL is to provide the local administrations with up to date image data, within the limits of some obvious financial constraints. Because significant changes in the landscape appear at different rates over time and space, it was suggested to devise a methodology to find out where these changes would require a rapid update of the imagery. In regard to this situation, a pilot project has been set up in the year 2000, aiming at detecting the location, the extent and the nature of landscape changes in contrasted areas – urban, suburban, rural – from adequately processed very high resolution (VHR) satellite images – typically IKONOS multi-spectral (4m) and panchromatic (1 m) images. Hence, this project deals with various issues related to multi-source analysis, geometric and radiometric aspects of processing VHR data, diachronic analysis, in order to provide the administration with the basic knowledge and the appropriate tools to carry out the proposed task.

2. DATA

Geographic study area: Wavre & Ottignies-Louvain-la-Neuve (Belgium)
Satellite imagery used: IKONOS images of Louvain-la-Neuve, Ottignies, Liège, Bierset
Other data: PPNC, DTM of IGN and DTM of PICC

3. METHODOLOGY

This research presents the proposed operational methodology for change detection including all the processing steps from the digital image processing (image fusion technique, ortho-rectification analysis, change detection schemes). Along the way it also introduces an assessment of the possible complementarities and convergence of VHR satellite imagery and aerial photography. Many change detection methods are documented in the literature, though only a small number of these are appropriate in the case of concern. In every case however, a new set or series of geographical and/or image datasets conveying the information of the actual ground occupation will have to be acquired and used as a comparison reference to the ortho-photomap imagery.

The change detection method chosen in our case study is based on the direct comparison of the ortho-photomap and the classification result of a most recent VHR satellite image taken as reference. To be short, we will have to go through the following sequence of steps to set up and perform a complete change detection analysis: acquisition of the source materials to be compared with the actual photomap coverage as also the ancillary data necessary to prepare the datasets; preparing the acquired data to fit the geometry of the photomap, in order to allow direct comparison between the diachronic datasets; specific pre-processing tasks to perform the actual diachronic analysis in order to facilitate the comparison stage; performing the comparison study and quantifying the results.

In all cases the methodology has to remain simple and efficient as it is to be implemented and used on a routine basis within the DGPL administration. Also, all the processing steps were performed keeping in mind the actual hardware equipment and software availability of this administration which at the time being sums up to current database creation and management tools, the ESRI's ArcView 3.x GIS software package, and to be acquired in the near future, the Erdas Imagine basic image processing software, upgraded to allow for the ortho-rectification (Imagine OrthoBASE module) of satellite images.

4. OUTPUTS AND RESULTS

The topics discussed in this paper show that in order to define a policy for the progressive renewal of the coverage of ortho-photomaps derived from aerial photography, a viable alternative is to proceed to a diachronic analysis for change detection between the actual cover and VHR satellite imagery. The resulting analysis provides an indication of where a coverage renewal would be appropriate and constitutes thus an aid to any decision process for this matter. It is of course now up to the DGPL administration to proceed to the diachronic analysis and to produce the concomitant change detection map for the whole region.

For now, part of the proposed methodology rests on a somewhat tedious manual screen digitising procedure. However, in a near future, with increasing quality of the acquired ortho-photomap coverage, as also with a progressive improvement of the organization of - and the access to - the available ground occupation databases, this task of updating will certainly evolve towards more automation. A particular attention should be paid to the existing PICC database, which unfortunately could not be incorporated in time into this case study. The proposed methodology relies on sophisticated technologies involving digital image and GIS processing for which specific training is required. This expertise could be provided with the aid of appropriate consultancy such as can be offered by university departments involved in remote sensing and GIS related matters. A symbiosis with some research

departments would be an efficient manner to assist the introduction of high technology into the administrations and to keep the necessary knowledge and skills up to date. It would result in improved product and service quality and also enable the administrations to become less dependent of some monopolistic private companies.
Another topic of vital interest in relation with our subject is the rapid evolution of spatial imagery products. Although currently available satellite images can serve many purposes, 1 m resolution panchromatic imagery still doesn't compete favourably with the 40 cm resolution colour images stemming from aerial photography, and are therefore less suitable for many spatial planning surveys and management activities at large scale. But that was for yesterday. Today, new generation satellites are planned, some are already orbiting, and start producing higher resolution images - for now up to about 70 cm resolution - at a very competitive price of a few tens of dollars per km2, depending upon the quality of the ordered product. Such images would almost certainly provide a viable alternative for replacing aerial ortho-photos in areas of slow rate of change such as rural and forest land. Whatever, these facts clearly show the evolutionary trends: better image quality, product homogeneity, reduced costs, complete coverage acquired within reasonable delays, and rapid revisit times. What else could we ask for ? Within this scenario the answer for updating an image database is of course immediate. And how logical and cost-effective would it be to get all the administrations concerned to agree on a common acquisition of such an image cover, all of them are hungering to use for their own needs. It would benefit to all.

5. EXECUTION

Period: 01/07/1999-31/05/2002

Laboratory:

UNIVERSITE DE LIEGE (ULG)
Laboratory SURFACES
Department of Geomatics
Allée du 6 Août 17, Bâtiment B5, Sart Tilman, B – 4000 Liège, Belgium
Phone: +32 4 36 65 424 Fax: +32 4 36 65 693
E-mail: donnay@geo.ulg.ac.be URL: http://www.geo.ulg.ac.be/Surfaces/

User partner :

MINISTERE DE LA REGION WALLONE
Direction Générale des Pouvoirs Locaux (DGPL)
Résidence Concorde, Rue Van Opré 91, B – 5100 Namur, Belgium
Phone: + 32 81 32 37 11 Fax: + 32 81 30 90 93

6. RELATED DISCIPLINE

Land planning & infrastructures

7. EXECUTIVE SUMMARY

This communication was presented at the International Symposium of Remote Sensing of Urban Areas : DONNAY J.-P., SEBA G., de BETHUNE S., LEGROS G. & BINARD M. (2002). A Methodoly for Updating Large Scale Ortho-Photomaps by Means of VHR Satellite imagery. *Proceedings of the 3rd International symposium of Remote Sensing of Urban Areas*, Istanbul, Tome II, pp. 575-583.

Introduction

Since the nineties we have entered the era of high-resolution satellite data and of large-scale digital ortho-photography. During those years, the DGPL administration (Direction Générale des Pouvoirs Locaux) of the Walloon Region (Belgium) started the build-up of a complete cover of very high resolution ortho-photomaps stemming from scanned aerial photographs, for an area of 16,844 km^2. Having no technical background in this field, the administration was not directly involved in the production process of the ortho-photomaps, but ordered them from two private companies. The overall cost for the total coverage has grown to well over 260 EUR per km^2.

Until now, the main task of the DGPL has been restricted to the distribution of the images to the local municipalities, for them to use in the course of various land and urban planning projects. However the DGPL is well aware that keeping spatial datasets current to reflect a rapidly changing landscape is a true logistical challenge and a potentially costly enterprise. It has also realised, together with other administrations involved in spatial land management topics, the necessity to acquire itself the basic knowledge and skills and therefore also the equipment and personnel to appropriately deal with such matters.

In consequence, and as a first approach towards this policy, this project has as principal objective to identify and evaluate tools and technologies for cost effectively updating high-resolution ortho-photos. Embedded in this objective is to provide the administration with a potential methodology to investigate the image database in order to decide where, when and how to go for a renewal of a series of VHR ortho-photomaps. The main decision criteria will essentially be deduced from the results of a change detection analysis performed between the actual ortho-photomap cover and a recent coverage of a VHR satellite image, namely an IKONOS 4 m multi-spectral image pan-sharpened to a 1 m resolution.

To proceed, we shall first give a brief description of the actual state of the ortho-photomap cover, before coping with the change detection analysis and its corollaries.

The ortho-photomap image database

In order to get a first insight into the problem, a database with the most relevant characteristics of the image cover was produced, revealing some surprising facts: profusion of image acquisition dates, image and filename formats, image sizes, colour and spatial resolutions, and varying and sometimes poor image quality.

At the present time, the image database consists of over 4200 distinct ortho-photos, almost half of which were taken during the summers of 1997, 1998 and 1999, in a series of 6 different flights. For the time being earlier flights remain undocumented. All the images are registered to the Belgian Lambert 1972 system.

Most of the images have a spatial resolution of 40 cm, and are clipped into tiles of 2 x 2.5 km², in concordance to the grid of the Belgian national topographic base map. The remaining images (more or less 300) are cut into varying sized – ranging from less than 1 to over 60 km² – often overlapping tiles. These images also have different spatial resolutions, ranging from 25 to 80 cm pixel sizes. They most probably correspond to the first ortho-photos provided by the private companies and unfortunately cover the more dense and populated urban and industrial areas of the Walloon Region, namely the cities of Liège, Charleroi and Namur.

All the ortho-photos are provided either as 8-bit colour images or as compressed jpeg files with as a consequence, the concomitant loss of much of the fine and detailed spectral information of the original aerial photographs. This makes these images totally useless in the scope of any automatic feature extraction process by image classification means.

Clearly, from this simple analysis, due to the ageing and sometimes to the rather poor image quality of the original cover, it already seems evident that some first potential candidate areas for updating could be located on flight lines over the three main cities in the north of the Walloon Region, Liège, Namur and Charleroi, where rapid changes are known to have taken place.

From this short overview, the need also clearly arises for a comprehensive definition of image product quality if the DGPL is to order new photogrammetric flights in the future.

Change detection analysis

The objectives of the analysis

It is well known to land managers and planners that in rapidly developing areas the currency of spatial data can be very short-lived, even, in some instances, as short as a year. On the other hand, in more static areas, where no development has occurred, or where the area is already fully developed, photographic coverage may sometimes be usable for over five to ten years.

Hence, in order to define a policy for a selective and progressive update of the imagery, the study essentially amounts to establish a method on how to determine which areas of the Walloon Region have undergone significant change since the last acquired image cover, and how to determine the relative magnitude of the change as also the priority of each change area, keeping in mind that the cost of acquisition of ortho-imagery also increases measurably on a unit basis for smaller areas under study. Then, the final decision remains in the hands of the administrative authorities who may still have to take into account other selection criteria than the simple cost effectiveness of the undertaking or a simple priority ranking.

At the present time, as mentioned earlier, some areas are already known to be on a priority list, without even to have the data to be controlled much further. Similarly, other areas are known to be less prone to change and wont ask so much time for the controlling process to confirm lower priority. This is of course the case of the 30% of territory covered by forest and of the 45% of the Region mainly covered by agricultural land. Therefore, the methodology developed hereunder applies more specifically to critical areas where it is not immediately clear from other sources, which level of priority to give, or to confirm priority assumptions. These areas correspond in most cases of intermediate to highly urbanised environments.

The final goal of course is to come up at the end of the control process for the whole region with some sort of priority map based on this change analysis, to be used as a consistent aid in the decision making process.

The different processing stages of the change detection analysis

Many change detection methods are documented in the literature, though only a small number of these are appropriate in the case of concern. In every case however, a new set or series of geographical and/or image datasets conveying the information of the actual ground occupation will have to be acquired and used as a comparison reference to the ortho-photomap imagery.

The change detection method chosen in our case study is based on the direct comparison of the ortho-photomap and the classification result of a most recent VHR satellite image taken as reference.

To be short, we will have to go through the following sequence of steps to set up and perform a complete change detection analysis:

- Acquisition of the source materials to be compared with the actual photomap coverage as also the ancillary data necessary to prepare the datasets;
- Preparing the acquired data to fit the geometry of the photomap, in order to allow direct comparison between the diachronic datasets;
- Specific pre-processing tasks to perform the actual diachronic analysis in order to facilitate the comparison stage;
- Performing the comparison study and quantifying the results.

In all cases the methodology has to remain simple and efficient as it is to be implemented and used on a routine basis within the DGPL administration. Also, all the processing steps were performed keeping in mind the actual hardware equipment and software availability of this administration which at the time being sums up to current database creation and management tools, the ESRI's ArcView 3.x GIS software package, and to be acquired in the near future, the Erdas Imagine basic image processing software, upgraded to allow for the ortho-rectification (Imagine OrthoBASE module) of satellite images.

