SPSD II

IMPROVED PREDICTION OF WIND POWER IN BELGIUM

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GENERAL ISSUES

AGRO-FOOD

PART 1

SUSTAINABLE PRODUCTION AND CONSUMPTION PATTERNS — ENERGY

TRANSPORT

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SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY
(SPSD II)

Part 1:
Sustainable production and consumption patterns

FINAL REPORT

IMPROVED PREDICTION OF WIND POWER IN BELGIUM

CP/54

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October 2006

D/2007/1191/42
Published in 2007 by the Belgian Science Policy
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0. Introduction

0.1. Context

In the planning and engineering phases of wind energy projects, there is a need for high quality statistics of meteorological parameters and for validated methods to make extrapolations from measured data to specific wind turbine sites. The historical meteorological data in Belgium collected by RMI are not directly suitable for use in wind energy projects, because of historical changes in observation methods and changes of station characteristics.

Optimising the site of the measuring location and method with regards to utilisation for wind energy application can enhance the direct use of the measured data significantly. The service of RMI could constitute an important added value for wind energy project developers. The relevance of the work that is reported here lays in the importance of wind energy in the framework of sustainable development. Onshore wind energy in Belgium has a long-term potential of more than 1000 MW.

0.2. Objectives

The objective of the project is to improve the basis for the accurate prediction on short and long term of the power generated by wind energy plants in Belgium. The project focussed on the quality of the meteorological data and the description of the different meteorological stations in terms of surroundings and set up of the measurement. Further an analysis of different models and tools have been evaluated for extrapolation from observation sites to specific sites of interest.

The detailed objectives are:

- To define a set of reference long term stations and to reanalyse historical wind data of these stations into a format appropriate for resource mapping and other relevant analyses for wind energy;
- To prepare a roughness map for resourceful wind areas on the Belgium territory based on remote sensing information in a format suitable for resource mapping;
- To evaluate suitable prediction models for complex terrain for their application in Belgian situations by analysis and experimental validation
- To formulate recommendations on the optimisation of measuring stations for wind power applications

Remark: The objective of the project is NOT to improve the data and methods for predicting wind energy output and NOT for forecasting. With prediction is meant: the (long term) calculation of the annual energy output of a wind turbine or wind park based on measured historical data. With forecasting is meant: the (short term) forecast of the output of a wind turbine or wind park for the coming hours or days based on forecasted weather information.

0.3. outcomes

The project has generated the following specific deliverables:

- Report with survey of recommended wind reference stations, including detailed station descriptions (measurement set-up and station surroundings) statistics and qualifications of the analysed data,
- Frequency distributions in the format of WasP tables, have not been delivered as this information is property of KMI.
- Extreme wind speeds values for the different stations for turbines selection.
- An accompanying CD Rom with relevant annexes.
- Updated roughness maps of the Belgian territory in vector format appropriate for input in wind resource calculation models;
- Results of comparative analysis of the listed wind models and of the case studies investigated;
- Recommendations on upgrading of measuring network for wind energy purposes

0.4. Detailed description of the scientific methodology

0.4.1. Project overall method

The overall method used in the project is presented in Figure 1. In the initial phase the three major constituting elements of the resource evaluation will be investigated: the wind data (Task 1), the terrain roughness maps (Task 2) and the different models (Task 3). After completion of these activities, the basic elements are available for verification (Task 4) of the prediction method, in the form of self and cross predictions on the long term period. In the last stage of the project, recommendations and guidelines (Task 5) are drafted for using the data sources and methods in specific situations in Belgium. An evaluation is made (Task 6) of the present measurement set-up and recommendations are made for improved measurements.

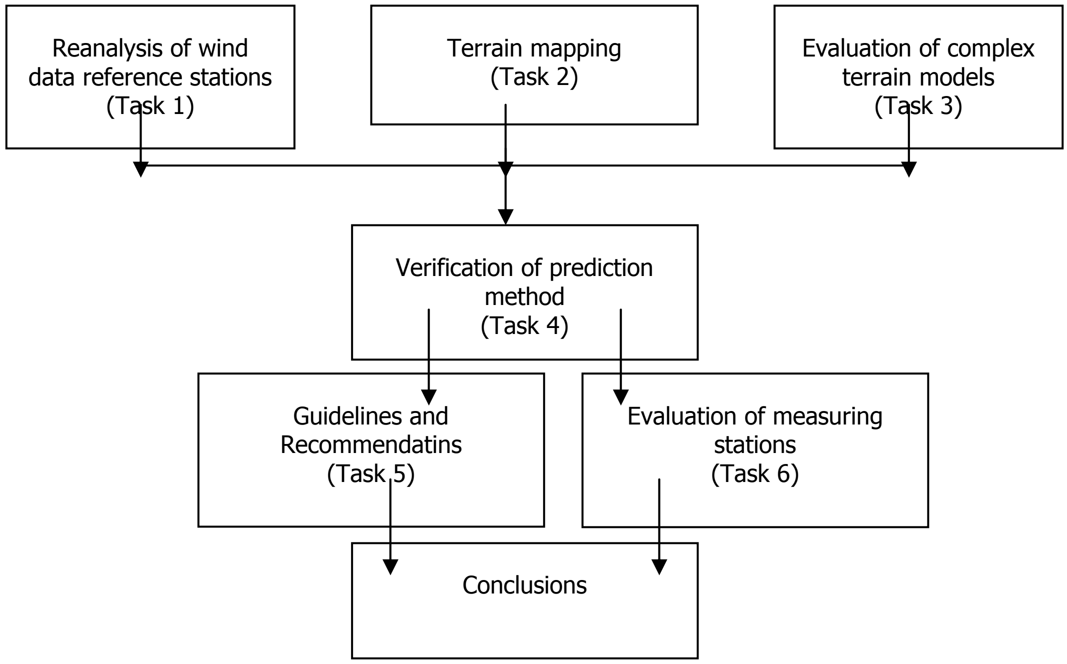


Figure 1 Overall work method of the project

0.4.2. Task 1: Qualification of wind data and of reference meteorological stations

The qualification of the wind data includes the definition of a set of wind observation stations and corresponding historical measured data series sufficiently representing the long term wind climate and covering the territory of Belgium relevant for wind power generation. The 'RMI' observation stations constitute the basis for the reference set. Ideally the entire set should enable correlation with short term on site measurement for every potential wind power location in Belgium. The focus is on measured wind data for the last 10 to 15 years (from 1988 onwards).

0.4.3. Task 2: Preparation of terrain roughness maps

Terrain roughness maps have been prepared forming the basis for regional wind resource evaluation for the whole Belgian territory. The maps have been drafted on the basis of zoning maps, CORINE land use maps and topo10GIS vector/raster maps. The maps have been modified in order to adjust them to the most recent terrain situations. The maps have the resolution needed for the calculation of the wind resources with professional wind energy software tools. In this way, the resulting maps can be used for short and long-term wind resource prediction purposes.

0.4.4. Task 3: Evaluation of wind field models

A number of existing wind field models for regional wind resource mapping purposes have been evaluated. The models calculate the three-dimensional wind field over a selected area of complex terrain, based on input of meteorological data and terrain data. The capacity of the selected models to predict the local wind climatology have been assessed by comparison of calculated and observed wind speeds. Existing high-quality wind speed are used. This research is particularly useful for hilly regions, for which there is currently a lack of well-verified wind modelling methods. The validity and suitability of the models for various types of terrain in Belgium will be evaluated in case studies. The investigated models include ARPS (VITO), TVM (UCL), MAR (UCL), Maestro Wind (ATM PRO) and WAsP.

The models tested in the project are summarised in Table 1.

Model	**Operated by partner**	**Model scale**
ARPS	Vito	meso
TVM	UCL	meso/micro
MAR	UCL	meso
Maestro WIND	UCL/ATM PRO	meso/micro
Wasp	3E	micro

Table 1 Evaluated models

The validity of the models for the various relevant terrain topologies in Belgium are evaluated by carrying out case studies. The modelling results are compared with measured data.

A number of sites have been selected where the simulated wind field can be compared with actual observations on the spot. The sites have a varying degree of complexity. Simple terrain means mainly flat, with a reasonable variation of roughness and obstacles. Complex terrain essentially means terrain with a large variation in terrain elevation and slopes.

0.4.5. Task 4: Verification of the methodology

The objective of this task was to qualify the reference wind measuring stations for long term prediction purposes. The self-prediction capacities of reference stations were evaluated by comparing measured and calculated wind regime. Cross predictions of reference stations are be made. The approach consists of the following elements:

- Self-prediction: For each of the selected long term reference stations. By using the detailed station description as obtained in Task 1, and roughness maps of Task 2, the predicted wind climate is calculated on the basis of the observed wind climate.
- Cross-prediction: For selected stations it is verified how well one station is able to predict the wind climate at the other. The method used for the cross predictions is depending on their relative distances and geographical positions..
- Comparative evaluation: Possible causes for significant deviations between observed and calculated wind regimes will be analysed. If required, adaptations will be implemented to station surrounding descriptions or even in the roughness maps.

0.4.6. Task 5: Recommendations and guidelines

The major findings of the project are summarised in a separate chapter, containing recommendations and guidelines for the purpose of predicting wind power in Belgium.

0.4.7. Task 6: Evaluation and recommendations for data measurements

A critical review of the Belgian measuring network for wind energy has been undertaken, based upon specific data requirements for wind energy projects. Some and recommendations for possible improvement of the measuring network are made. The results can be used as a basis for new strategies in measuring meteorological data in Belgium.

1. Task 1: Reference meteorological stations and wind data

1.1. General

In the framework of the qualification of the meteorological stations for wind energy applications in Belgium, a review is made of the existing stations. The set mainly consists of stations operated by the Meteo Wing (military aviation) and Belgocontrol (civil aviation). These stations have long time series of synoptic data. In addition, to be as complete as possible, the automatic weather stations (AWS) of RMI are reviewed.

The objective is to collect information to enable a description of the wind measuring station and their surroundings. The description allows judging the conditions, reliability and quality of the data sets from those stations in view of their use for wind energy application. The description allows making suitable spatial extrapolations of the wind climate starting from those stations. For this purpose a description has been made of the surroundings of the station: obstacles, terrain roughness and orography (relief). On the basis of the assessment, a classification has been made of the reference stations.

1.2. Methodology

1.2.1. Instrumentation

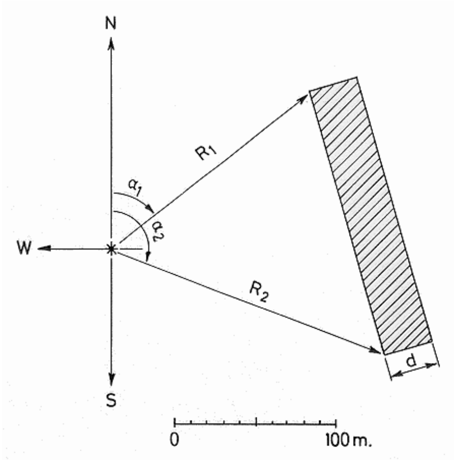
Most of the stations we have visited have more than one meteorological mast. Therefore it is important to know which one is used for the synoptic report. With a GPS instrument (Garmin etrex summit), the position of each mast has been located. The precision of this instrument is ± 5 a 10 m.

A clinometer *Suunto tandem* with integrated compass has been used to verify the altitude of the obstacles and their location on the map.

A distance meter *LRF 900* from *Leica* has been used to verify the distance between the mast and the objects within a range of 500 meters (the accuracy of the instrument is 0.5 % within a range of maximally 800-meter range).

1.2.2. Description of an obstacle

This document shows a detailed description of the obstacles around the mast within a range of 500 m.. Each obstacle has been specified by its position relative to the site, its dimensions and has been assigned a porosity (0 means no porosity, e.g. a building). Figure 2 defines the quantities that specify a single obstacle.



α_1	angle from N to first corner [º]
R_1	*radial distance to first corner [m]*
α_2	*angle from N to second corner [º]*
R_2	*radial distance to second corner [m]*
h	*height of obstacle [m]*
d	*depth of obstacle [m]*
P	*estimated porosity (fraction 0-1)*

Figure 2 Quantities to specify a single obstacle

Obstacles are thus specified relative to a specific site location and are not linked directly to the topographic map.

To have a visual appreciation of the surroundings of the mast, pictures have been taken into the directions 0, 30, 60,…, 330 degrees and if available, air pictures are also included.

1.2.3. Overview of all visited sites

We have visited 28 stations: 7 from Belgocontrol, 9 from Meteo Wing and 12 AWS stations of RMI. In Figure 3 this stations are plotted on a map:

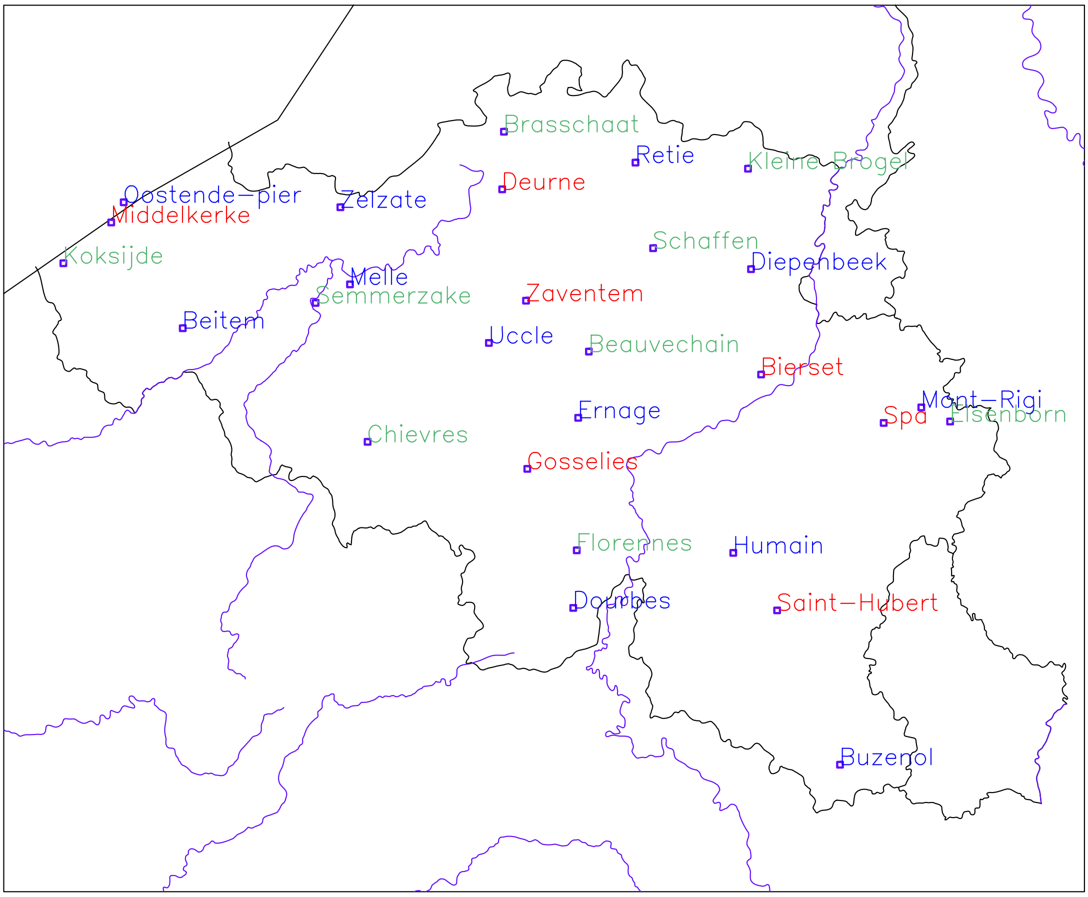


Figure 3 Synoptical network Belgium (red: Belgocontrol, green: Meteo Wing, blue: RMI)

1.2.4. Evaluation method and criteria

For the final evaluation of the stations we will have to check at least the following properties of the station:

- Is the site opening sufficient (e.g., following the WMO criteria for wind measurements) ?
- Has there been a significant change in obstacles around the mast ? (For the evaluation of obstacles, guidance can be taken from a "note technique" de Météo France) [1].
- When and how many times has the mast been displaced ?
- How many changes in sensor type have been detected ?
- Which is the quality of the delivered data (interruptions in the data set (a.o. missing data) and how does the data set compare with surrounding stations)?

The evaluation method and criteria to assign a station a certain quality label have not yet been exactly defined.

1.3. Description of the stations

In this section, a thorough description of every station will be given. For every visited station, the correct geographical location of the mast will be given in Lambert 72 coordinates, together with the altitude in m above sea level (a.s.l.) and the height of the mast will be expressed in m above ground level (a.g.l.). To facilitate map search, the correct map number is given for every station. Hereby the map numbers as edited by the National Geographic Institute are used in this work. Before continuing with the detailed site description, a brief instrument history will be given when necessary. To describe in fine detail the surroundings of the mast within 500 m, a listing of every obstacle in the area is tabled together with its characteristics as described in 1.2.2.

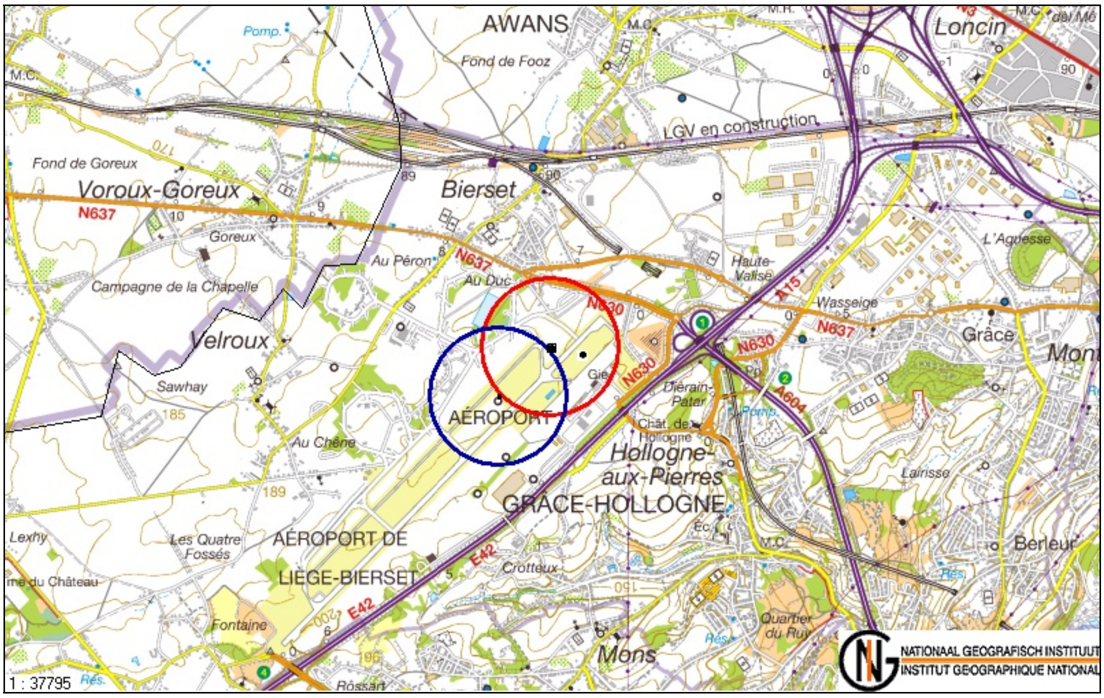
Also maps from NGI are included in this report. They show the location of the mast as a dot. I also marked a colored circle with a radius of 500 m around the mast. The Red circles correspond to the new mast locations, the blue ones to the previous mast location the green ones to the alternate mast location. The scale of the map is 1:37795.

1.3.1. Bierset

1.3.1.1. Location:

Mast	Lambert 72		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)		
Synop	226875	148929	180	10
old mast	226492	148577	178	10

Map: 42 ½



1.3.1.2. Instrument history:

Since 15th of March 1998 Belgocontrol became responsible for the synoptical reports. Since then, Vaisala instrumentation is used on the current location. (This Vaisala is in use at Belgocontrol since the 30th of October 1995).

Before the 15th of March 1998, the Meteo Wing was responsible for the communication of the synoptical messages. (RMI received for 2 months from 15th of March until 15th of May 3 hourly data in the envelopes. Afterwards the envelopes were again hourly)

The mast, used by Meteo Wing, was located between the two runways (see annex).

The Meteo Wing introduced a Vaisala anemometer at Bierset in 1991 or 1992 with the introduction of the FMA[1]. It is assumed that a Fuess was in use since 1970.

This airport is going to expand within the next years. Therefore it is necessary to find a better location for the anemometer. Also within the near future (± 2008) the mast location will change. This is because the runway is going to be extended till 3700 meters (actual situation: 3287 m).

[1] semi automatic station

1.3.1.3. Site description:

The airport of Bierset is situated at about 8 km westwards from the city of Liege. It is a site, which has and is going to be subjected to a lot of changes.

The concave curvature properties of the runway are included in this report. The slope of the runway is + 1.2 % within directions (220) and (40). The lowest point of both runways is located on runway 22R at an altitude of 174 m a.s.l. The highest point of both runways is located at the end of runway 22L at an altitude of 201 m a.s.l.

On the 7th of April, 2002, the construction of a new passenger terminal has been started. In March 2005, the terminal is officially in use.

The aerodrome of Bierset is located within complex terrain. The west side of the site is gently undulating with altitudes between 150 and 180 m a.s.l. Within direction (360), the topography is decreasing. The terrain in the sectors (90) → (210) is quiet complex and urbanised. Within these sectors, the topography is descending towards the valley of the river the Maas.

Obstacle description

Study circle: 500 m

Obstacles map (position and numbering of obstacles on map) :

Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	0	300	15	400	8	40	0.5	Trees
2	110	430	113	540	9	20	0	Hangar
3	125	430	135	430	18	50	0	Terminal
4	143	435	170	500	8	40	0	Hangar
5	110	750	170	750	15	20	0.5	Trees
6	280	500	285	500	15	20	0	Hangar
7	290	380	310	380	15	130	0.5	Pine trees
8	320	260	340	250	6	40	0.5	Trees
9	314	350	316	350	2.5	5	0	bunker
10	340	22	342	23	2	3	0	Ils-container
11	343	330	349	340	6	8	0	house

Within direction ((75) – (95)) an old fort is situated on a ridge at 660 meters. The altitude of the ridge is at 195 m a.s.l. with trees of about 18 meters.

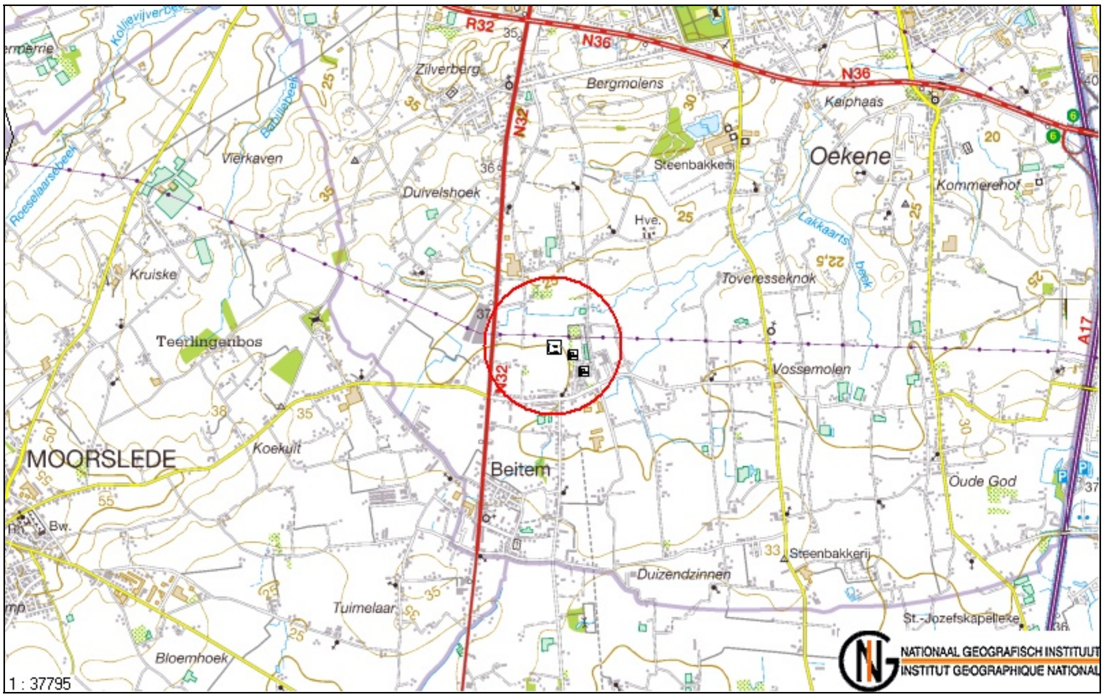
Control Tower at 755 m within direction , altitude: 25 m.

1.3.2. Beitem

1.3.2.1. Location:

Mast	Lambert 72		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)		
synop	62280	177821	25	10.5

Map: 28/4



1.3.2.2. Measurement period:

1st of August, 2003, 7 a.m. →

1.3.2.3. Instrumentation:

Wind velocity sensor LISA

Wind direction sensor RITA Gray

1.3.2.4. Site description:

The meteo station Beitem of RMI is located in the municipality of Moorslede at the Provinciaal Onderzoeks- en Voorlichtingscentrum voor Land- en Tuinbouw (POVLT), ± 4.5 km southwards from the centre of Roeselare. The location of the meteo mast at Beitem has known different locations. Our AWS has been installed on this site since 2000. First, the location of the mast was located to close to the nearby buildings at about 40 meters from the shed and 80 meters from the greenhouse. The new location is situated in the centre of the agricultural field from the POVLT . The surroundings can be described as a flat area with few windbreaks.

Obstacle description recent location
Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	25	280	35	295	12	1	0.5	Trees
2	35	320	40	360	4.5	50	0	Greenhouse
3	42	309	45	325	6	8	0	House
4	45	335	47	337	8	10	0	House
5	57	300	67	284	6	20	0	Farm
6	80	210	84	210	4.5	35	0-1	Open-closed greenhouse
7	85	210	113	240	4.5	35	0	greenhouse
8	114	222	122	184	8	20	0	Shed
9	130	210	134	222	6	45	0	shed

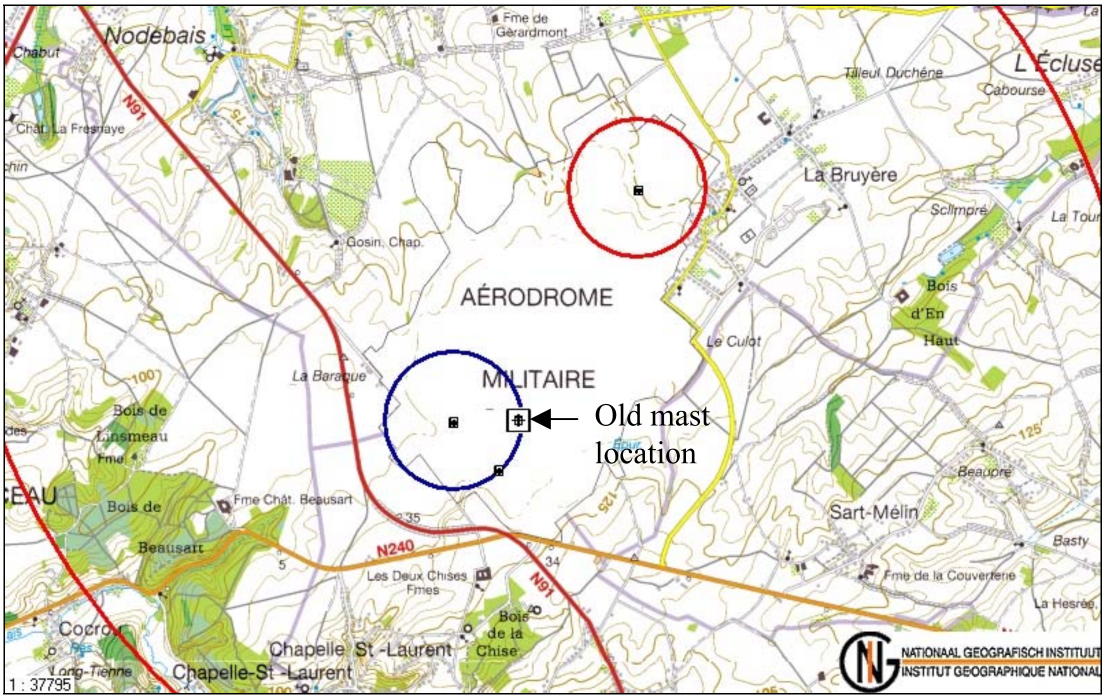
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
10	135	230	143	280	5	55	0	building
11	140	234	143	223	8	55	0	shed
12	143	330	150	325	13	20	0	Building
13	155	296	160	285	8	30	0	Building
14	160	280	164	265	18	1	0.7	Poplar
15	164	265	166	330	18	1	0.35	Poplar
16	175	375	199	400	8	10	0	Houses
17	175	410	199	440	8	20	0	Houses
18	200	360	203	350	10	0.5	0.5	Trees
19	202	383	203	387	8	20	0	House
20	204	395	206	400	10	10	0	House
21	206	360	208	365	8	20	0	Shed
22	215	385	218	390	9	2	0.5	Trees
23	231	270	235	265	10	30	0	House
24	242	300	252	300	10	60	0.1	Farm
25	270	455	272	440	8	8	0.1	Houses
26	290	445	294	390	6?	35	0	Warehouse
27	305	450	320	380	9	1	0.5	Pollard willow
28	323	385	325	380	8	15	0	Farm
29	334	390	337	380	8	25	0	Farm
30	339	415	344	400	8	10	0	Farm
31	344	360	346	358	8	30	0	Farm

1.3.3. Bevekom/Beauvechain

1.3.3.1. Location:

Mast	Lambert 72		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)		
22	178864	161593	98	10
04	177515	159904	109	10
Old	177980	159920	112	10

Map: 32 5-6, 32 7-8.



The anemometer of Bevekom is located on an air base. Bevekom (also called Beauvechain) is the head quarter of the Meteo Wing. Since the beginning of the nineties, 2 anemometers are installed at both extremities of the runway. Therefore, only one anemometer was used which was located at about 430 meters from the control tower in direction (30).

Between 1991-1992 and 4th of January 2001, mast (04) was used for the synoptical reports. Thereafter, it changed into mast (22) on 4th of January 2001.

On 3rd of October 2000, a changeover took place from FMA → AWS.

1.3.3.2. Site description:

The air base of Beauvechain is a large open area, surrounded by trees. The anemometers are well exposed. Hereafter follows the obstacle description:

1.3.3.3. Bevekom (22)

Obstacle description

Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	78	470	86	500	12	5	0.5	Array of trees
2	86	500	93	475	15	20	0.5	Trees
3	106	440	115	450	16	5	0.5	Trees
4	115	450	118	450	8	6	0	House
5	121	425	126	425	6	6	0	White House
6	126	450	129	450	10	4	0.5	Trees
7	129	450	132	450	20	5	0.5	Trees
8	155	406	159	415	8	5	0.5	Trees
9	159	415	175	500	8	5	0.75	Trees
10	235	84	238	86	2	2	0	ILS-container
11	290	430	323	350	20-24	45	0.5	Fir-trees
12	331	512	335	488	20	40	0.5	Fir-trees
13	344	382	350	394	15	10	0.5	Trees
14	354	500	357	531	7	20	0	Hangar

1.3.3.4. Bevekom (04)

Obstacle description
Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

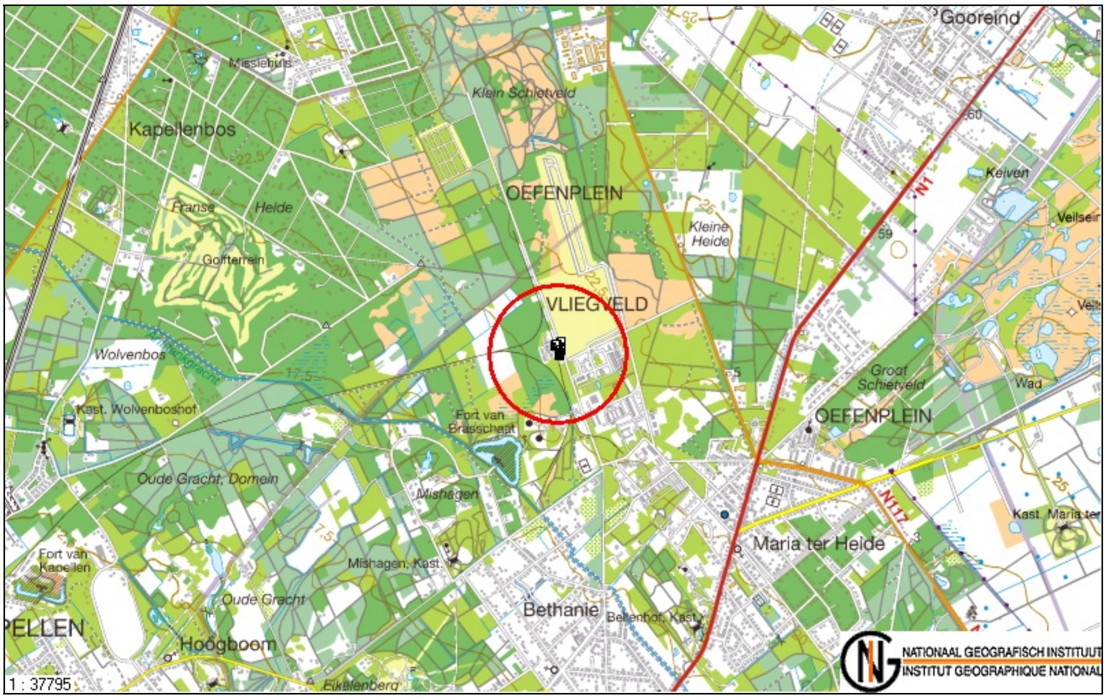
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	136	560	138	540	9	8	0	Tower
2	138	540	140	520	3	12	0	Building
3	147	430	151	417	7	20	0	Hangar
4	157	470	500	159	7	20	0	Hangar
5	190	248	194	262	8	4	0.5	Trees
6	200	226	212	200	4	5	0	Talud
7	274	304	285	250	10-16	400	0.5	Trees
8	300	250	330	333	10-16	300	0.5	Trees

1.3.4. Brasschaat

1.3.4.1. Location:

Mast	Lambert 72		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)		
synop	159290	225125	21	18

Map: 07/8



1.3.4.2. *History of the station:*

Since 1978, the anemometer was already located on the roof of the traffic tower, which is situated in the southwestern part of an open plain with dimensions of 500*600 m (see map).