The source materials

In our case study, we have opted for the acquisition of VHR imagery from the IKONOS satellite, which produces panchromatic images with 1 m ground resolution and 4-band multi-spectral channels at 4 m ground resolution. This option gave us the opportunity to become familiar with this quite new type of imagery, as also to find out if this type of imagery could offer a reliable alternative to produce ortho-photomaps in areas where spatial resolution concerns are less restrictive, or still, if they could be of any potential use for the different administrations coping with land management and planning tasks at a cost effective price.

According to the preferences of the DGPL we have thus acquired several IKONOS satellite images over two selected study areas, one corresponding to the city of Liege, the second area being located in the centre of the region over the cities of Wavre and Ottignies-Louvain-la-Neuve. We will further analyse the case of this second study area chosen for its variability of landscape and also because it presented some known recent ground occupation changes (new housing lots) in the suburban periphery of the city of Waver.

To cover this area, two 11 x 11 km^2 partially overlapping images were acquired, one taken in May and the other in November of the year 2001, thus well after any of the Region's ortho-photomaps. Both images are of the Geo Bundle type, hereby meaning the basic 1 m panchromatic channel and four corresponding 4 m multi-spectral channels. Both the panchromatic and multi-spectral channels are geometrically and radiometrically corrected and map projected conforming to the Belgian Lambert projection of 1972, with a corresponding 1- or 4 m pixel-size respectively. The spectral characteristics of the images allow for the production of natural colour composites as also of false colour infrared composites.

It should be noted that Space Imaging directly provides 1 m resolution multi-spectral pan-sharpened images as also very high precision ortho-rectified imagery, but of course at a much higher expense than the basic Geo Bundle image type. It was however decided at the onstage of this study to acquire the basic low-cost datasets and to process them us by means of the appropriate imaging software tools to pan-sharpened and ortho-rectified products. This would not only reduce costs, but also allow a continuous production quality assessment all along the different processing stages and to use the basic imagery and model it appropriately for other applications as well.

Hence for quality testing purposes two other Space Imaging products of the May image were also acquired :

- A Geo colour type image, corresponding to a set of four multi-spectral pan-sharpened channels, in order to test our own pan-sharpening algorithms against this Space Imaging's commercial product;
- A Geo Ortho product of the panchromatic channel, in order to control the quality of our own ortho-rectification procedures.

All the image datasets were provided with a wide dynamic range (11 bits) in a standard 16 bit image file format.

Digital elevation data, necessary for the ortho-rectification processing stage of the satellite images, were acquired from the Belgian National Geographic Institute under the form of a set of X,Y,Z triplets within an ASCII file. Altimetric accuracy is of the order of 5 to 10 meters only. These data were further processed by interpolation algorithms to produce a digital elevation model. A complete cover for the whole of the Walloon Region is in the process of making, and will be made available to the administration at the end of the project.

In the final stage of our study, we were also provided with a large scale (1:1000) cartographic vector database of the study area (PICC : Plan Informatique de Cartographie Continue) made up of over 100 different thematic layers and produced by the MET (Ministère de l'Equipement et des Transports). According to their topicality, these very detailed data will of course in the future be incorporated in the process of change detection analysis. They will also be critical in the process of registration of our image products and are already of use for assessing registration and ortho-rectification quality. The PICC data base also provides a very dense set of elevation data from which a very precise digital terrain model could be produced if the need arises.

The general image pre-processing stage

Several pre-processing operations have to be routinely applied to the satellite imagery in order to obtain images, which can be overlaid exactly to the ortho-photomaps.

First the multi-spectral images are resampled by cubic convolution to 1 m resolution and then pan-sharpened. This processing aims at producing 4 new multi-spectral channels by fusing the resampled channels with the panchromatic band. This allows to obtain sharp colour images of the scene, ideal for visual computer assisted image interpretation. Many different algorithms have been proposed to so artificially increase the spatial resolution of the multi-spectral channels. One which works best – the Local Mean and Variance Matching (LMVM) algorithm – (de Béthune & *al.*, 1998a, 1998b) and very well preserves the original multi-spectral radiometry was devised at our laboratory and can be implemented directly by using the Erdas Modelmaker module (Cornet & *al.*, 2001). Although this algorithm produces somewhat less sharp images than the pan-sharpening (undocumented) algorithm used by Space Imaging Co., the minimal loss of spectral information content allows further classification algorithms to be applied to these images, without significant alteration of the classification results (figure 1).

The next step is to proceed to the ortho-rectification of the satellite scenes. Again this has become a quite straightforward process using the Erdas OrthoBASE module. All that is needed is a set of several scores of well selected ground control points measured on the ortho-photomap and the previously produced digital elevation model. For the case at hand, we obtained a RMS measure of 2.35 m comparing favourably well to the 2.3 m value obtained for the ortho-rectified image computed by Space Imaging Co. Further, visual assessment of our ortho-rectification by means of the PICC geographical database also gives total satisfaction. Obviously our cost effective choice for acquiring Space Imaging's basic Geo Product holds on.

For convenience, other pre-processing tasks can be performed according to the preferences of the operator or depending on the case at hand. One can chose to clip the resulting ortho-rectified pan-sharpened IKONOS reference image to the dimensions of the individual ortho-photomap tiles and proceed further tile per tile, or on the contrary, to mosaic the individual tiles to cover the area of a complete IKONOS scene. Future work still has to show which approach is more convenient or cost-effective if any. In this respect the performance of the available hardware might also have to be taken into account. Very large images are often antonymous of performance.

Figure1. Raw and pre-processed IKONOS data (original approx. scale 1:3000). From top to bottom : panchromatic image (1m res.) – multi-spectral image (4 m res.) – merged images with the LMVM algorithm (1 m res.) – merged images with the Space Imaging algorithm (1 m res.)

The specific pre-processing stage to the diachronic analysis

In order to compare two images in the course of a temporal analysis the first idea often comes down to differentiate (or divide) the images (or specific image bands or combination of bands) and to compute from the difference (or ratio) image some expression of change (Eastman & McKendry, 1991; Sabins, 1997). This is of course feasible to some limit in the case of two images taken at different times, if they have been acquired in nearly identical conditions, and can be radiometrically calibrated. But even then, the resulting images will come up with differences not expected for, or simply not desired within a specific context, as also may remain silent or ambiguous on changes for which the radiometry has but a poor discriminative power. Many different schemes have been devised, but the results are rarely satisfactory to the investigators (Sing, 1989). The same author mentions that some of these methods applied to the same data may produce different results, suggesting that they are strongly scene depend.

Another approach we have attempted is the so called "post classification comparison". The two images are classified into the principal ground occupation types and the resulting classifications are then overlaid to single out the difference areas looked for (Seba, 2001). This approach is attractive indeed, because it can almost be fully automated. Supervised classification algorithms such as the maximum likelihood classifier have become classics in the field of remote sensing and are straightforward to use; the post classification comparison stage amounts to a simple overlay procedure current in many GIS software applications. Unfortunately, if the IKONOS image is ideal for obtaining good quality classification results, this is certainly not the case of the ortho-photomap cover with but a too poor and quite variable spectral quality to produce any reliable classification results. In it's actual state this cover is also much too heterogeneous in composition to ensure that a unique and consistent well responding change detection algorithm would work properly.

Hence we are left over with the only remaining feasible approach, namely by visual interpretation and comparison of the images on the screen and by hand digitising the observed changes. This method also ensures that only significant changes will be taken into account, excluding some temporal changes uniquely bound to differences in the phenologic development or to seasonal variations of the vegetation cover, and which are always difficult to delimit by automated means.

Screen digitising is a tedious work. We can however alleviate this task by making use of the classification results obtained from the IKONOS image. In effect, we are looking for specific changes, most often corresponding to the appearance of new construction yards, housing lots, new roads etc., which correspond to the disappearance of other features such as for instance pasture land or forest stands. Most changes will therefore occur within two or three classes only. By segmenting the ortho-photomap according to the IKONOS classification image, each segment will then in turn be screen digitised to indicate where significant changes have appeared in the ground occupation. It is thought, that this approach of selectively screening each class separately will ease somehow the dull digitising task of the operator as his attention focuses on only one class at the time. However, again, this may simply be a matter of personal convenience.

We have performed the above mentioned processing steps for a certain number of ortho-map tiles near the city of Waver where active housing developments were known to have taken place recently. Figure 2 illustrates a small except within one of these tiles. The four images shown correspond from top to down respectively to the original photo-map of a residential area, the corresponding IKONOS image, the classification map of the IKONOS image and the ortho-map with the digitised change-polygons. In this case, the classification image is composed of 5 classes only, where the pastel green colour corresponds to grassland, dark green to tree cover or hedges, orange to constructions, purple to mineral road surfaces, and brown to bare soil. As can be seen from the digitised change polygons, the significant change corresponds mostly to the appearance of new houses, i.e. only the housing class of the classification incorporates all the significant changes observed. All other observed changes correspond mostly to transitions from grassland to bare soil or vice-versa. They are not significant and of course have not been incorporated in the digitisation.

The diachronic analysis

For now the methodology has only been tested over a few neighbouring tiles within the administrative boundaries of the city of Waver, where the observed changes are restricted to the construction and the road classes. Nevertheless, this experience has given us enough confidence into the methodology to push it further.

Future work, will be done at the DGPL administration, who, after some appropriate training, shall carry out the data acquisition phase of the project:

- Acquiring the IKONOS satellite image cover for the whole Region;
- Performing the ortho-rectifications and the image pan-sharpening of the satellite imagery;
- Producing the supervised classifications, and
- Carrying out the digitisations.

Only after the data acquisition phase will it become possible to synthesise the data and produce a spatial representation of the diachronic analysis as also to draw the general update priority trends directly related to the measured change density. As a first experience in satellite remote sensing within a GIS application, this is certainly an engaging challenge for the administration.

Figure 2. The stages of the diachronic analysis (original approx. scale 1:3000)
From top to bottom : original photo-map of a residential area – corresponding IKONOS image – classification map of the IKONOS image (see legend in the text) – ortho-map with the digitised change-polygons

Conclusion

The topics discussed in this paper show that in order to define a policy for the progressive renewal of the coverage of ortho-photomaps derived from aerial photography, a viable alternative is to proceed to a diachronic analysis for change detection between the actual cover and VHR satellite imagery. The resulting analysis provides an indication of where a coverage renewal would be appropriate and constitutes thus an aid to any decision process for this matter. It is of course now up to the DGPL administration to proceed to the diachronic analysis and to produce the concomitant change detection map for the whole region.

For now, part of the proposed methodology rests on a somewhat tedious manual screen digitising procedure. However, in a near future, with increasing quality of the acquired orho-photomap coverage, as also with a progressive improvement of the organisation of - and the access to - the available ground occupation databases, this task of updating will certainly evolve towards more automation. A particular attention should be paid to the existing PICC database, which unfortunately could not be incorporated in time into this case study.

The proposed methodology relies on sophisticated technologies involving digital image and GIS processing for which specific training is required. This expertise could be provided with the aid of appropriate consultancy such as can be offered by university departments involved in remote sensing and GIS related matters. A symbiosis with some research departments would be an efficient manner to assist the introduction of high technology into the administrations and to keep the necessary knowledge and skills up to date. It would result in improved product and service quality and also enable the administrations to become less dependent of some monopolistic private companies.

Another topic of vital interest in relation with our subject is the rapid evolution of spatial imagery products. Although currently available satellite images can serve many purposes, 1 m resolution panchromatic imagery still doesn't compete favourably with the 40 cm resolution colour images stemming from aerial photography, and are therefore less suitable for many spatial planning surveys and management activities at large scale. But that was for yesterday. Today, new generation satellites are planned, some are already orbiting, and start producing higher resolution images - for now up to about 70 cm resolution - at a very competitive price of a few tens of dollars per km^2, depending upon the quality of the ordered product. Such images would almost certainly provide a viable alternative for replacing aerial ortho-photos in areas of slow rate of change such as rural and forest land. Whatever, these facts clearly show the evolutionary trends: better image quality, product homogeneity, reduced costs, complete coverage acquired within reasonable delays, and rapid revisit times. What else could we ask for ? Within this scenario the answer for updating an image database is of course immediate. And how logical and cost-effective would it be to get all the administrations concerned to agree on a common acquisition of such an image cover, all of them are hungering to use for their own needs. It would benefit to all.

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FEASIBILITY STUDY T4/DD/015

ADVANCED CONTEXTUAL IMAGE PROCESSING OF SATELLITE IMAGERY FOR LAND PLANNING AND MANAGEMENT IN CROSS BORDER AREAS

J.-P. DONNAY

UNIVERSITE DE LIEGE (ULG)
DEPARTMENT OF GEOMATICS
LABORATOIRE SURFACES
Allée du 6 Août 17, Bâtiment B5, Sart Tilman
B – 4000 LIEGE
BELGIUM

1. CONTEXT AND OBJECTIVES

The last phase of the project " *Application of spaceborne remote sensing to the identification of conurbations and analysis of the impact of major regional planning projects on the environment*" was realised in 1997. This last phase has as main objective the identification of the potential uses of the Lille transborder agglomeration and of the Calais-Boulogne littoral land use maps for country planning of this Franco-Belgian territory. Following on from this study, the land use map of the Franco-Belgian Lille area is one of the main sources for the project GROOTSTAD (Grensoverschrijdend Ontwikelings en Ordeningschema voor de frans-belgische metropole Lille - via Terra - Élaboration d'un Schéma Transfrontalier de Développement et d'Aménagement du territoire pour la métropole lilloise franco-belge). This project is in the frame of the "terre" program of the European Commission (DG XVI). This project works with an ascending process of planning under the control of the COPIT (Conférence Permanente Intercommunale Transfrontalière).

2. DATA

Geographic study area: The transborder agglomeration of Lille

Satellite imagery used:

SPOT PAN (08/10/1993; KJ = 040-277)

SPOT XS (21/06/1993; KJ=040-247)

Other data:

- Land cover and land use maps realised by SIRS – EUROSENSE
- Population data [INSE (1990) et INS (1991)]
- Communal boundaries

3. METHODOLOGY

- Improvement of the added value of the satellite land cover map of the Lille transborder agglomeration by modelling with the potential methodology.
- The functions and the potential models used exploit the raster nature of satellite images. The area of satellite pixels is very small in comparison with the surface of classical census tracts. Moreover, they cover all the space without gaps or overlaps. Uniformity of pixels allows to avoid or to limit the fluctuation effect in the segmentation of space and that is usually very sensitive with spatial models. Variations in pixel size and of the size of the convolution windows allow examining the same geographical reality at the current scale but also at higher and/or lower scales.

4. OUTPUTS AND RESULTS

- Residential potential;
- Urban potential;
- Urban Morphological Zone (UMZ) simple;
- Urban Morphological Zone (UMZ) adapted to the communal boundary;
- Comparison between UMZ obtained by morphological closing and by threshold of urban potential;
- Map of the density of population;
- Eco-landscape segmentation.

5. EXECUTION

Period : 01/01/1997-30/06/1997

Laboratory:

UNIVERSITE DE LIEGE (ULG)
Department of Geomatics
Laboratoire SURFACES
Allée du 6 Août 17, Bâtiment B5, Sart Tilman, B – 4000 Liège, Belgium
Phone: +32 4 366 53 13 Fax: +32 4 366 56 93
E-mail: donnay@ulg.ac.be

User partner:

INTERCOMMUNALE DE DÉVELOPPEMENT ÉCONOMIQUE DES ARRONDISSEMENTS DE TOURNAI, D'ATH ET DES COMMUNES AVOISINANTES (IDETA)
Rue St-Jacques 11, B – 75 Tournai, Belgium
Phone: + 32 69 23 47 00 Fax: + 69 23 47 01
E-mail: ideta@honet.be

6. RELATED DISCIPLINES

Land planning & infrastructures
Urban & suburban

7. EXECUTIVE SUMMARY

Objective

Potential model computed from urban occupation has already been successfully used in urban network analysis and in urban area segmentation. In the frame of this feasibility study, it was used for the delimitation of the trans-border agglomeration of Lille.

The potential

The potential is based on a very simple structure, which can become more sophisticated for particular analysis. It transforms a discrete distribution of data to a statistical surface. This surface can be described and analysed as a model. Two values are associated with each point of the thematic relief. The first one is a scalar and the second one is a gradient. The structure can be analysed based on its quantitative, qualitative and geographical components. The model is stable which means that it is not sensitive to the choice of the weighting factors used with the classes. Nevertheless, the study scale must be properly specified in order to choose correctly the size of the convolution windows and the extent of analysed geographical phenomenon. Due to the fineness and the regularity of pixels, satellite land-cover maps are data very well adapted for statistical surfaces computation.

Data and steps

Initially, we had a satellite land-use map and the delimitation of the trans-border agglomeration realised by SIRS-EUROSENSE according to the EUROSTAT methodology. The same kind of process was performed by the Laboratoire SURFACES. The two delimitations present differences. This can be explained by the fact that the urban mask of the Laboratoire SURFACES follows a stricter definition which does not include the communication network classes.
In this feasibility study, the proposed methodology is complementary to the EUROSTAT one. It is based on applying thresholds on urban potential surfaces. The threshold is defined interactively to fit best the delimitation produced by the EUROSTAT methodology. This approach emphasises the contextual information and offers the possibility to measure a "level" of urbanisation.
One might think that it is better to define agglomeration by a stripe rather than by a line. In this case and with the potential methodology, a constant range in the definition of the stripe can correspond at the ground level to a variation in the stripe thickness. Nevertheless, a precise line adapted to legal boundary must be specified for operational decisions and for statistical uses.
In the trans-border agglomeration of Lille, the area determined by the potential method is close to the area defined by the EUROSTAT methodology. The differences can be explained by the properties of each method. The morphological "closing" suppresses discontinuity below a specified threshold. This method maintains urbanisation and particularly scattered urbanisation. The thresholding of the urban potential is less sensitive to a failure, for example, in the classification along the communication network. With this approach, the urbanisation is more generalised.

Then, the potential tends to weight the urbanisation and to eliminate the scattered urbanisation.
An evaluation must be done to consider the advantages and the disadvantages of the observed discordance. Nevertheless, it must be stated that the big size of the convolution window, used in the urban potential computation, allows a better analysis of the phenomenon in its whole and in its local variations (structure of urban axes). Moreover, the quantitative attributes of urban potential allow discriminating an internal pattern inside of the agglomeration. Eventually, the limits of the agglomeration can be interactively moved.
The 50% rule is used to adapt the agglomeration limits to legal communal boundaries. This rule introduces a part of arbitrary, which provokes fluctuations more important than the one observed between the two methodologies. Town-planers of "Agence de Développement et d'Urbanisme de Lille Métropole (ADULM)" are more interested by the use of morphological agglomeration (before the application of the 50% rule) and especially by the analysis of urban potential variations along the agglomeration boundary.
Indeed, the commune size deeply influences the 50% rule results. On the one hand, a small commune with few agricultural areas and small scattered habitation nuclei can be selected and on the other hand, a larger commune with bigger urban nuclei but lost within a big agricultural area can be rejected.

Advantages of the potential and density approaches for delimiting an agglomeration

The old Belgian communal subdivision (before 1975 fusion) was used for the trans-border agglomeration of Lille because today's Belgian communal size is very different from the French one. But this solution does not resolve the comparison problem of the agglomeration population at the European level.
With a density approach, it is possible to obtain an estimation of the population included in the morphological agglomeration (without using the 50% rule) on a better basis.
One disadvantage of the potential is the difficulty of interpretation. But, in reality, the potential value is more precise than the density and the possibilities of interpretation are more significant. Some meta-data are needed for the exploitation of the potential by the user.

Prospects

This is the first time that the population of the trans-border agglomeration of Lille is studied by density representation. The socio-economical variable is the residential communal population. The ADULM representatives want to extend this study to other variables such as the number of employment, the number of children in school age.

More accurate data of census must be used like the INSEE "îlots" in France and the "secteurs statistiques" in Belgium. Only variables available in France and in Belgium at a similar level of division can be analysed in this new trans-border study. It could be also useful to extend the research to the exploitation of the potential model to the regional space and to the segmentation of urban areas.

FEASIBILITY STUDY T4/DD/016

USE OF VERY HIGH-RESOLUTION (VHR) IMAGERY FOR CONTROL AND UPDATING OF LEGAL LAND OCCUPATION MAPS IN URBAN AREAS

M. BINARD

UNIVERSITE DE LIEGE (ULG)
DEPARTMENT OF GEOMATICS
LABORATOIRE SURFACES
Allée du 6 Août 17, Bâtiment B5, Sart Tilman
B – 4000 LIEGE
BELGIUM

1. CONTEXT AND OBJECTIVES

One of the preoccupations of the sector plans is the parsimonious management of territory. This last implies a good local management. Actually, in some regions, reserves for additional housing developments can be appear like insufficient and/or can have a negative impact on the land market. In other places, reserves for additional housing developments can look like to generous and simply not justified. Moreover, beside economical social and esthetical preoccupations appear some ecological constraints. Therefore, it is legitimate to update the oldest sector plans with an integration of physical and ecological constraints. Sector plans have to reflect the present situation and this last is a fundamental information needed for the elaboration of country planning projects.

Classically, needed information is obtained by the combined exploitation of aerial photographs and verification in the field. Ups to now, satellite images of means resolution are not able to cope with the requirement of sector plan. In fact, this can be explained by the lack of geometrical and spectral resolution of sensor that can not fit the scale needed by author of project.

2. DATA

Geographic study area: Commune of Malmedy (Sheet NGI 50/6) (Belgium)

Satellite imagery used:

SPOT XS of 07/08/1992 (KJ=46-247)

IRS-1C Pan and LISS-III of 03/05/1997

The expected VHR images were not available during the time of this study

Other data:

- Photography KOSMOS KVR-1000 (summer 1992)
- Orthophotomaps of NGI (1995)
- Files of sector plans for the Walloon Region
- Topographic maps at 1/10.000 and at 1/25.000 of NGI

3. METHODOLOGY

- Unfortunately, digital VHR satellite images (geometric resolution about 1 m for the panchromatic mode) are not yet available for this feasibility study. To surmount this lack of data aerial orthophotoimages of NGI are be used as simulation data.
- First, the study of the conformity between the evolution of land use and sector plan specifications and secondly the availability of field for additional housing developments, are be processed by Computer-Assisted Photo-Interpretation (CAPI). Default between legal situation and field situation (land use) are be mapped directly on the screen.

- The crossing of build-up map with sector map allows the estimation of reserve of habitat.

4. OUTPUTS AND RESULTS

- Map of the build-up area;
- Map with the comparison between build-area and sector specification;
- At the growing level observed during these last years, habit reserve are sufficient until the end of the next century;
- Localisation of build-up areas and estimation of reserve of habitat are given in function of slope and aspect;
- Technical and urbanistic report.

5. EXECUTION

Period: 01/01/1998-30/09/1997

Laboratory :

UNIVERSITE DE LIEGE (ULG)
Department of Geomatics
Laboratoire SURFACES
Allée du 6 Août 17, Bâtiment B5, Sart Tilman, B – 4000 Liège, Belgium
Phone: +32 4 366 53 13 Fax: +32 4 366 56 93
E-mail: Binard@geo.ulg.ac.be

User partner:

MINISTERE DE LA REGION WALLONNE - DIRECTION GENERALE DE L'AMENAGEMENT DU TERRITOIRE, DU LOGEMENT ET DU PATRIMOINE - DIRECTION DE L'AMENAGEMENT NORMATIF (DGATLP)
Rue des Brigades d'Irlande 1, B – 5100 Namur, Belgium
Phone: + 32 81 33 21 11 Fax: + 32 81 33 21 10

6. RELATED DISCIPLINES

Cartography
Land planning & infrastructures
Urban & suburban

7. EXECUTIVE SUMMARY

The ageing of the regional sector plans as also the recent changes in map content as defined by the new Walloon code on land planning of 27 November 1997 justify the analysis of new updating methodologies.

Most important in regard to the updating strategy to be adopted is the question of the availability of land for additional housing developments. This study therefore focuses on the assessment of available construction sites and some of their characteristics. The study area coves map sheet 50/6 of the Malmedy-Saint-Vith sector. The original method proposed in this case study is based on computer assisted photo interpretation of digital ortho-photomaps, combined with some sector map information. The method is user-friendly and leads immediately to quantitative assessments, also facilities of conceiving and editing of thematic maps. Further useful information is obtained by combining the map information with a digital terrain model of the area.