With the installation of the semi automatic station (FMA) at Brasschaat, the mast has been moved towards the meteo park on 06/05/1991, only a few meters away from the west border of the open plain. Since the measured values were also here too low, compared with the nearby stations of Woensdrecht (Netherlands) and Deurne, it has been decided to move the anemometer between some buildings and trees and place the anemometer on a mast with an altitude of 18 meters on 24/03/1999.

Since this intervention, the measurements are still too low. Only when the wind is coming from the east, comparable measurements with the stations of Woensdrecht and Deurne are met. Therefore we will not use the data from this station.

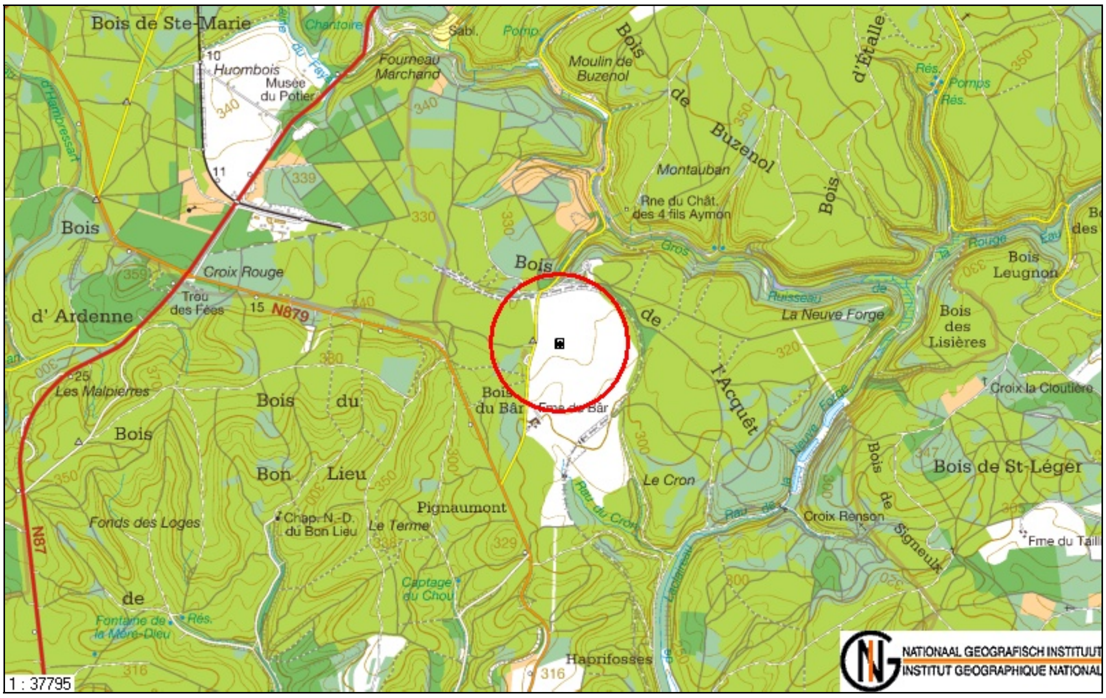
The most suitable location would be the centre of this open plain, but since this plain is used for operational issues (helicopters), it has been decided that setting up a mast in the centre would be too dangerous.

1.3.5. Buzenol

1.3.5.1. *Location:*

Mast	Lambert 72 X (m)	Lambert 72 Y (m)	Alt (m a.s.l.)	Alt (m a.g.l.)
Synop	238068	35002	324	10.5

Map: 71/2



1.3.5.2. *Measurement period:*

3rd of April, 2003, 6 a.m. →

1.3.5.3. *Instrumentation:*

Wind velocity sensor LISA

Wind direction sensor RITA Gray

1.3.5.4. Site description:

The automatic weather station (AWS) of Buzenol is located in the most southern part of Belgium; at about 17 km WSW from Arlon and ± 7 km NE from Virton. The AWS is almost completely surrounded by forest within a range of 5 km and is situated in an open plain within the forest. The slope of this open terrain is descending towards direction SSE with a slope of ± 3 %. Within the opposite direction, the slope is ± 1.8 %.

Obstacle description recent location
Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

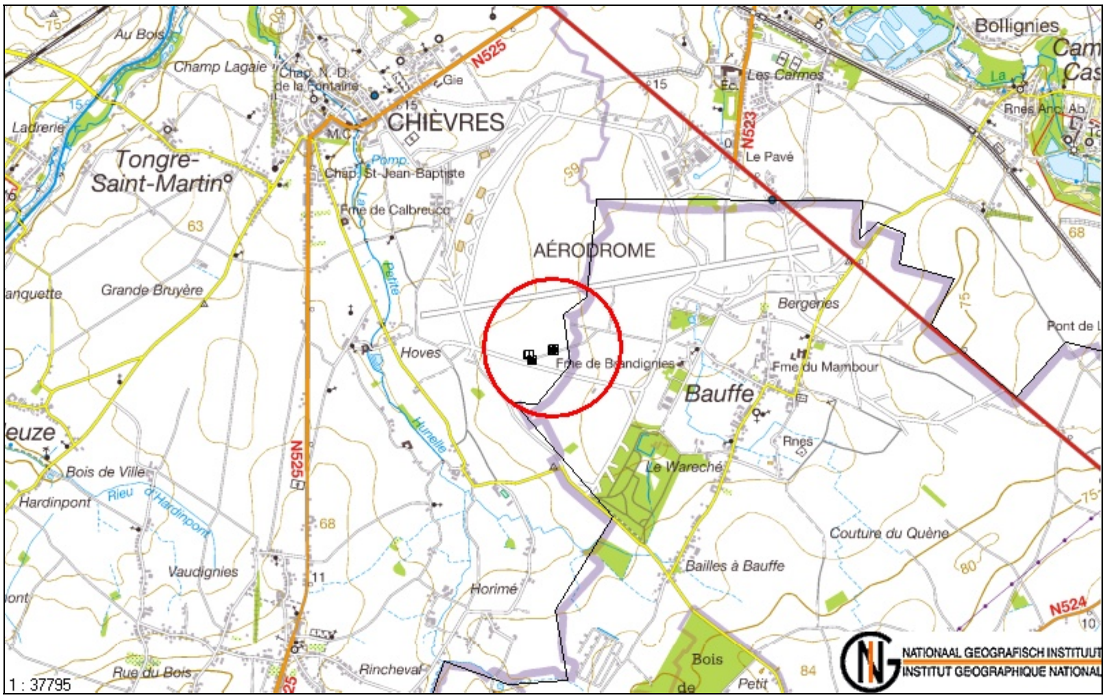
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	260	225	322	400	20-26	-	0.5	Leafy forest
2	322	400	02	440	22	-	0.5	Forest
3	14	450	37	500	16-18	-	0.5	Forest
4	37	500	95	550	26-28	-	0.5	Forest
5	95	550	140	680	26-28	-	0.5	Forest
6	196	595	199	565	9	10	0	Farm
7	199	565	204	608	9	10	0	Farm
8	207	650	240	305	22-26	-	0.5	Forest
9	240	286	248	256	26-17	-	0.5	Trees
10	247	300	249	280	10	25	0	Building
11	252	250	264	290	8	50	0	Building

1.3.6. Chièvres

1.3.6.1. Location:

Mast	Lambert 72		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)		
synop	111936	140300	60	10

Map: 38/6



1.3.6.2. Instrument history:

On 12-10-1987, a new mast with Fuess instrumentation has been installed at Chièvres.

Before 1-9-1993, the mast was located at its current location.

Between, 1-9-1993 and 16-12-1993, a temporary anemometer was installed on the roof of the traffic tower (meteo building).

The FMA system has become operational on 16-12-1993. Since then, the instrumentation used is Vaisala and the location of the mast has been moved to its actual place.

On 25/10/2000 a changeover took place from FMA → AWS.

Since 07/05/1999, the station is open from 5h00 till 17h00 and closed during the weekends so there is less data available since then. The time period 1994 → 1998 is the best reference period for Chièvres.

1.3.6.3. Site description:

The site at Chièvres is located on military domain (USA). The terrain is characterised by a large open area between some windbreaks and few buildings. Within direction (75)–(80) at about 900 meters distance from the mast, trees with an altitude of ± 24 m can be found.

Obstacle description recent location

Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

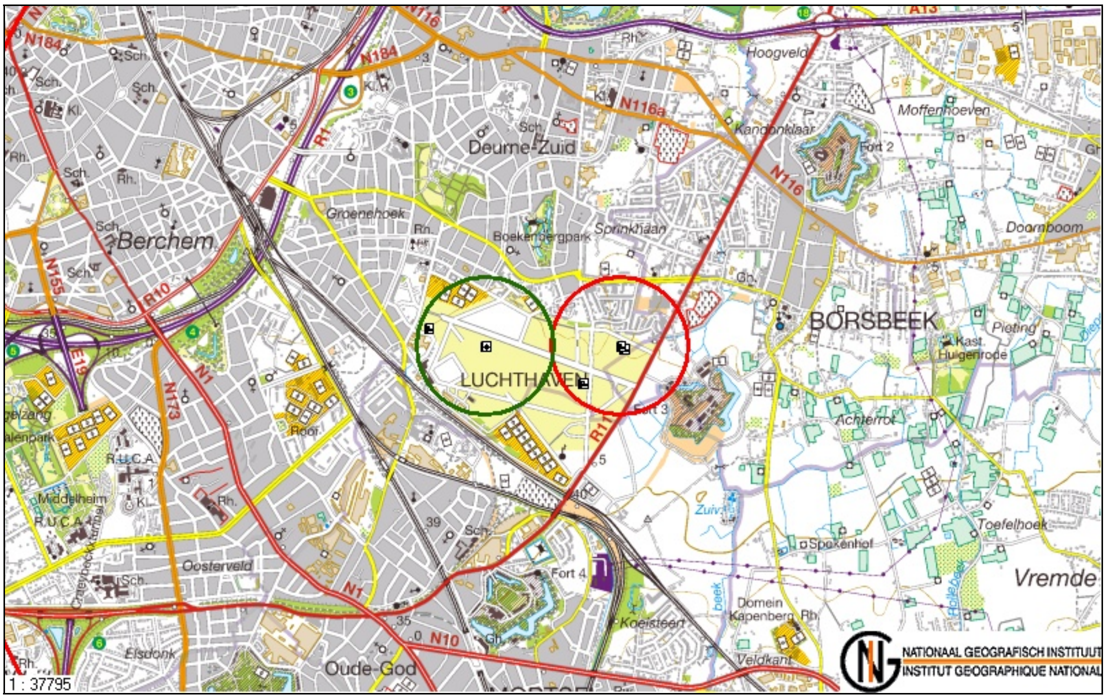
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	28	243	29	243	2	2	0	DVOR
2	131	435	136	438	8	20	0	Hangar
3	167	700	173	700	15	50	0.5	Trees
4	256	161	260	161	12	30	0	Traffic Tower

1.3.7. Deurne

1.3.7.1. Location:

Mast	Lambert 72		ED 50		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)	Longitude	Latitude		
Synop	157201	208928	4°28'22.9"	51°11'28.0"	10	10
Future location	156926	208658	4°28'08.7"	51°11'19.3"	10	10
Alternate	156219	208926	4°27'32.3"	51°11'28.0"	10	10

Map: 15/4



1.3.7.2. Instrument history:

The instrumentation changed on 12-12-1985 from Fuess into Vaisala. Since 1970 a mechanical Fuess has been used.

1.3.7.3. Site description:

Deurne is located in a suburban area of Antwerpen, at ± 5.5 km SE from the city center. In the northern sectors, houses are located close to the anemometer (± 110 m).

The location of the mast has not changed yet. In the future, this mast will be displaced to the centre of the aerodrome, so there will be no obstacles within a range of 500 m.

Obstacle description recent location

Study circle: 500 m

Obstacles map (position and numbering of obstacles on map) :

Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	35	100	65	225	9	5	0.5	Trees
2	36	350	51	465	7	70	0	Commercial center

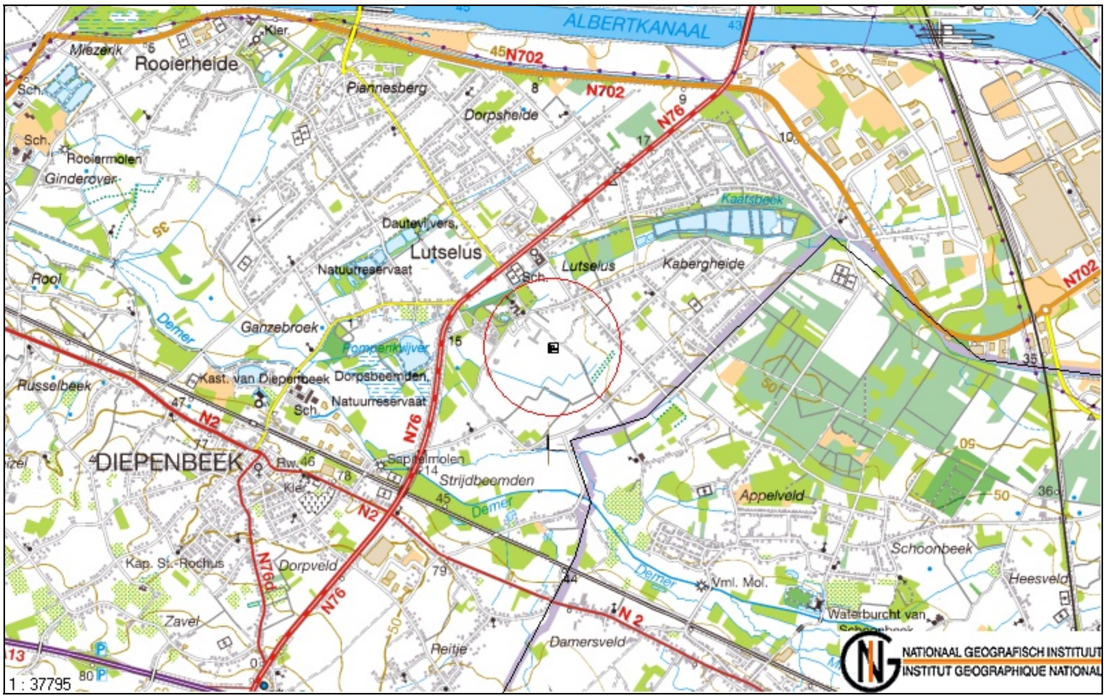
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
3	58	60	68	60	7	20	0.1	DVOR (since 1995)
4	65	250	78	240	2.5	8	0	Houses
5	90	330	102	350	19	5	0.5	Poplar
6	118	510	120	520	9	30	0	Fort
7	123	420	128	420	9	35	0	Fort
8	130	430	132	425	9	30	0	Fort
9	295	435	322	200	15	20	0.5	Trees
10	313	250	336	180	8	8	0	Flat buildings
11	328	250	3	200	8	8	0	Flat buildings
12	348	120	65	230	2.5	8	0	Houses

1.3.8. Diepenbeek

1.3.8.1. Location:

Mast	Lambert 72		ED 50		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)	Longitude	Latitude		
Synop	226053	178914	5°27'05.45"	50°54'58.95"	39	10.5

Map: 26/5



1.3.8.2. Measurement period:

29th of June, 2004 →

1.3.8.3. Instrumentation:

Wind velocity sensor LISA

Wind direction sensor RITA Gray

1.3.8.4. Site description:

The AWS of Diepenbeek is situated in an open space, surrounded by nearby houses and windbreaks of Canadian poplar with heights of 28 m. The site is most open in southern direction.

Obstacle description recent location

Study circle: 500 m

Obstacles map (position and numbering of obstacles on map) :

Obstacle dimension

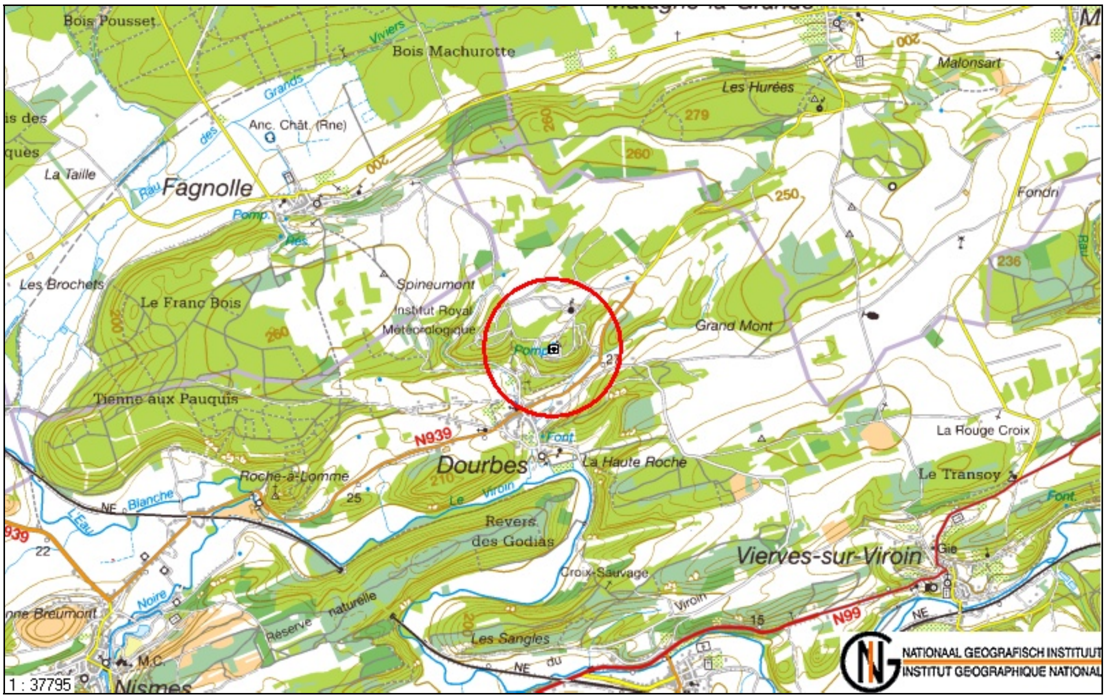
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	240	75	262	100	4	40	0.4	Fir tree
2	265	446	290	385	22	10	0.5	Array of trees
3	278	135	286	134	3.5	90	0	Building
4	292	172	327	177	3.5	12	0	Building
5	327	200	343	100	16-13-9	5	0.7	Array of trees
6	341	270	353	270	9	12	0.1	Houses
7	353	300	18	385	9	12	0.1	Array houses
8	11	290	27	380	9	12	0.1	Array houses
9	27	380	32	370	8	12	0.1	Houses
10	40	380	43	380	8	12	0	House
11	43	240	46	243	7	12	0	House
12	54	195	59	198	6	35	0	Building
10	67	84	70	84	6	3	0.5	Tree
11	88	116	108	207	4	1	0.5	Array of trees
12	123	300	131	360	15	5	0.5	Array of trees
14	191	253	195	263	26	5	0.5	Array of trees
15	199	326	204	327	8	5	0.5	Array of trees

1.3.9. Dourbes

1.3.9.1. Location:

Mast	Lambert 72		ED 50		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)	Longitude	Latitude		
Synop	166188	87209	4°35'46.4"	50°05'48.2"	235	10.5

Map: 58/5



1.3.9.2. Measurement period:

15th of December, 2000 →

1.3.9.3. Instrumentation:

Wind velocity sensor LISA

Wind direction sensor RITA Gray

1.3.9.4. Site description:

The AWS of Dourbes is located at the Geophysical Centre of RMI. The mast is installed on the top of a hill on this large domain. The anemometer is surrounded by nearby trees and forest. The northern part of the site is more or less gently undulating terrain (plateau), while the topography in the southern part is sloping downwards to the valley (see map).

This site can be characterised as complex terrain.

Obstacle description recent location

Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	168	101	183	104	12	20	0	Building
2	192	107	200	110	6	8	0	Building
3	234	11	245	10	2.5	2	0	Container
4	257	50	260	49	2.3	2	0	Container
5	215	78	290	48	4	75	0.5	Trees
6	290	48	340	40	8	5	0.5	Trees
7	348	32	02	39	8	10	0.5	Trees
8	12	42	125	44	7	90	0.5	Trees

1.3.10. Elsenborn

1.3.10.1. Location:

Mast	Lambert 72		ED 50		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)	Longitude	Latitude		
New	278781	131892	6°11'05.0"	50°29'04.2"	568	10
Old	278727	131808	6°11'02.2"	50°29'01.5"	568	10

Map: 50 –50A

1.3.10.2. Instrument history:

This station started in 1984. A Fuess has been used since then. The location of this Fuess was close to the meteo building.

The Fuess has been changed by a Vaisala since the introduction of the semi automatic station (FMA) in 1993?. Since then, the mast was located at about 240 m from the meteo building.

In 2004, the location of the mast changed again and has moved 100 m further in direction NNE to its current location. The reason for this displacement is the planning for the construction of a hangar on the old location in the near future. This will shelter the new anemometer into direction (240).

Elsenborn delivered since 1987 hourly data on a regular bases. Between 1984 and 1987 the synop reports were until 1985 three hourly and since 1985 hourly between 4 a.m. U.T. and 4 p.m. U.T. during the week and occasionally during the weekends.

1.3.10.3. Site description, current location:

Obstacle description recent location

Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	202	105	204	105	2.5	6	0	Cabine
2	214	218	216	217	5.5	15	0	Hangar
3	218	243	222	243	7	7	0	Meteo Building
4	232	250	236	252	7	10	0	Tempory Hangar
5	212	300	228	300	12-15	20	0.5	Trees
6	282	290	355	680	17-15	20	0.5	Trees

1.3.10.4. Site description, old location:

Obstacle description recent location

Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

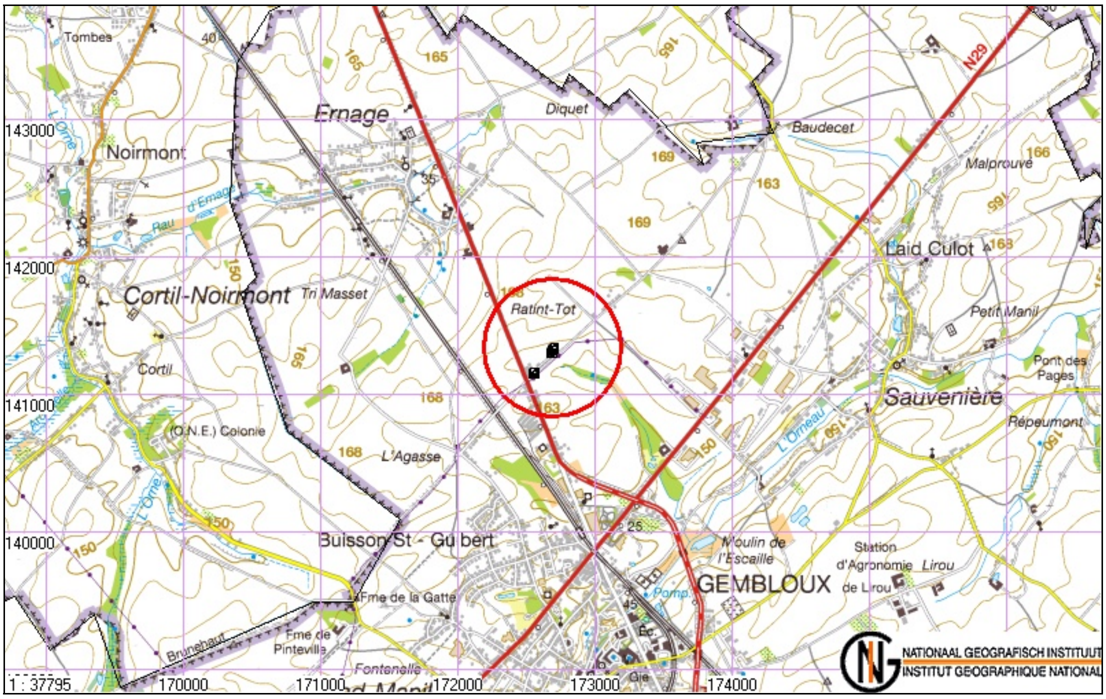
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	215	220	232	220	12-15	10	0	Trees
2	219	150	221	150	2.5	10	0	Garage
3	221	121	225	121	5.5	15	0	Hangar
4	224	147	231	149	7	10	0	Meteo building
6	245	163	253	173	7	10	0	Tempory Hangar
8	261	281	267	281	17	20	0.5	Trees
9	300	285	358	800	17-15	20	0.5	Trees

1.3.11. Ernage

1.3.11.1. Location:

Mast	Lambert 72		ED 50		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)	Longitude	Latitude		
Synop	172697	141325	4°41'25.7"	50°34'58.9"	157	11

Map: 40/6



1.3.11.2. Measurement period:

3rd of April, 2003, 6 a.m. →

1.3.11.3. Instrumentation:

Wind velocity sensor LISA

Wind direction sensor RITA Gray

1.3.11.4. Site description:

The AWS of Ernage is situated at the northern border of the province of Namen at about 2 km N from the municipality of Gembloux and about 1.5 km SSE from the center of Ernage. It is located in an open terrain between many windbreaks. The terrain is gently undulating between altitudes a.s.l. 150 and 170 m. At ± 1 km SE of the mast, there is an SME zone (Small and medium sized enterprise).

Within a range of 5 km, two forests are present: one in the sector (50-60) at about 4.5 km and the other in the sector (150-180), also at ± 4.5 km.

Obstacle description recent location

Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	29	15	45	14	4	7	0	Building
2	47	380	53	375	8	10	0	Building
3	60	290	65	162	14	5	0.5	Row Trees
4	59	340	64	350	8	15	0	Farm
5	60	270	63	280	8	40	0	Hangar
6	76	750	81	700	15	5	0.5	Row trees
7	118	485	139	160	10	40	0.5	Trees
8	169	660	174	680	15	140	0.5	Trees
9	192	420	203	330	8	10	0.2	Row Buildings
10	211	350	218	320	8	10	0	Buildings
11	220	260	221	250	15	20	0	Building

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
12	220	280	227	260	15	10	0	Building
13	224	250	225	250	10	8	0	Building
14	219	270	224	255	8	8	0	Building
15	229	224	234	220	6	15	0	Building
16	228	205	232	200	5	10	0	Open building
17	220	220	225	214	6	10	0	Garages

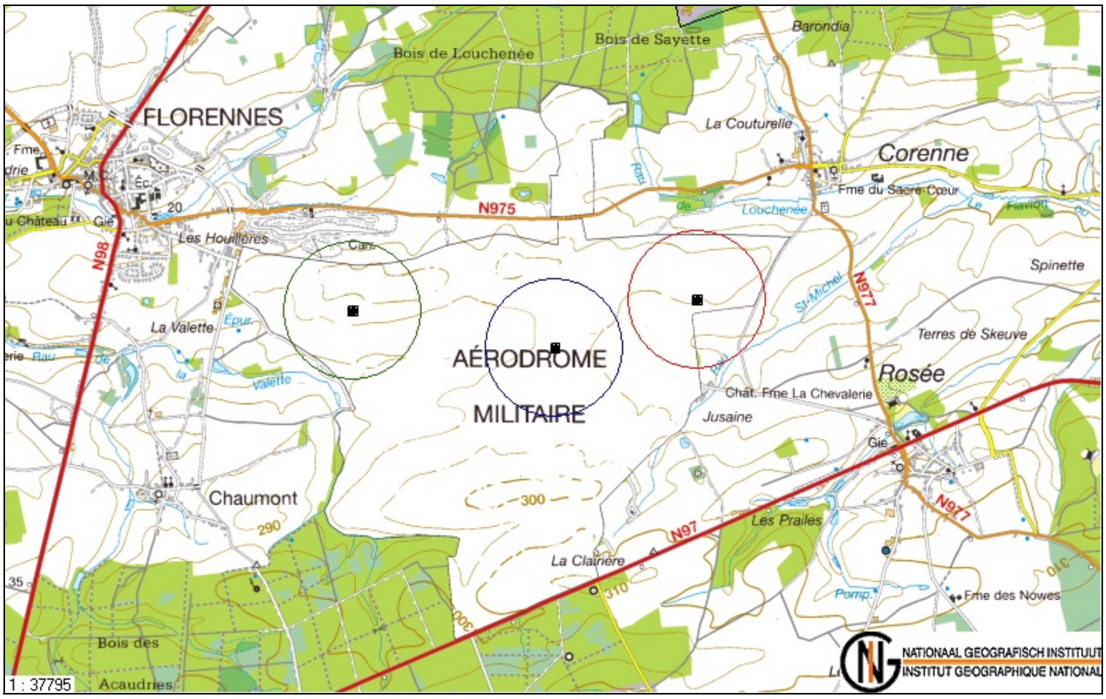
1.3.12. Florennes

1.3.12.1. Location:

Mast	Lambert 72		ED 50		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)	Longitude	Latitude		
synop (26)	171174	103641	4º40'00.6"	50º14'39.5"	280	10
alternate (08)	168660	103564	4º37'53.7"	50º14'37.3"	282	10
old mast	170134	103292	04º39'08.06"	50º14'28.33"	280	6.4

The right dot on the map is the current synop location, the centred dot is the old mast location, the left one, the alternate mast.

Map: 53/5, 53/6



1.3.12.2. Site description:

This synoptic station is located on a military airport. The anemometer has been dislocated several times. The first time it has been dislocated as far as we know was on May 23rd, 1975. Before this date, the mast was located at about 200 m from the met-office at 10 m height. The new mast location was somewhere in the centre of the runways. It was a mast with an altitude of 6.4 meter with Fuess-instrumentation. The next change took place in 1992. At this time, the sensor type changed into Vaisala and since this moment Florennes uses two anemometers at both extremities of the runway for operational issues. The meteo mast used for the synop is located at the E part of the runway.

The aerodrome of Florennes is located between two higher located woods: in the north (355) we have "Le bois de Louchenée" and in the south (175) we have "Bois de Bruêre" and "Bois La Croix" Looking at the two cross-sections in directions (355 – 175) and (264 – 084), you get a kind of funnelling effect at Florennes.

1.3.12.3. Florennes (1975-1992)

The station is equipped with automatic analog recording (Fuess-instrumentation) of:

- Instantaneous wind speeds (knots)
- Totalised 10-minutes mean wind speeds (knots)
- Instantaneous wind direction

Anemometer height a.g.l.: 6.40 m

Site description (from member of RMI, who visited the site in 1989):

"The general impression one gets from the topography of Florennes is that it is rather flat to gently rolling, surrounded by woods at larger distances (horizon). Within direction (120), a slight descent of the terrain can be noticed. The directions (30-120) degrees and (225-270) degrees seem to be unobstructed areas for the wind approach. The terrain slope is only important towards the south. A few scattered trees (4-5 m height) are located at about 50 – 70 meters from the mast along the cross runway. One big obstacle is situated near the mast at about 8 m distance: a building for power supply with dimensions (6,4,3)."

Obstacle description recent location
Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	11	12.6	43	8	4.8	3.2	0	Building
2	43	15.8	48	15.4	10.10	1.2	0.8	Open mast of metal bars
3	299	27	310	26	3.6	3.6	0	building

1.3.12.4. Florennes (Synop (26))

Site description:

The mast is located on a complex terrain. Within the direction (120) → (230) the terrain is sloping down (3.5 %). A water tower is located in direction (200) with an altitude of ± 25 m at 2250 m distance and a terril of 35 meters in altitude within the sector (275) at a distance of 2750 m.

Obstacle description recent location
Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	9	208	11	208	2.5	5	0	Container
2	60	50	85	44	3-6	3	0.75	Scattered trees
3	179	390	188	410	12-8	80	0.5	Trees
4	187	470	199	560	12-8	100	0.5	Trees
5	210	202	225	170	3	4	0.5	Array of trees
6	225	215	228	220	2.5	10	0	Building
7	232	325	235	335	7	20	0	Hangar
8	234	265	237	275	5	8	0	House
9	230	270	252	216	6	5	0.5	Array of trees
10	238	170	241	168	5	20	0	House
11	245	448	260	456	14	10	0.5	Fir trees
12	255	420	260	408	6	8	0	House
13	294	200	296	200	2.5	3	0	ILS

1.3.12.5. Florennes (08)

Hereafter follows the obstacle description of the alternate mast:

Obstacle description recent location
Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

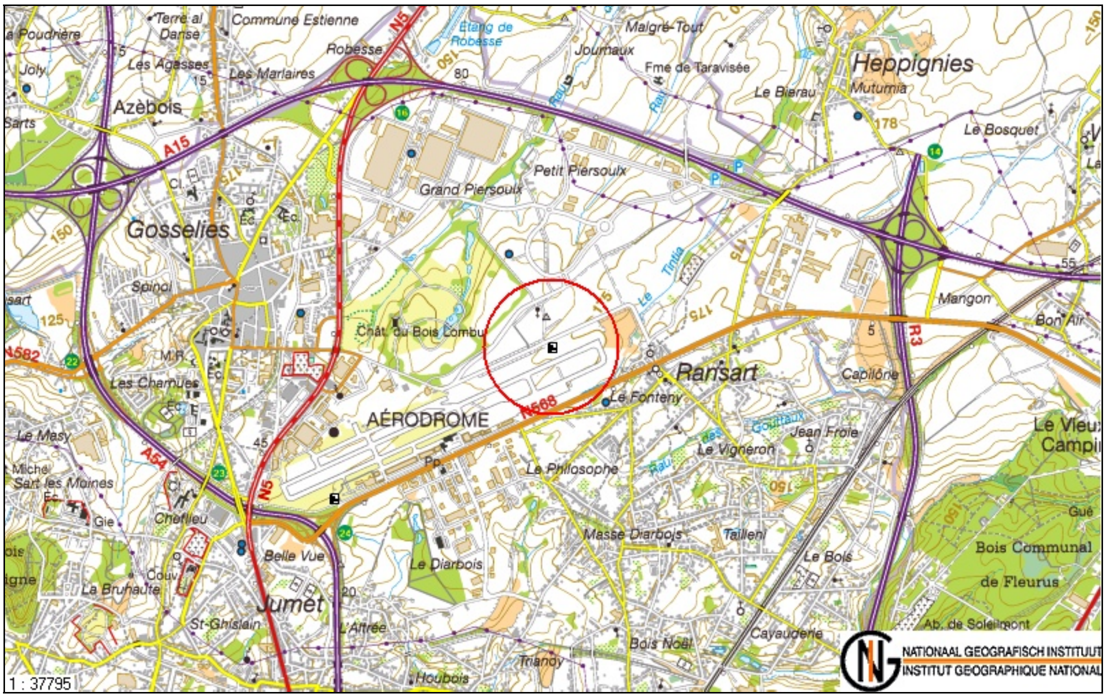
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	330	214	63	283	8	40	0.5	trees
2	63	283	68	450	8	20	0.5	trees
3	75	450	100	500	12	20	0.5	Trees
4	270	450	288	150	12	20	0.5	Trees
5	288	150	330	214	12	20	0.5	Trees
6	330	500	345	500	35	100	0	terril

1.3.13. Gosselies

1.3.13.1. Location of the mast:

mast	Lambert 72		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)		
synop	156805	128163	178	10

Map: 46 3-4



1.3.13.2. Site description:

The mast is located on the aerodrome of Gosselies airport. The sectors (90) → (300) within a range of 5 km are almost completely urbanised. In the sectors (300) → (90) the urbanisation is less dense.

The topography around the mast isn't flat. Within the directions (240)→ (30) you find a ridge. The altitude difference in direction (300) is 5 meters on 150 m!!

There is in the annex an obstacle map available from the aerodrome.

Obstacle description recent location

Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	0	473	08	480	8	20	0	Building
2	65	57	67	57	2	2	0	Container ILS

1.3.14. Humain

1.3.14.1. Location:

Mast	Lambert 72		ED 50		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)	Longitude	Latitude		
Synop	213307	98439	5°15'23.7	50°11'40.2	295	10.3

Map: 54/7

1.3.14.2. Measurement period:

3rd of April, 2003, 6 a.m. →

1.3.14.3. Instrumentation:

Wind velocity sensor LISA

Wind direction sensor RITA Gray

(The mast at Humain is 24 m in height and two anemometers are installed)

1.3.14.4. Site description:

The AWS station of Humain is located in the province of Luxemburg at the radio astronomic station of Humain. It is located on a hill, surrounded by open fields and forest. The more dense forests are situated at ± 1.6 km (towards 330), 2.3 km towards W and 3.6 towards SE. The nearest cities are Humain (1.3 km towards N), Marche en Famenne (7 km towards NE) and Rochefort (4.5 km towards SW).

Obstacle description recent location
Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

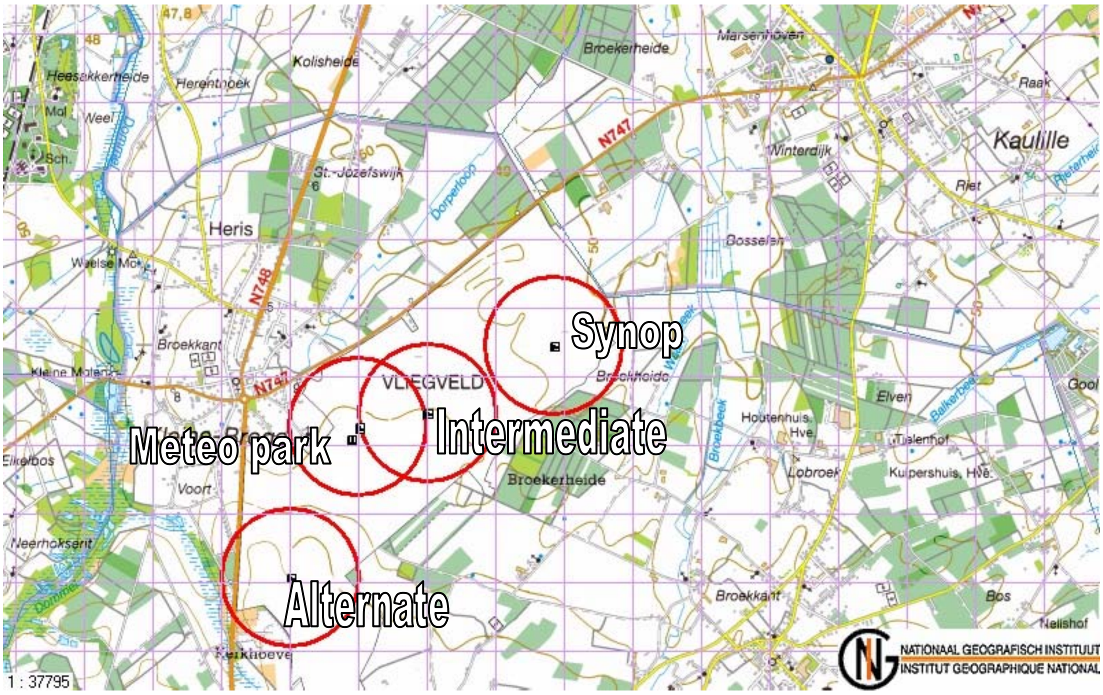
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	341	86	2	50	4-6	3	0.5	Row trees
2	17	275	37	308	10-12	4	0.5	Row trees
3	37	350	47	380	12-15	5	0.5	Row trees
4	47	380	62	490	17	250	0.4	Forest(fir trees)
5	62	490	69	524	17	1000	0.4	Forest
6	141	414	146	418	12?	4	0.5	Row trees
7	155	720	170	750	22	5	0.5	Row trees
8	176	250	188	246	6	8	0	Building
9	175	550	190	550	20-25	200	0.5	Forest
10	218	250	222	246	4.5	11	0	Building
11	222	230	225	230	3.5	6	0	Building
12	225	207	230	222	6	19	0	Building
13	270	812	312	640	20-25	175	0.5	Forest
14	319	400	336	425	16-20	50	0.4	Fir trees

1.3.15. Kleine Brogel

1.3.15.1. Location:

Mast	Lambert 72		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)		
Synop (23)	227938	207714	51	10
Alternate (05)	226019	206025	62	10
Intermediate	227016	207224	55	10

Map: 18/5



1.3.15.2. Site description:

Kleine Brogel is situated in the north eastern part of Belgium. The site is located on a military aerodrome, which is surrounded by mostly pine trees with altitudes between 12 and 15 meters.

1.3.15.3. Kleine Brogel (Intermediate)

This intermediate location has been used between 01/01/1989 and 31/12/1991. Before 1989, the mast was located in the meteo park.

Obstacle description recent location

Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	300	200	20	385	12-15	-	0.5	Pine trees
2	20	180	55	587	12-15	-	0.5	Pine trees
3	100	500	170	500	12-15	-	0.5	Pine trees
5	248	250	252	250	10	-	0	Traffic tower

1.3.15.4. Kleine Brogel (Synop (23))

This location is in use since 1992. The mast is almost completely surrounded by trees. Unobstructed air is coming from the sectors (50) and (230).

Obstacle description recent location

Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	0	350	3	470	12-15	35	0.5	Pine trees
2	10	400	25	400	12	110	0.5	Pine trees + Birch
3	45	330	60	330	10	50	0.5	Birch
4	75	400	170	110	12	110	0.5	Birch
5	110	170	210	500	12-15	150	0.5	Pine trees
6	237	250	239	250	2	2	0	Container ILS

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
7	260	500	335	270	12-15	100	0.5	Pine trees

1.3.15.5. Kleine Brogel (05)

The mast is located in the southern part of the runway, on an altitude of 62 m a.s.l. The roughness around the mast is determined by the presence of heathland, with few scattered bushes within directions (270) → (50).

Obstacle description recent location

Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

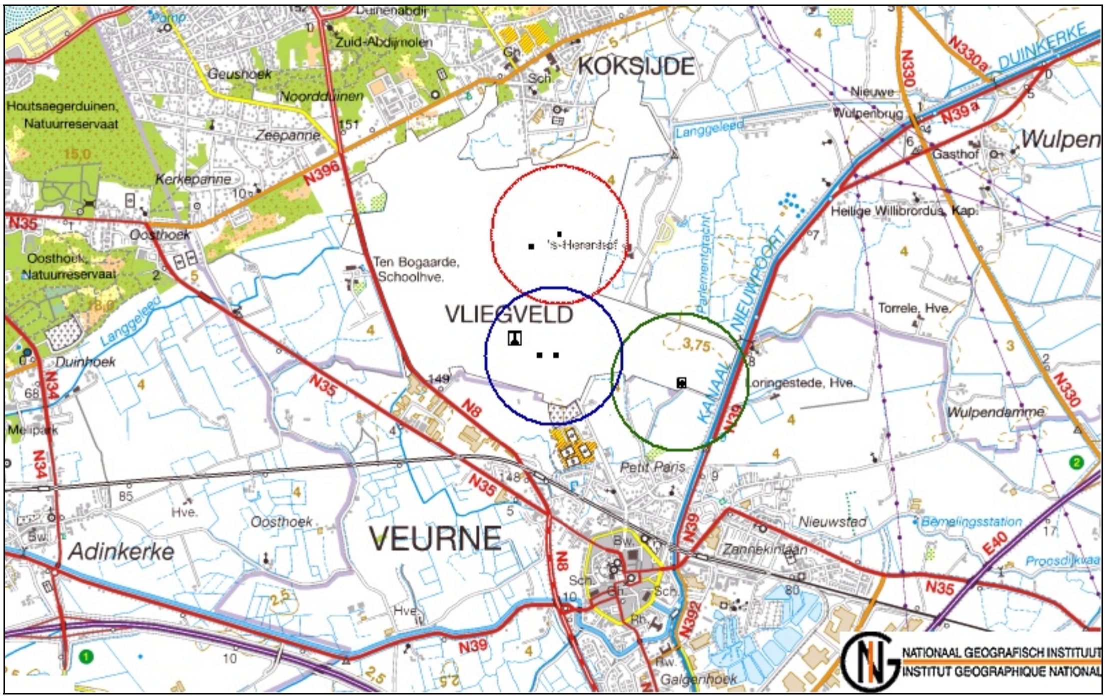
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	10	370	30	700	12-15	70	0.5	Pine trees
2	70	500	140	200	12	80	0.5	Pine trees
3	140	200	155	150	5	20	0.2	barak
4	175	135	210	325	14	100	0.5	Birch
5	220	140	250	145	10	150	0.5	Birch
6	270	90	30	180	2	3	0.75	Scattered trees
7	270	300	0	380	12	280→5	0.5	Birch

1.3.16. Koksijde

1.3.16.1. Location:

Mast	Lambert 72		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)		
Synop	29948	199668	4	10
Alternate	30838	198592	4	10
Old	29918	198785	4	10

Map: 11 / 7-8



1.3.16.2. History *of the instruments:*

The measurements at Koksijde have started in 1946. Since 1991 all the observations are recorded automatically by the FMA system. The AWS[2] system has been introduced in August 2000 or August 2001. For the history of the anemometers used at Koksijde we only know that since 1991 the instrumentation used is Vaisala. Before this date, it is assumed that a Fuess was used, installed on a roof of a garage with an altitude of 3 m. The height above ground level of the mast was 10 m.

1.3.16.3. Koksijde (Synops)

The synops mast is situated in the northern part of the aerodrome. The site has almost no obstacles within a range of 500 meters. The topography is flat. It is completely surrounded by cropland (mostly sugar beets) and scattered farmhouses.

In northern direction, the city of Koksijde is situated. The coastline is located on 3300 meters from the mast in direction NNW. Between the coastline and the mast in northern direction, stretches the dune valley 'De Doornpanne' with altitudes up till 18 meter a.s.l.. In direction NNW is situated the highest point of the Belgium coastline: "De Hoge Blekker" with an altitude of 33 m .a.s.l.

It has to be stressed that apple trees with an altitude of 3 meters are present under the mast.

Obstacle description recent location

Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	50	800	70	800	10	120	0.1	Trees + farm
2	80	900	90	900	10	50	0.1	Trees+farm
3	100	555	110	510	10	60	0	farm
4	112	376	118	376	6	2	0.3	trees
5	195	313	203	313	3.5	25	0	bunker
6	270	230	270	230	3.5	4	0	DVOR
7	300	550	315	600	10	60	0	Farm

[2] Automatic Weather Station

1.3.16.4. Koksijde (Alternate)

The Alternate mast in Koksijde is situated in the Southern part of the base on 4700 meters of the coastline. Sometimes when the sea breeze isn't strong enough, both masts detect a different wind direction. Also this mast has almost no obstacles within a range of 500 meters. The sectors 150, 180, 210 and 240 are urbanised terrain.

Hereafter follows the obstacle description of the alternate mast:

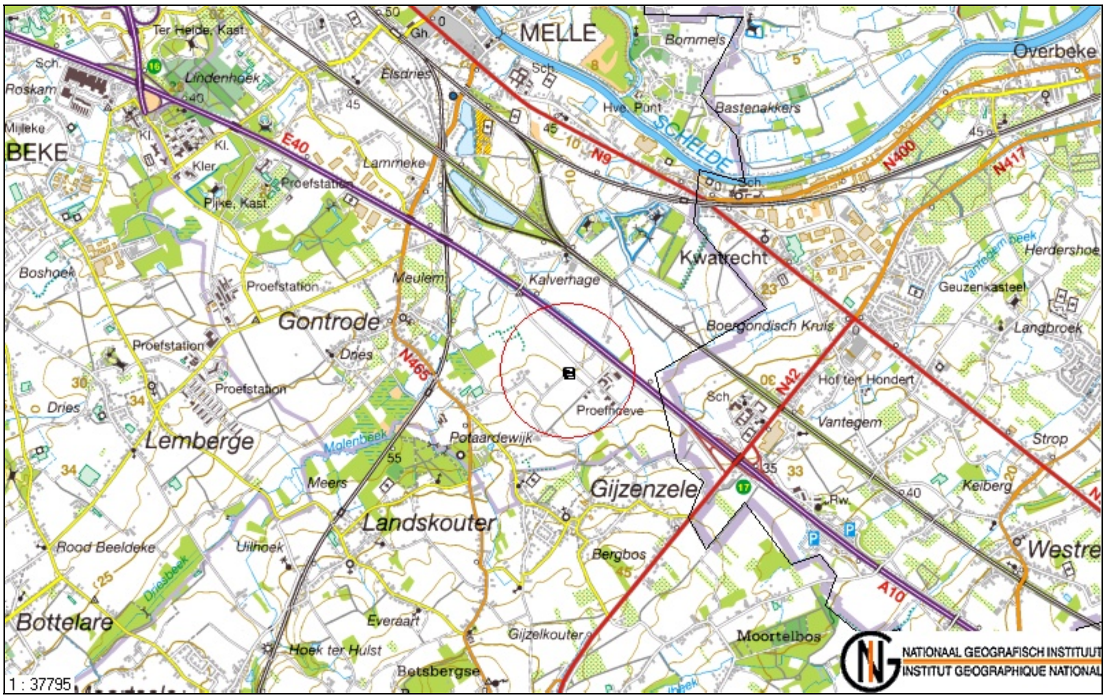
Obstacle description recent location								
Study circle: 500 m Obstacles map (position and numbering of obstacles on map) : Obstacle dimension								
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	122	330	140	330	8	2	0.4	Wind break+house
2	208	380	214	380	10	25	0	farm
3	240	60	265	60	3.5	20	0	bunker

1.3.17. Melle

1.3.17.1. Location:

Mast	Lambert 72		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)		
Synop	111169	185723	15	10.3

Map: 22/6



1.3.17.2. Measurement period:

2nd of April, 2003, 6 a.m. →

1.3.17.3. Instrumentation:

Wind velocity sensor LISA

Wind direction sensor RITA Gray

1.3.17.4. Site description:

The AWS of Melle is located on property of the University of Ghent ("De proefhoeve"). It is situated nearby the highway (E40). The meteo park at Melle has at it's disposal a mast of 30 meter, with the possibility to fix an instrument on a flexible arm, which can reach a height of maximum 27 m.

Within the near future, some wind turbines with a diameter of 150 m will be constructed in the nearby surroundings. This could have a negative influence on the anemometric measurements at a height of 30 m.

Obstacle description recent location

Study circle: 500 m

Obstacles map (position and numbering of obstacles on map) :

Obstacle dimension

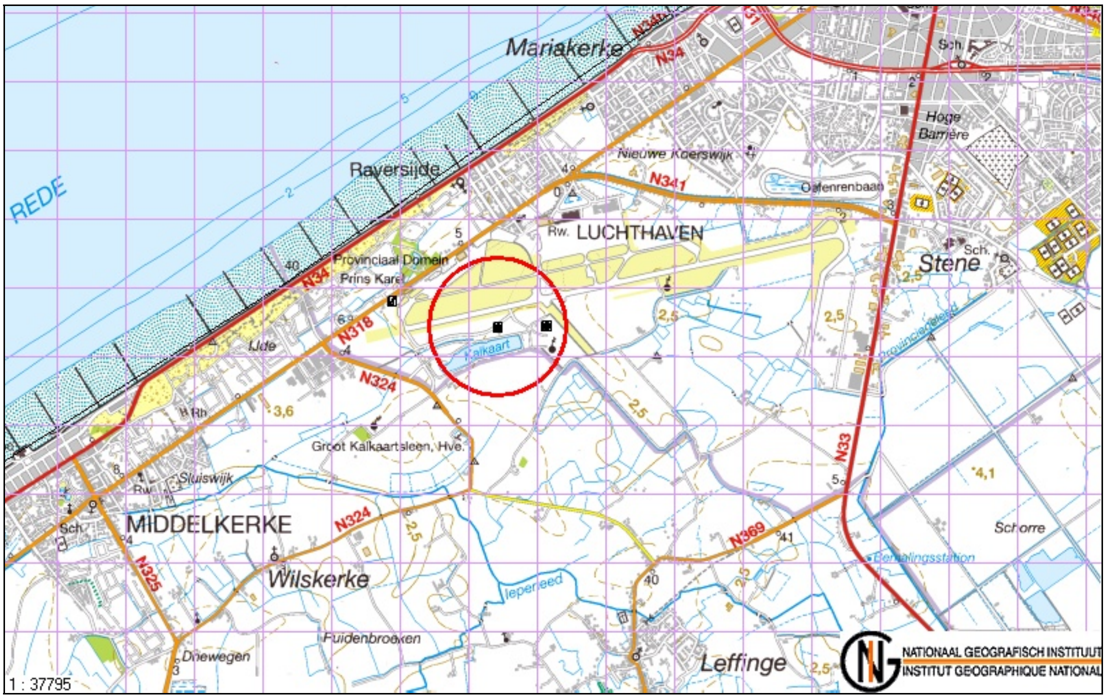
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	42	340	45	320	20	5	0.5	Trees
2	45	250	49	250	20	5	0.5	Tree
3	45	340	50	360	8	50	0	Building
4	45	75	107	185	2	2	0.8	Array trees
5	50	590	60	600	17	5	0.5	Array trees
6	60	600	73	500	20	4	0.5	Array trees
7	65	500	73	380	20	25	0.5	Trees
8	77	310	81	340	20	5	0.5	Poplar
9	87	340	90	315	8	50	0	Building
10	87	270	95	245	8	12	0	Building
11	95	270	96	268	8	25	0	Building
12	97	235	105	210	8	20	0	Building
13	97	235	101	230	8	50	0	Building
14	105	265	112	255	8	12	0	Building
15	106	300	112	285	8	10	0	Building
16	117	250	123	240	8	35	0	Building
17	120	310	126	300	8	40	0	Building
18	122	370	127	365	8	25	0	Building
19	122	180	125	210	19	4	0.5	Array trees
20	126	190	128	190	6	10	0	House
21	132	180	139	180	8	22	0	Building
22	134	210	143	220	15	4	0.5	Trees
23	143	190	150	195	6	20	0	Building
24	153	464	160	478	28	50	0.5	Trees
25	160	465	175	515	4-5	3	0.5	Pollard willow
26	195	435	200	430	8	8	0	Trees, House
27	204	500	205	490	6	10	0	House
28	208	470	210	460	6	10	0	House
29	232	260	233	220	10	3	0.5	Pollard willow
30	241	195	251	195	7	10	0	House
31	250	405	253	410	10	10	0	Building
32	258	405	263	415	8	20	0	House
33	263	400	265	375	10	12	0	House
34	270	375	272	355	6	25	0	Building
35	270	325	273	310	6	30	0	Building
36	275	385	302	395	4	25	0.5	Array trees
37	302	395	310	515	4	25	0.65	Array trees

1.3.18. Middelkerke

1.3.18.1. Location:

Mast	Lambert 72		ED 50		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)	Longitude	Latitude		
Old location	44930	210605	2°52'00.7"	51°11'48.1"	3	12.7
New location	44708	210709	2°51'49.2"	51°11'51.3"	3.5	10

Map: 12/2



1.3.18.2. Instrument history:

Since 1972, the station is equipped with automatic analog recording (Fuess-instrumentation) of:

- Instantaneous wind speeds (knots)
- Totalised 10-minutes mean wind speeds (knots)
- Instantaneous wind direction

The altitude of the old mast was 12.7 m above ground level. A Vaisala on 01/01/1993 replaced this Fuess anemometer. On 10/05/2004 a new mast was installed on a new location, meeting the WMO regulations of 10 meters.

1.3.18.3. Site description:

The airport of Oostende is situated near the coastline at ± 5.5 km southwestwards from the city centre of Ostend and 3.2 km northeastwards from Middelkerke. The mast is located at about 1100 meters from the coastline. Since 1955, RMI receives synoptical data from this site.

The old location was located close to a lake. Caravans around the lake were put there from 1970 onwards, beginning at the W-side of the lake, reaching the NNE-side by 1976. The caravans at the

E-side of the lake are added later in the eighties and were located close to the mast (10-15 meters). During summer months, cultivation on the surrounding fields reaches about 50 to 70 cm. Hereafter is a description of the obstacles around the old mast.

Obstacle description old location:

Obstacle description recent location								
Study circle: 500 m Obstacles map (position and numbering of obstacles on map) : Obstacle dimension								
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	10	7	30	8	3	3	0	Nearby building
2	350	20	30	30	3	4	0	Scattered caravans
3	29	138	30	140	3	4	0	building
4	160	270	169	270	10	20	0	Farm
5	190	40	280	10	2.5	7	0	About 7 to 8 detached caravans
6	280	200	355	70	2.5	30	0	Caravan site

The displacement of this mast to the new location, closer to the runway (situated at ± 100 m in direction N) took place on 10-05-2004. As can be seen from the pictures, the site around the lake is no longer a caravan park and most of the caravans are gone. Hereafter follows the obstacle description:

Obstacle description new location:

Obstacle description recent location								
Study circle: 500 m Obstacles map (position and numbering of obstacles on map) : Obstacle dimension								
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	87	304	90	304	3	4	0	Caravan
2	136	465	146	485	10	80	0.1	Farm
3	145	64	145	64	2	2	0	Small marquee
4	160	39	160	39	2.5	4	0	Caravan
5	210	500	222	500	10	50	0.1	Farm
6	242	96	242	96	2.5	2	0	Goniometer
7	230	639	241	639	10	1	0.4	Trees
8	239	238	250	368	2.5	2	0.1	Scattered caravans
9	280	45	280	45	2.5	2	0	Container ILS

Until the replacement of the current instrument type Vaisala into Thies, the synoptic reports are still manually derived. The Fuess instrument is still used as a backup instrument. The observer mentioned that there is a difference of a few knots between the 08 (synops) and the mast 26, which is situated approximately 1800 meters from the coastline.

1.3.19. Mont-Rigi

1.3.19.1. Location:

Mast	Lambert 72		ED 50		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)	Longitude	Latitude		
Synop	270901	134732	6°04'28.7"	50°30'42.1"	673	10.5

Map: 50/2

1.3.19.2. Measurement period:

23-01-2001, 3 p.m.→

1.3.19.3. Instrumentation:

Wind velocity sensor LISA

Wind direction sensor RITA Gray

1.3.19.4. Site description:

The AWS station of Mont Rigi is situated within nature reserve on heathland surrounded by few scattered bushes. It is located close to the highest point of Belgium (Botrange) on an altitude of 673 m a.s.l. Northeastwards, some nearby buildings are close to the station. The terrain is open in the directions (145) → (300). The terrain is is sloping downwards with a percentage of ± 3.6 % in direction southwest.

Obstacle description new location:

Obstacle description recent location

Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	42	96	64	107	6.5	15	0	Building
2	60	65	76	87	7	15	0	Building
3	67	90	68	92	7	35	0	Building
4	83	175	90	187	13	25	0	Building
5	321	139	42	50	4-6	110	0.5	Trees
6	78	54	127	125	8	5	0.5	Trees
7	160	122	185	105	2.5	20	0.7	Bushes
8	265	570	295	435	9-12	-[3]	0.4	Fir-tree

[3] border forest

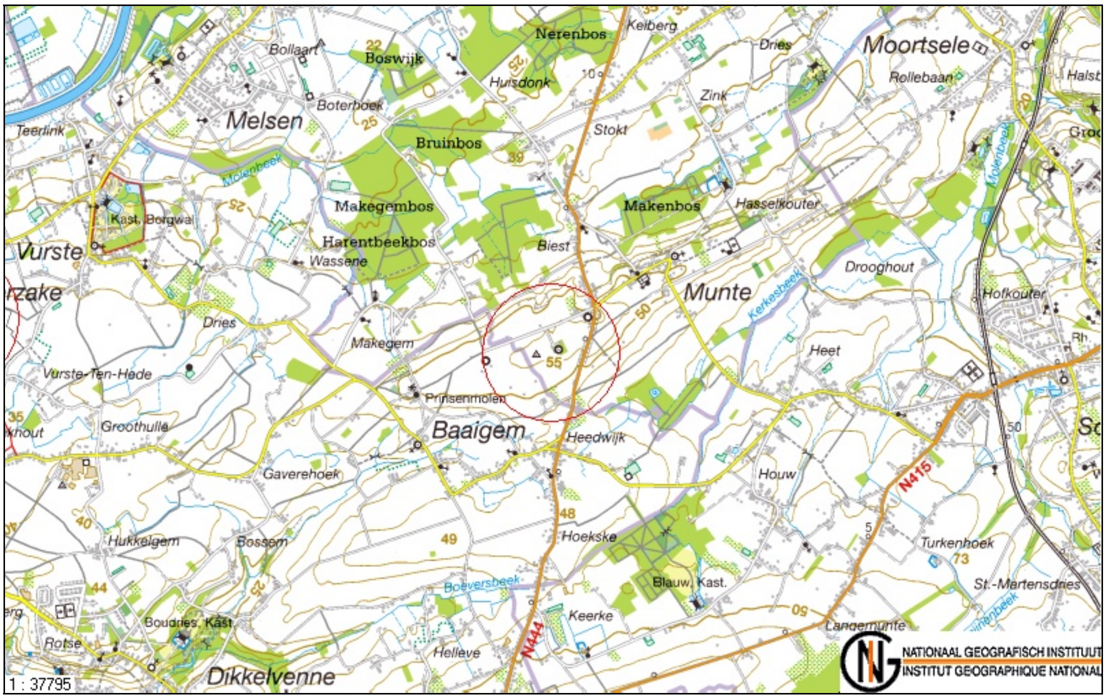
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
9	262	70	270	70	2.5	5	0.6	Bushes
10	145	105	155	170	2.5	5	0.6	Bushes

1.3.20. Munte

1.3.20.1. Location:

Mast	Lambert 72		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)		
Old	105262	181152	55	14
New	105276	181123	55	10

Map: 22/5



1.3.20.2. Instrumentation:

The anemometer was first located on the roof of a building of the relay station of Munte, which has been build on an elongated hill. The most important obstacles were trees and the relay antenna around the building. Since the introduction of the semi-automatic station (FMA), the mast was moved to the meteo park. Before this change, the instrumentation used was Fuess. Afterwards it changed into Vaisala.

The station of Munte has started in 1969 and has stopped on 31-12-1996. Since then, the meteo station moved to Semmerzake. The meteo station was situated at the west edge of the site (± 1 ha). The anemometers were not sheltered in the directions (170) → (350).

After visiting the site now, we can conclude that these anemometers were at a certain moment in time too much influenced by the height of the trees. Today, the altitude of the trees measures ± 35 m. In 1990, this was already 11 meters.

1.3.21. Oostende-Pier

1.3.21.1. Location:

Mast	Lambert 72		ED 50		Alt (m T.A.W.)	Alt (m a.g.l.)
	X (m)	Y (m)	Longitude	Latitude		
Synop	48793	215400	2°55'14.8"	51°14'25.7"	11.51	15.5

Map: 12/2

1.3.21.2. Measurement period:

4-4-2001, 1 p.m.→

1.3.21.3. Instrumentation:

Wind velocity sensor LISA

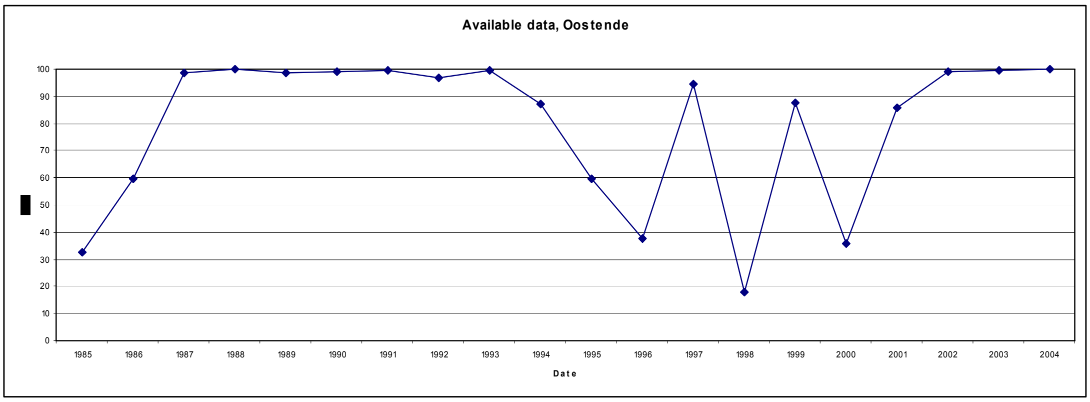
Wind direction sensor RITA Gray

1.3.21.4. Missing data history:

From 01/01/1985 → 01/08/1986: 3 hourly data.

From 01/08/1986 → 01/08/1994. Hourly data.

Since 01/08/1994 many interruptions (see graph)



1.3.21.5. Site description:

The mast of Oostende-Pier has once been moved for a few meters in January 1996. Before this time, the mast (10 m) was installed on the roof of a building with Fuess instrumentation (mechanical Fuess). Afterwards it has been installed on a mast with a height of 15 m and the instrument used was a Vaisala. The altitude of both instruments (Fuess and Vaisala) remained the same, so the obstacle description is representative for the whole time period.