Research, on the one hand, confirms the availability of land for additional housing developments, and on the other reveals the consequences of bad urbanisation policies (promotion and development of linear housing developments, insufficient control over quarrying activities, etc.) the "new code" introduces new town planning requirements (more detailed zoning analysis taking into account the environmental aspects, creation of protected areas, impact surveys, ground occupancy estimation) and strengthens the prospect of using this methodology further on.

FEASIBILITY STUDY T4/11/050

THE USE OF VERY HIGH-RESOLUTION DATA FOR THE MONITORING OF VEGETATION AND WATER IN URBAN AREAS

E. WOLFF

UNIVERSITE LIBRE DE BRUXELLES (ULB)
INSTITUT DE GESTION DE L'ENVIRONNEMENT ET D'AMÉNAGEMENT DU TERRITOIRE (IGEAT)
Boulevard du Triomphe – CP 246
B – 1050 BRUXELLES
BELGIUM

1. CONTEXT AND OBJECTIVES

This study was achieved in collaboration with the Green areas department of the IBGE-BIM. Its missions concern the management and the development of regional green areas, as well as the development and the implementation of regional policies of natural heritage conservation. Since 1997, the IBGE-BIM has a geographical database of green areas of Brussels (inventory of green areas, ponds, front gardens, trees along streets, and a greenness index per blocks). This "Green Network" database was achieved using aerial photographs, topographical maps and ground survey. It is used regularly. In order to stay useful, it should be completed and updated. The use of very high-resolution satellite data (IKONOS imagery) to complete and update the database was studied technically and economically.

2. DATA

Geographic study area: Brussels, test-area of 11 km x 11 km SE of the administrative region

Satellite imagery used :

IKONOS panchromatic and multispectral dating of 08/06/2000

IKONOS multispectral dating of 07/10/2000 + OSTC archived images : SPOT XS 042-247 dating of 27/06/1992

Other data:

- DTM produced by IGEAT from contour lines with a 2 m interval inside the region of Brussels or a 10 m interval outside the region
- Numeric aerial orthophotos of the NGI (1 m resolution – panchromatic)
- The "Green Network" database of the IBGE-BIM

3. METHODOLOGY

- IKONOS images were orthorectified using the IKONOS module of ORTHOENGINE (PCI software). A DTM was achieved for this purpose.
- The NDVI values of the IKONOS image of June 2000 were compared to the ones of the SPOT image of June 1992. These values were compared for each block of the region but also for all green areas listed in the "Green Network" database. The NDVI was also used to estimate the areas of green open spaces for each block; these estimated areas were compared to the one included into the Green Network database.
- IKONOS images were also classified into 7 types of vegetation and water. Two methods were applied : the maximum likelihood on filtered data (mean filter in a 3 by 3 moving window) and an object oriented classification based on fuzzy logic applied on a segmented image

4. OUTPUTS AND RESULTS

- The orthorectification of the IKONOS images reduces the horizontal geometric accuracy from 50 m to 5 m.
- The comparison of vegetation index at several times is useful to detect greenness changes in the city. This vegetation index can updated the greenness index of each block as well as the green open area. It is more recent and reliable than the index that are currently included in the database.
- Both classification methods give similar accuracy (Kappa's of 0.83 and 0.84). The method based on the segmentation has a generalisation level, which is more relevant that the maximum likelihood applied on filtered images. This classification result allows updating and refining the vegetation zones included in the objects of the database.
- An economical analysis showed that the annual update of these results could be obtained and extended to the whole region of Brussels at a minimal cost of 900 000 FB. Nevertheless, the price of very high resolution is in constant evolution; the launch of new civilian satellites should lead to decreased acquisition costs.

5. EXECUTION

Period: 01/05/2000-30/04/2001

Laboratory:

UNIVERSITÉ LIBRE DE BRUXELLES (ULB)
Institut de Gestion de l'Environnement et d'Aménagement du Territoire (IGEAT)
Boulevard du Triomphe – CP 246, B – 1050 Bruxelles, Belgium
Phone: +32 2 650 50 76 Fax: +32 2 650 50 92
E-mail: ewolff@ulb.ac.be URL: www.ulb.ac.be/igeat/igeat/ige5.htm

User partner:

IBGE/BIM
Gulledelle 100, B – 1200 Bruxelles, Belgium
Phone: + 32 2 775 75 11 Fax: + 32 2 775 76 21
E-mail: info@ibgebim.be

6. RELATED DISCIPLINES

Land planning & infrastructures
Urban & suburban
Cartography
Data/service policy

7. EXECUTIVE SUMMARY

The potentialities of very high-resolution satellite images (IKONOS) have been analysed for the monitoring of vegetation and water urban areas in the Region of Brussels.

The Green areas department of the IBGE-BIM is the end-user of this study. Its missions concern the management and the development of regional green areas, as well as the development and the implementation of regional policies of natural heritage conservation. Since 1997, the IBGE-BIM has had a geographical database of green areas of Brussels (inventory of green areas, ponds, front gardens, trees along the streets, and a greenness index per block). This "Green Network" database was achieved using aerial photographs, topographical maps and ground survey. It is used regularly. In order to remain useful, it should be completed and updated. The use of very high-resolution satellite data (IKONOS imagery) to complete and update the database was studied technically and economically.

Two IKONOS images (a panchromatic and a multispectral) were recorded on 8 June 2000 for an area of 11 by 11 km covering the south-eastern part of Brussels. A second multispectral image was acquired on the same area on 7 October 2000; this image was delivered in two pieces. A multispectral SPOT image dating from 21 July 1990 was also used as a temporal reference. The quality of the IKONOS images was analysed taking into account the recording conditions: cloud cover, length and direction of the shadows (linked to the recording date and hour), slant effect (linked to the elevation of the satellite). A cloud cover of maximum 20% is guaranteed when acquiring IKONOS images; the one of June 2000 has a cloud cover of 0% whereas the one of October has a cloud cover of 15 to 20%. In practice, an image presenting 20% of cloud cover has little interest for an exhaustive monitoring of vegetation. For an operational use, this cloud cover limit should not exceed 5%. Moreover, for an annual or biannual follow-up of vegetation, it is recommended to work with images registered at the same period of the year with similar geometric conditions. Having similar vegetation development, similar slant effect and shadows facilitates the standardisation of the analyses.

The objectives of this study were specified by confronting the needs of the Green areas department of the IBGE-BIM to the quality of the acquired images and the technical possibilities of analysis. Specifically, the presence of shadows and slant effect prevents the systematic detection of new tree plantations along the streets. The poor quality of the image of October also limited the potentialities of multitemporal analysis.

Acquired images are GEO products of Space Imaging; it is the cheapest product, but with the poorest geometric accuracy (horizontal accuracy of 50 m). An optimal use of VHR imagery in this study requires a maximal horizontal precision of 5 m. This precision was obtained by orthorectifying and assembling the images using the

ORTHO ENGINE module of PCI software. A DTM was interpolated from contour lines (2 meters inside the Region and 10 meters outside). A number of GCP were located on 1 : 10 000 topographic data and aerial orthophotos (1-meter resolution).
Contrast was stretched and colour composition was achieved on both images. The 4-meter multispectral image was fused with the 1-meter panchromatic image by using the RGB-IHS transformation. NDVI were computed on IKONOS and SPOT data.
Change analysis was performed by comparing vegetation index at several dates. NDVI values were averaged for each block and green urban areas of the database larger than 4 000 m² (i.e. 10 SPOT pixels) and not too elongated. Then, the NDVI values computed on the IKONOS image of June 2000 were compared to the ones of the SPOT image of June 1992. In addition, green surfaces per block were estimated and compared to the ones extracted from the 1 : 10 000 topographical database dating of 1988. These comparisons allow locating changes in the city: increase or decrease of the greenness.
Resulting changes were assessed with our knowledge of the city using all documentation available; still, half of these changes remained unexplained, probably because of the difference in resolution between satellite images under comparison (IKONOS and SPOT). Interpreted changes are mainly constructions of new buildings or conversion of barren land into new green open space. Changes in the green objects of the database are fewer; they concern 15% of the objects. These better results could be explained by a more homogeneous land cover distribution in green open spaces than within the blocks. Located changes are mainly either unused vegetated areas or areas along the railway that were greened or built up, or unused land that were developed into lawns, garden or park. Results are really encouraging, and would be even more if two VHR multispectral images were available and compared. In addition, the computation of a vegetation index covering the whole Brussels region would allow to update the greenness rate per block of the "Green Network" database, as well as the vegetated area per block. These data could be used as indicators in the set up and implementation of environmental strategies in the Region of Brussels. They are more recent and more reliable than the ones that are presently in the database.
Another part of the study concerns the update of vegetation zones. The multispectral classification of VHR images allows to delineate vegetation zones precisely and to update those of the Green Network database. A legend in 7 classes was set up: built up/barren, dark and light water, herb, shrub, deciduous trees, coniferous trees. Two classification types were applied and give similar accuracy (Kappa of 0.83 and 0.84). On the one hand, the supervised multispectral classification (maximum likelihood) is performing well if it is applied on averaged images in a 3 by 3 moving window. Non-averaged images lead to poor classification results. On the other hand, the very new classification software (object-oriented, using fuzzy logic) was also tested. The image

is segmented prior to the classification; this offers the advantage of a more appropriate generalisation than the one achieved by the mean filter. Given the complexity of this software, the numerous possibilities of E-COGNITION were not all tested in the framework of this study but they seem very promising and would probably improve classification of very high-resolution satellite images.

Using the classification results of main vegetation types, one can not only update the vegetation field of the green urban spaces of the database, but also map and quantify the vegetation types inside the blocks. Vegetation types would be more precisely delimited than the class “garden” coming from the 1 : 10 000 topographical database; indeed, in the topographical database roads and tracks are used to delineate polygons for which a land cover is attributed, whereas the land cover classification leads to homogeneous zones closer to reality.

The annual cost of an update as it was tested in this study, but extended to the whole region of Brussels, was assessed. According to current prices of IKONOS imagery, it would amount to a minimum of 900 000 FB. But the price of these images has doubled in 2001 and is evolving very rapidly. Moreover, other very high- resolution images will soon be available; some competition will probably lead the prices down in a short or medium term. Let us notice that the NGI is distributing numerical aerial orthophotos in panchromatic at 1 meter resolution for the whole country. They do not offer the same advantage as the IKONOS imagery as they are updated every 5 years and are only available in panchromatic.

To conclude, the use of very high-resolution satellite images (IKONOS) offers interesting perspectives for the update of the Green Network database of the IBGE-BIM. Some problems and limits were underlined: quality uncertainty of the IKONOS images, difficulty of the orthorectification, new methods of classification, … But their relatively low costs and their easy processing (compared to aerial photos), their repetitiveness are clear assets for their use. Let us notice that the concept of green urban space as defined in the database combined land cover consideration with land regulation (ownership, private or public access, …). Therefore, the delineation of these objects will never be possible on the unique basis of satellite imagery (or aerial photos). A complementary ground survey remains necessary.

These results could easily be extended to the whole region of Brussels, and beyond its limits. Annual or biannual results would allow updating the environmental statistics on greenness in the city. The techniques under use have the advantage of producing a detailed information on greenness, quite rapidly and at a relatively low cost, on the inside of the blocks, or more generally on private areas; this information is difficult to get by another mean. These areas are getting more and more attention in the implementation of the Green Network strategy.

New classification techniques should be tested more in detail for land cover identification using very high-resolution data. They could be combined with the urban database URBIS 2. A more in-depth analysis of the panchromatic potentialities should be conducted (e.g. tracing of pedestrian and cycle tracks, detailed classification of built up types).