Obstacle description recent location
Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

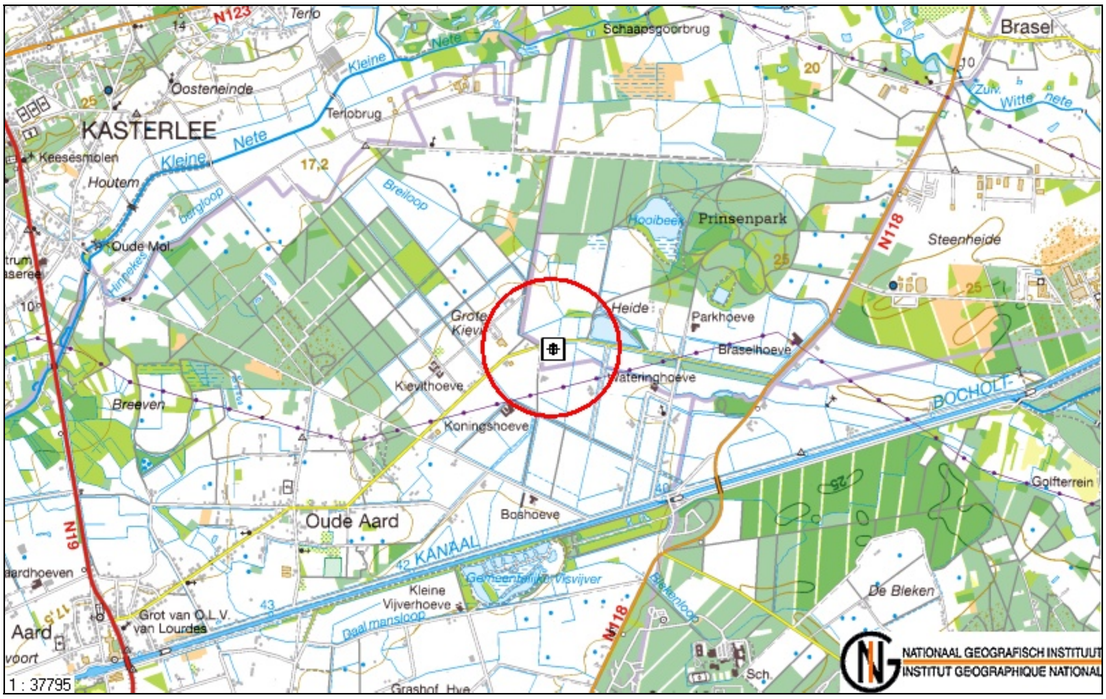
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	168	570	195	510	30	50	0	Flat buildings
2	195	510	212	940	30	50	0	Flat buildings
3	198	780	201	800	104	40	0	Flat building
4	212	180	223	180	6	10	0	Pier west
5	210	1	300	1	5	10	0	Building

1.3.22. Retie

1.3.22.1. Location:

Mast	Lambert 72		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)		
synop	196007	212593	21	10.5

Map: 17/1



1.3.22.2. Measurement period:

14-02-2002, 1 a.m.→

1.3.22.3. Instrumentation:

Wind velocity sensor LISA

Wind direction sensor RITA Gray

1.3.22.4. Site description:

The terrain of Retie is characterised by farmland with many windbreaks. This farmland is characterised by the many closely spaced windbreaks, where the average separation is a few hundred metres. This site nevertheless can be valued as representative for this area, when you compare this site location with the nearby surroundings.

In sector E we have at ± 2.5 km a factory and further, between 3.5 and 5 km, there is an industrialised zone, with a power plant, located at 5 km eastwards from the mast. The chimney pipes are about 125 m in altitude and are 4.3 m across at the top. The cooling tower is 75 m in altitude.

Obstacle description recent location
Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	289	107	301	91	8.5	8	0	Building
2	301	70	321	75	14	10	0.5	Trees
3	351	67	1	67	15	5	0.5	Tree
4	300	260	15	260	12-15	10	0.6	Row trees
5	15	260	48	380	15	40	0.5	Trees
6	15	64	73	230	15	8	0.7	Row trees
7	48	380	73	260	28	10	0.5	Row trees
8	75	250	87	390	15	10	0.5	Trees
9	87	430	110	415	28	5	0.5	Poplar
10	358	225	24	279	12	-	0.5	Trees

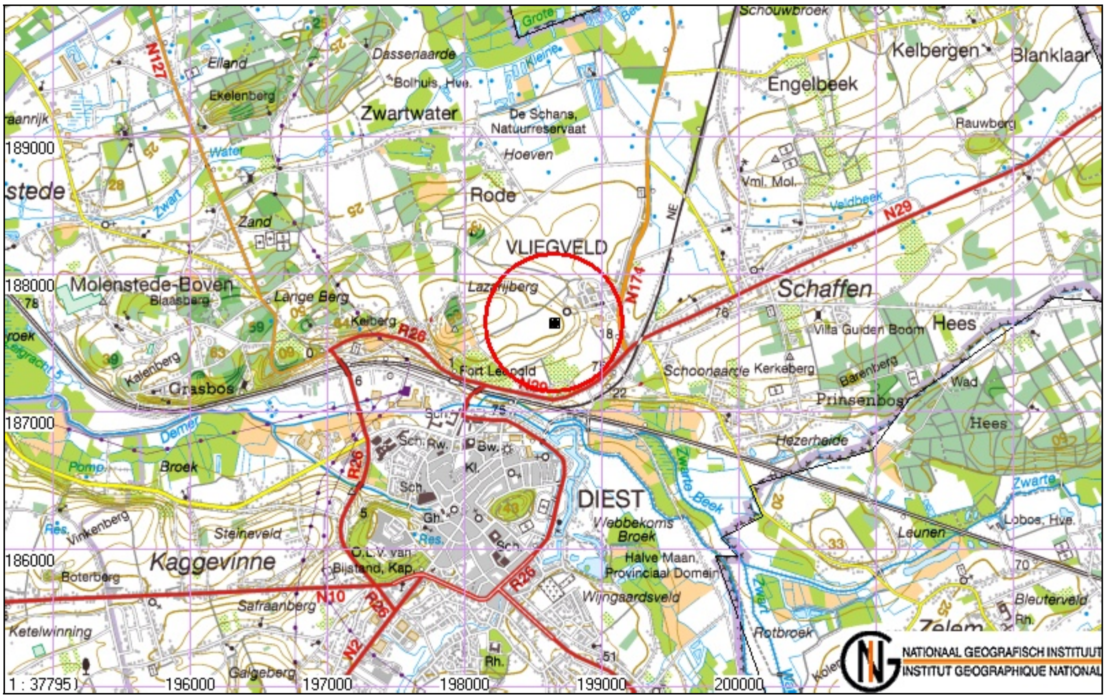
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
11	111	415	135	470	8-9	-	0.5	Row trees
12	135	372	138	371	7	40	0	Farm
13	139	372	143	373	6	35	0	Farm
14	194	217	201	211	8	35	0	Farm
15	201	177	213	175	8	10	0	Farm
16	200	144	207	88	1.5	3	0.5	Row trees
17	207	88	233	128	1.5	3	0.5	Row trees
18	215	190	285	95	18-20	10	0.5	Row trees
19	285	95	289	135	14	5	0.5	Row trees
20	251	310	260	330	8	40	0	Farm
21	267	310	290	230	27	5	0.5	Trees
22	274	210	276	190	8	8	0	Building
23	280	175	284	185	6	8	0.4	Open shed
24	275	400	277	390	7	50	0	Building
25	277	370	279	360	7	60	0	Building

1.3.23. Schaffen

1.3.23.1. Location:

Mast	Lambert 72		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)		
Synop	198664	187642	51	11

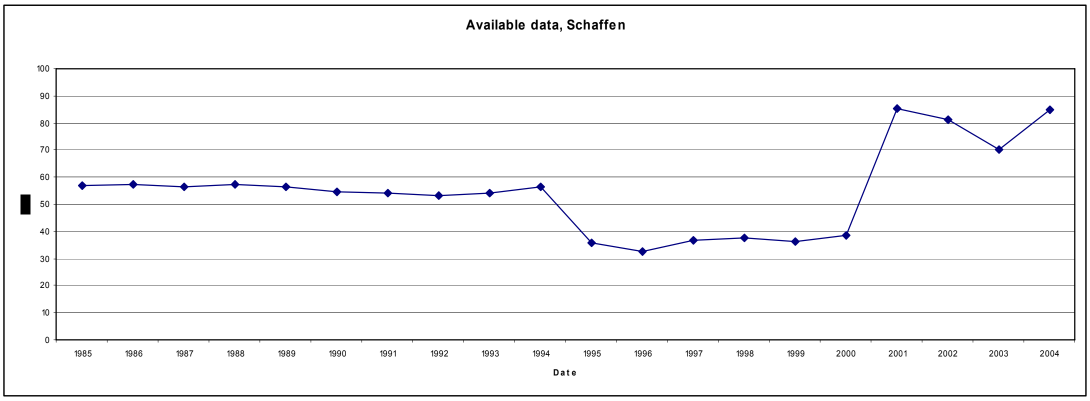
Map: NGI: 25 5/6.



1.3.23.2. History of the instruments:

In 1991, the FMA system has been installed and became operational in 1992. In 2000, a system changeover took place to the AWS. Before this changeover, the mast was located on the same place. The height of the old mast was 8 m and changed into 11 m in 1992, with the introduction of the FMA system.

Today, the Meteo station is open from 5h30 local time till 19h00 local time. It is closed during the weekends and holidays or there has to be a military exercise. Hereafter a graph is plotted which shows the availability of data for Schaffen during the time period 1985-2005:



1.3.23.3. Site description:

Schaffen is a part of the community of Diest and is situated in the north east of "Vlaams-Brabant", between the shelved "Hageland" and the wooded "Kempen".

The mast is located on a hill in the valley of the Demer, at 51 m a.s.l. The cities of Diest and Schaffen are situated respectively in SSW and E direction of the anemometer on an altitude of ± 25 m a.s.l. The nearby buildings (except for the tower) do not shelter the anemometer, since the buildings are located on altitudes of 40 m a.s.l.(sports hall) and 30 m a.s.l. within direction NE.

The landscape within a range of 5000 m is a typical shelved one, with isolated hills till 65 m a.s.l.

Obstacle description recent location

Study circle: 500 m

Obstacles map (position and numbering of obstacles on map) :

Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	37	122	41	122	9	8	0	Tower
2	45	180	58	180	10	15	0	Sports hall[4]
3	50	123	54	124	2.5	5		Building
4	52	450	55	480	22	21	0	Balloon hangar[5]
5	60	450	62	480	16	15	0	Balloon hangar
6	75	250	90	250	10	80	0.5	Sawmill
7	195	128	230	250	12-14	10	0.5	Trees

Within a range of 500 there are no significant obstacles since the mast is located on the top of a hill. In the direction 280 we found the highest point at an altitude of 65 m a.s.l.

[4] Situated on 40 m a.s.l.

[5] Situated on 30 m a.s.l.

1.3.24. Saint – Hubert

1.3.24.1. Location:

Mast	Lambert 72		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)		
Synop	224279	80808	557	10.85

Map: 59/ 7-8

The station is equipped with automatic analog recording (Fuess-instrumentation) of:

- Instantaneous wind speeds (knots)
- Totalised 10-minutes mean wind speeds (knots)
- Instantaneous wind direction

Anemometer height a.g.l.: 10.85 m

1.3.24.2. Site description:

Saint-Hubert is located at the SE-part of Belgium, which is one of the highest locations in the Ardens. As can be seen from the topographic map, the anemometer of Saint-Hubert is indeed located at the almost highest area, compared with the surroundings. Only within direction (70 – 110) the topography is slowly rising.

From old pictures (± 1989) in directions (180), (210), (240), (270) and topographic maps, it is clear that the area slopes down significantly between the S and the W. On recent pictures it isn't possible anymore to see the valley within the mentioned directions, due to the presence of the fir-trees in the mentioned directions. There is a height difference between the airfield and Saint-Hubert (250) of more than 100 m within a distance of about ± 1.7 km.

Obstacle description recent location
Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	40	650	55	342	21-25	-	0.6	Fir-trees
2	55	342	100	600	21-25	-[6]	0.6	Fir-trees
3	100	600	120	570	21-15	-	0.6	Fir-trees
4	119	371	130	360	15	-	0.6	Fir-trees
5	120	192	121	121	2	2	0	Cont. Gonio
6	130	360	250	120	14-18	-		Fir-trees
7	263	500	273	630	21	300	0.5	Fir-trees

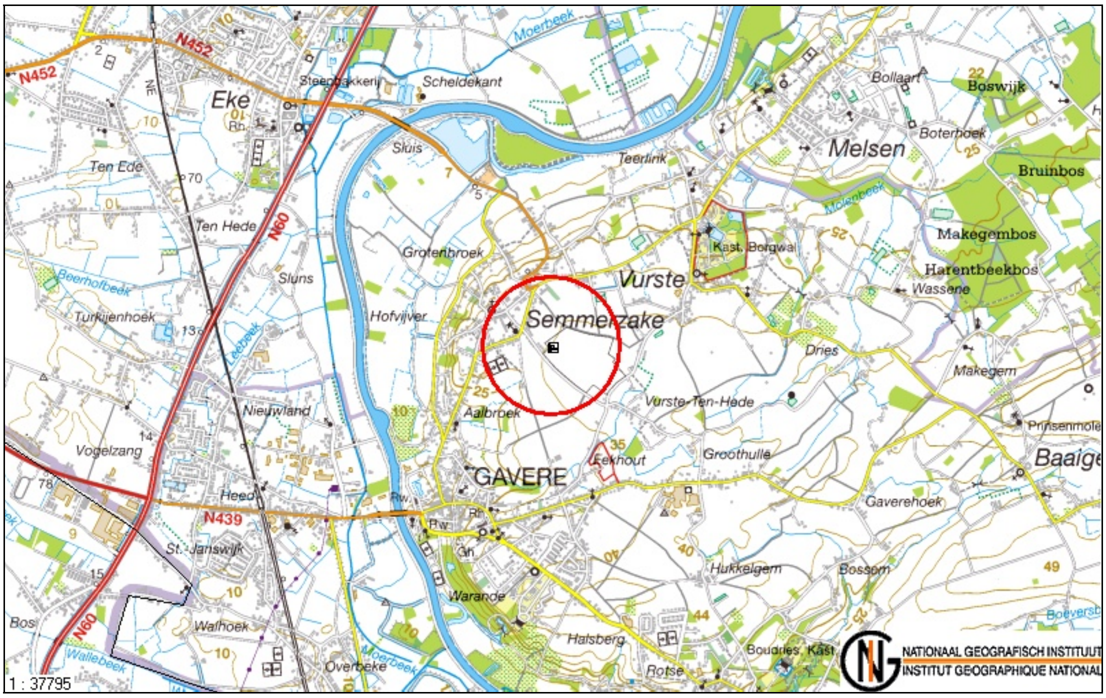
1.3.25. Semmerzake

The meteo of Semmerzake is located on a military domain. It is operational since 1-1-1997. Before this date, the station was located at Munte.

1.3.25.1. Location:

Mast	Lambert 72		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)		
synop	100870	181373	35	10

Map: 22/5



1.3.25.2. Site description:

Semmerzake is located on a plateau in the valley of the Schelde. Typical for this region is the presence of windbreaks of poplar.

[6] border forest

Remark:

This site has too many obstacles, which are located too close from the mast.

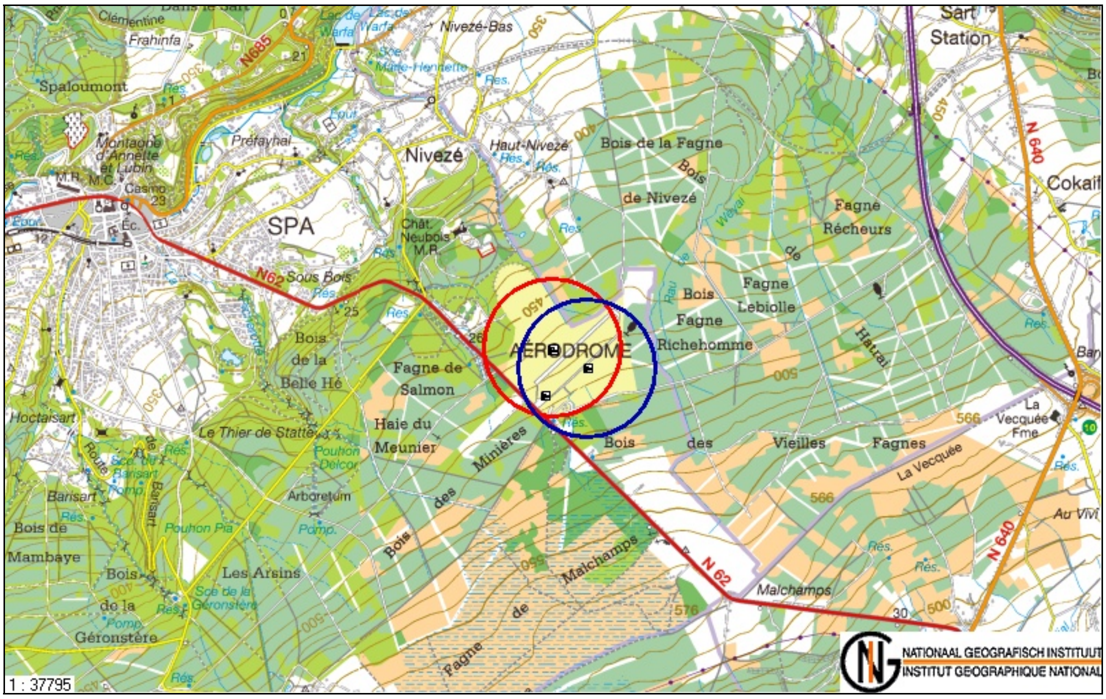
Obstacle description recent location								
Study circle: 500 m								
Obstacles map (position and numbering of obstacles on map) :								
Obstacle dimension								
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	250	87	273	40	2	1	0.4	Hedge
2	255	62	290	120	6-8	12	0.33	Houses
3	290	300	292	300	11	6	0	Mill
4	296	78	299	86	8	4	0.5	Trees
5	310	230	340	402	8.3	10	0.33	Houses
6	346	405	353	440	8	20	0	Shed
7	340	400	352	343	18	5	0.5	Poplar
8	358	402	04	360	10-12	25	0.5	Trees
9	55	225	62	205	10-12	20	0.5	Trees
10	65	72	65	97	5-6	4	0.5	Pollard willow
11	79	132	89	132	25	25	0	Radar
12	100	230	109	230	7-8	30	0.5	Pollard willow
13	110	250	132	305	7-8	5	0.5	Pollard willow
14	136	368	140	368	9	20	0.5	Pollard willow
15	143	162	145	162	3	8	0	Building
16	145	75	155	75	7	8	0	Meteo building
17	162	77	170	77	5	5	0	Building
18	155	112	175	100	8-10	25	0.5	Trees
19	175	105	195	105	12-14	5	0.75	Weeping willow
20	240	1450	241	1450	35	6	0	Building

1.3.26. Spa

1.3.26.1. Location:

Mast	Lambert 72		ED 50		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m)	Y (m)	Longitude	Latitude		
New	259434	131236	5°54'43.2"	50°28'57.1"	464	10.5
Old	259689	131100	5°54'55.9"	50°28'52.5"	475	10.95

Map: 50/1



1.3.26.2. Measurement period

1.3.26.3. Instrumentation

The station is equipped with automatic analog recording (Fuess-instrumentation) of:

- Instantaneous wind speeds (knots)
- Totalised 10-minutes mean wind speeds (knots)
- Instantaneous wind direction

Anemometer height a.g.l.: 10.95 m

The anemometer has been moved towards the centre of the aerodrome on 3-7-2002, since Belgocontrol was planning to place some hangars on the old location of the mast.

1.3.26.4. Site description:

The airport of Spa is located at the NW site of a ridge of higher levels directed from the SW to the NE. The gradient is remarkable as can be inferred also from the topographic map and the pictures (annex). The height levels between 400 m and 500 m a.s.l. show a strong gradient. The slope is ± 4% along the direction SW-NE between altitudes of 450 and 500 m a.s.l.

This specific orientation of the runway in Spa and the orientation of the forest around the aerodrome is explaining the specific behaviour of the wind at this site. Here is the dominant wind direction SE instead of SW and this can be explained by the specific topography. Since the station is located at almost the top of the hill and there is a strong gradient in topography present, catabatic winds can occur here.

Object description old location[7]:

Obstacle description recent location								
Study circle: 500 m								
Obstacles map (position and numbering of obstacles on map) :								
Obstacle dimension								
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	345	375	15	750	20	1125	0.5	Trees
2	20	425	45	225	30	2500	0.5	Woods
3	45	225	75	200	30	2750	0.5	Woods
4	75	200	105	225	30	3000	0.5	Woods
5	105	225	135	450	30	2250	0.5	Woods
6	135	450	165	175	30	450	0.5	Woods
7	165	175	195	250	30	875	0.5	Woods
8	195	250	225	550	30		0.5	Woods
9	315	375	345	450	20	1000	0.5	Trees

Object description recent location:

Obstacle description recent location								
Study circle: 500 m								
Obstacles map (position and numbering of obstacles on map) :								
Obstacle dimension								
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	253	450	300	315	15	-[8]	0.5	Forest
2	320	650	345	650	15	-	0.5	Forest
3	30	215	45	850	19	-	0.5	Forest
4	60	600	80	563	19	-	0.5	Forest
5	80	563	115	700	19	-	0.5	Forest
6	121	308	131	297	6	15	0	Hangar
7	140	400	180	490	19	-	0.5	Trees
8	158	395	162	401	6	40	0	Hangar
9	180	450	447	183	10	10	0	House
10	185	407	188	433	8	4	0	Garage
11	189	434	194	483	8	20	0	Building

1.3.27. Uccle

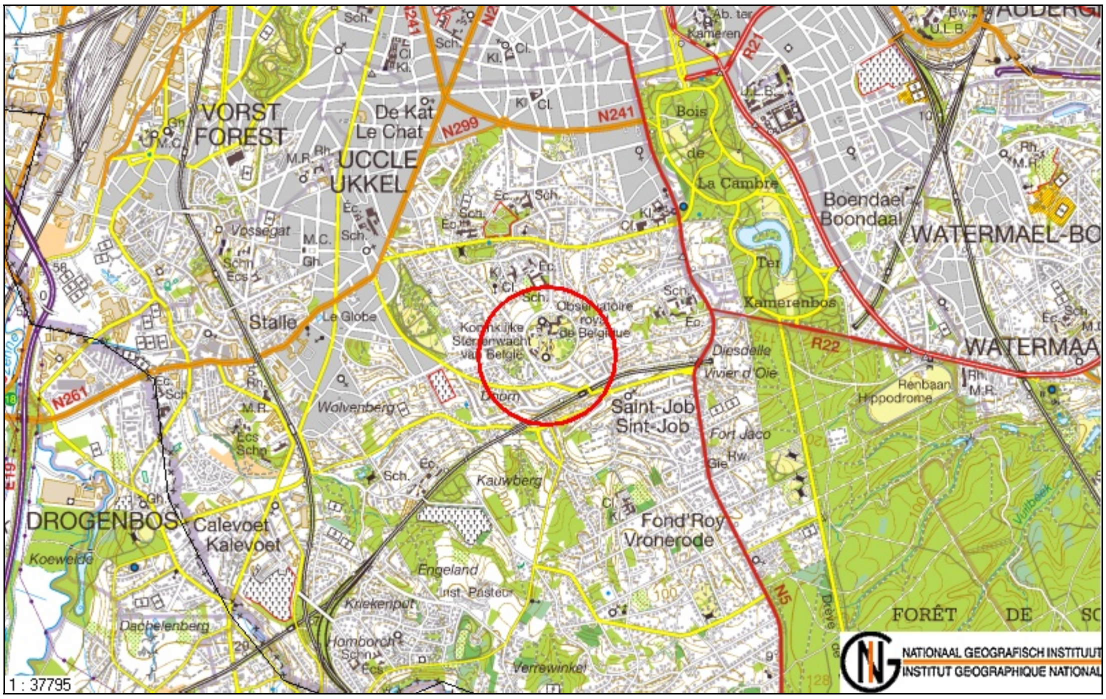
1.3.27.1. Location:

mast	Lambert 72		ED 50		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m.)	Y (m)	Longitude	Latitude		
Ukkel zuid	149278	165132	4°21'35.2"	50°47'50.9"	100	30

Map: 31/7

[7] description made in 1989 by staff member of RMI

[8] This is the border of the forest



1.3.27.2. Site description:

Uccle is situated in the southern suburbs of Brussels. Since the mast is surrounded by trees and buildings which are too close to the mast, the height of the mast is chosen to be more than 10 m, e.g. 30m.

1.3.28. Zaventem

The synoptic mast of Zaventem has been submitted to some important changes in mast location and the used sensors over a time period of almost 50 years. The locations of the masts are given in Lambert 72 coordinates:

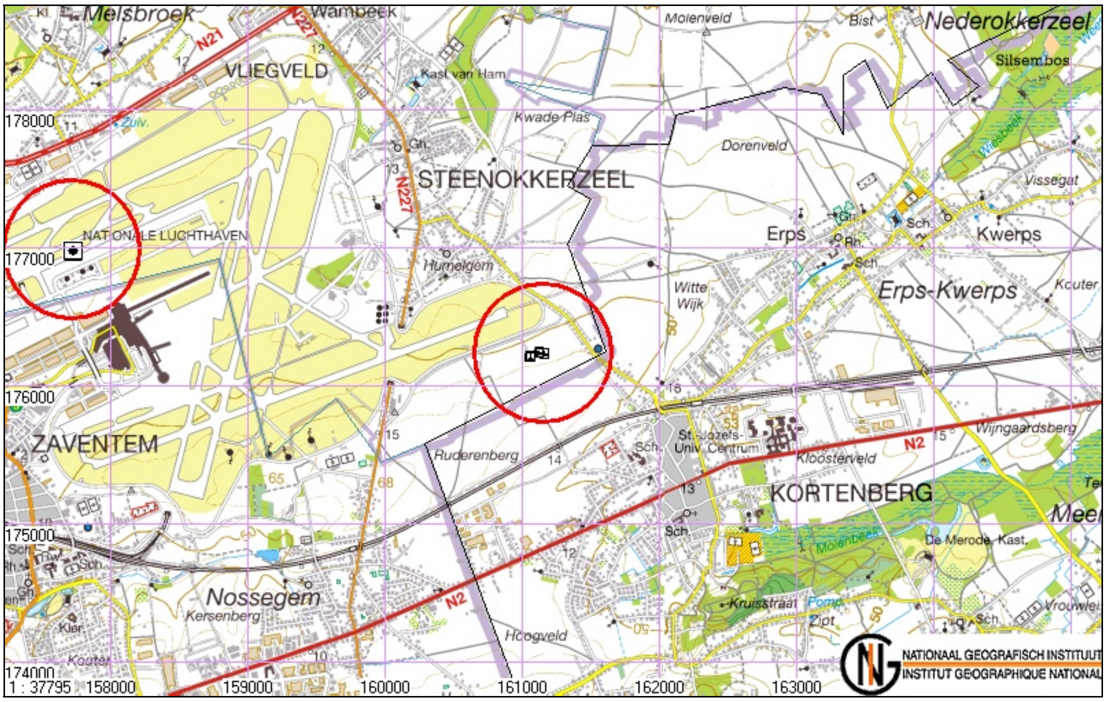
1.3.28.1. Location:

mast	Lambert 72		ED 50		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m.)	Y (m)	Longitude	Latitude		
Old location[9]	157725	176978	4°28'47.4"	50°54'14.1"	37	10.6
New location[10]	161164	176229	4°31'34.2"	50°53'48.6"	53.5	10

Map: 31 ¾

[9] Old location of the mast (? – 30th of September 1980)

[10] Location of the actual mast (1st of October 1980 - now):



1.3.28.2. History of the measurements:

The old mast location was situated in the middle of airport runway 25R, at about 200 meters southwards this runway and 3520 meters towards the west from the current location.

1.3.28.3. Site description:

Until 30th of September 1980, this mast was the operational unit. The immediate surroundings around the mast are reasonable flat. Unobstructed air comes within the sectors (50)-(90) and (235)-(260). Vegetation on the surrounding fields is not allowed to be higher than 50 cm. The anemometer above ground height is 10.7 m.

1.3.28.4. Zaventem (Old location)

Obstacle description old location
Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	116	175	145	125	6	25	0	Buildings + oil tanks
2	145	675	155	750	36	100	0	Main airport building
3	152	125	169	125	6	10	0	Two oil tanks
4	158	475	180	550	8	60	0	Buildings
5	186	580	216	1050	8	150	0	buildings

1.3.28.5. Zaventem (New location)

The actual location of the synoptic mast is situated outside the airport area, south east of the airport. It is situated in the municipality Steenokkerzeel. It is operational at this location since October 1980.

The new location of the synoptic mast Zaventem is situated about 1 km SE from Humelgem and 1.5 km NW from Kortenberg. It is situated on a hill named the Ruderenberg. The highest point is situated on 1.5 km in the sector 220-240.

From 11-02-04 onwards, the measurements of the synoptic data are automatically recorded in Zaventem. Prior to that date, the observer wrote down the information from the instrument at 10 minutes before the hour. Now the software automatically records it. The observer needs only to fill in the synoptic data afterwards. This gives us more certainty over the exact moment of registration.

Obstacle description new location

Study circle: 500 m
Obstacles map (position and numbering of obstacles on map) :
Obstacle dimension

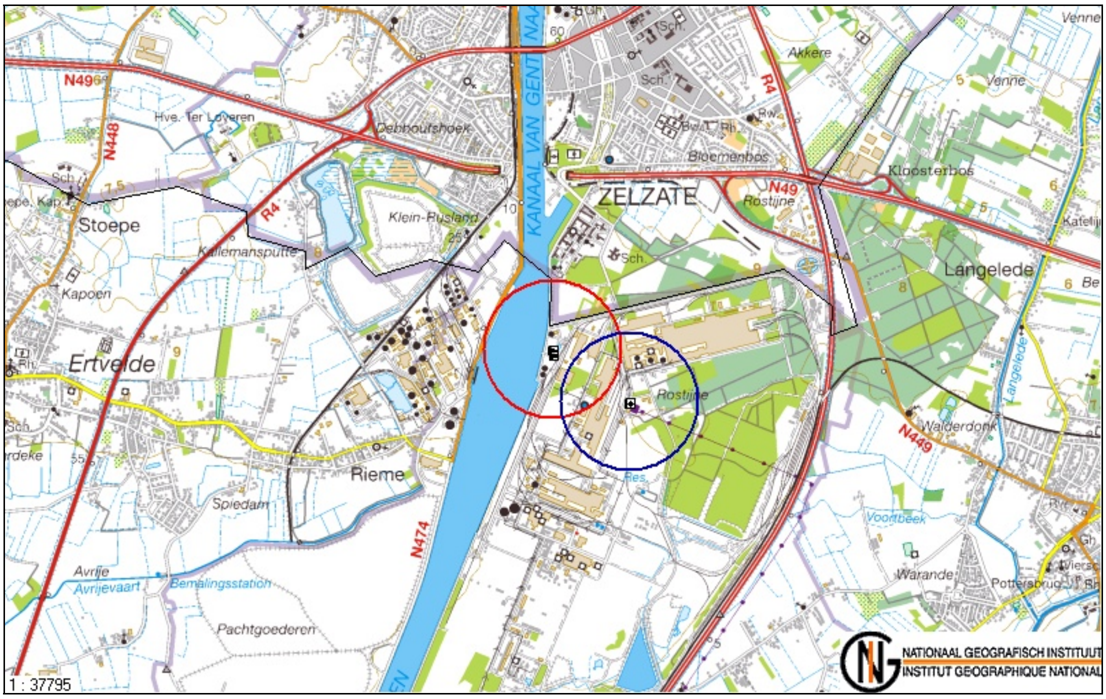
Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	52	300	70	300	15		0.75	Isolated trees
2	70	194	73	194	2.5	5	0	building
3	70	260	81	300	10	20	0	Houses+trees
4	83	330	84	330	10	20	0	house
4	85	383	89	383	30	15	0	tower
5	91	145	93	145	2	4	0	building
6	90	550	100	500	15	5	0.4	trees
7	103	500	128	450	12	5	0.4	trees
8	258	110	263	110	6	8	0	meteo
9	329	52	331	52	2	1	0	Small building

1.3.29. Zelzate

1.3.29.1. Location:

Mast	Lambert 72		Alt (m a.s.l.)	Alt (m a.g.l.)
	X (m.)	Y (m)		
Old	111070	207639	8	23.5
New	110501	208020	8	10.5

Map: 14/2



1.3.29.2. Instrumentation:

Wind velocity sensor LISA

Wind direction sensor RITA Gray

1.3.29.3. Site description:

Since 1967, synoptical reports are generated at Zelzate (Sidmar). Sidmar is a steel factory. On the site, there are many high buildings. Since 1967, the mast was located on the roof of "post 150 kV". The dimensions of this building were (xyz) 100 m,300 m,8.5 m, where the longest direction was oriented in direction NNE-SSW. There were many problems detected with the accuracy of the wind vane.

Since 2002, the station has been moved to a waterpoint at the site, close to the canal and is now part of the AWS network of RMI.

Obstacle description recent location

Study circle: 500 m

Obstacles map (position and numbering of obstacles on map) :

Obstacle dimension

Nr	Alpha 1 (°)	R1	Alpha 2 (°)	R2	H	d	P	Comments
1	345	120	20	150	8	10	0	Building
2	335	95	345	125	12	5	0.5	Trees
3	10	158	32	220	12-15	25	0.5	Trees
4	35	60	55	30	15->8	5	0.7	Birch
5	65	115	160	112	15	5	0.5	Array of trees
6	58	250	111	140	8	55	0	Building
7	130	40	140	40	12	5	0.5	Trees
8	160	120	185	140	17	5	0.5	Array of trees
9	165	15	172	18	2.5	1	0	Construction
10	147	46	170	46	2.5	12	0.5	Trees
11	148	120	172	215	10	110	0	building
12	170	58	225	58	2.5	50	0.5	Trees
13	190	120	203	120	11	40		Silo
14	245	55	258	75	2.5	4	0.2	Construction

1.4. Instrument history

Table 1 gives the available information up to now on the changes in sensors for the stations of Belgocontrol. Such information for the Wing Meteo and useful information on the history of the instrument calibration are not yet available.