FEASIBILITY STUDY T4/02/058

GENT SEEN FROM SPACE: IMPROVEMENT OF THE WEBSITE OF THE CITY OF GHENT

M. DE DAPPER

UNIVERSITEIT GENT (RUG)
DEPARTMENT OF GEOGRAPHY
Krijgslaan 281 Gebouw S8/A1
B – 9000 GENT
BELGIUM

1. CONTEXT AND OBJECTIVES

Up to now the use or satellite images for change detection in urban areas is not popular due to the resolution of the sensor. This might be changed with the new available sensors with a very high resolution. Even for GIS projects, the Municipality of Gent has never used a satellite image before. As higher resolution images become widespread (e.g. Space Image IKONOS-1, resolution 1m), these images could also be used for "local level" studies. Further development of the website of Gent is a possible way for helping people to come to a better insight into remote sensing documents, specifically those images concerning people's own environment (the town of Gent and surroundings). For that purpose yet available archive and more recent images will be used. The examples that will be developed are illustrating the multitemporal and multiscale approach. There are 5 themes selected:

- Gent and the world: Landsite MSS image of Gent and its 6 sister towns projected on a world overview, with geographical description of each of them.
- "Change" detection: Comparison of imagery of the eighties and the nineties with specific attention to urbanisation and green belt supply.
- Multiscale approach: to show people how Gent is "looking" on the images of different sensors with different resolutions, using an image sequence starting from rough resolution images (NOAA-AVHRR) through medium resolution images (archive images of RESURS-01 and/or Land sat MSS) up to fine resolution images (SPOTXS and/or SPOT-P).
- Following theme 3 theme 4 concerns the utility of the Russian KVR-1000 sensor images and/or the Space Image IKONOS-1 images for studies of small areas as citizens' own environment, zooming in on these high resolution images on the Internet.
- Comparison of the high resolution images with available aerial photographs selecting 2 areas in Gent, e.g. the dock area and the town centre.

Each of the presented images and approaches will be discussed in a brief text. In such a way the Internet user can have a better understanding about the technology and methodology of the remote sensing documents.

2. DATA

Geographic study area: City of Gent

Satellite imagery used:

- LANDSAT MSS-20/08/1984 – path/row 199/24 – ID LM5199024008423390
- LANDSAT ETM- 18/10/1999 – path/row 198/25 – Id: E1SC : L70RWRS.002:2000321403

- SPOT – 17/05/1998 – ID: 1 041-247 17/05/1998 10:31:38 1p
- SPOT – 08/08/1998 – ID: 1 040-246 08/08/1998 10:36:38 2X
- IKONOS 2 – 09/05/2000 – ID: 2000050910404020500010518048
- LANDSAT MSS – 01/10/1986 – path/row: 195/25 – ID: LM5195025008627490
- LANDSAT MSS – 10/08/1975 – path/row: 211/24 – ID: LM2211024007522290
- LANDSAT MSS – 11/09/1975 – path/row: 117/35 – ID: LM2117035007525490
- LANDSAT MSS – 12/06/1986 – path/row: 202/37 – ID: LM5202037008616390
- LANDSAT MSS – 28/04/1987 – path/row: 202/37 – ID: LM5202023008711890
- LANDSAT MSS – 18/05/1986 – path/row: 187/19 – ID: LM5187019008613890
- LANDSAT MSS – 01/08/1987 – path/row: 195/30 – ID: LM5195030008721390

Other data:

- Topographical map 1:50.000
- Aerial photographs: 45 cm resolution and 10 cm resolution April 1995
- Digital data containing information about street co-ordinates (Lambert)

3. METHODOLOGY

Selection of different kinds of satellite images (low and high resolution) preparation of the images using ILWIS 2.1 for windows (colour composites, false colour composites, georeference, cut,) preparation of the explaining texts construction of the website in co-operation with the GIS and IT department of the City of Gent

4. OUTPUTS AND RESULTS

Gent is presented by 6 different kinds of satellite sensors (NOAA AVHRR, Land sat TM and MSS, Land sat 7 ETM+, SPOT, IKONOS 2) and two scales of aerial photographs (45cm resolution and 10cm resolution). Most important is the zoom on Gent from low-to high-resolution images ending with aerial photographs with 10cm resolution. In these way the difference between low-and high-resolution images is explained. While navigating pop-ups will give the information about the location.

5. EXECUTION

Period : 01/10/1999 – 31/03/2000

Laboratory:

UNIVERSITEIT GENT (RUG)

Department of Geography

Krijgslaan 281, Gebouw S8/A1, B – 9000 Gent, Belgium

Phone: +32 9 264 46 90   Fax: +32 9 264 49 85

E-mail: Morgan.DeDapper@rug.ac.be   URL: http://www.admin.rug.ac.be/

6. RELATED DISCIPLINE

Urban & suburban

7. WEB SITE

http://www.gent.be/gent/TELSAT/

FEASIBILITY STUDY T4/12/061

IMPLEMENTATION OF A WWW SITE PRESENTING LIÈGE VIEWED FROM SPACE USING SATELLITE IMAGES

J.-P. DONNAY

UNIVERSITE DE LIEGE (ULG)
DEPARTMENT OF GEOMATICS
Laboratoire SURFACES
Allée du 6 Août 17, Bâtiment B5, Sart Tilman
B – 4000 LIEGE
BELGIUM

1. CONTEXT AND OBJECTIVES

The web site "Liege viewed from space" lies within the framework of the project "City promotion", which aims at presenting new aspects of Belgian cities to the public. Similar sites were developed for Brussels and Gent.

If the first objective of this site is to present the city of Liege viewed from space using different satellites, such as LANDSAT, SPOT, KOSMOS and IKONOS, it also attempts to promote the city of Liege on the web.

The subject was addressed from a historical viewpoint by presenting all the territory of the old Principality of Liege. In so doing, the visitor can discover not only the city of Liege, but also 25 other cities from satellite imagery. Each city was put back in its historical context by linking it to the history of the Principality. However, in the context of this feasibility study and within the time allowed, the presentation of each city is often limited to the listing of the main historical facts and the main curiosities. Consequently, they are not exhaustive. However, a special attention was given to the city of Liege.

2. DATA

Geographic study area: City of Liege (Belgium)

Satellite imagery used:

- SPOT XS 1992
- LANDSAT TM 24/05/1992
- KOSMOS KVR-1000
- IKONOS

3. EXECUTION

Period: 01/01/1996 - 31/12/2000

Laboratory:

UNIVERSITE DE LIEGE (ULG)

Department of Geomatics, Laboratoire SURFACES, Allée du 6 Août 17, Bâtiment B5, Sart Tilman, B – 4000 Liège, Belgium

Phone: +32 4 366 54 24   Fax: + 32 4 366 56 93

E-mail: donnay@geo.ulg.ac.be

User partner:

ECHEVINAT DE L'ENVIRONNEMENT ET DU CADRE DE VIE DE LA VILLE DE LIEGE

Féronstrée 94/96 (1er étage), B - 4000 Liège, Belgium

Phone: + 32 4 222 44 22

4. RELATED DISCIPLINE

Urban & suburban

5. WEB SITE

http://www.geo.ulg.ac.be/liege

FEASIBILITY STUDY T4/11/062

BRUSSELS VIEWED FROM SPACE : DEVELOPMENT OF A WEBSITE

E. WOLFF

UNIVERSITE LIBRE DE BRUXELLES (ULB)
INSTITUT DE GESTION DE L'ENVIRONNEMENT ET D'AMÉNAGEMENT DU TERRITOIRE (IGEAT)
Boulevard du Triomphe – CP 246
B – 1050 BRUXELLES
BELGIUM

1. CONTEXT AND OBJECTIVES

The objective of this study is to develop to a web site which presents the Brussels-Capital Region from satellite images and aerial photographs. The web site presents to the public an attractive and educational overview about the use of satellite imagery for urban planning. More particularly, the site gives to teachers an interesting support to initiate the students into a multiscale analysis of satellite images in the urban environment.

2. DATA

Geographic study area : City of Brussels (Belgium)

Satellite imagery used :

NOAA DMPS

LANDSAT TM:	199/fl	01/05/1990		
	198/024	23/05/1989		
	198/025	23/05/1989		
	197/fl	03/05/1990		
LANDSAT ETM+:	198/025	18/10/1999		
LANDSAT MSS:	Helsinki		188/018	26/06/1986
	Santiago de Compostella		205/030	25/01/1992
	Bergen		201/018	05/06/1992
	Avignon		196/030	06/09/1992
	Krakow		188/025	26/04/1993
	Bologna		192/029	24/05/1993
	Reykjavik		220/015	19/10/1993

SPOT XS:

Bruxelles	042/247	27/06/1992
Prague	063/249	26/05/1989

IRS: Bruxelles 21/08/1997

IKONOS (P-1m & MS-4m) : Bruxelles 08/06/2000

Other data:

- Aerial photographs (Eurosense Company 13/04/1996)
- Europa:
  - Country boundaries (ESRI)
  - Population density data (ESRI)
- Belgium:
  - Built areas and industrial zones from CORINE Land cover data (NGI, 1995)
  - Demographic data (population Census, 1997)
- Bruxelles:

- Boundaries of the morphological city (MURBANDY project, EC/DG JRC)
- Main roads from "TELE-ATLAS Belgium" data

3. METHODOLOGY

Satellite images provided by OSTC (cf. listing above) and digital aerial photographs of Brussels (1996) provided by the Centre for computing of the Brussels-Capital Region were collected. Moreover, the following images were added on the site: Archive images DMSP/OLS (low-resolution night images), a mosaic of LANDSAT TM images from 1989-1990, IRS image from 1997 (for more details, see http://www.ulb.ac.be/igeat/telgis/bxl - copyright of the images). Complementary data were also used to make the interpretation of the images easier or to illustrate comments: Administrative boundaries, population data, land cover (Corine land cover). In some cases, vector data were superimposed on images to substitute the current land cover for the past land-cover situation, to show existing relations with communication infrastructures and with administrative and socio-economical structures. The data came mainly from the MURBANDY project (ED/DG JRC). The images were processed in order to be integrated in the site: geo-registration, colour compositing and contrast stretching, subset and compression in .jpg format. Geographic and historical comments were written to initiate into the interpretation of satellite images and to put back them in their context.

4. OUTPUTS AND RESULTS

The web site was developed in French only (Dutch and English versions could be developed in the future). A special attention was focused on graphics and site user-friendliness. Seven themes were presented: (1) The "Slide Show" allows a rapid insight without comments about the different kinds of images from small to large scale; (2) "Brussels in Europa": small-scale night images show Brussels in its geographical continental context and relativise its importance in relation to other European cities; (3) "The European cities for culture in 2000": Brussels takes part in the nine European cities for culture in the 2000 year, each of them is illustrated by means of archive satellite images (SPOT XS and LANDSAT MSS); (4) The theme "Brussels in Belgium" shows the localisation of Brussels in Belgium by using the mosaic of the LANDSAT TM images performed by the National Geographic Institute; (5) "Brussels, the morphological city": Vector data can be superimposed on a subset of the ETM+ LANDSAT image from October 1999 in order to highlight the expansion of the morphological city; (6) "The Brussels-Capital Region": A SPOT-IRS merged image is used as theme background, several vector layers can be superimposed and delimit, among other things, the expansion of the developed sites at different times (from the 12th century till now). Some "historical vestiges" still visible in the city are presented in more details (zooms and subsets of aerial photographs): buildings, parks, large industrial zone or areas representative of different times; (7) "The south-east of Brussels": The panchromatic IKONOS image from June 2000 gives an overview of the potentialities of the very high resolution satellite imagery in urban environment. Furthermore, icons give permanent access to the home page, the contact email address and the information pages: satellite infos and general infos (copyright, bibliography and partners).

5. EXECUTION

Period: 01/10/1999-31/04/1999

Laboratory:

UNIVERSITE LIBRE DE BRUXELLES (ULB)
Institut de Gestion de l'Environnement et d'Aménagement du Territoire (IGEAT)
Boulevard du Triomphe – CP 246, B – 1050 Bruxelles, Belgium
Phone: + 32 2 650 50 76 Fax: + 32 2 650 50 92
E-mail: ewolff@ulb.ac.be URL: www.ulb.ac.be/igeat/igeat/ige5.htm

User partner:

CENTRE D'INFORMATIQUE POUR LA REGION BRUXELLOISE (CIRB)
Avenue des Arts 20, B – 1000 Bruxelles, Belgium
Phone: + 32 2 282 47 70 Fax: + 32 2 230 31 07
Contact person: M. H. Feuillien, Directeur général

6. RELATED DISCIPLINE

Urban & suburban

7. WEB SITE

http://www.ulb.ac.be/igeat/telgis/bxl

CHAPTER IX

MARKET RESEARCH

FEASIBILITY STUDY T4/F3/063
FEASIBILITY STUDY T4/67/064

STIMULATION OF CLUSTER FORMATION WITH A VIEW TO DEVELOPING THE BELGIAN MARKET IN EARTH OBSERVATION APPLICATIONS

E. BREMS [(1)]
V. SCHREURS [(2)]

STIMULATION OF CLUSTER FORMATION AS REGARDS EARTH OBSERVATION FOR ENVIRONMENTAL APPLICATIONS OF SPOT-VEGETATION DATA WITH A VIEW TO PROMOTING DEVELOPMENT OF THE EARTH OBSERVATION MARKET IN BELGIUM

D. FRANSAER [(2)]
J. VAN RENSBERGEN [(2)]
D. VAN SPEYBROECK [(2)]

GEOGRAPHIC INFORMATION MANAGEMENT NV (GIM) [(1)]
Researchpark Haasrode
Interleuvenlaan 5
B – 3001 HEVERLEE
BELGIUM

VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK
(VITO) [(2)]
Boeretang 200
B – 2400 MOL
BELGIUM

1. CONTEXT AND OBJECTIVES

In October 1998, the Faculty of Economic and Applied Economic Sciences of the K.U.Leuven performed a study for the OSTC. This "Study on the Potential of Cluster-Based Innovation Policies for Earth Observation in Belgium" aimed to assess whether a cluster-based policy approach would be useful to stimulate the commercial exploitation of the EO (Earth Observation) expertise present in Belgium. Indeed, a lot of EO expertise is available in Belgium, both in universities, research institutes and private companies, but it is quite dispersed. This fragmentation of (research) activities makes it difficult to develop a significant critical mass when being active on the international market.

By means of study work, a questionnaire and a workshop, the researchers gathered information regarding the interest of the Belgian players and their opinion with respect to cluster-based initiatives. It appeared that for some segments, namely agriculture & forestry on the one hand and VGT applications on the other hand, a potential exists for implementing a cluster-based policy.

Following this study, in April 1999, the OSTC has launched a call for proposals concentrating on the formation of two clusters, one for the segment 'agriculture" and one for "SPOT-VEGETATION" applications. The aim of this initiative is to strengthen the market position of Belgian companies and organisations having EO activities and expertise by stimulating the formation of clusters. This call for proposals resulted in two cluster initiatives, one called "Agrinet" (led by G.I.M. – Geographical information Management NV) and the other one called "VEGETATION cluster initiative" (led by Vito – Flemish Institute for Technological Research).

Both cluster projects starting from a different viewpoint, they concentrated on bringing interested people together and discussing possible co-operation and cluster formation. These discussions and exchanges of thoughts have led to the conviction that the efforts for creating two clusters should better be joined and should focus on the definition and development of one single Earth Observation cluster. From November 1999 on, joint initiatives have been taken by Vito and GIM to initiate a Belgian EO cluster, to define its structure, its role and responsibilities.
The final result is a report that proposes a practical cluster structure, ideas and recommendations on how to make it operational. It summarises and discusses the market inquiry and thereby provides an indication of the commitment of the different Belgian players.

2. EXECUTION

Period:

15/06/1999-29/02/2000 (T4/F3/63)
15/06/1999-29/10/1999 (T4/67/64)

Laboratories:

GEOGRAPHIC INFORMATION MANAGEMENT NV (GIM)
Researchpark Haasrode, Interleuvenlaan 5, B – 3001 Heverlee, Belgium
Phone: + 32 16 40 30 39   Fax: + 32 16 40 69 39
E-mail: info@gim.be

VLAAMSE INSTELLING VOOR TECHNOLOGISCH ONDERZOEK (VITO)
Boeretang 200, B – 2400 Mol, Belgium
Phone: + 32 14 33 55 11   Fax: + 32 14 33 55 99
E-mail: vito@vito.be

User partners:

GIM NV
Interleuvenlaan 5, B – 3001 Heverlee, Belgium
Phone: + 32 16 40 30 39 Fax: + 32 16 40 69 39
E-mail : vital@gim.be
Contact person: Vital Schreurs

VITO
Boeretang 200, B – 2400 mol, Belgium
Phone: + 32 14 33 55 11   Fax: + 32 14 33 55 99
E-mail: vito@vito.be
Contact person: Jan Kretzschmar

3. EXECUTIVE SUMMARY

The report of these projects describes the set-up and the results of a market analysis and provides recommendations for the set-up of a cluster on Earth Observation, named EOCluster. The market analysis was based on an evaluation of existing clusters and on a questionnaire to interested organisations, i.e. companies, universities and institutes. The inquiry has been sent to 28 organisations of which 15 have replied. Their answers together with an analysis have been included in this report.

The proposed objectives of the cluster are :

- To increase the critical mass with respect to Earth Observation expertise and skills in Belgium.
- To further develop the market for Earth Observation applications for Belgian organisations.

The cluster should be a network of private companies, universities and research organisations having competencies in Earth Observation. Competencies are rather wide and oriented towards more than one application field. Customers can profit of the wide variety of expertise in both technical aspects as well in using earth observation data for specific applications. Synergy and complementary in competencies guarantee a better service provision (price/quantity) to customers.

Benefits for members are found at both sides of the balance income/expenditures, and at the short as well as the longer term. Market development needs to result in economic growth and an increase of income that would not, or not as fast, be achieved without the cluster. This market development is also crucial to ensure sustainability of the EO sector in the long term, as it will enhance the independence of government financing. Joined initiatives result in a decrease of expenditures for certain goods and services, staff recruitment and training. Marketing costs are used more efficient (higher visibility, better and more widely representation). The cluster will stimulate innovation and guide its members in establishing and securing innovation avenues in order to build a longer-term future. It's obvious that for the latter issue, research institutes and universities have an important role.

As recommendations, this report states :

It is recommended that an EOCluster is organised. The cluster should take on the form of a non-profit organisation (like a vzw/asbl). The cluster should provide the EO Community in Belgium with enabling services and networking in the general interest of the EOCluster and its members. The cluster should organise activities with respect to market development and start these activities at least in the market segments of agriculture ('Agrinet") and environmental monitoring ("Vegetation"). In case interesting opportunities arise in other segments, the cluster can enlarge its focus towards such fields as cartography, risk management, meteorology, urban planning, minefield detection, marine and coastal applications, etc…

The main activities of this EOCluster should be :

- Represent the cluster and its members towards third parties.
- Advice and consult governmental bodies (such as OSTC, DGIS,…) regarding market-oriented EO-initiatives.
- Establish and maintain information and communication lines between the cluster members.
- Stimulate co-operation and cross-fertilisation between cluster members and initiatives of other clusters.
- Support the organisation of training programmes, skill development and personnel recruitment.
- Organise prospecting activities, workshops and conferences, name building and announcements on behalf of the cluster. Participate in fairs and expositions.
- Organise a helpdesk functionality to the EO data user community in Belgium. This is best achieved by collaborating with existing initiatives, like EODesk.
- Organise market development activities for specific market segments.

CHAPTER X

VALORISATION

TELSAT GUIDE
EDUCATIONAL WEBSITES
CD-ROM *BEO*
PORTFOLIO OF PROJECT SHEETS*

FEDERAL OFFICE FOR SCIENTIFIC, TECHNICAL AND CULTURAL AFFAIRS (OSTC)
DEPARTMENT OF SPACE RESEARCH AND APPLICATIONS
APPLICATIONS PROGRAMS FOR EARTH OBSERVATION
Wetenschapsstraat 8 Rue de la Science
B – 1000 BRUSSELS

*Educative and promotional products developed for OSTC

1. TELSAT GUIDE

1.1 Purpose

Focusing on the needs and interests of the Belgian Remote Sensing community, the TELSAT Guide aims to pilot both the potential and the experienced user of satellite data through the rapidly expanding universe of remote sensing.
Practical and up-to-date information is provided on:

- satellites and sensors
- distribution of data
- products and applications

Special attention is devoted to Belgian remote sensing expertise in general, and Belgian remote sensing projects in particular those financed by the OSTC under the TELSAT and other programmes.
The TELSAT Guide was originally developed in a static html form in 1995-1996 for the OSTC by the Department of Forest Management and Spatial Information Techniques of the University of Gent. Since 1997, the TELSAT Guide has been managed by the Earth Observation help Desk (EODesk). In 1998, it was extended and redesigned in a dynamic database form by Geographic Information Management NV (GIM) in collaboration with Icon. The implementation of some additional tools by GIM in 2000 led to the current version of the TELSAT Guide.

1.2 Content

The TELSAT Guide consists of several sections, each covering another type of EO resources. The various sections of this guide were defined using the CEO Recommendations on Metadata (Recommendations on Metadata - A User Guide provided by the Centre for Earth Observation Programme of the European Commission).
For the implementation of the CEO Recommendations on Metadata, a database driven approach was chosen. As a result, the TELSAT Guide is mainly an on-line, dynamic database around which the WWW interface offers, through the different sections, different views to the database .

1.3 Overview of the different sections

1.3.1 About us

This section explains the purpose and content of this guide, the assignments of the EODesk and the evolution of the Belgian Earth Observation programmes.

1.3.2 Announcements

This section contains

- the latest additions to the TELSAT Guide database;
- information on remote sensing related events such as conferences, workshops, seminars, expert meetings, etc.;
- information on promotional actions, professional opportunities, calls for proposals, upcoming Invitations to Tender, etc.

1.3.3 EO Education

This section which, at the beginning, only contained a short introduction to Remote Sensing and a glossary, was recently developed under the STEREO programme: EOEdu now offers on-line access to theoretical information selected from the CD-Rom BEO (Introducing Remote Sensing, Applications, Satellites and Sensors characteristics, Glossary) as well as to pages with useful links and a teacher's corner with educational announcements and resources.

1.3.4 EO Resources

This section allows you to perform a search directed by choosing some parameters and get information on:

- the most common satellite platforms and the sensors on board;
- all kinds of organisations that are involved in Earth observation: private companies, administrations, research institutes, data distributors, etc.;
- services rendered by companies or organisations in the framework of remote sensing, with special focus on Belgian service providers.
- publications such as project reports, articles, books, CD-ROM's... These documents are often published in the framework of a project granted by OSTC, or as general reference books in the context of remote sensing.

A search tool allows a multi-criteria search for persons, projects, sensors and documents linked to numerous application fields.

1.3.5 EO Data

This section provides you with detailed information on the projects executed within the framework of the OSTC programs. The projects of the programs TELSAT, STEREO and VEGETATION are included, but also CEO projects, projects of Global Change, DUP projects and sustainable development, etc.
It also contains an image catalogue holding the meta-information of the OSTC satellite image archive, as well as a metadata base of well-documented test sites in Belgium and Africa.
In this section, the queries can be performed through a 'normal' database search or through the 'geosearch', which allows spatial queries.

1.3.6 Data Entry

This section allows you to register as ‘content provider’ in order to introduce data in the TELSAT Guide.

2. EDUCATIONAL WEBSITES

2.1 EduSat

2.1.1 Description

EduSat is an educative website allowing one to discover and to explore satellite imagery. Paving the way by representing various satellite image types and various landscapes this website has the objective to promote the use of satellite imagery.

2.1.2 Content

The website offers the possibility to download numerous images in full resolution, all of which are accompanied by a short description:

- ***Belgium***

  This part of the website allows accessing a SPOT image of region by selection it on a list of 3624 villages. A SPOT mosaic of Belgium is available as well.

- **SPOT**
  - *SPOT Demo Collection*
    This section contains an image gallery illustrating the wide variety of world landscapes.
  - *EduSPOT*
    A number of panchromatic and/or multispectral images of numerous European towns can be accessed.
- **Kosmos**
  A satellite image from the Kosmos satellite is available for the city of Liege.
- **IKONOS**
  High resolution images of Brussels, Gent and Liege are at disposal.

2.2 Themes

2.2.1 Description

The purpose of this site is to present satellite images on the basis of three themes. The website gathers together the information provided by the educative posters *The Silk Roads*, *Across Africa* and *Deserts of the World* by means of texts, photos, music and links.

2.2.2 Content

This website provides a description of the key issues satellite images as seen on the posters:

- *The Silk Roads*
  Venice, Baghdad, Balkh, the Karakorum Road, Kashi, Urumqi, Yuandum, Xi'an
- *Across Africa*
  Cairo, Aswan High Dam, Khartoum, Sudd, Kivu, Rukwa Lake, Soweto, Cape Town
- *Deserts of the World*
  Atacama, Great Salt Lake, Draa Valley, Ismailia, Sai, Namib, Taklamakan, Great Victoria

2.3 City Promotion

2.3.1 Description

The aim of *City promotion* is to promote three Belgian cities on the Web by means of satellite imagery. In order to create three separate sites dedicated to Liège, Ghent and Brussels viewed from space, City promotion is engaged to combine the existing sites into a single point of access in order to show these cities on a regional, Belgian and European scale. The features they have in common and the interactions between the cities are highlighted from both geographical and historical standpoints. At the local level, the spotlight is turned on each city with the aid of IKONOS imagery, which provides ground-level resolution ranging from 4 to 1 m.