Table 2 Historical overview of changes in sensor type for wind measurements for the stations of Belgocontrol

Station	Type Anemometer	Date of first utilisation or replacement
Zaventem	Fuess	1960
	Fuess	01-10-1980
	Vaisala	13-5-1986
	Thies	11-2-2004
Saint-Hubert	Fuess	Since 1968
Spa	Fuess	1970
	Replacement Fuess	3-7-2002
Deurne	Fuess	1970
	Vaisala	12-12-1985
Oostende	Fuess	1972
	Vaisala DR 21	21-06-1995
	Replacement Vaisala	10-5-2004
Gosselies	Fuess	1970
	Vaisala	28/11/1986
Bierset	Fuess	1970
	Vaisala	1991-1992 (FMA)
	Replacement Vaisala	15-03-1998

The anemometric network, operated by Belgocontrol, is presently going to change all of its anemometers into Thies. When they will be changed, the wind data for the synoptic reports will be generated automatically.

For the network of Meteo Wing it was communicated (personal communication, 2005) that since 1991-1992, with the introduction of the semi-automatic stations, the anemometers have been changed into Vaisala at all the stations. The precise installation data could not be retrieved for all the stations. In the section "description of the sites" more detailed information can be found.

The automatic weather station (AWS) network operated by RMI has been thoroughly tested in the nineties at the station of Melle. However, the first operational AWS started at Dourbes on 15-12-2000.

1.5. Instrument properties

The properties of the anemometric instruments, operational for the anemometric Belgium network for the period of interest (1985-2004) are mentioned in Table 3 below:

Table 3: description of the properties of different sensor types;

Wind sensor	Principle	Measuring range	Threshold of measuring	Resolution	Accuracy	Weight [kg]	Network
Wind velocity sensor LISA	Light barrier (opto electronic)	0-60 m/s	0.3 m/s	40 pulses/ revolution	± 1 %	2	RMI
Wind direction sensor RITA Gray	Graycode 8 bit (opto electronic)	1…360 º	0.1 m/s	1.4º	± 2 º	2	RMI
Vaisala WAA12 anemometer	Graycode 6 bit (opto electronic)	0…75 m/s	0.4 m/s	0.1 m/s	± 2 %	0.875	All
Vaisala Wind Vane WAV 12	Graycode 6 bit (opto electronic)	0…360 º	0.3 m/s	5.6º		0.930	All
Thies, wind transmitter	Gray-code 8 bit (Opto electronic)	0.5 – 75 m/s	0.5 m/s	0.05 m wind run	± 2 %	1	Belgocontrol
Thies, wind vane	Parallel 8 bit Gray-code	0…360 º	0.5 m/s at 30º indicator deflection	± 2.5 º	± 2.5 º	1.8	Belgocontro
Fuess 90Z		0 – 40 m/s	-	-	dd =10º ff = 1 m/s	35	All

The most important difference between these four anemometric instrument types is related to their weight. The weight influences the inertness of the instruments. A Fuess is therefore more inert than the Vaisala instruments, which are very light in weight and are therefore also the most fragile ones. The inertness of the instrument also influences the threshold of measuring for the wind direction and for the wind speed. For the wind direction this weight effect results in less fast fluctuations in the detection of the wind direction and a higher threshold value to detect wind direction and wind speed, due to this higher inertness. (Problems of calm winds)

The experience RMI has with the new instruments (Lisa and Rita) implemented in the AWS network is that they are reliable and few problems are reported since the introduction of these instruments.

1.6. Overview Mast Location

The terminology "Mast 1" and "mast 2" are used for stations of Meteo Wing where Mast 1 is the master, used for the synoptic data.

Table 4 Overview of every mast with its location and characteristics

Station	Mast nr	Lambert X (m.)	Lambert Y (m)	Longitude ED50	Latitude ED50	Alt. a.s.l. (m)	Period	Alt. Mast a.g.l. (m)
Bierset								
belgocontrol	23	226875	148929	5º27'25.0"	50º38'48.3"	180	>15/03/98	10
old		226492	148577	5°27'05.3"	50°38'37.1"	178		10
Beitem								

Station	Mast nr	Lambert X (m.)	Lambert Y (m)	Longitude ED50	Latitude ED50	Alt. a.s.l. (m)	Period	Alt. Mast a.g.l. (m)
		62280	177821	3°07'22.5"	50°54'17.8"	25		10.5
Bevekom								
Mast 2	04	177515.062	159904.34	4°45'35.6"	50°44'59.4"	109	<04-01-2001	10
Mast 1	22	178864.291	161592.64	4°46'44.9"	50°45'53.8"	98	04-01-2001	10
old		177980	159920	4°45'59.3"	50°44'59.8"	112		10
Brasschaat								
Mast 1		159289.77	225124.78	4°30'11.98"	51°20'11.96"	21	?	18
Buzenol								
		238068	35002	5°35'19.3"	49°37'15.9"	324		10.5
Chièvres								
Mast 1		111936	140300	3°49'57.6"	50°34'22.9"	60		10
Deurne								
Synop	29	157201	208928	4°28'22.9"	51°11'28.0"	10		10
new		156926	208658	4°28'08.7"	51°11'19.3"	10		10
Alternate	11	156219	208926	4°27'32.3"	51°11'28.0"	10	?	10
Diepenbeek								
		226053	178914	5°27'05.45"	50°54'58.95"	39		10.5
Dourbes								
		166188	87209	4°35'46.4"	50°05'48.2"	235		10.5
Elsenborn								
	New	278781	131892	6°11'05.0"	50°29'04.2"	568		10
	Old	278727	131808	6°11'02.2"	50°29'01.5"	568		10
Ernage								
		172697	141325	4°41'25.7"	50°34'58.9"	157		11
Florennes								
Mast 1	26	171173.979	103641.26	4°40'00.6"	50°14'39.5"	280	>1992	10
Mast 2	8	168659.798	103563.77	4°37'53.7"	50°14'37.3"	282	>1992	10
old		170134.262	103292.05	04°39'08.06"	50°14'28.33"	280	<1992	6.4
Gosselies								
		156805	128163	4°27'57.0"	50°27'54.4"	178		10
Humain								
		213307	98439	5°15'23.7"	50°11'40.2"	295		10.3
Kleine Brogel								
Mast 1	23	227938	207714	5°29'04.1"	51°10'29.9"	51	>1992	10
Mast 2	5	226019	206025	5°27'24.1"	51°09'36.2"	62	>1992	10
intermediate		227016	207224	5°28'16.3"	51°10'14.5"	55	1989-1992	10
old		226512	207100	5°27'50.2"	51°10'10.7"	55	<1989	10
Koksijde								
Mast 1		29948	199668	2°39'22.4"	51°05'43.8"	4	?	10
Mast 2		30838	198592	2°40'09.4"	51°05'09.6"	4	?	10
Old		29918	198785	2°39'21.9"	51°05'15.2"	4		

Station	Mast nr	Lambert X (m.)	Lambert Y (m)	Longitude ED50	Latitude ED50	Alt. a.s.l. (m)	Period	Alt. Mast a.g.l. (m)
Melle								
		111169	185723	3°49'01.5″	50°58'52.6″	15		10.3
Middelkerke								
	Old	44930	210605	2°52'00.7"	51°11'48.1"	3	< 10/05/04	12.7
	New	44708	210709	2°51'49.2″	51°11'51.3″	3.5	>= 10/05/04	10
Mont-Rigi								
		270901	134732	6°04'28.7"	50°30'42.1"	673		10.5
Munte								
	Old	105262	181152	3°44'00.7″	50°56'23.2″	55		14
	New	105276	181123	3°44'01.4"	50°56'22.2"	55		10
Oostende-pier								
		48793	215400	2°55'14.8"	51°14'25.7"	11.5		15.5
Retie								
		196007	212593	5°01'42.7"	51°13'20.1"	21		10.5
Schaffen								
Mast 1		198664	187642	5°03'47.6"	50°59'52.0"	51		11
Saint-Hubert								
		224279	80808	5°24'24.4″	50°02'05.0"	557		10.85
Semmerzake								
		100870	181373	3°40'15.7"	50°56'29.1"	35		10
Spa								
	New	259434	131236	5°54'43.2"	50°28'57.1"	464		10.5
	Old	259689	131100	5°54'55.9"	50°28'52.5"	475	>=3/07/02	10.95
Ukkel		149278	165132	4°21'35.2"	50°47'50.9"	100		30
Zaventem								
		161164	176229	4°31'34.2"	50°53'48.6"	53.50	>=1/10/'80	10
		157725	176978	4°28'47.4"	50°54'14.1"	37.00	<1/10/'80	10.6
Zelzate								
	oud	111070	207639	3°48'48.0"	51°10'41.8"	23.5		8
	nieuw	110501	208020	3°48'18.6"	51°10'53.9	10.5		8

1.7. Findings and conclusions from station visits

For this project, we will focus on the time period 1985 – 2004. After we have visited the stations, we will start with the statistical analysis of the data. We can already conclude that most of the stations are well located in the landscape. We can also exclude one station because some very important criteria are bit respected (see Table 5).

Table 5: Station rejected up to now following the criteria mentioned in paragraph 3.2.2.

Station	Comment
Brasschaat	The height of the mast is 18 meters and is sheltered in almost all directions. Only for winds coming from the east the values observed are comparable with nearby stations.

1.8. References

[1] Note technique nr 35. Classification d'un site. Meteo France, November 1999

[2] "Wat men moet weten om zonder zorgen te navigeren met GPS" - 13blz- 1.086Kb , http://www.ngi.be/NL/NL2-1-6.shtm

[3] Michel Leroy, Note technique nr 35. Classification d'un site. Meteo France, Novembre1999

[4] J.W. Verkaik, Documentatie Windmetingen in Nederland, 2001

- McCuen, R.H. (2003). Modelling hydrologic change – statistical methods. Boca Raton: Lewis Publishers.
- Zar, J. (1999). Biostatistical analysis. New Jersey: Prentice-Hall.
- ICAO DOC 9837, Manual on Automatic Meteorological Observing Systems at Aerodromes, Draft september 2004.

2. Task 2: Terrain mapping: Roughness and Orography

2.1. Task 2a: Terrain roughness maps

2.1.1. Introduction

In order to calculate the effects roughness and of topography on the wind it is necessary to describe systematically the characteristics of the topography and roughness. These are:

- The influence of the terrain surface, referred to as the roughness of the terrain.
- The influence of the orography such as hills, cliffs, mountains, escarpments,….
- The influence of obstacles in the close neighbourhood of the envisaged site.

The roughness of a particular surface area is determined by the size and distribution of the roughness elements in that area. For land surfaces these are typically vegetation, built-up areas and the soil surface.

It should be noted that in general the roughness length has to be considered as a climatological parameters because the roughness of an area changes with foliation, vegetation, snow cover and so on. The energy production of a wind turbine must be determined on the basis of climatology, primarily because of the variations of the weather, however, the seasonal variations in the local terrain characteristics can also have a profound influence.

2.1.2. Input data

The following data have been used:

2.1.2.1. CORINE Land Cover files

The objective of the pan-European project CORINE Land Cover (CLC) is the provision of a unique and comparable data set of land cover for Europe. It is part of the European Union programme CORINE (Co-ordination of Information on the Environment). The mapping of the land cover and land use was performed on the basis of satellite remote sensing images. The interpretation has been complemented with analysis of exogenous data (topographic maps, aerial photography, …). The scale of this data basis is 1:100 000 and is well adapted to a regional mapping.

The subject of the database is land use, which is determined by the physical nature of the objects, which is different from a land use defined by the socio-economic function of the objects.

The CORINE Land Cover data basis for Belgium contains polygons. Their spatial unity can relate to two types of zones. In the first type, the land cover can be considered as homogeneous. The second type is a combination of elementary zones, which, apart from their variations, represent occupational structures considered to belong to the same class of soil occupation. Figure 1 gives a view on a detail of the database. The attributed codes to the polygons are given in Table 6.

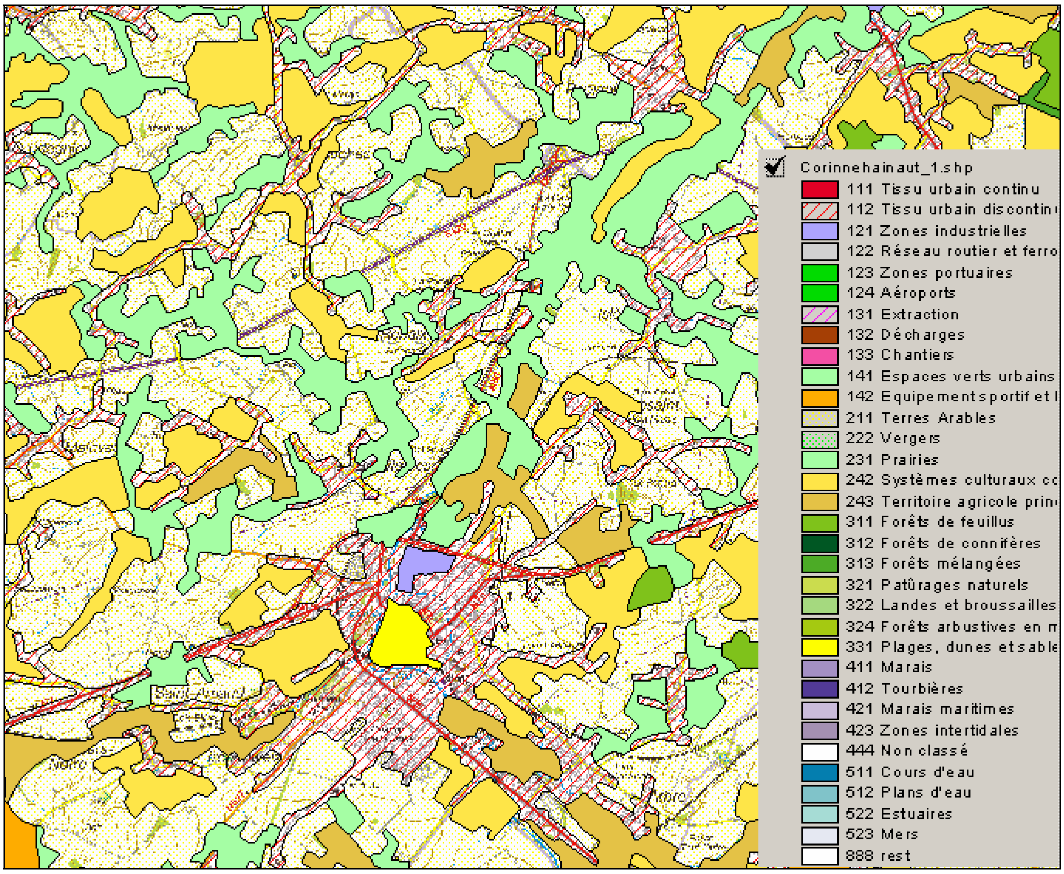


Figure 4 Example of CORINE Land Cover

CORINE Land Cover is based on satellite images taken in 1989 and 1990 and has been completed in 1995. The version used for this project corresponds to the updated situation in 2000.

The CLC database is particularly well suited for the definition of terrain roughness because this depends on the actual land use (and not on an assigned land use).

Table 6 Classification of the land use types in the CORINE database

ARTIFICIAL SURFACES

URBAN FABRIC
- 111 Continuous urban fabric
- 112 Discontinuous urban fabric

INDUSTRIAL, COMMERCIAL AND TRANSPORT UNITS
- 121 Industrial, commercial and public units
- 122 Road and rail networks and associated land
- 123 Port areas
- 124 Airport

MINES, DUMPS AND CONSTRUCTION SITES
- 131 Mineral extraction sites
- 132 Dump sites
- 133 Construction sites

ARTIFICIAL NON-AGRICULTURAL VEGETATED AREAS
- 141 Green urban areas
- 142 Sport and leisure facilities

AGRICULTURAL AREAS

ARABLE LAND
- 211 Non-irrigated arable land

PERMANENT CROPS
- 221 Vineyards
- 222 Fruit trees and berries plantations

PASTURES
- 231 Pastures

HETEROGENEOUS AGRICULTURAL AREAS
- 242 Complex cultivation patterns
- 243 Land principally occupied by agriculture, with significant areas of natural vegetation

FOREST AND SEMINATURAL AREA

FORESTS
- 311 Broad-leaved forest
- 312 Coniferous forest
- 313 Mixed forest

SCRUBS AND/OR HERBACEOUS VEGETATION
- 321 Natural grassland
- 322 Moors and heathland
- 324 Transitional woodland-scrub

OPEN SPACES WITH LITTLE OR NO VEGETATION
- 331 Beaches, dunes, sand
- 332 Bare rock
- 333 Sparsely vegetated areas
- 334 Burnt areas
- 335 Glaciers and perpetual snow

WETLANDS

INLAND WETLANDS
- 411 Inland marshes
- 412 Peat bogs

COASTAL WETLANDS
- 421 Salt marshes
- 423 Intertidal flats

WATER BODIES

INLAND WATERS
- 511 Water courses
- 512 Water bodies

MARINE WATERS
- 521 Coastal lagoons
- 522 Estuaries
- 523 Sea and ocean

For wind energy resource calculations, it is advised to take into account the roughness of the region for up to 20 km from the site of interest (cfr. WAsP, WindPro). Therefore, at the country borders, information of the roughness of the neighbouring countries is necessary. The CORINE database of France, Germany, Luxembourg and the Netherlands have been purchased (not completely, only the parts containing the regions at the Belgian border). The classification of the land use types for the CORINE database of the surrounding countries is identical to the classification of the Belgian CORINE database (Table 6).

The description of each code according to the CORINE land cover database is given in [10].

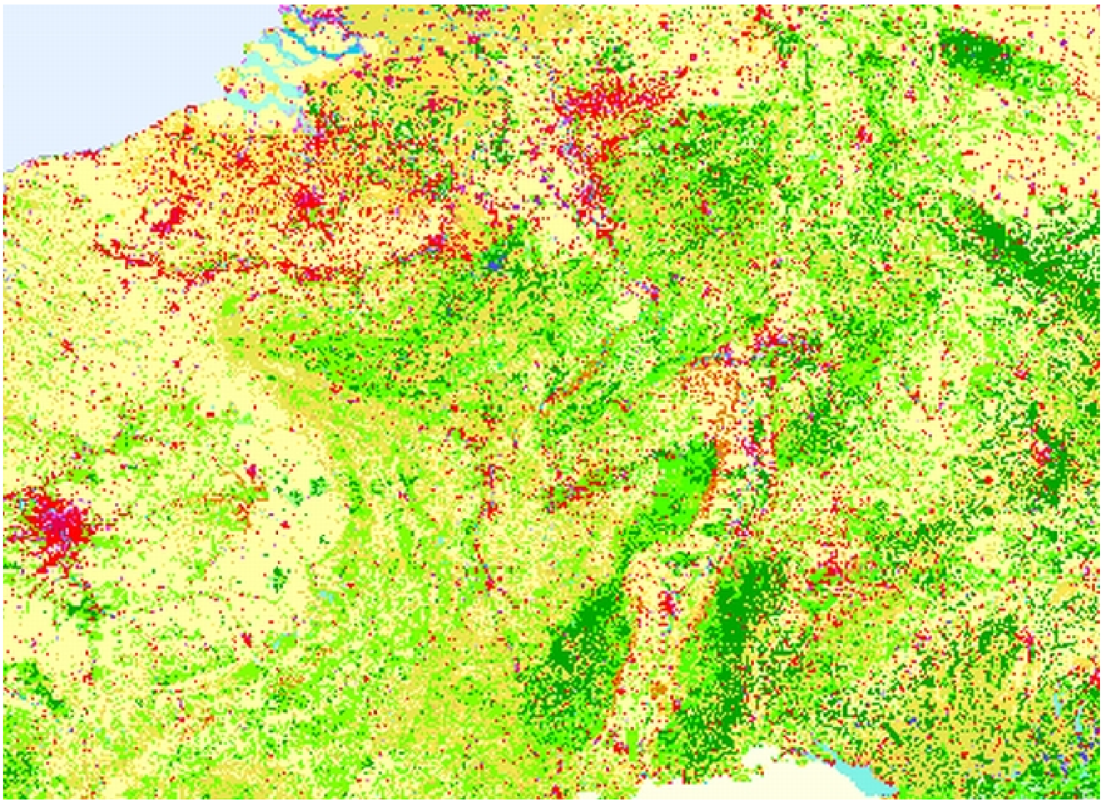


Figure 5 CORINE map for Belgium and the border areas of the Netherlands, Germany, Grand Duché Luxembourg and France

2.1.2.2. *The zoning maps*

The zoning map are maps that shows the legal designation of land use. This legal designation reflects the intent of policies found in planning strategies from the regions (Flanders, Walloon, Brussels). It is through regional zoning maps that the local and regional government regulates land use activities. The land use by-law establishes zones and regulates the development that can take place within the zones (actual permitted use) but can also designate possible future land-use. Examples of land use are: residential area, agricultural area, industrial area, nature reserve, traffic infrastructure, etc…

The regional zoning maps of Flanders, Walloon and Brussel are available in digital format with accompanying colour codes and legend on CD-ROM in both vector and raster format. The digital regional zoning maps of Flanders can also be consulted on the Internet (http://www.gisvlaanderen.be/Geo-Vlaanderen).

Zoning maps give information about the by-law destination of areas, not about their actual land use.

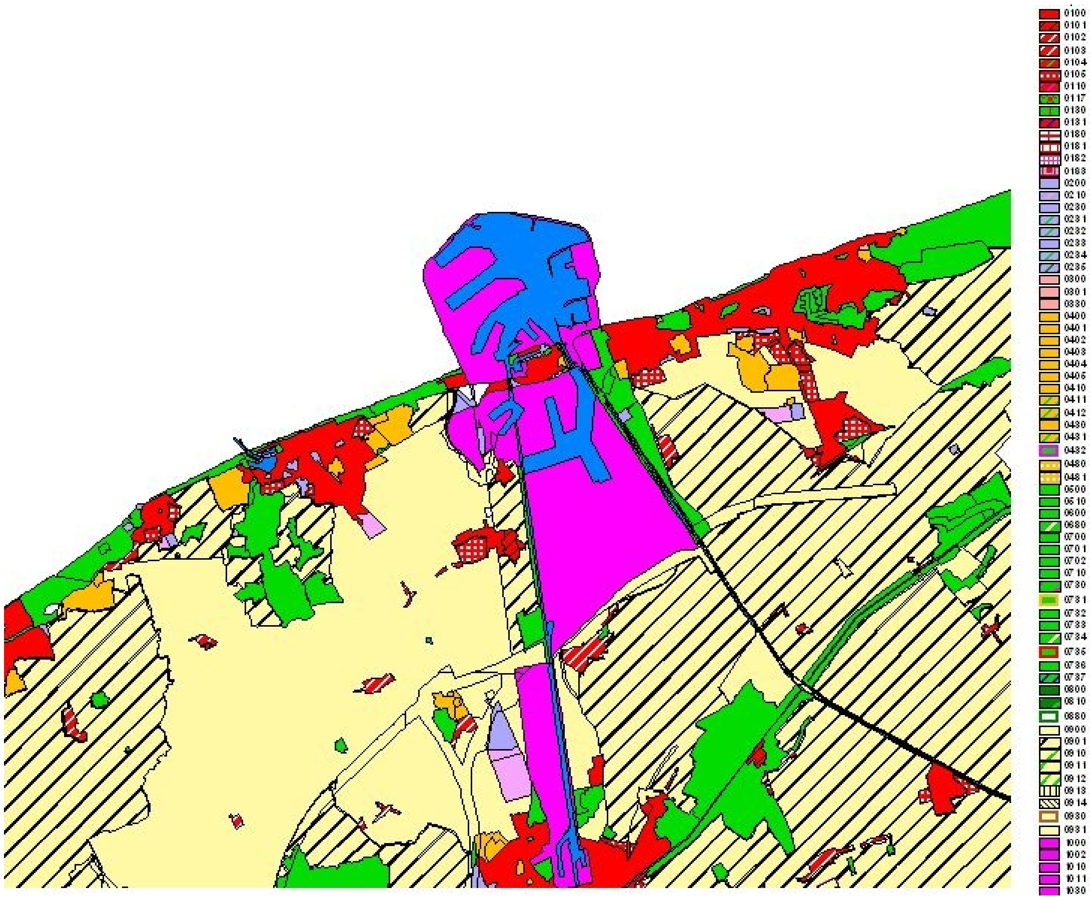


Figure 6 Example of Zoning Map

Just like the CORINE land cover database, each polygon is assigned a code which describes the destination of this area.

The zoning maps are used in order to refine the classification of certain categories defined in CORINE: for example continuous urban terrain, or mixed urban terrain.

CORINE does not make a distinction between rural and urban habitat. However these classes represent quite different terrain roughness to calculate with. These two classes have been defined based on the zoning maps and computer aided visualisations.

2.1.2.3. Topographic maps scale 1:10000 (updated between 1995 and 2002)

These digital topographic maps are in coloured raster format on the scale of 1:10000. Each maps covers an area of 8x6 km². These digital topographic maps are used for checking purposes of the assigned roughness class based on the CORINE database and the zoning maps.

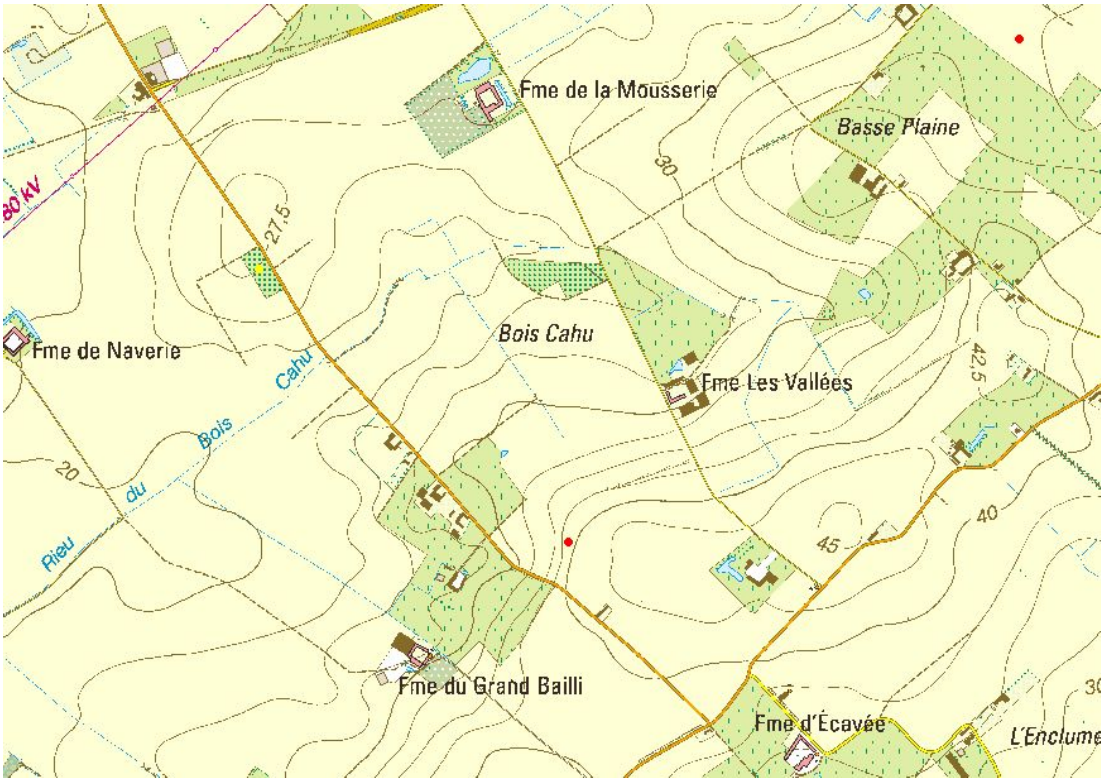


Figure 7 Example of a topographic map scale 1:10000

2.1.3. Methodology

The methodology of creating the roughness map for Belgium is described here below. The CORINE Land Cover database is used as the main input. These are checked with the regional zoning maps and in case of confusion, the topographic maps are consulted.

The Corine database, the database of the regional zoning maps and the topographic maps are imported in a GIS application like ArcView. A number of manipulations and specific adaptations have to be executed:

- Transformation of full polygons into hollow polygons
- Refinement of the CORINE classification, f.i.: adjustment to the categories continuous and non-continuous urban terrain
- Single code definition of overlapping areas.
- Definition of the corresponding roughness length based on the Corine and/or zoning map codes.

In this way, the roughness database for Belgium has been created. The result is a database in shape format that can be imported in a GIS application like ArcView.

To meet the objective of this research project, this roughness database should be converted in a WAsP compatible roughness map. Therefore, the shape formatted roughness database has been imported in the software tool "WindPro". WindPrO is a Windows 98/ME/NT/2000/XP modular based software suite for the design and planning of single wind turbines and wind farms. One of it's features is that it allows to manually create roughness areas based on underlying digital maps (f.i. topographic maps), or a roughness database in polygon shape format can be imported. The created or imported roughness areas then have to converted to a WAsP compatible map file by means of the export option in the roughness area object. Each code classification under the CORINE land use database or the zoning maps has to be assigned a corresponding roughness length here (see Chapter 2.1.4).

The described methodology is symbolically summarised in the following figure.

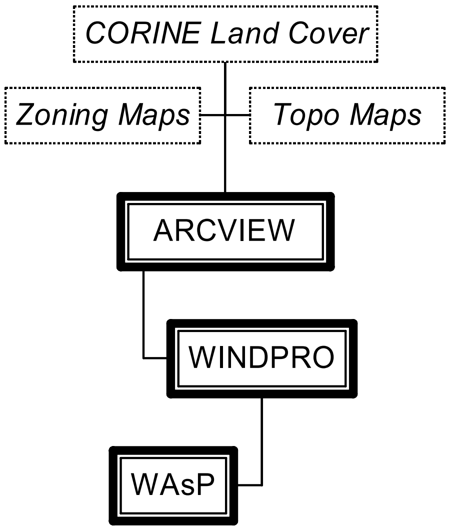


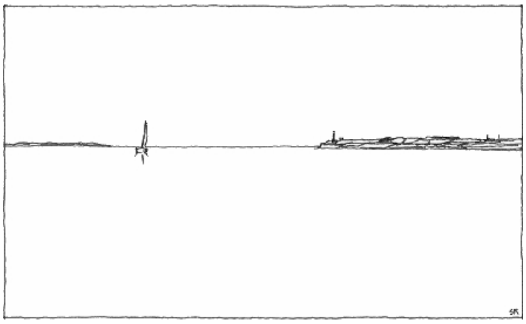
Figure 8 Metholodogy of creating the roughness maps

The WAsP map roughness file is an ASCII file which contains the co-ordinates of the roughness lines. Two roughness values are associated with each contour line: the roughness at the left hand side and right hand side of the separation.

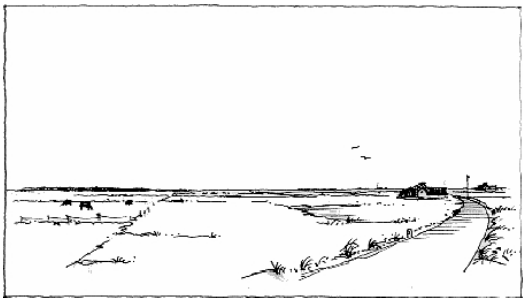
2.1.4. Definition of roughness lengths

For the definition of the corresponding roughness length for each type of land use, a detailed reference study was performed ([5], [6], [7], [8], [9]).

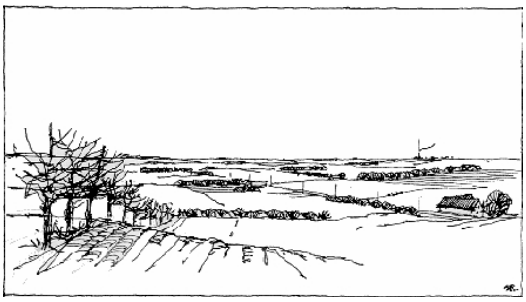
The roughness of a particular surface area is determined by the size and distribution of the roughness elements it contains; for land surfaces these are typically vegetation, built-up areas and the soil surface. In the European Wind Atlas ([7]) the different terrains have been divided into four types, each characterised by its roughness elements. Each terrain type may be referred to as a roughness class. A description and illustration of four such roughness classes is given in the figures below which furthermore give the relation between roughness length and roughness class, the former being the commonly used length scale to characterise the roughness of a terrain.



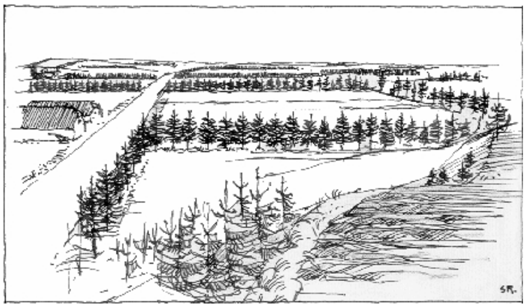
Example of terrain corresponding to roughness class 0: water areas. This class comprises the sea, fjords, and lakes. The roughness length is z0 = 0.0002 m. However, the roughness must be specified as 0.0 m in WAsP.