The site was created by SURFACES on behalf of and in collaboration with the OSTC, in conjunction with the TELSAT 4 programme, under contract number T4/12/73.

2.3.2 Content

City Promotion offers plenty of information on Brussels, Liège and Ghent. By means of aerial and satellite imagery, an interactive map tool, old maps, photographs and texts one can find out how these three cities, which have been at the heart of Europe since time immemorial, have become the crossroads of the regional, Belgian and European land mass.
Hyperlinks provide direct access to the separate websites:

- *Brussels seen from space*
  This website realised by IGEAT (ULB) under contract number T4/11/62 has the objective of demonstrating the possibilities of remote sensing, in an urban context, more particularly of very high resolution data (IKONOS).

- *Gent seen from space*
  Realised by the city of Gent in collaboration with the Geography Department of the University of Gent under contract number T4/02/58. It allows the public at large to familiarise oneself with satellite imagery. It offers the possibility of viewing an IKONOS image of a chosen street, as well as the actual position of a given satellite.

- *Liege seen from space*
  Realised by the laboratory Surfaces of the University of Liege under contract number T4/12/61. While the primary objective of this website should be presenting the city of Liege seen by different satellites, it also seeks to promote the city of Liege on the web.

2.4 EduWeb

2.4.1 Description

EduWeb is the portal to the aforementioned websites brimming with information on satellite imagery, which are available in four languages (French, Dutch, English and German).

3. BELGIAN EARTH OBSERVATION

3.1 Description

BEO is an interactive trilingual (French, Dutch, English) CD-ROM primarily conceived for secondary school students.

The CD-ROM includes an encyclopaedic part (basic principles of remote sensing, most common satellites and sensors, applications, glossary) and a software, which allows one to get familiarised with a range of satellite image treatment techniques. By opening the gates to the remote sensing world, the CD-ROM brings a contribution to the promotion of satellite data use.

3.2 Content

3.2.1 Basic principles of remote sensing

A random selection of basic remote sensing principles (data acquisition, image processing, radar, GIS) illustrated by means of figures and animations.

3.2.2 Satellites, sensors and their images

An overview of the most common satellites and sensors: technical characteristics, image distributor contact info, a large amount of image types. Special attention is paid to meteorological satellites.

3.2.3 Applications

A range of applications covering very different domains (agriculture, ecology and forestry, humanitarian interventions, applied meteorology, marine environment, regional and city planning, environmental risks, global monitoring) illustrates the type of information remote sensing can offer.

3.2.4 Belgian research

How do federal authorities finance remote sensing research? What are the political guidelines on this matter? By means of hyperlinks an access to research institutes active within the domain is offered.

3.2.5 Glossary

For a better comprehension of the texts a series of explanations is gathered in a glossary directly accessible or by links within the texts.

3.2.6 BEO Interactive

BEO Interactive is an image processing software to be installed on a local hard disk allowing one to manipulate satellite images oneself in an independent way or step-by-step following the exercises proposed by BEO Basic and BEO Plus. The BEO Basic exercises guide one through the basic remote sensing principles and allow one to get familiarised with the tools and functionalities of image processing software. The BEO Plus exercises illustrate the importance of remote sensing for given applications.

4. APPLICATIONS FORMS

Earth Observation and Geo-Information Systems

4.1 Description

During the TELSAT programme, about 30 institutions had the opportunity to carry out feasibility studies (20) and/or pilot projects (15), mainly in the areas of agriculture, forestry, cartography, city and country planning.
The increasing diversity of image types and the multisensor and geographic information systems approach are characteristic for integrated information systems aimed at problem solving.

4.2 Content

Twenty-five projects are described in this publication. These are arranged by application type:

- agriculture
- hydrology
- forestry and ecology
- mapping and urbanisation
- geo(morpho)logy, bathymetry and archaeology

A list of addresses of scientific promoters and involved users is added at the back.

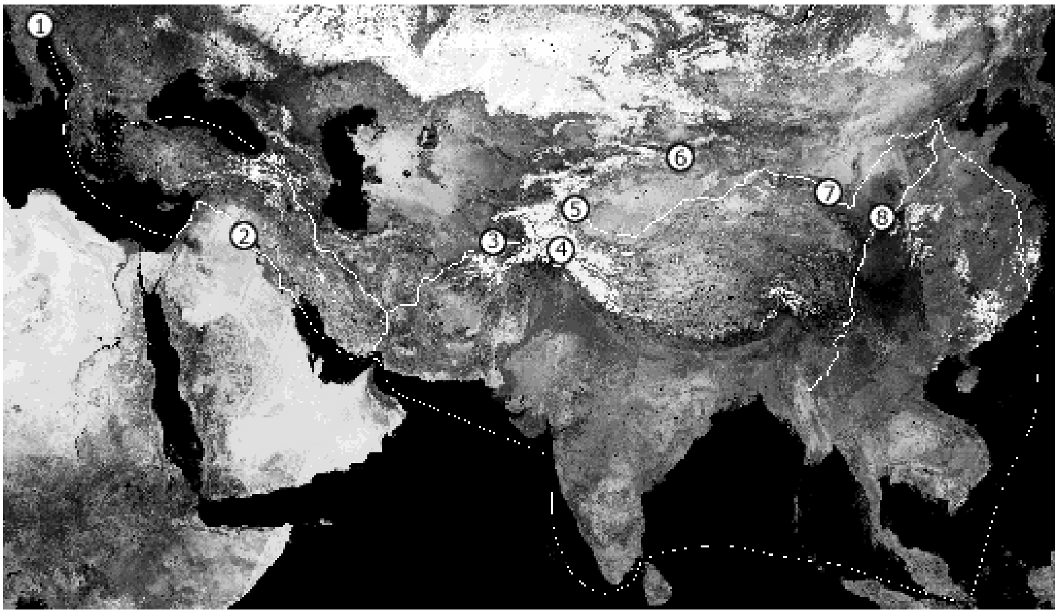
THE SILK ROAD

J.-P. DONNAY

UNIVERSITE DE LIEGE (ULG)
DEPARTMENT OF GEOMATICS
Laboratoire SURFACES
Allée du 6 Août 17, Bâtiment B5, Sart Tilman
B – 4000 LIEGE
BELGIUM

GENERAL INFORMATION

The Silk Road is a network of caravan routes used since Antiquity. Silk was long the major commodity carried along this more than 7,000-km long transcontinental route. The Silk Road had always facilitated economic and cultural exchanges. However, the



West did not truly become aware of the Silk Road's existence until the Venetian merchant Marco Polo published the account of his travels (13^{th} century). Although the Silk Road lost its importance in the 16^{th} century, notably due to the development of maritime transport, it is currently undergoing a resurgence of activity and has even been modernised. This is because of its importance as a gateway to and means of restoring old ties for Western China and the newly independent States of Central Asia. Merchants, tourists, researchers, goods, ideas and innovations are thus continuing to move up and down the fascinating road linking Europe and Asia.

2. THE MAIN MAP AND THE INSETS

2.1 Main map

The main map, titled ***The Silk Road***, consists of a satellite map (in natural colours) made by assembling a series of images acquired by the VEGETATION-SPOT 4 system. It serves as a background on which the Silk Road network is plotted.

2.2 Site specific insets

2.2.1 Venice

Venice belongs to an archipelago located in a northern lagoon in the Adriatic Sea.

(Source: SPOT XS of 25/11/1987; false colour IR composite)

2.2.2 Baghdad

Baghdad is located in Mesopotamia, at the end of the navigation route along the Tigris River.

(Source: SPOT XS of 06/06/1997; false colour IR composite)

2.2.3 Balkh or Wazirabad

Balkh, is located in the middle of a rich agricultural region in northern Afghanistan.

(Source: LANDSAT 7 of 17/07/1999; false colour IR composite)

2.2.4 The Karakoram Highway

This new road connects the Chinese town of *Kashi* with Pakistan and Afghanistan.

(Source: LANDSAT 7 of 25/09/1999; natural colour composite)

2.2.5 Kashi and environs

Kashi (a.k.a. *Kashgar*) is located at the foot of the Pamir Mountains, at the entrance to the *Tarim* Basin, with the *Takla Makan* desert at its centre.

(Source: LANDSAT 7 of 25/09/1999; natural colour composite)

2.2.6 Urumqi

Urumqi has a remarkable geographic situation at the crossroads of two major routes. The first one follows the northern piedmont of the *Tien Shan*, while the second follows a passage that links the *Tarim* Basin to the *Dzungarian* Basin.

(Source: SPOT XS of 25/03/1996; natural colour composite)

2.2.7 Yuandum - Wuwei

The image covers the region of Yuandun, between *Tumenzi* and *Wuwei*. It is the eastern entrance to the 800-km-long *Gansu* corridor, which is tucked between the *Qilian* Mountains to the west and *Tengger* Desert to the east.

(Source: SPOT XS of 25/03/1996; natural colour composite)

2.2.8 Xi'an

Xi'an is located at the convergence of two rivers in NW China.

(Source: SPOT XS of 25/09/1999)

4. INFORMATION ABOUT EDITION, AUTHOR AND COPYRIGHT

The Surfaces Laboratory of the Geomatics Department, Liege University, was responsible for the mapping and for co-ordinating the work.

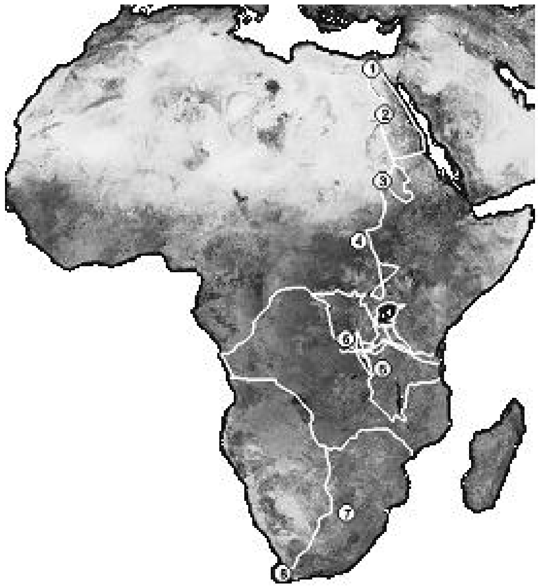
VALORISATION T4/XX/802

STRAIGHT ACROSS AFRICA

P. DE MAEYER

UNIVERSITEIT GENT (RUG)
Department Geography
Krijgslaan 281 Gebouw A1
B – 9000 GENT
BELGIUM

GENERAL INFORMATION



The poster gives an idea of the different landscapes encountered in Africa along a section from North to South. This line runs from Cairo to Cape Town, hewing roughly to the meridian 30°E. A variety of landscapes are found which correspond to different climate, relief and vegetation groups. The selected sites in the inset maps represent typical vegetation groups or illustrate the anthropic impact.

The important explorer routes for East and Central Africa are also represented on the map.

The extreme climatic conditions and the lush vegetation of the eastern part of the African continent formed the most important impediments to European discovery and exploitation of this part of Africa. Only at the end of the 19th century did explorers succeed in penetrating to the centre of the Rift during the expeditions in search of the sources of the Nile and later also of the Congo River. The Nile expedition remained a challenge for many years, one further heightened by a prize offered by the Royal Geographical Society of London.

2. THE MAIN MAP AND THE INSETS

The poster includes a main map, a relief map, a three-dimensional model, a global Meteosat image and eight auxiliary maps. The inset maps present spatial thematic and technical sub-aspects, the other maps cover the entire continent.

2.1 Main Map – Colour Composite SPOT4-Vegetation of Africa

The image illustrates the continent's significant vegetation differences. These are primarily the result of the climatic and relief differences. The routes of the most important 19th-century expeditions searching for the sources of the Nile and Congo are overlaid.

2.2 Relief Map

The map presents the orography and the main rivers of the African continent.

2.3 Meteosat image

This image is characteristic for the kilometre-scale sensors which make possible to collect data over large surfaces on a regular basis. The image gives a clear picture of the clouds in the Intertropical Convergence Zone.