Example of terrain corresponding to roughness class 1: open areas with few windbreaks. The terrain appears to be very open and is flat or gently undulating. Single farms and stands of trees and bushes can be found. The roughness length is z0 = 0.03 m.



Example of terrain corresponding to roughness class 2: farm land with wind-breaks, the mean separation of which exceeds 1000 m, and some scattered built-up areas. The terrain is characterised by large open areas between the many windbreaks, giving the landscape an open appearance. The terrain may be flat or undulating. There are many trees and buildings. The roughness length is z0 = 0.10 m.



Example of terrain corresponding to roughness class 3: urban districts, forests, and farm land with many windbreaks. The farm land is characterised by the many closely spaced windbreaks, the average separation being a few hundred metres. Forest and urban areas also belong to this class. The roughness length is z0 = 0.40 m.

Figure 9 Illustration of roughness classes and roughness lengths

Areas of different roughness are apparent on most topographical maps. Examples are: water areas (the sea, fjords, lakes), sand surfaces, bare soil, moor, open farmland, farmland with many shelter belts, forests, villages, and cities.

The landscape can be classified into areas of similar roughness on basis of the information contained in topographic maps, zoning maps, land use maps, as well as any other information available, e.g. aerial photographs. This classification may be thought of as dividing the landscape into a number of terrain types or roughness classes – often in more detail than the classes mentioned above. When the classification has been done, a roughness length z0 can be assigned to each class; one possible relation between roughness class and roughness length is given here below ([7]). The table below indicates the relation between roughness length, terrain surface characteristics and roughness class given in the European Wind Atlas. This table is used as a guideline for assigning roughness length values.

Table 7 Table of roughness lengths

z_0 [m]	Terrain surface characteristics	Roughness Class
1.00	city	
0.80	forest	
0.50	suburbs	
0.40		**3** (0.40 m)
0.30	shelter belts	
0.20	many trees and/or bushes	
0.10	farmland with closed appearance	**2** (0.10 m)
0.05	farmland with open appearance	
0.03	farmland with very few buildings/trees	**1** (0.03 m)
0.02	airport areas with buildings and trees	
0.01	airport runway areas	
0.008	mown grass	
0.005	bare soil (smooth)	
0.001	snow surfaces (smooth)	
0.0003	sand surfaces (smooth)	
0.0002		**0** (0.0002 m)
0.0001	water areas (lakes, fjords, open sea)	

It should be noted, that in general the roughness length as applied in WAsP has to be considered as a climatological parameter because the roughness of an area changes with foliation, vegetation, snow cover and so on. The energy production of a wind turbine must be determined on the basis of climatology, primarily because of the variations of the weather; however, the seasonal variations in the local terrain characteristics can also have a profound influence.

Note also, that on input the roughness of water must be given as 0 (zero), in order for WAsP to distinguish between water areas and very smooth land surfaces.

Based on the descriptions above and Table 7, each code classification under the CORINE land use database or the zoning maps has been assigned a corresponding roughness length (see Table 8).

Table 8 Legend of CORINE database and corresponding roughness length

Code	Name	Freq. (%)	z0 (m)
111	Continuous urban fabric	2.3	1.0
112	Discontinuous urban fabric	12.9	0.5
121	Industrial or commercial units	1.6	1.0
122	Road and rail networks and associated land	0.3	0.1
123	Port Areas	0.2	1.0
124	Airports	0.2	0.03
131	Mineral extraction sites	0.3	0.15
132	Dump sites	0.1	0.15
133	Construction sites	0.2	1.0
141	Green urban areas	0.2	0.2
142	Sport and leisure facilities	0.6	0.3
211	Non-irrigated arable land (*)	34.6	0.07..0.1
222	Fruit trees and berry plantations	0.5	0.39
231	Pastures	9.6	0.05
242	Complex cultivation patterns (*)	19.5	0.07..0.1
243	(…) agriculture, with (…) natural vegetation	3.8	0.1
311	Broad-leaved forest	3.0	0.75
312	Coniferous forest	4.1	0.75
313	Mixed forest	2.6	0.75
321	Natural grassland	0.1	0.03
322	Moors and heathland	0.7	0.2
324	Transitional woodland-scrub	0.3	0.5
331	Beaches, dunes, sands	0.1	0.0003
411	Inland marshes	0.3	0.03
412	Peat bogs	0.1	0.03

421	Salt marshes	0.1	0.0002
423	Intertidal flats	0.0	0.0002
511	Water courses and Water bodies	0.7	0.0001
512	Coastal lagoons	0.0	0.0001
522	Estuaries	0.2	0.0001
523	Sea and ocean (**¨)	0.0	0.0001

Notes:

(*) The classes 211 and 242 represent together 54% of the Belgian surface. The correct definition of their roughness length is very important. Tests and control calculations have been performed to check the performance of the roughness maps of each province. It was found that for the western provinces (West-Vlaanderen, Oost-Vlaanderen, Antwerp and Hainaut), the performance of the roughness maps was best when classes 211 and 242 were assigned the value 0.07 m, while for the eastern provinces (Limburg, Brabant, Liège, Namur and Luxembourg), this value was raised to 0.10 m.

(**¨) Roughness of water: The roughness length of surfaces covered by vegetation may vary with the wind speed. For example, the bending of stalks by the wind can change the form of the surface. A similar phenomenon occurs for water waves where both the height and form of the waves are dependent on wind speed. From dimensional arguments, the following equation can be obtained for the roughness over water when viscous effects and the surface tension of the water are neglected ([11]): $z0 = b \cdot u*2/g$, where b is a constant (approx. equal to 0.014), g the gravitational acceleration, and u* the friction velocity.

During the development of WAsP it was attempted to use both the equation above and a fixed value for the roughness of water areas, roughness class 0. It turned out that a fixed value of 0.0002 m gave results as good as the Charnock equation for the moderate to high wind speeds of interest to wind energy applications, hence all calculations in WAsP are obtained with this value. Note, however, that on input the roughness of water must be given as 0 (zero), in order for WAsP to distinguish between water areas and very smooth land surfaces

The province of West-Vlaanderen borders with the North Sea. The 20 km band of the North Sea was assigned the roughness value 0 m.

2.1.5. Example of the methodology

An example of the methodology is give below:

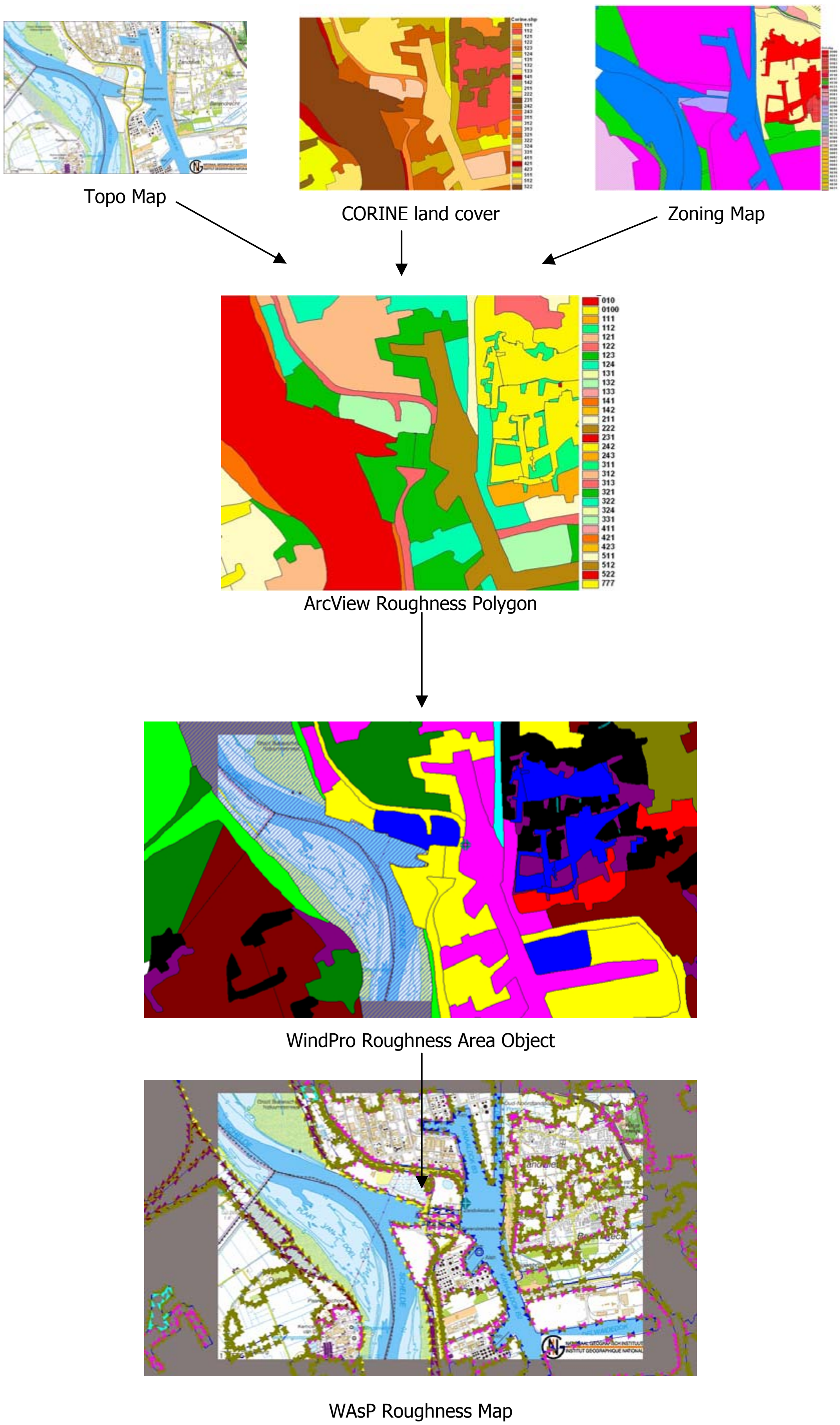

Topo Map
CORINE land cover
Zoning Map
ArcView Roughness Polygon
WindPro Roughness Area Object
WAsP Roughness Map

Figure 10 Example of the creation of the roughness maps

The description of the resulting WAsP Roughness file is given in 2.1.9.

Note: Each European country has its own co-ordinate reference system. For Belgium, the Lambert72 projection is used. All delivered data (CORINE, zoning maps, topo maps) are defined in this co-ordinate system. The neighbouring countries have their own co-ordinate systems: for France, this is the NTF Lambert II étendu, for the Netherlands the databases were defined in the RD system, for Germany in in Gauss-Krüger Zone 3 and in UTM WGS84 zone 32, Gauss-Krüger Zone 4 or UTM Zone 32 projections. The shape formatted roughness maps in ArcView have remained in their original projection system, while the WAsP formatted roughness maps (ASCII files) were all converted to the Belgian Lambert72 projection system since WAsP and WindPro cannot mix up different projection systems in one calculation.

2.1.6. Results

The following figures give the resulting roughness maps (in ArcView shape format) for the 10 provinces of Belgium.

The roughness lines are created on the basis of « modified »CORINE Land Cover for all provinces and also for a buffer zone outside the country border, with a width of 20 km.

The figures below give only the roughness code classification (according to the CORINE land cover database) and the roughness length according to Table 8 within the borders of each province. The 20 km buffer around the province borders are not shown here. As mentioned before, these are given in the database and are defined in other reference co-ordinate systems.

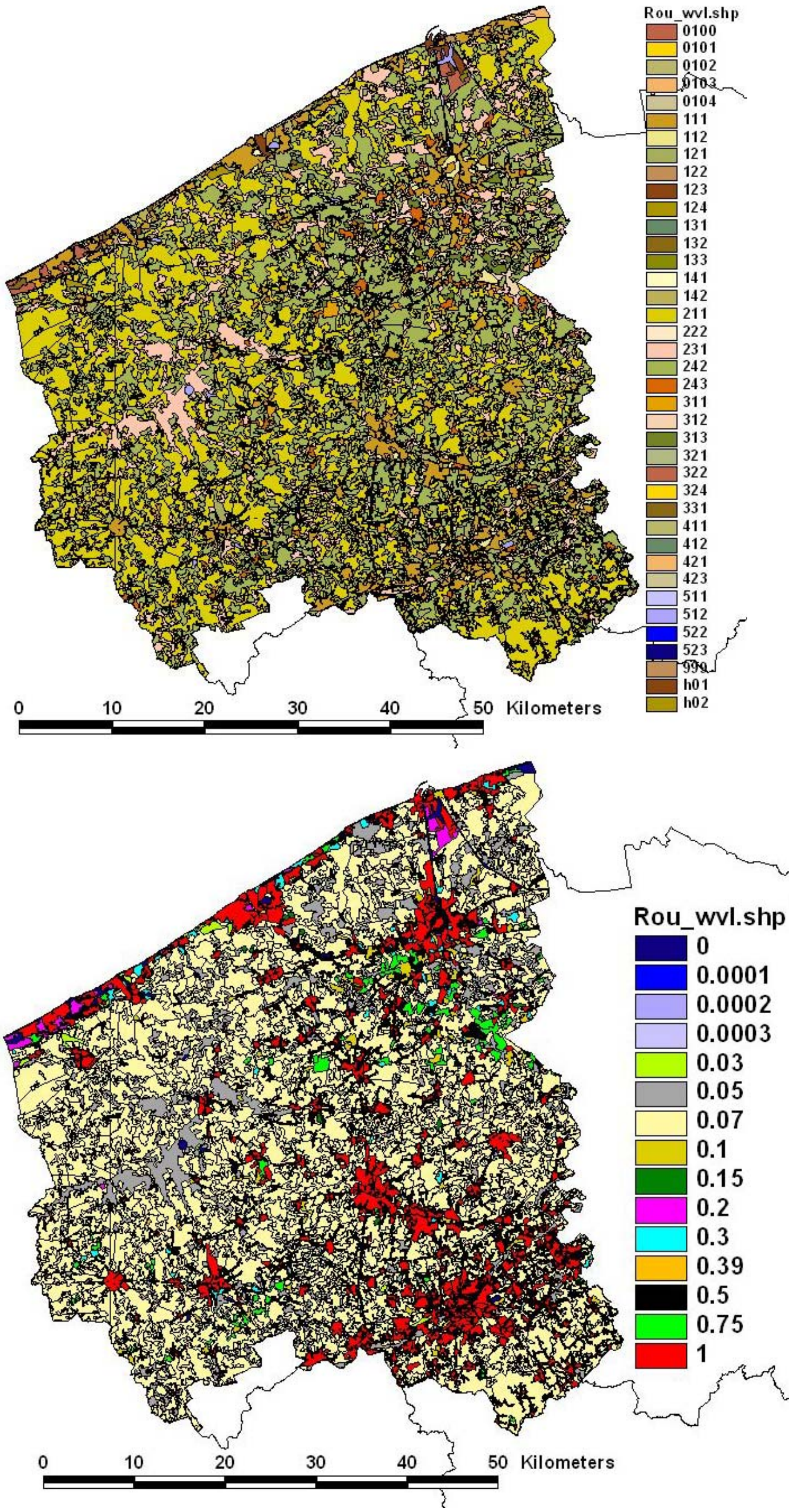


Figure 11 Resulting roughness maps the province "West-Vlaanderen". (a) classification according to code (b) classification according to roughness length

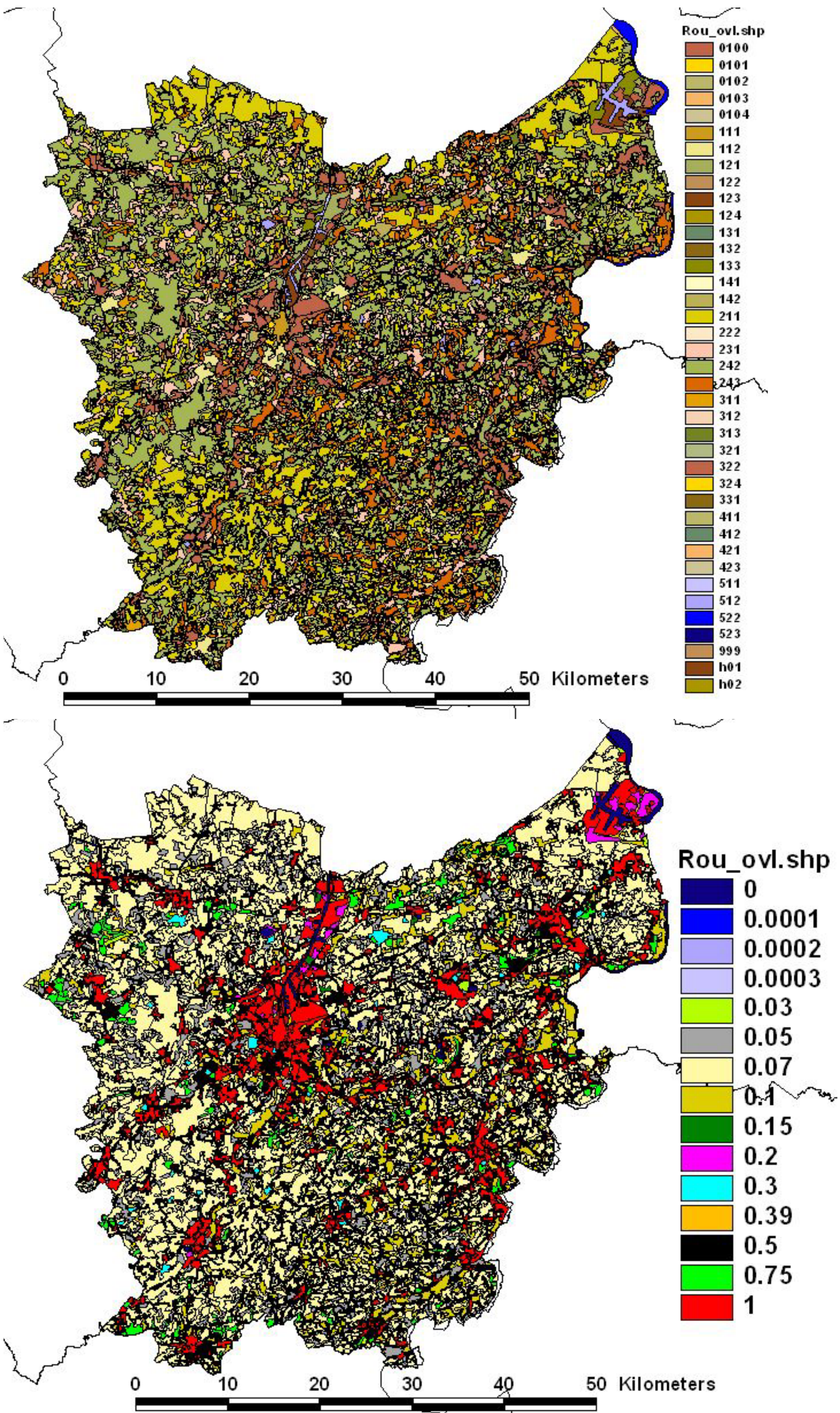


Figure 12 Resulting roughness maps the province "Oost-Vlaanderen". (a) classification according to code (b) classification according to roughness length

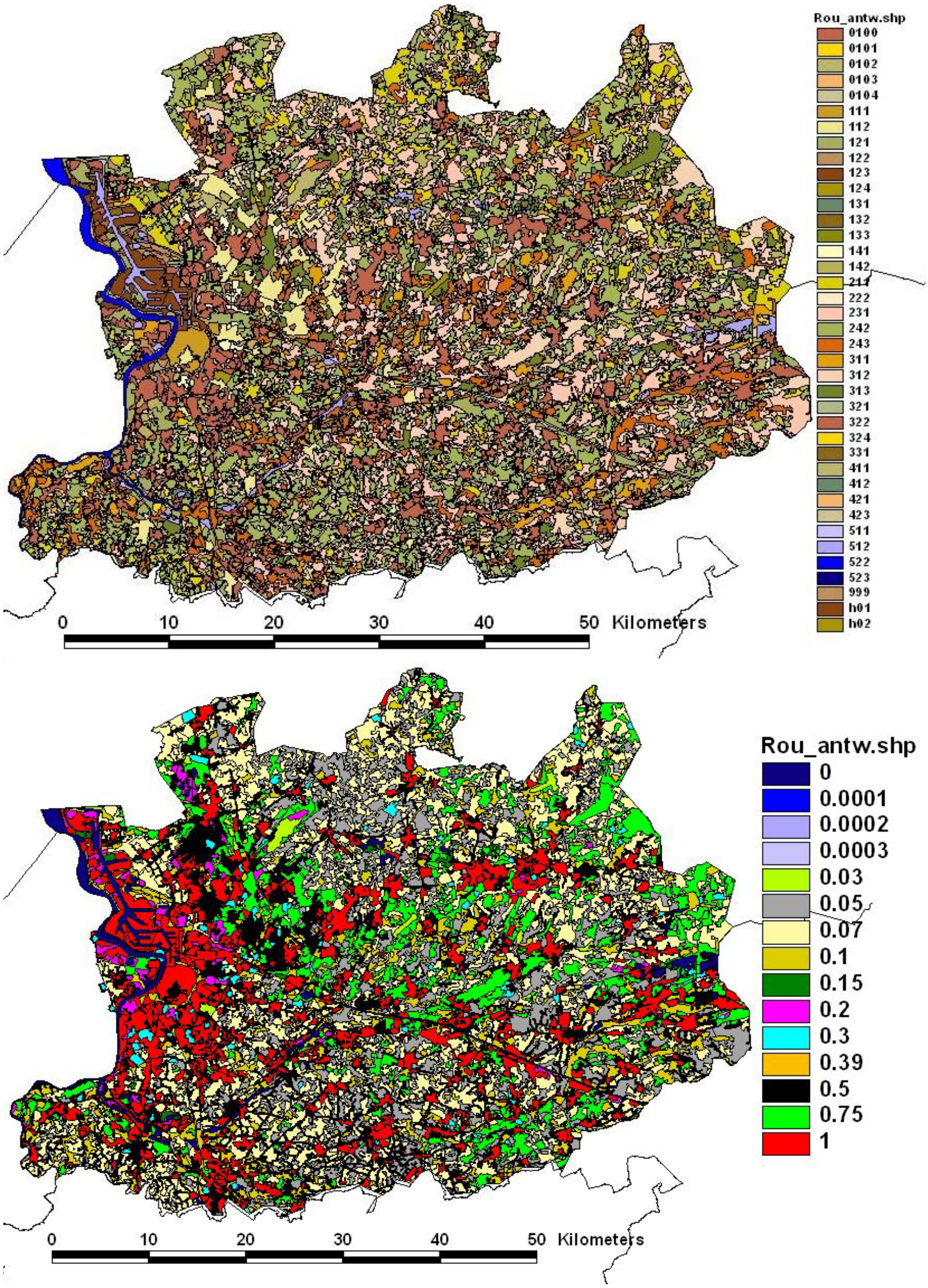
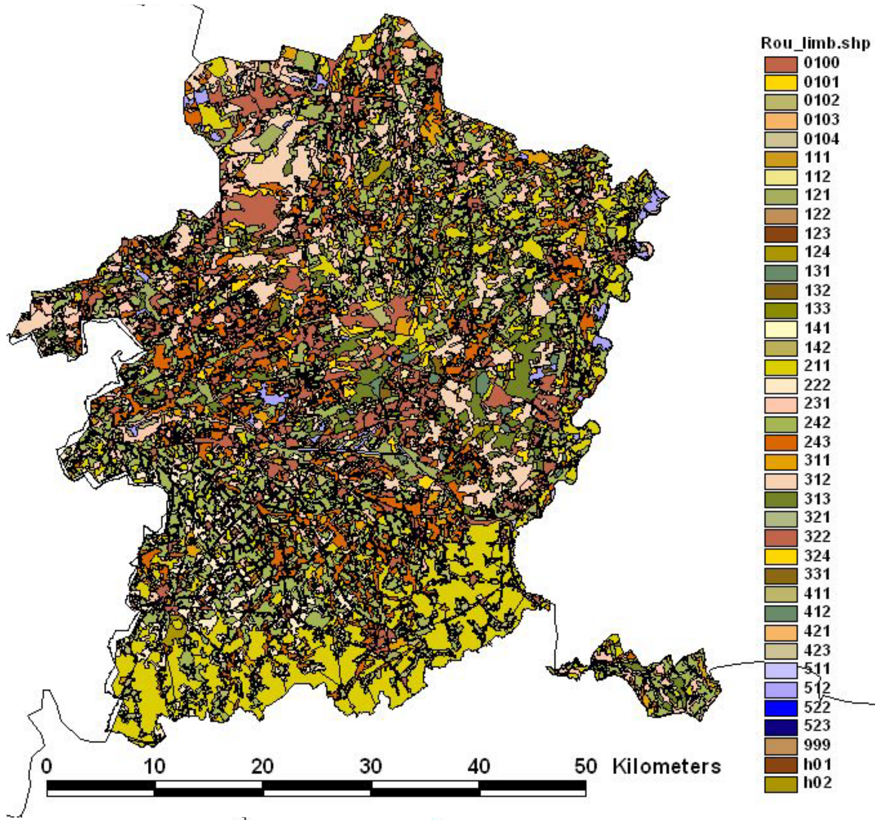


Figure 13 Resulting roughness maps the province "Antwerpen". (a) classification according to code (b) classification according to roughness length



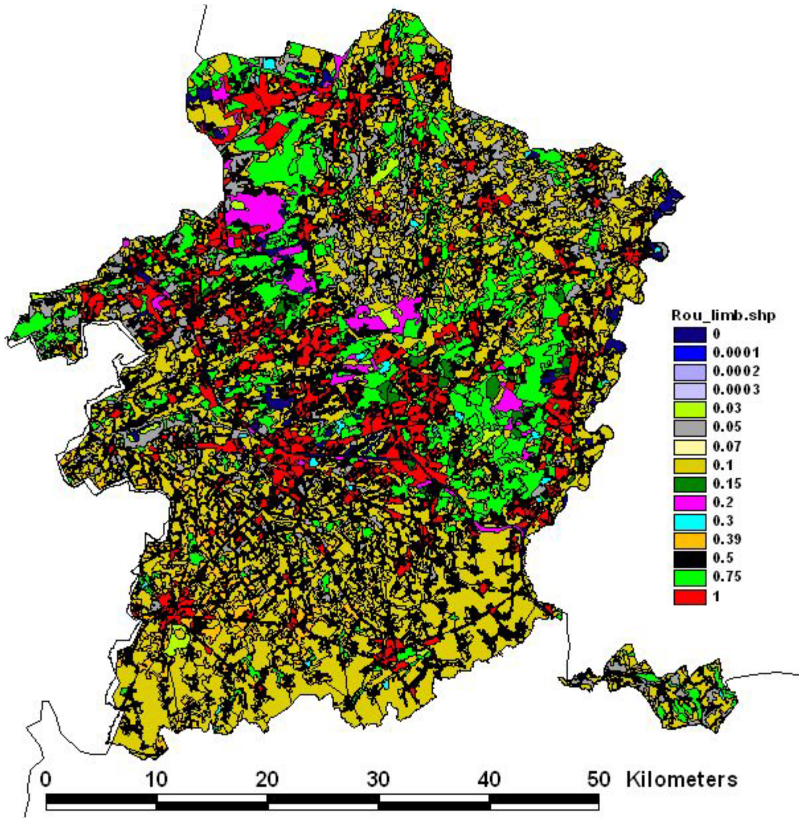


Figure 14 Resulting roughness maps the province "Limburg". (a) classification according to code (b) classification according to roughness length

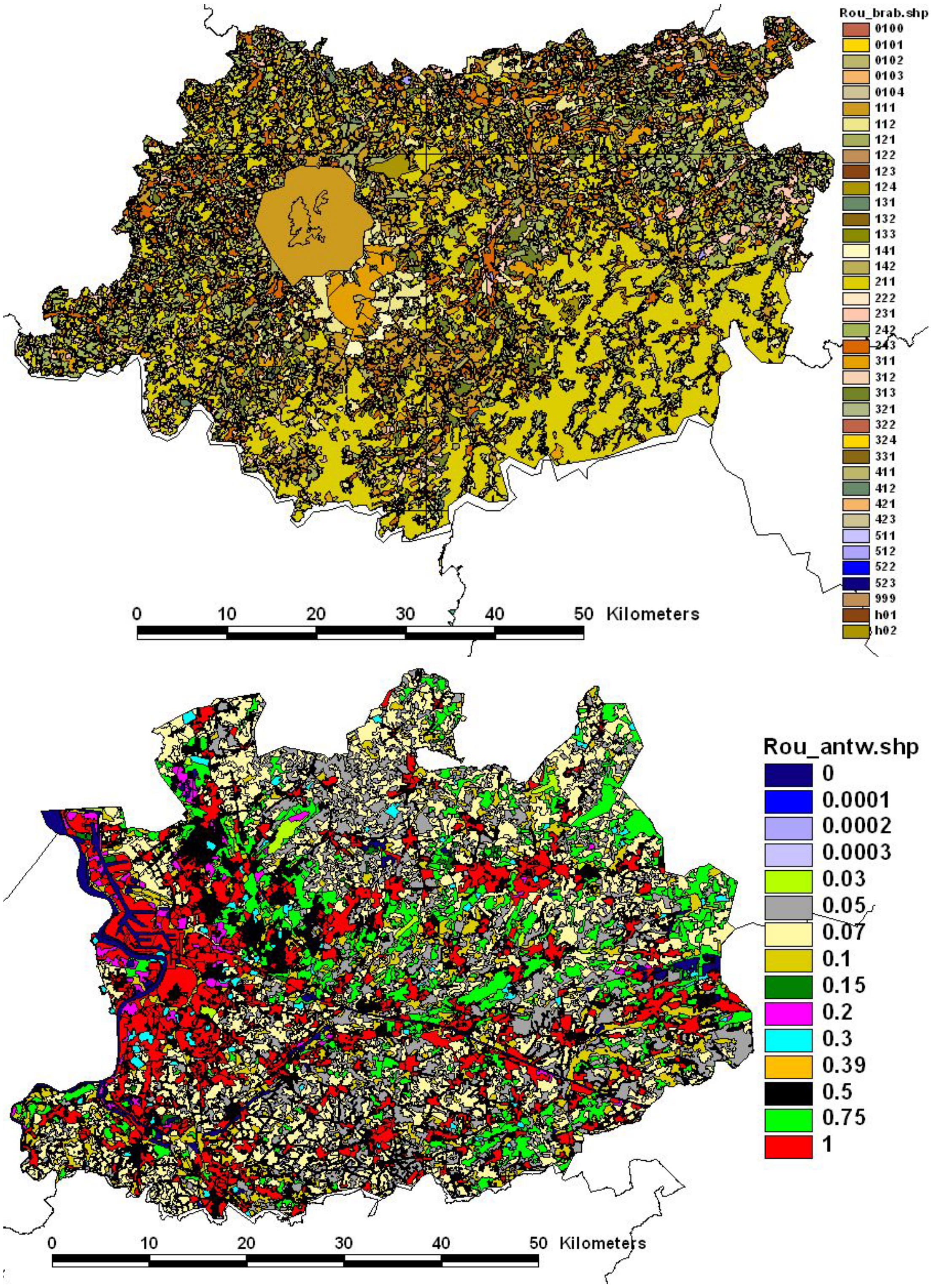


Figure 15 Resulting roughness maps the province "Brabant". (a) classification according to code (b) classification according to roughness length

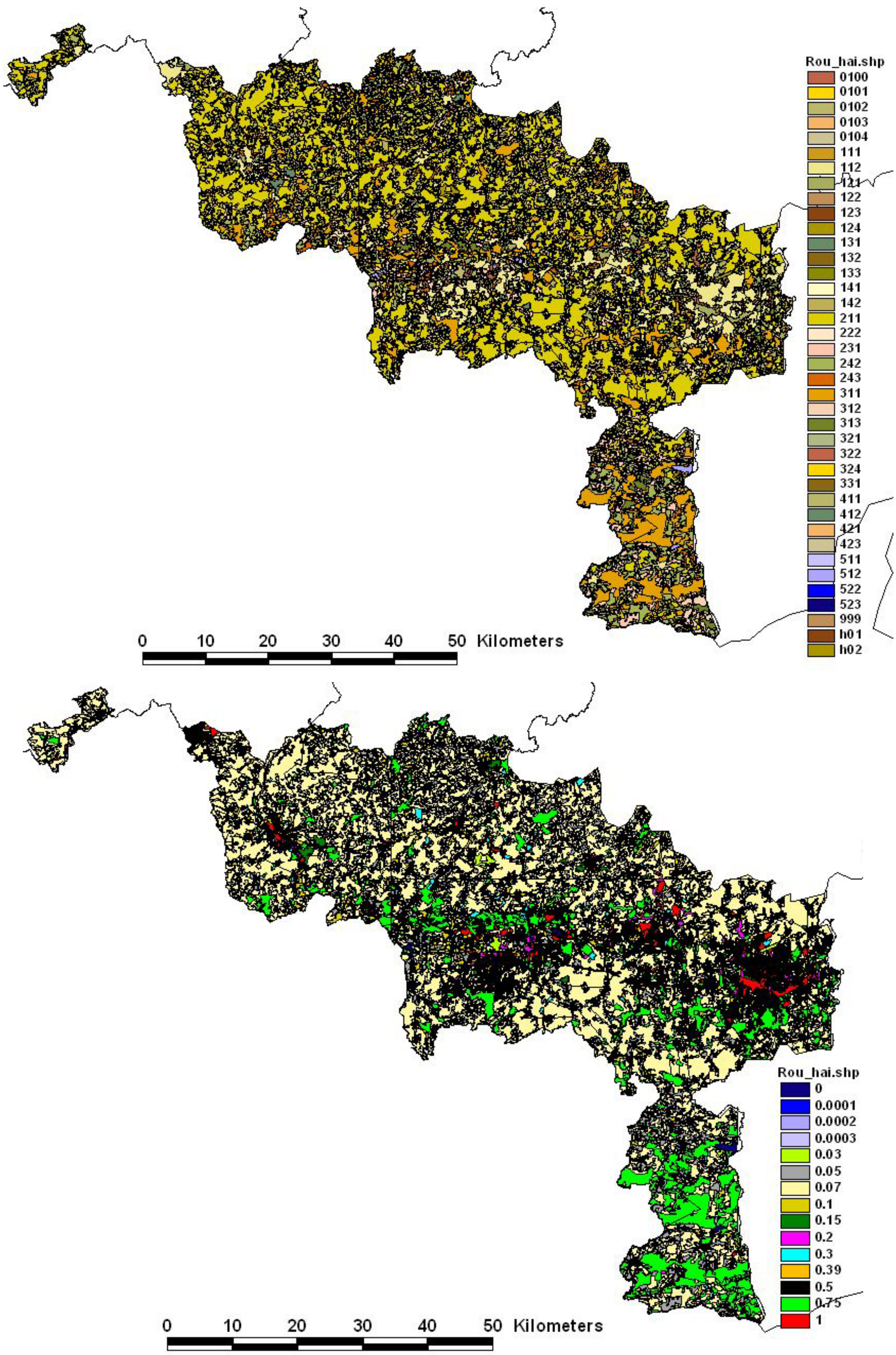


Figure 16 Resulting roughness maps the province "Hainaut". (a) classification according to code (b) classification according to roughness length

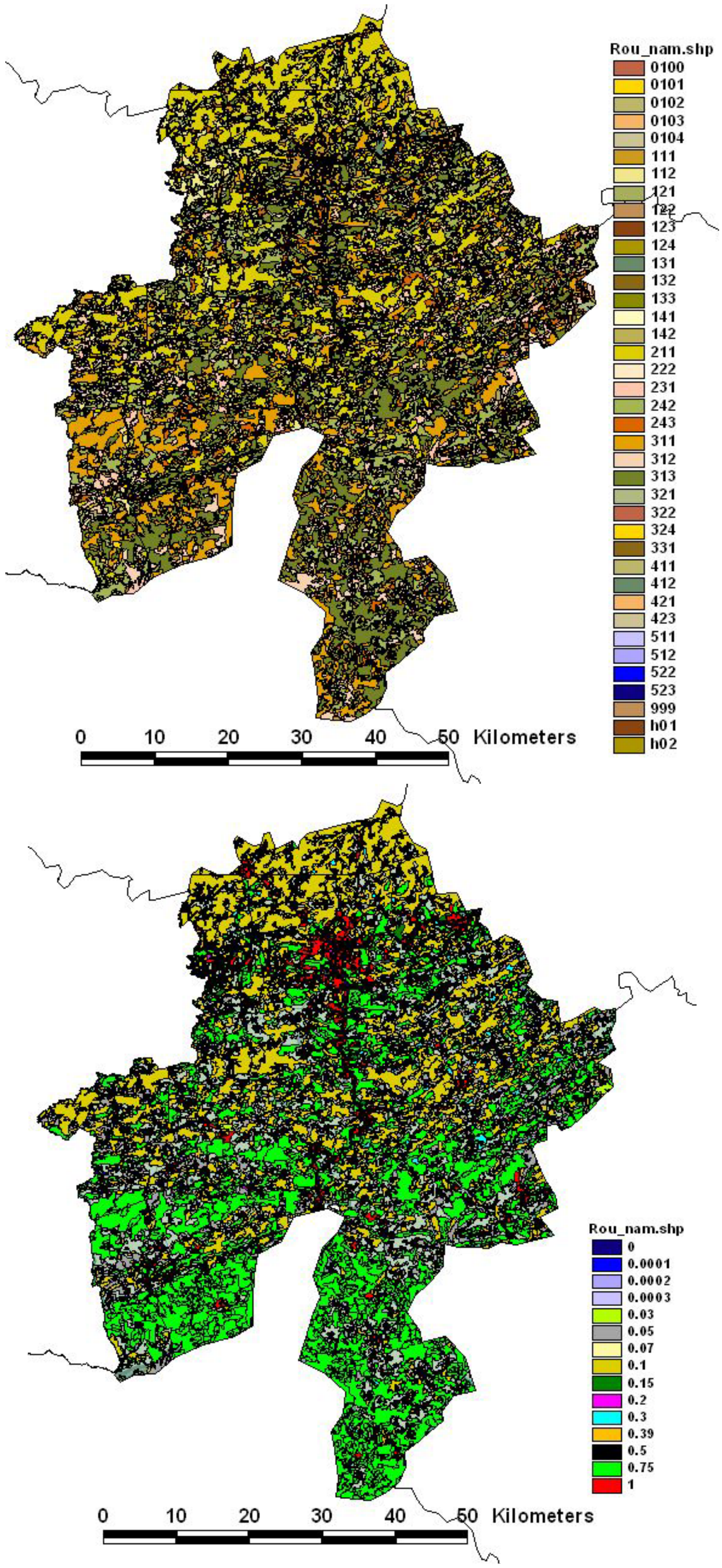


Figure 17 Resulting roughness maps the province "Namur". (a) classification according to code (b) classification according to roughness length

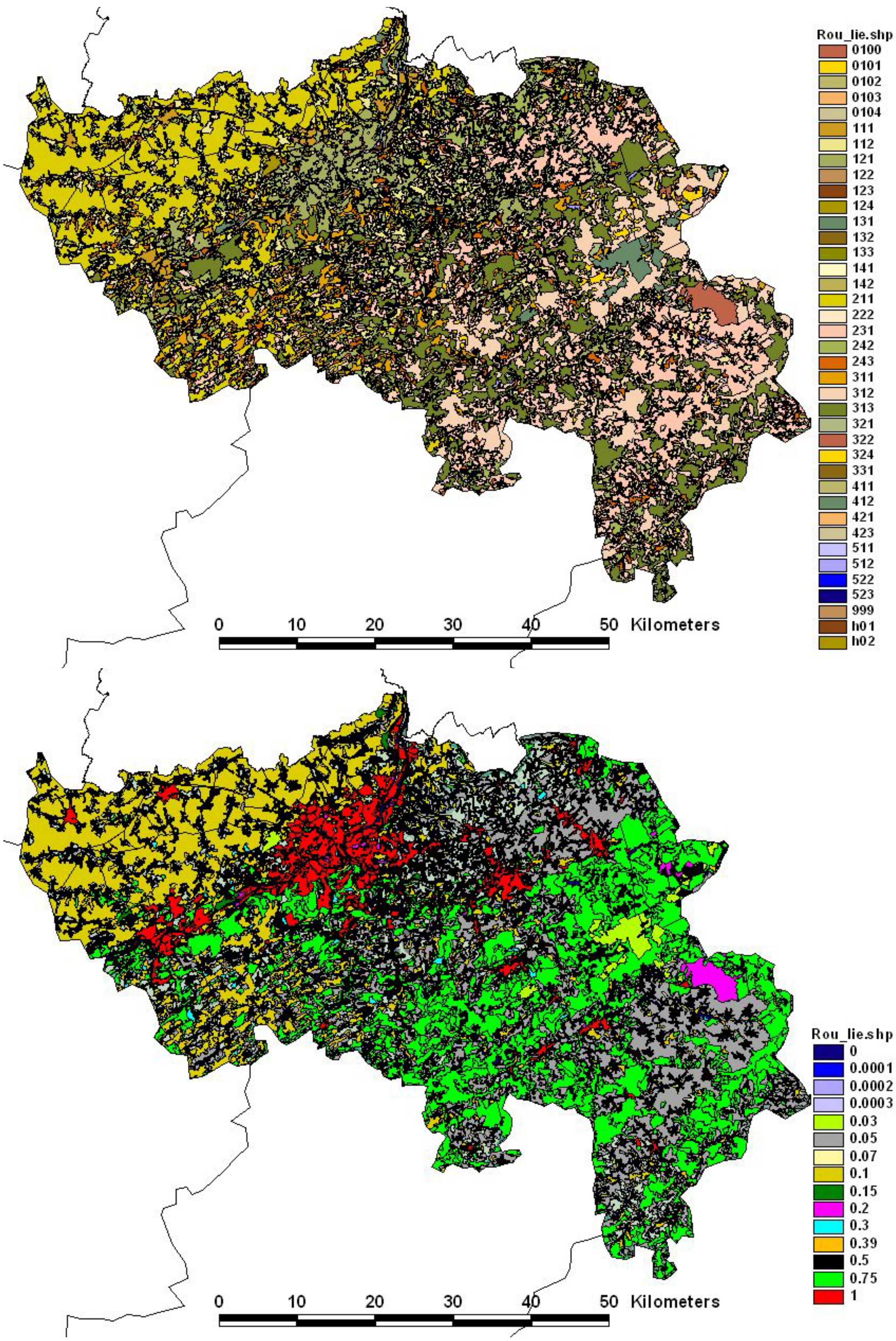


Figure 18 Resulting roughness maps the province "Liège". (a) classification according to code (b) classification according to roughness length

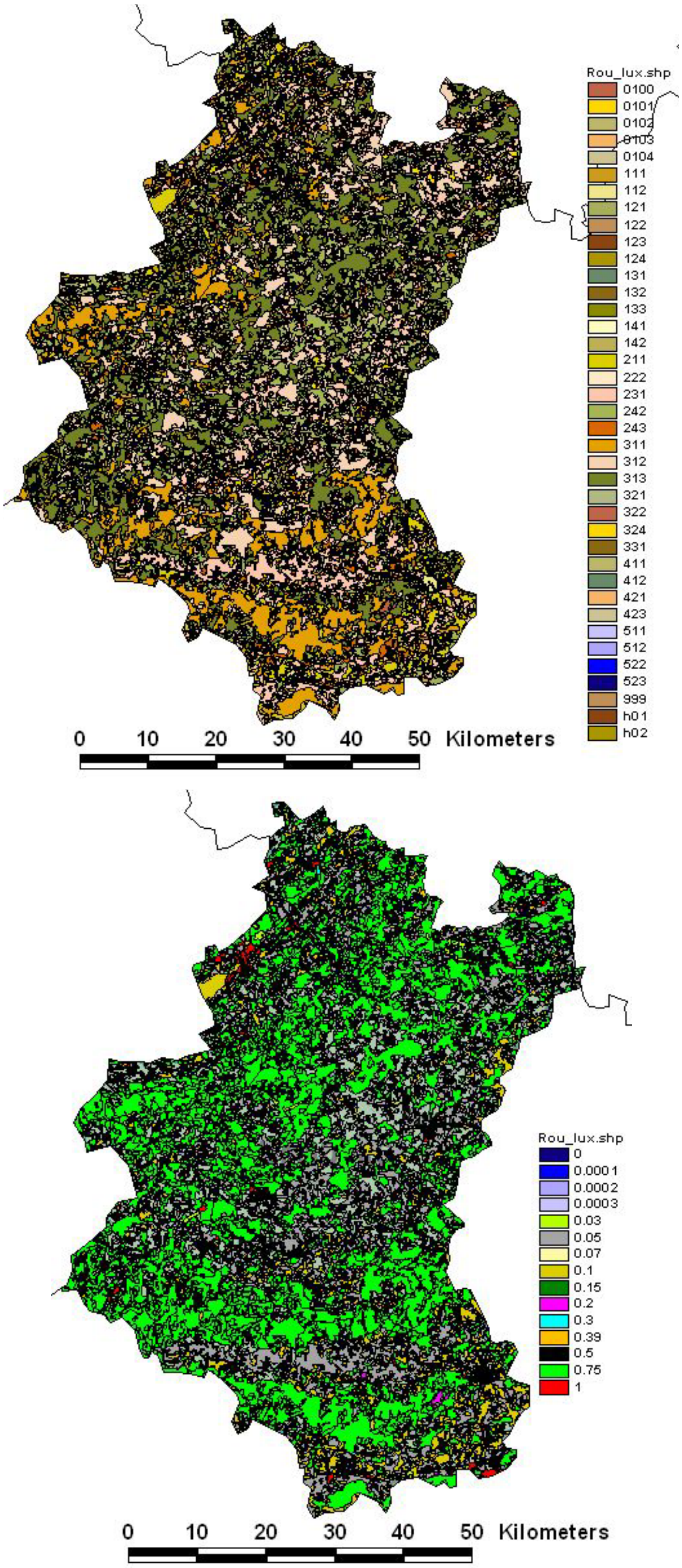


Figure 19 Resulting roughness maps the province "Luxembourg". (a) classification according to code (b) classification according to roughness length

The distribution of the roughness lengths (frequency of occurrence) per province is summarised in the table below.

Table 9 Frequency of occurrence of the roughness lengths per province

Roughness length [m]	West-Vlaanderen	Oost-Vlaanderen	Antwerpen	Limburg	Brabant	Hainaut	Namur	Liège	Luxembourg
0.0001	0.1%	0.3%	0.5%	0.5%	0.3%	0.5%	0.1%	0.1%	0.1%
0.0002	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.0003	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
0.0300	0.2%	0.1%	0.2%	0.3%	0.1%	0.4%	0.2%	0.3%	0.2%
0.0500	6.1%	4.3%	5.6%	3.5%	5.2%	16.2%	8.5%	7.4%	22.8%
0.0700	37.4%	16.6%	16.1%	0.0%	0.0%	34.5%	0.0%	0.0%	0.0%
0.1000	1.4%	3.7%	6.2%	18.3%	26.1%	6.7%	26.5%	17.6%	27.0%
0.1500	0.1%	0.1%	0.3%	0.3%	0.2%	0.9%	0.5%	0.2%	0.2%
0.2000	0.3%	0.4%	1.0%	0.4%	0.3%	0.7%	0.1%	0.3%	0.1%
0.3000	0.7%	0.5%	0.9%	0.4%	1.0%	1.1%	0.8%	0.6%	0.4%
0.3900	0.0%	0.1%	0.1%	1.0%	0.9%	0.0%	0.0%	0.4%	0.0%
0.5000	44.3%	65.6%	57.1%	66.8%	54.6%	12.1%	44.8%	62.4%	36.3%
0.7500	1.0%	1.2%	4.0%	3.5%	3.5%	8.4%	13.2%	7.1%	11.9%
1.0000	8.1%	7.1%	7.9%	5.1%	7.8%	18.6%	5.2%	3.5%	1.0%

The roughness maps of the border areas in the neighbouring countries are made in the same way. These are not depicted here but they are given in the database.

2.1.7. Accuracy

In general, the borders between different terrain occupations are very precisely indicated in CLC. The principal difficulty is the assignment of one single roughness length per theme: on-site terrain observations indicate for example quite different roughness lengths for one single theme « arable land ». If for example a parcel is surrounded by bushes or hedges, the assigned value will underestimate the roughness length. Another example is the Corine Code 142 (Sport and leisure facilities) which could refer to a golf terrain as well as to a football stadium. Of course, the appropriate value of the roughness length is for both situation completely different.

It seems difficult anyway to reduce the uncertainty for a regional mapping. For a particular site to be evaluated, the on-site terrain observations could allow to refine the roughness values and to reduce the uncertainties due to modelling.

Fault ranges of a factor 2 on the roughness lengths changes the estimated wind speed with about 15%.

2.1.8. Database

The roughness maps of Belgium are available on the CD-ROM that is delivered together with this report.

The roughness maps are available in shapefile format (for GIS applications like ArcView, ArcInfo, MapInfo,…) and in ASCCI map format, compatible for the WAsP software.

The roughness maps are divided by province and by country. For the WAsP map files, all the roughness files are in the Belgium Lambert72 projection system. For the shapefile format, the roughness maps of each country is delivered in original projection systems:

- Belgium: Lambert72
- France: NTF Lambert II étendu
- Netherlands: RD system
- Germany: UTM Zone 32 projections

For Grand Duché Luxembourg, the roughness mapping was done manually based on topographic maps. These manual operation was performed directly in the Belgium Lambert72 projection system.

It is the responsibility of the end user to use the right projection system. The WAsP map files are all converted into the Belgium Lambert72 projection system because WAsP can not mix up different projection systems in one energy yield calculation.

2.1.9. Addendum : WAsP terrain map file (*.map)

Data are stored in an ASCII (text) file with the default file name extension 'map'. The map-file can be established by digitisation of lines from a map sheet or may be prepared by reformatting existing digital map information.

The general format of the file is shown below. Numbers in the same line of the file must be separated by blank space(s) or a comma.

Line	Contents
1	Text string identifying the terrain map: + ...
2	Fixed point #1 in user and metric [m] coordinates: X_1(user) Y_1(user) X_1(metric) Y_1(metric)
3	Fixed point #2 in user and metric [m] coordinates: X_2(user) Y_2(user) X_2(metric) Y_2(metric)
4	Scaling factor and offset for height scale (Z): Z_{metric} = {scaling factor}(Z_{user} + {offset})
5a	Height contour: elevation (Z) and number of points (n) in line: Z n
5b	Roughness change line: roughness lengths to the left (z_{0l}) and right (z_{0r}) side of the line, respectively, and number of points: z_{0l} z_{0r} n
5c	Roughness and contour line: roughness lengths to the left and right of the line, respectively, elevation and number of points: z_{0l} z_{0r} Z n
6–	Cartesian coordinates (X, Y) of line described in 5a, 5b or 5c: X_1 Y_1 [... X_n Y_n] X_{n+1} Y_{n+1} ... where [] embrace optional numbers and n is > 0

Figure 20 General format of the WAsP map file

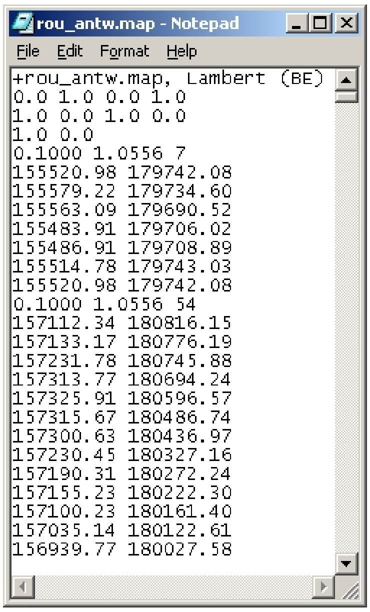
The pattern given in line 5 (a, b or c) and 6 is repeated as many times as there are height contours/roughness change lines in the file. Each line in the map must be described by a minimum of two points.

The '+'-sign in column one of the first line of the file indicates that co-ordinates in the file are Cartesian. Earlier versions of WAsP (4.X and 5.X) can also read maps given in polar co-ordinates.

Line 2 and 3 specify a simple co-ordinate transformation from user co-ordinates (the numbers given in the file, from line 6 and onwards) to metric co-ordinates. If the user co-ordinates given in the file are metric and absolute (like the UTM system provided on many maps), line 2-3 may be replaced by a single line containing non-numeric input.

Example

The following window shows part of a roughness map file, opened in the Notepad text editor. In this case there is no transformation of co-ordinates (line 2-3) or the elevation values (line 4): the co-ordinates and elevations are given in [m].




```
+rou_antw.map, Lambert (BE)
0.0 1.0 0.0 1.0
1.0 0.0 1.0 0.0
1.0 0.0
0.1000 1.0556 7
155520.98 179742.08
155579.22 179734.60
155563.09 179690.52
155483.91 179706.02
155486.91 179708.89
155514.78 179743.03
155520.98 179742.08
0.1000 1.0556 54
157112.34 180816.15
157133.17 180776.19
157231.78 180745.88
157313.77 180694.24
157325.91 180596.57
157315.67 180486.74
157300.63 180436.97
157230.45 180327.16
157190.31 180272.24
157155.23 180222.30
157100.23 180161.40
157035.14 180122.61
156939.77 180027.58
```

Figure 21 Example of a WAsP roughness map file

2.2. Task 2b: Orography

2.2.1. Introduction

Orographic elements such as hills, cliffs, escarpments and ridges exert an important influence on the wind. Near the summit or crest of these features the wind will accelerate while near the foot and in valleys it will decelerate.

2.2.2. Input data

Height contours or lines with constant elevation for Belgium are available on the topographic maps. However, these topographic maps are in raster format and their information can not be extracted for detailed analysis. Therefore, digital orographic data of Belgium has been consulted. Different sources have been found and used:

- DTED data form NGI
- DataForWind
- SRTM
- GTOPO30
- SRTM30

2.2.2.1. DTED –Lambert data form NGI

The digital terrain model from NGI (National Geographic Insitutue of Belgium) has been created by scanning, vectorisation and identification of the height contour lines on the topographic maps on the scale of 1:50 000. The height value is determined in reference to the Belgian zero level.

The first version of this digital terrain model was referenced in the WGS72 projection system (DTED-WGS). The interval between the grid points was 2 seconds in the longitude direction and 1 second in the latitude direction. The second version of this digital terraiin model is referenced in the Lambert72 projection system (DTED-Lambert). This second version is based on the origianl DTED-WGS version. The intervals between the grid points are the same. The result is an irregular distribution of the grid points.

The DTED-Lambert model has a vertical accuracy of 3.8 m in lower Belgium, 7.8 m in mid Belgium and 10.2 m in high Belgium. The reliability of the data is 90%.

This digital terrain data is available in ASCII format and contains the Lambert East, the Lambert North co-ordinate and the elevation of the grid point in reference to the Belgium zero-level. Each DTED file covers an area of 15 min by 15 min.

An example of such a DTED-Lambert is given below for the (complex) site of Amay, which will be described in detail later (Task 3). The selected DTED-Lambert file is 515e5030.dbf.

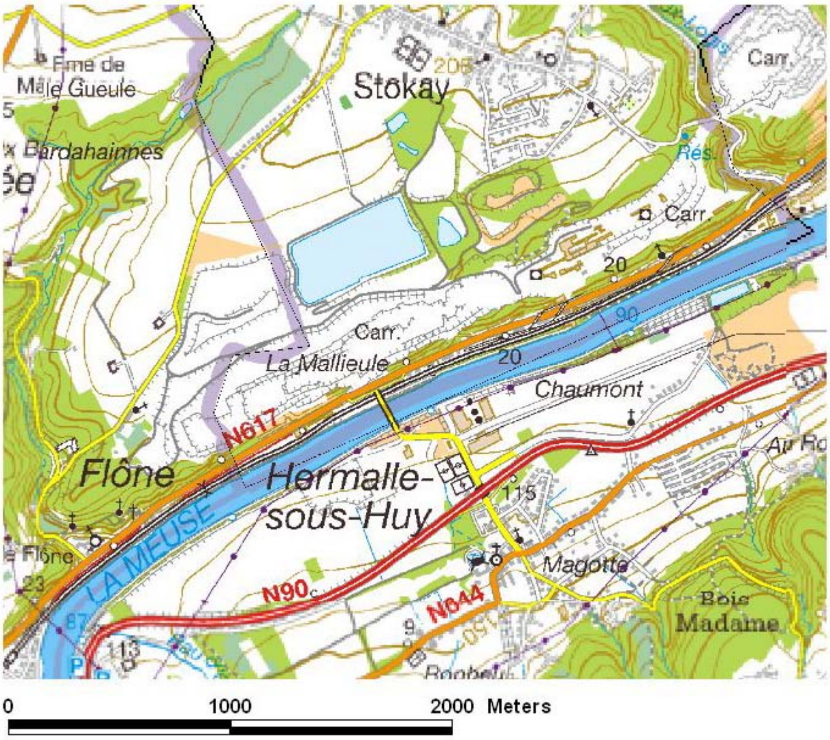


Figure 22 Site of Amay

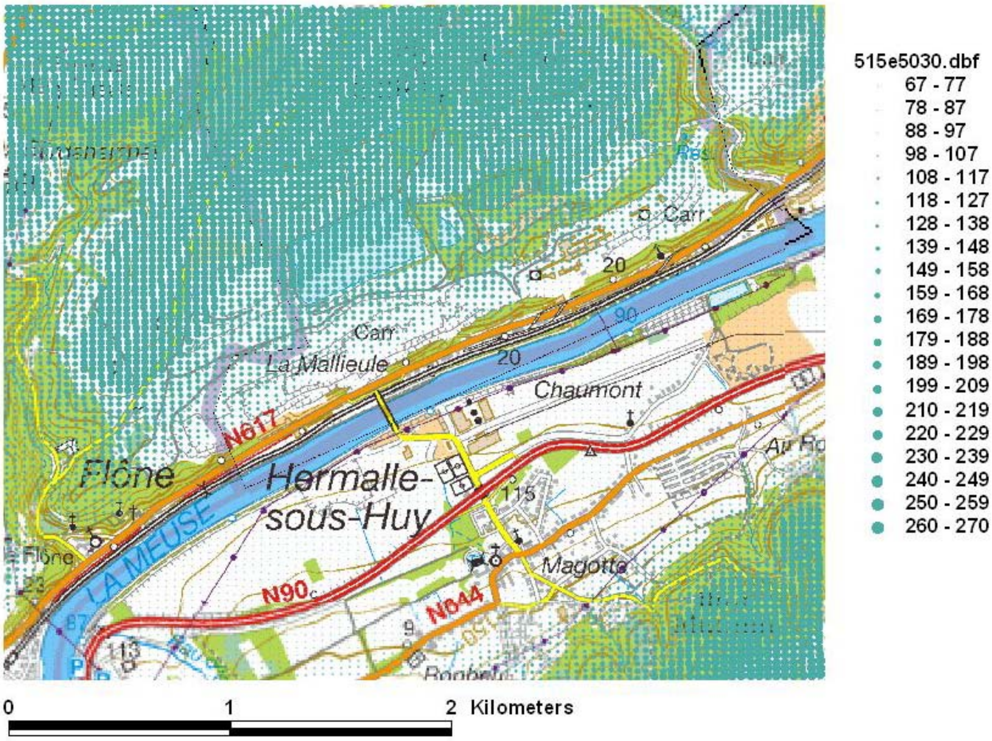


Figure 23 Site of Amay with the DTED-Lambert grid points

The grid points are marked as graduated symbols on the figure above. The size of the grid points reveals the height. The distance between the grid points equals 39 m in the longitude direction and 30 m in the latitude direction.

After conversion to continuous contour lines by means of the ArcView Spatial Analyst tool, the original height contour lines on the topographic maps are recreated.

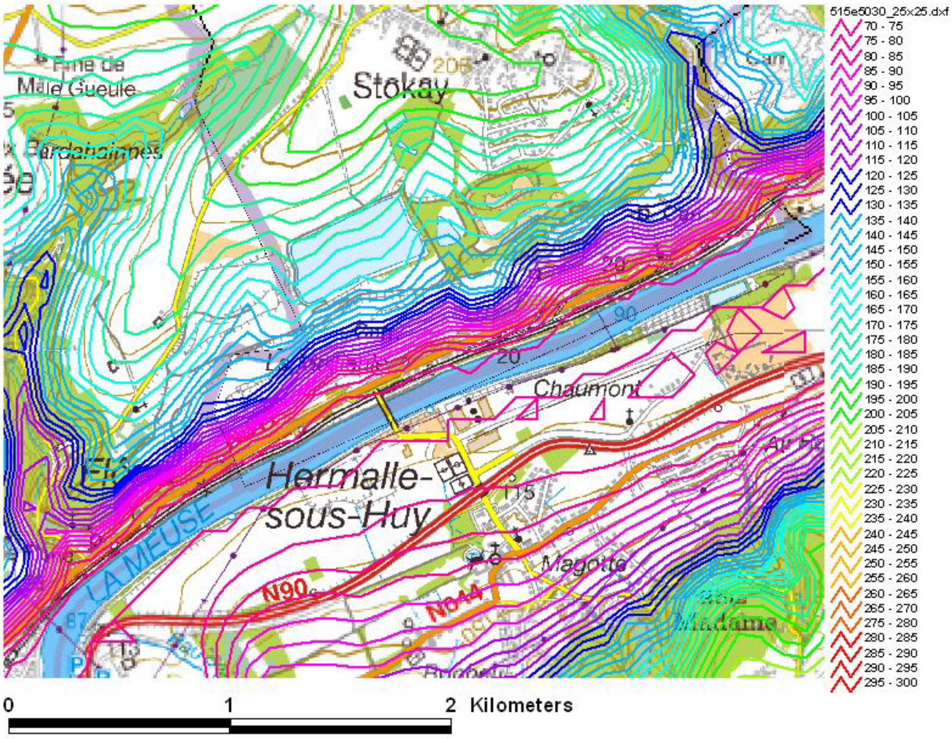


Figure 24 Site of Amay with the continuous height contour lines based on the DTED-Lambert data

The methodology and accuracy of this conversion will be discussed in the following chapters.

2.2.2.2. DataForWind: Services for Professionnals in Wind Energy

DataForWind are proposing to professionals of the wind industry an easy access to relevant geo-information for on-shore wind farms. In the website http://www.dataforwind.com/, you will access to relief information available world-wide.

DataForWind is part of the EO-Windfarm project aiming at proposing in a One-Stop-Shop information for wind farm management and development.

The Orography Service allows an easy download of orographic information. The orography information is available for the entire landmass of the Earth between 60° N and 57° S with a statial resolution of 3 arc sec (± 90 m). The orography information can be extracted either in geographic co-ordinates and in UTM co-ordinates.

To download the data, you simple enter the co-ordinates of the border of the area and select to download the ASCII XYZ format.

The same example for the site of Amay is given in the figures below.

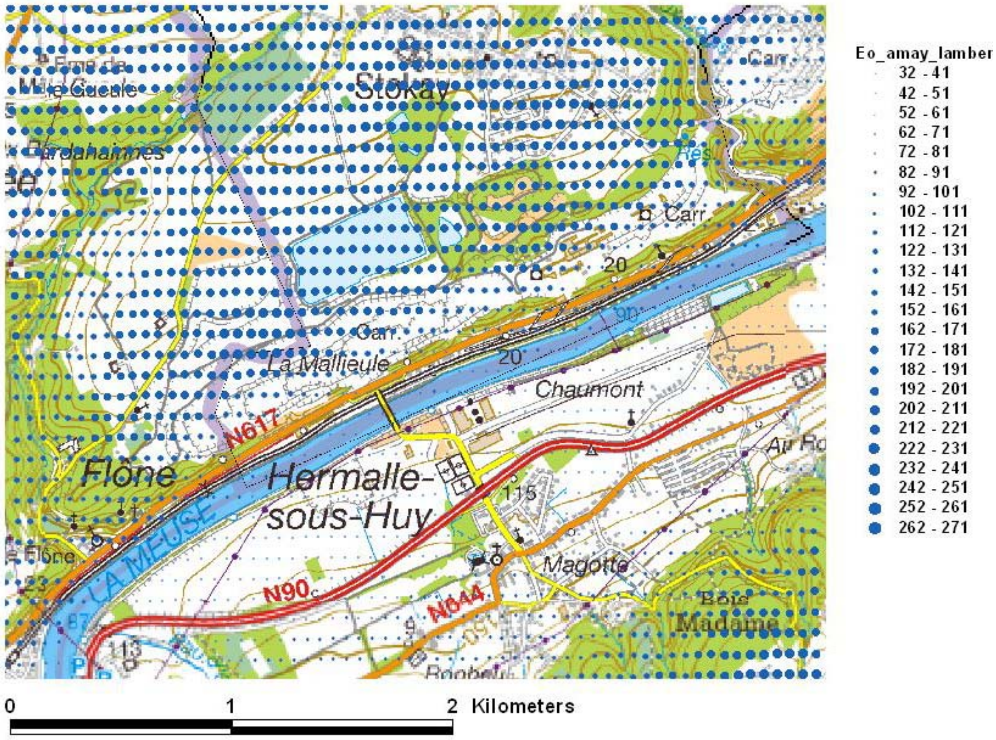


Figure 25 Site of Amay with the DataForWind grid points

The distance between the grid points equals 60 m in the longitude direction and 95 m in the latitude direction.