(Source: Meteosat 23/07/1994 11h15 UTC, false colour composite)

2.4 Three-dimensional model – Lake Kivu and Virunga

The three-dimensional model was created using a kilometre-scale digital elevation model, over which a satellite image was draped. From the North of Lake Kivu the observer looks further northwards.

(Sources: LANDSAT5 TM; false colour composite draped on a digital elevation model of NOAA)

2.5 Site specific insets

2.5.1 Cairo

On the right bank of the Nile one finds the historical centre of Cairo.

(Source: LANDSAT 5 of 25/04/1994, TM; false colour composite)

2.5.2 Aswan

Detailed image of the Aswan High Dam, at the lower end of Lake Nasser. It controls the floodwaters from the upstream Nile.

(Source: LANDSAT 7 of 07/08/1999, combination of the multispectral bands with a panchromatic one)

2.5.3 Khartoum

Capital of Sudan, at the confluence of the White and the Blue Nile.

(Source: LANDSAT 7 of 01/09/1999 TM; natural colour composite)

2.5.4 Sudd

Sudd is located in south central Sudan and forms the natural barrier between Northeast Africa and Central Africa.

(Source: LANDSAT 5 of 21/11/1994, TM; natural colour composite)

2.5.5 Kivu

The Kivu region is located in eastern Congo. It borders on Uganda, Rwanda, Burundi, and Lake Tanganyika on the east.

(Source: LANDSAT 5 of 07/08/1987, TM; false colour composite)

2.5.6 Lake Rukwa

This lake forms part of the African Rift.

(Source: ERS1 22947/7011 of 04/12/1995 and ERS2 3274/7011 of 05/12/1995)

2.5.7 Soweto

Already under the Apartheid's rule, before the second World War, separate towns were built in South Africa for the black population. Soweto (SOuth WEst TOwnship) is the largest one.

(Source: SPOT of 20/07/1999 – panchromatic)

2.5.8 Cape Town

Cape Town is located on the Table Bay.

(Source: LANDSAT 7 of 02/11/1999, ETM - false colour composite, with a panchromatic inset)

3. INFORMATION ABOUT EDITION, AUTHOR AND COPYRIGHT

Realisation by the University of Gent, 'Vakgroep Geografie' in collaboration with the Musée Royal d'Afrique Centrale (Département Géologie et Minéralogie, Section

Cartographie et Photointerprétation). Co-ordination by Laboratoire SURFACES, Département de Géomatique, Université de Liege.

VALORISATION T4/XX/803

DESERTS OF THE WORLD

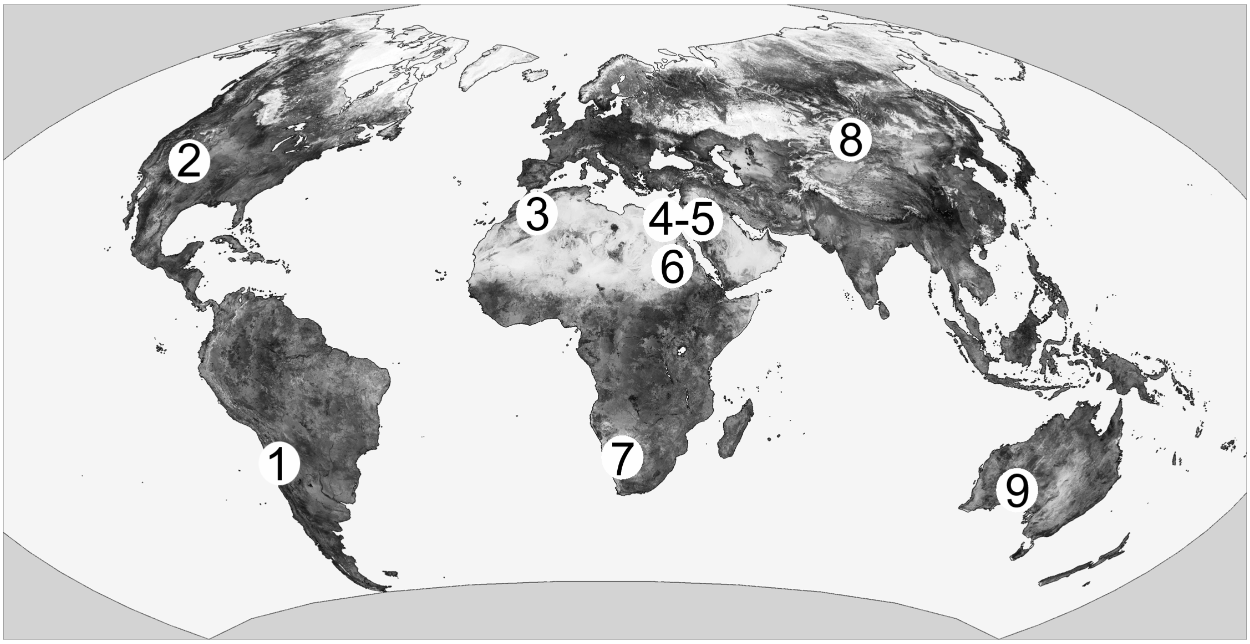
R. GOOSSENS

UNIVERSITEIT GENT (RUG)
Vakgroep Geography
Centre for Cartography and GIS
Krijgslaan 281 Gebouw A1
B- 9000 GENT
BELGIUM

1. GENERAL INFORMATION

Deserts cover one-fifth of our Earth's land surface. The Sahara, the world's largest unbroken desert region, extends from the Atlantic Ocean to the Red Sea, covering a total surface area of 9 million km^2. Deserts are among the very dry areas which, according to the Köppen climatic classification, receive less than 25 mm of precipitation per year. There are hot and cold deserts. A desert will be colder the closer it is to the poles and the higher the altitude at which it lies. This poster deals with the deserts lying between the tropics of Cancer and Capricorn. One also distinguishes between stony or rocky deserts and sandy deserts.

The dry desert areas are home to a surprisingly wide diversity of inhabitants: plants,



animals and people who, over the course of time, have optimally adapted to the extreme living conditions. Deserts are continually subject to changes for which both human beings and nature are responsible. Human activities can contribute to converting areas with sparse vegetation cover into desert-like conditions. This can be caused, for example, by the cutting or burning of vegetation, or overgrazing of livestock. The surface is exposed to wind, rain and direct sunlight, allowing erosion and dehydration to readily gain the upper hand. Dunes can move many meters per year, and in a short time cover cultivated areas with sand. In the context of an increasing loss of arable land due to desertification, with all the attendant socio-economic consequences, the UN Convention to Combat Desertification was drafted, and starting in 1999 a World Desert Day is being organised each year on June 17th.

In several countries (e.g. in Egypt, Israel and Southern California), efforts are being made to win back arable land from the deserts using fertilisers, soil structure improvers and intensive irrigation.

2. THE MAIN MAP AND THE INSETS

2.1 Main Map

The main map is made on the basis of SPOT – Vegetation satellite images.

2.2 Precipitation Map

The precipitation map shows the connection between the average annual precipitation and the desert areas. This small map also gives the sites, which correspond to the different inset maps.

2.3 Map of the vegetation types

The locations of the deserts in the intertropical area are plotted on this map.

2.4 Site specific insets

2.4.1 Atacama Desert

The Atacama Desert extends along the west coast of South America in Northern Chile.

(Source: LANDSAT TM, 15/01/1998 ; colour composite)

2.4.2. Great Salt Lake

Salt Lake is a typical salt desert, located in the state of Utah (USA), west of Salt Lake City.

(Source: LANDSAT MSS 24/07/1992 ; false colour composite)

2.4.3. Draa Valley

The Draa River originates in the Atlas mountains in Morocco and forms an inland delta in the Sahara.

(Source: SPOT Multispectral (XS) 30/03/1998 ; false colour composite)

2.4.4 Ismailia

Ismailia is a region in Egypt along the west bank of the Suez Canal.

(Source: ERS Radar of 01/11/1995 - LANDSAT TM 25/04/1994; false colour composite)

2.4.5 Sai

Sai is an island in the Nile in the northern Sudan.

(Source: SPOT Multi Spectral (XS) 16/01/1998 ; false colour composite)

2.4.6 Namib

The Namib Desert extends along the west coast of Africa.

(Source: LANDSAT 7 26/08/1999 ; false colour composite)

2.4.7 Taklamakan

The Takla Makan Desert extends over central Asia in Mongolia and China.

(Source: LANDSAT 7 25/06/1999 ; false colour composite)

2.4.8 Great Victoria

Great Victoria is a semi-desert covering a great part of central Australia.

(Source: LANDSAT MSS 24/10/1982 ; false colour composite)

3. INFORMATION ABOUT EDITION, AUTHOR AND COPYRIGHT

Realisation by the University of Gent, Vakgroep Geografie. Co-ordination by the Laboratoire SURFACES, Département de Géomatique, Université de Liege.

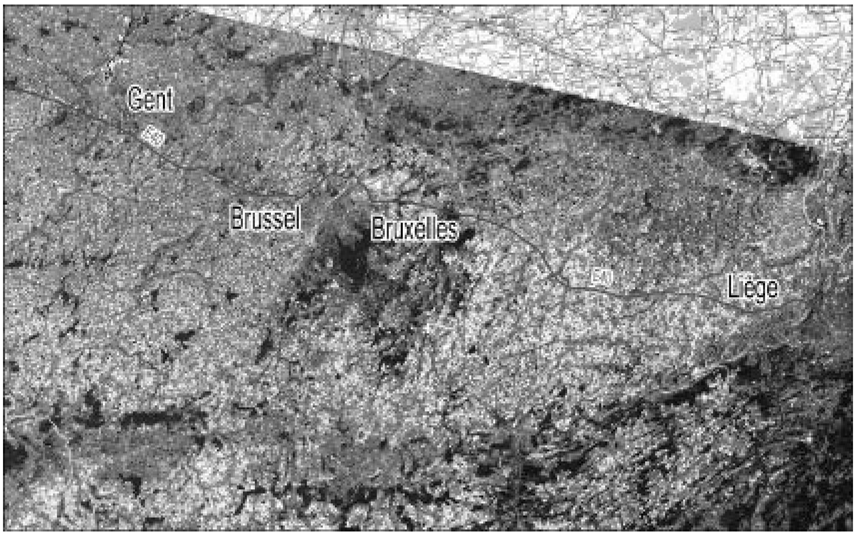
VALORISATION T4/XX/808

BELGIAN CITIES SEEN FROM SPACE

J.P. DONNAY

UNIVERSITE DE LIEGE (ULG)
DEPARTMENT OF GEOMATICS
Laboratoire SURFACES
Allée du 6 Août 17, Bâtiment B5, Sart Tilman
B – 4000 LIEGE
BELGIUM

GENERAL INFORMATION



The new millennium sees the dawn of a new era for earth observation. The new generation of satellites with very high-resolution (1-4 m) sensors aboard offers new possibilities due to the aerial photograph-like quality of the images.
The advantages of these images are manifold: high data acquisition rate because of the ever increasing number of satellites in orbit, digital data recording for direct use in GIS systems, importance of large area coverage, …
Today, the use of very high-resolution images plays a commanding role in areas such as regional and urban planning, geomarketing, risk and hazard assessment for insurance companies,…
The 1-m spatial resolution on offer by *IKONOS* allows for large-scale reproductions such as the 1 / 3 000 samples shown above. In addition to the visible light channels, the near infrared channel proves useful for vegetation monitoring applications.

2. THE MAIN IMAGES AND THE INSETS

The poster includes three main images, five detailed extracts, a relief map and an overview image.

2.1 Main images

The images are the result of combining the 4-m resolution visible light channels and the 1 m panchromatic black and white channel. The IKONOS images over the cities of Gent, Brussels and Liege are acquired respectively on 9th May 2000, 8th June 2000 and 13th June 2000.

2.2 Detailed Extracts

A full resolution extract is displayed in panchromatic mode. For the city of Brussels the method of image fusion is visualised as well.

2.3 Overview image

The image gives a clear picture of the spatial relations between the three agglomerations.

(source: LANDSAT 7 ETM+ of 18/10/1999, natural colour composite)

2.4 Relief map

The map presents the orography and the main rivers in Belgium.

3. INFORMATION ABOUT EDITION, AUTHOR AND COPYRIGHT

Realisation by Laboratoire SURFACES, Département de Géomatique, Université de Liege.