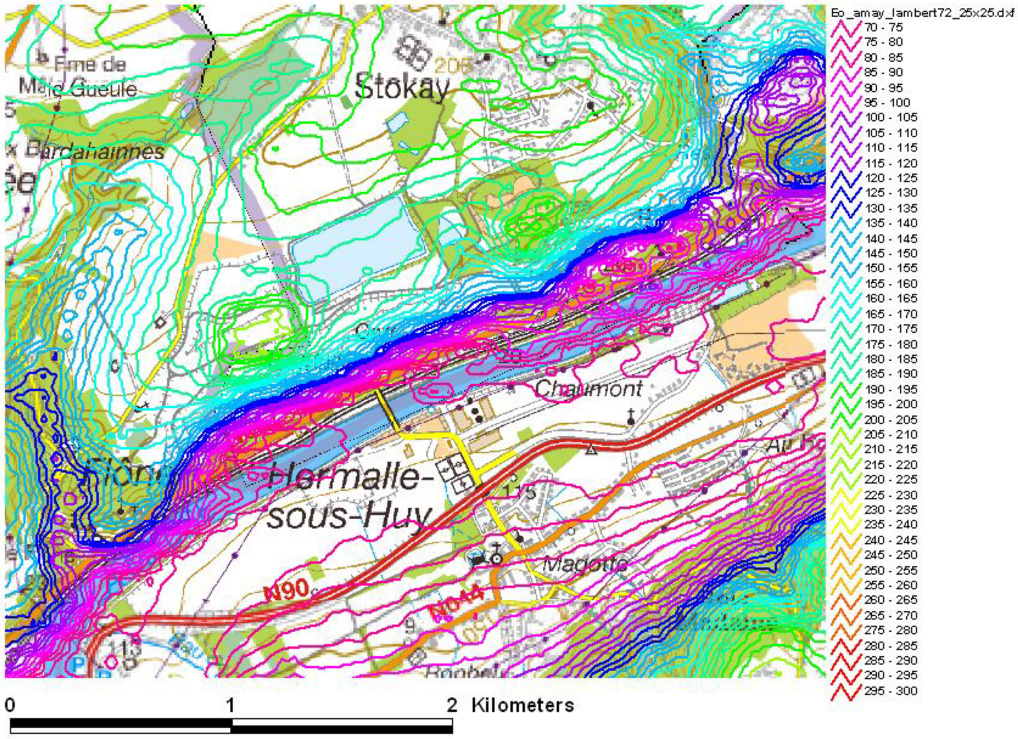


Figure 26 Site of Amay with the continuous height contour lines based on the DataForWind grid

2.2.2.3. SRTM

The Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale to generate a high-resolution digital topographic database of the Earth. SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000.

SRTM is an international project spearheaded by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and Space Administration (NASA).

The elevation data is sampled at 3 arc-seconds, which is 1/1200th of a degree of latitude and longitude, or about 90 meters.

The SRTM data is available at the US Geological Survey's EROS Data Center for download via File Transfer Protocol (ftp). These data are intended for use with a Geographic Information System (GIS) or other special application software, and are not directly viewable in a browser. Also, users should be aware that the digital topographic data and images are unedited and are intended for scientific use and evaluation. They are outputs directly from the SRTM interferometric radar processor and, for example, may contain numerous voids (areas without data), water bodies that may not appear flat, and coastlines that may be ill-defined. The data are available from the USGS server at ftp://e0mss21u.ecs.nasa.gov/srtm/. Data are also available through the USGS seamless server at http://seamless.usgs.gov/.

The USGS distributes global SRTM elevation data in 1º X 1º tiles. The filename is based on the co-ordinates of the lower left corner of the tile.

So far, no reliable height contour lines could be extracted from the SRTM data set.

2.2.2.4. GTOPO30

GTOPO30 is a global digital elevation model (DEM) with a horizontal grid spacing of 30 arc seconds (approximately 1 kilometer). GTOPO30 was derived from several raster and vector sources of topographic information.

GTOPO30, completed in late 1996, was developed over a three year period through a collaborative effort led by staff at the U.S. Geological Survey's EROS Data Center (EDC). The following organizations participated by contributing funding or source data: the National Aeronautics and Space Administration (NASA), the United Nations Environment Programme/Global Resource Information Database (UNEP/GRID), the U.S. Agency for International Development (USAID), the Instituto Nacional de Estadistica Geografica e Informatica (INEGI) of Mexico, the Geographical Survey Institute (GSI) of Japan, Manaaki Whenua Landcare Research of New Zealand, and the Scientific Committee on Antarctic Research (SCAR).

The distance between the grid points equals ca. 590 m in the longitude direction and ca. 925 m in the latitude direction.

The following picture shows the (withdrawn) grid points of the GTOPO30 data set on the map of Amay. Only 11 points can be found. There are numerous voids in the data set.

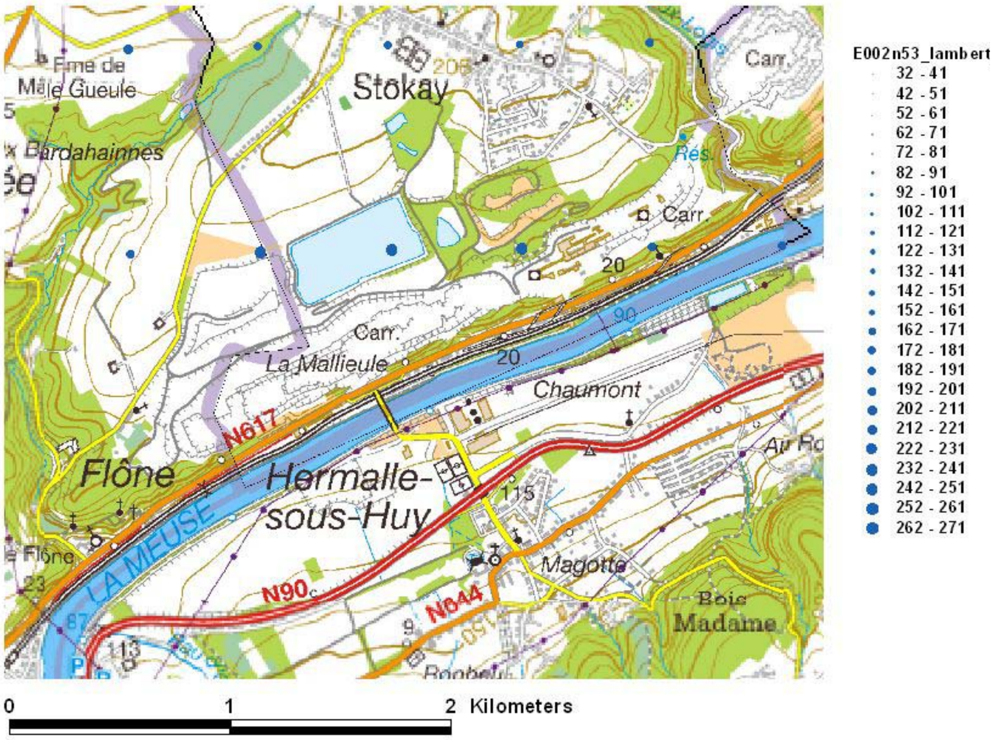


Figure 27 Site of Amay with the GTOPO30 grid points

2.2.2.5. SRTM30

Recently, an updated version of the USGS GTOPO30 has been released, with SRTM data used in place of the original data, when possible. It has the same horizontal grid spacing of 30 arc-seconds (approximately 1 kilometer). While SRTM30 has the same resolution as GTOPO30, it can be considered a more accurate global digital data set compared to GTOPO30 because of its seamless and uniform representation, due to the fact that it was created over a short period of time from a single source rather than from the numerous sources spanning many decades that went into creating the GTOPO30 data set.

This SRTM30 data can be downloaded from ftp://e0srp01u.ecs.nasa.gov/srtm/version2/

The following picture shows the (withdrawn) grid points of the SRTM30 data set on the map of Amay. 18 grid points can be found.

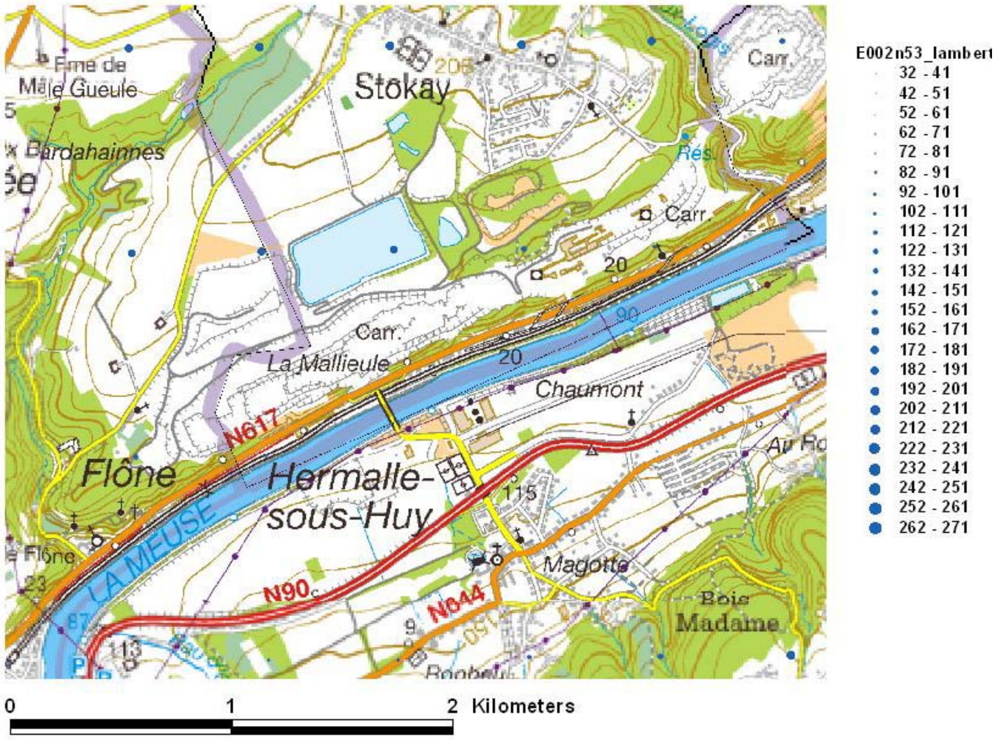


Figure 28 Site of Amay with the SRTM30 grid points

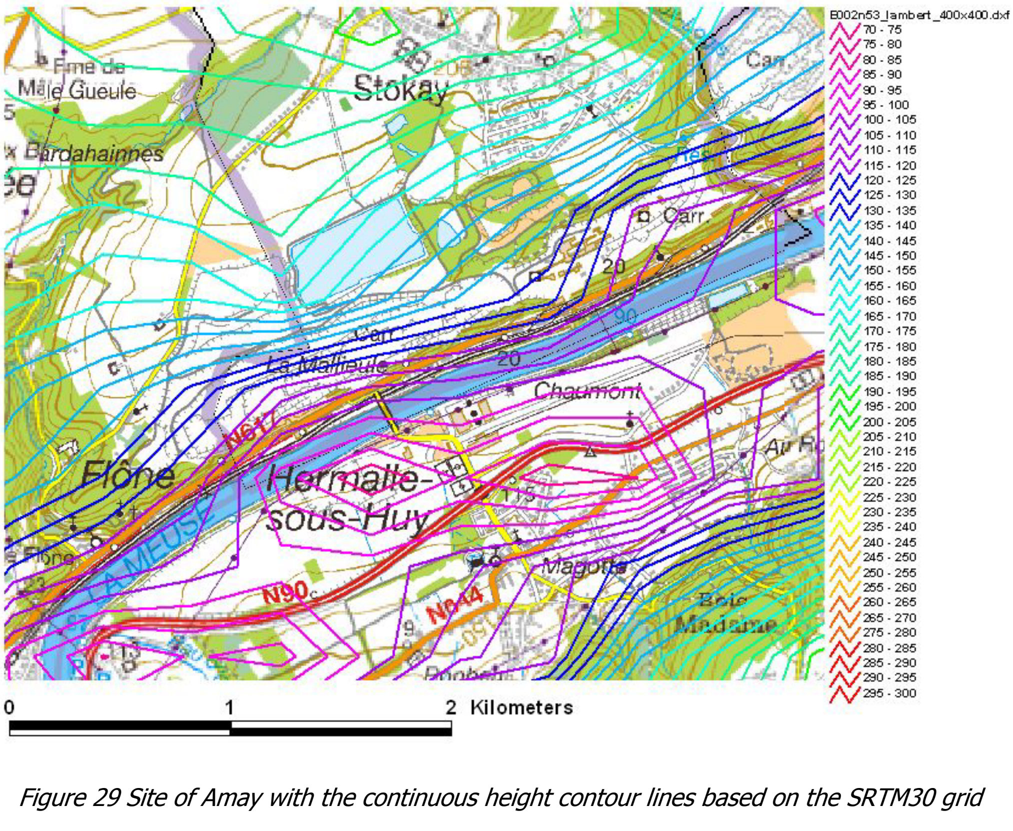


Figure 29 Site of Amay with the continuous height contour lines based on the SRTM30 grid

2.2.3. Data formats

Orographic data sets as mentioned in the previous chapter are available in different formats and in different projection systems.

Table 10 Formats and projection systems of the different used data sets

data set	Geographic	Lambert72	UTM WGS84	Format	Hor res [m] (lon x lat)
DTED		X		ASCII	±39x30
DataForWind	X		X	ASCII	±60x95
SRTM	X			DEM	±90x90
GTOPO30	X			DEM	±590x925
SRTM30	X			DEM	±590x925

The meso- and micro scale models investigated in this project, make use of these datasets. Some models (like WAsP) require a special format for the orographic data, similar to the WAsP roughness maps. The other models use orographic input data in their gird format.

It is not the intention of this research project to provide for each simulation model all input data in their appropriate formats. Reliable orographic data must have been defined on a very dense net, such as the DTED and DataForWind. Consequently, it is almost impossible within the framework of this project to provide for each model all orographical data confirm their appropriate format. For this reason, the CD-ROM delivered with this report, contains only the orographic data sets in their original format.

2.2.4. Accuracy

In order to obtain an idea of the accuracy of the different data sets, a test case has been defined to validate these data sets against the contour map of the site of Amay, along the river Meuse. The site of Amay is an excavation site with the characteristics of a complex terrain. The site has been measured and modelled in detail by the developer of the site. In this way, elevation data has been measured and analysed in AutoCad. This gives excellent opportunities to compare the different data sets of this project with the measured height contours.

The following AutoCad drawing shows the complex site of Amay with the height contours as red lines. Pictures of the site can be found under Task 3.

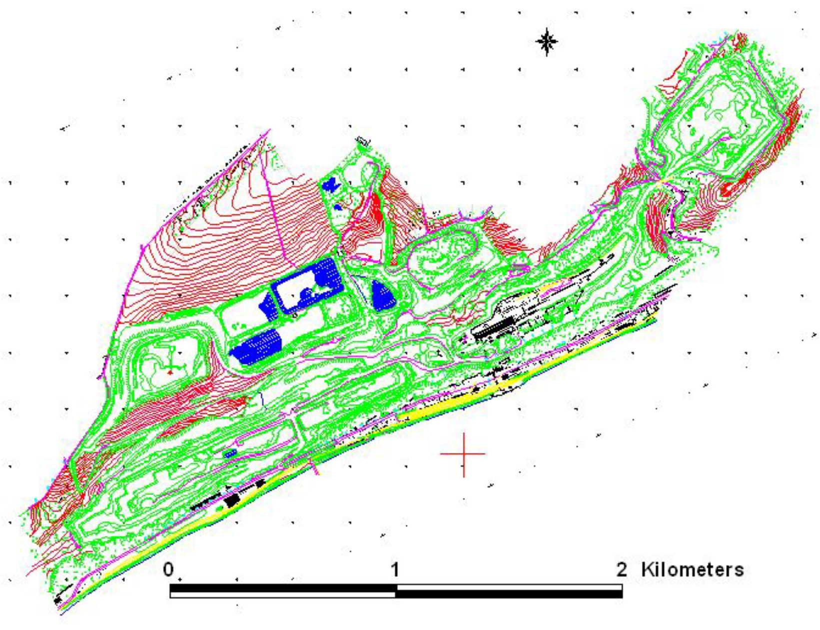


Figure 30 Site of Amay with measured elevation data and the height contour lines

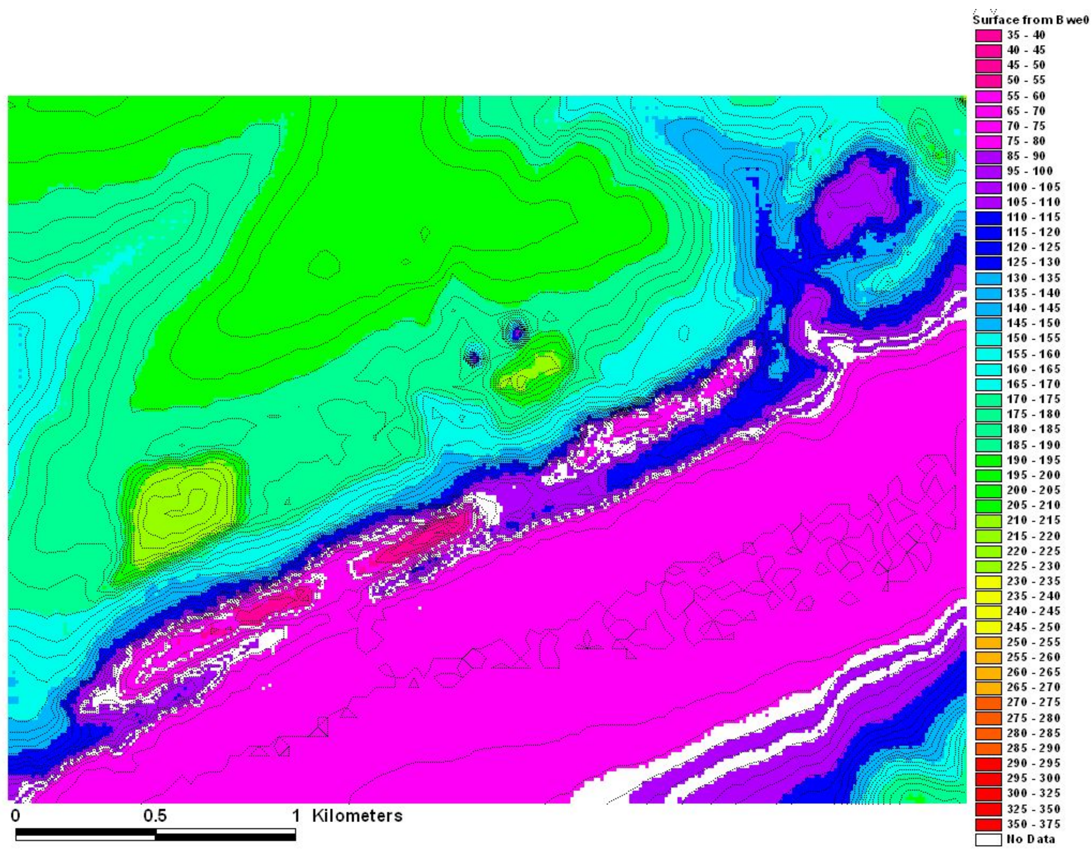


Figure 31 Derived elevation map for the site of Amay

For the DTED, DataForWind and SRTM30 data sets, the elevation value of the grid points in these data sets will be compared to the elevation data of the original grid points in the original AutoCad drawing in order to qualify the reliability of these data sets.

2.2.4.1. DTED-Lambert

For the DTED data sets, we can withdraw 2837 grid points that lay within the circumference of the excavation site of Amay. The elevation map derived from these grid points is also given below.

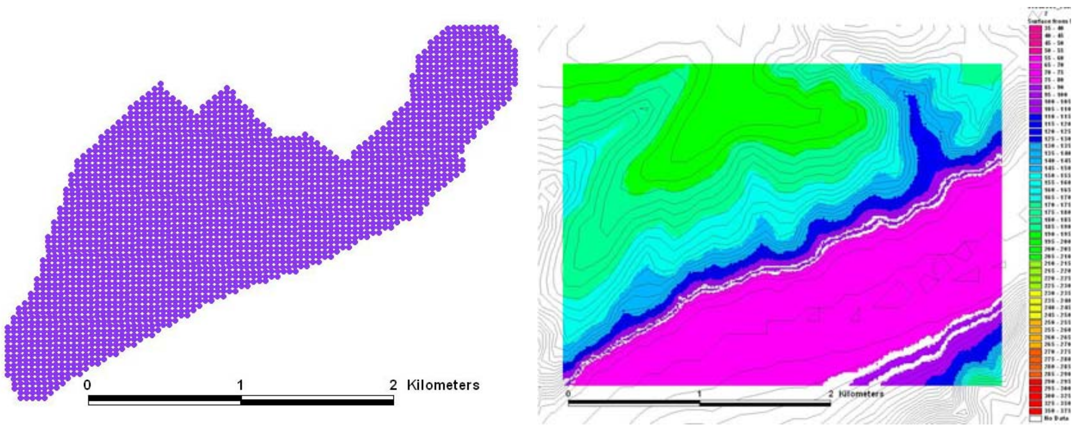


Figure 32 Withdrawn grid points of the DTED data set and the derived elevation map

The following table gives some statistics:

Table 11 Fault analysis between DTED data and the measured data set

	Difference in elevation [m]	Distance between grid points [m]
# Observations	2837	2837
Minimum	-86	0.33
Maximum	74.00	72.39
Average	-1.77	16.06
Standard deviation	25.16	10.50

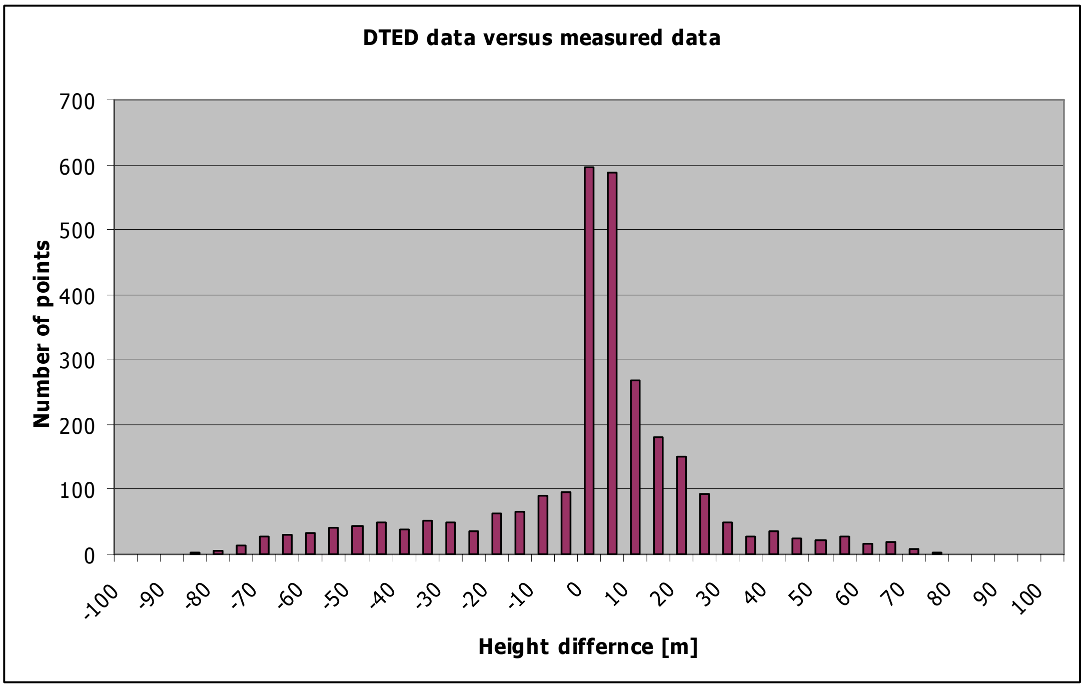


Figure 33 Comparison DTED data versus measured data

The main difference in elevation values are found in the local hills and valleys that are clearly viewed in

Figure 30 but are missing in Figure 33. Also the slope of the valley gives reason to important differences. The elevation difference map is show in the following figure.

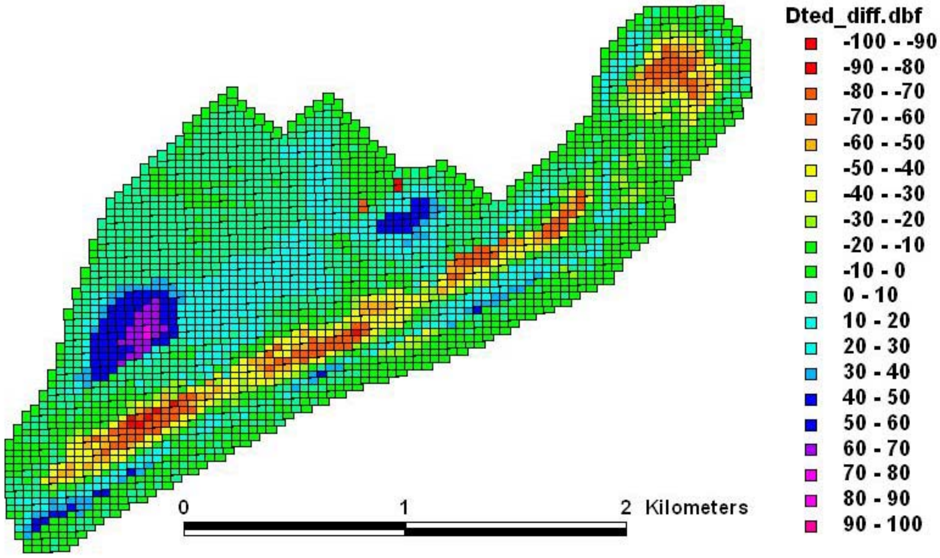


Figure 34 Elevation difference map

2.2.4.2. DataForWind

For the DataForWind data sets, we can withdraw 639 grid points that lay within the circumference of the excavation site of Amay. The elevation map derived from these grid points is given below.

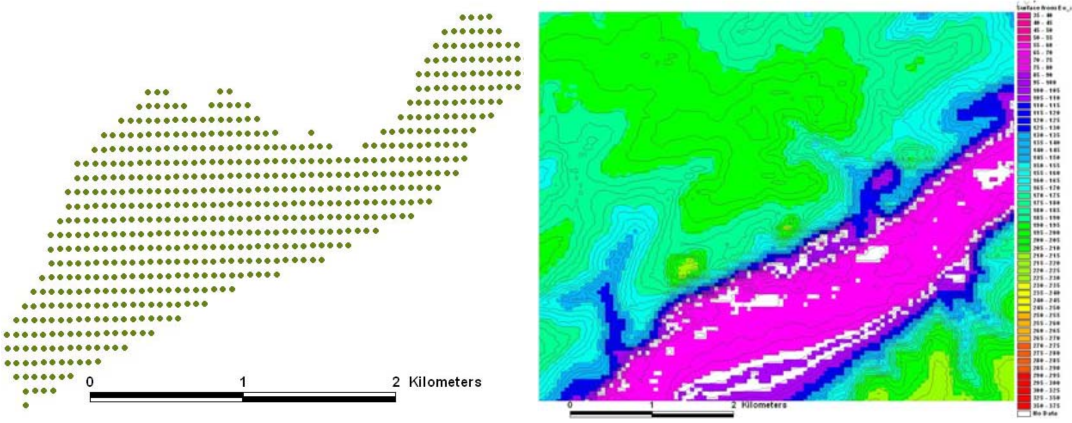


Figure 35 Withdrawn grid points of the DataForWind data set and the derived elevation map

Table 12 Fault analysis between DataForWind data and the measured data set

	Difference in elevation [m]	Distance between grid points [m]
# Observations	639	639
Minimum	-111	0
Maximum	55	69.08
Average	-16.27	16.71
Standard deviation	30.55	10.31

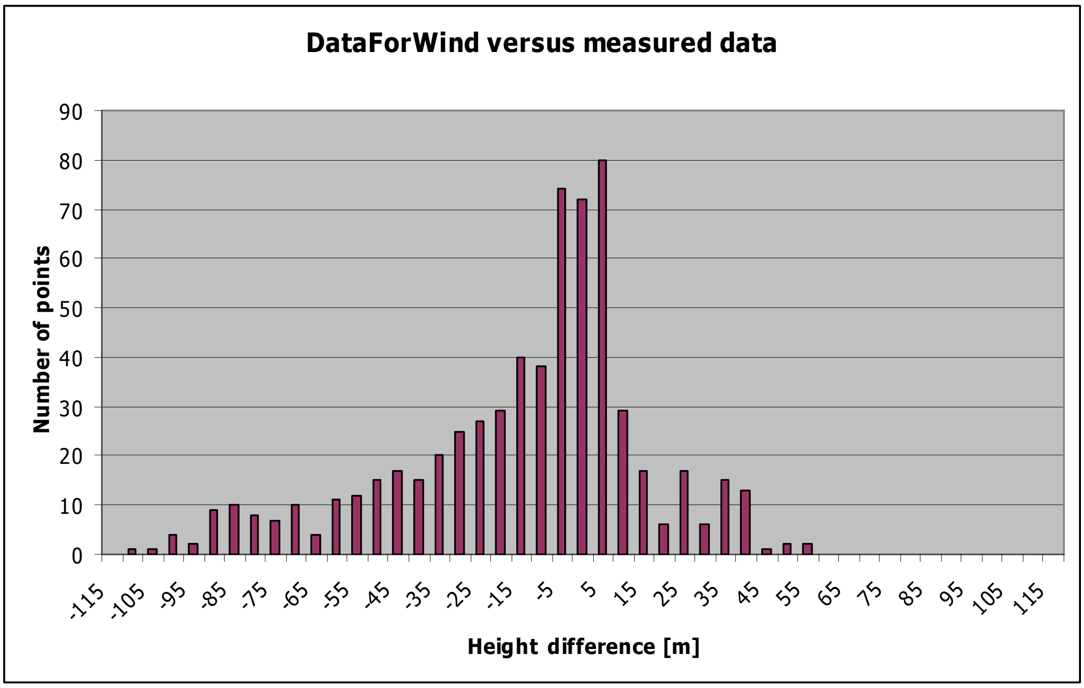


Figure 36 Comparison DataForWind data versus measured data

The average difference in elevation values is higher than for the DTED data set, although the two local hills are better visible in Figure 35 than in Figure 32. The higher average difference in elevation is due to the bigger grid distance.

The elevation difference map is show in the following figure. Again, it is observed that the slope of the valley give important differences.

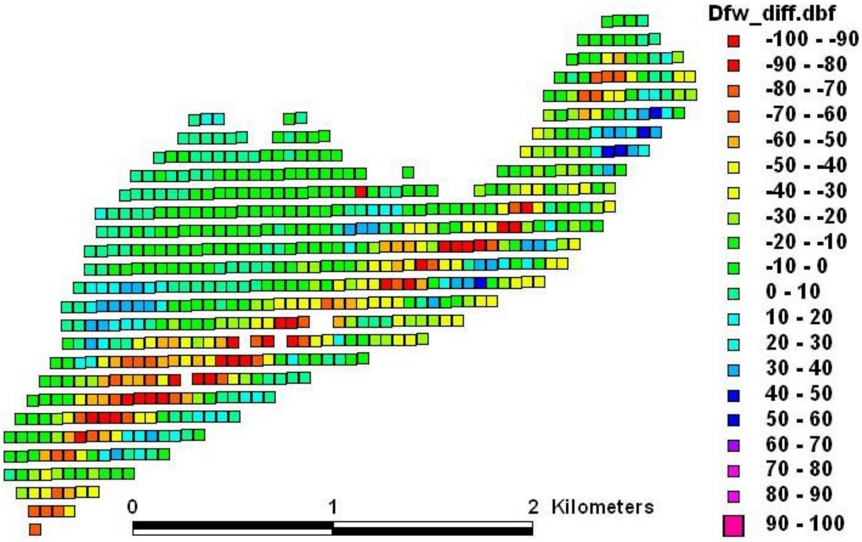


Figure 37 Elevation difference map

2.2.4.3. SRTM30

For the SRTM30 data sets, only 7 grid points lay within the circumference of the excavation site of Amay. The elevation map derived from these grid points is given below. The 7 grid points are drawn above the AutoCad drawing.

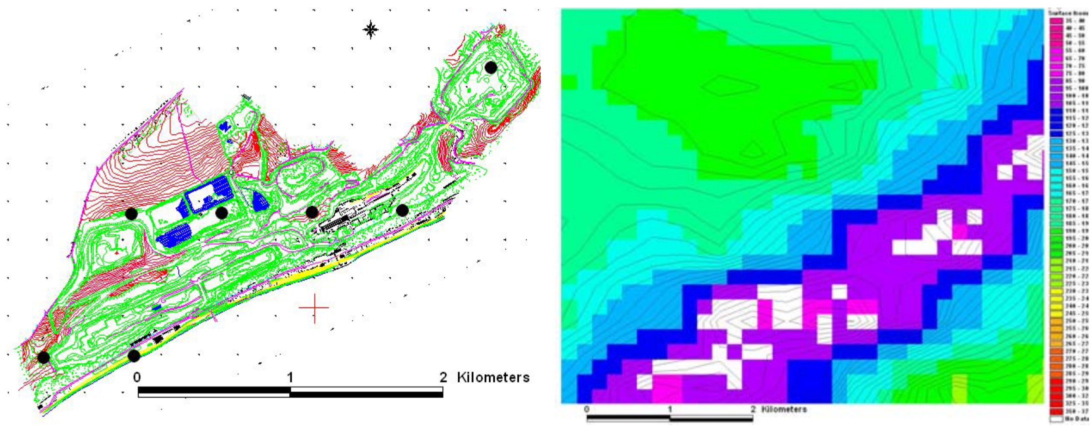


Figure 38 Withdrawn grid points of the SRTM30 data set and the derived elevation map

Table 13 Fault analysis between SRTM30 data and the measured data set

	Difference in elevation [m]	Distance between grid points [m]
# Observations	7	7
Minimum	-51	7.21
Maximum	19	46.4
Average	-2.86	20.65
Standard deviation	25.05	14.81

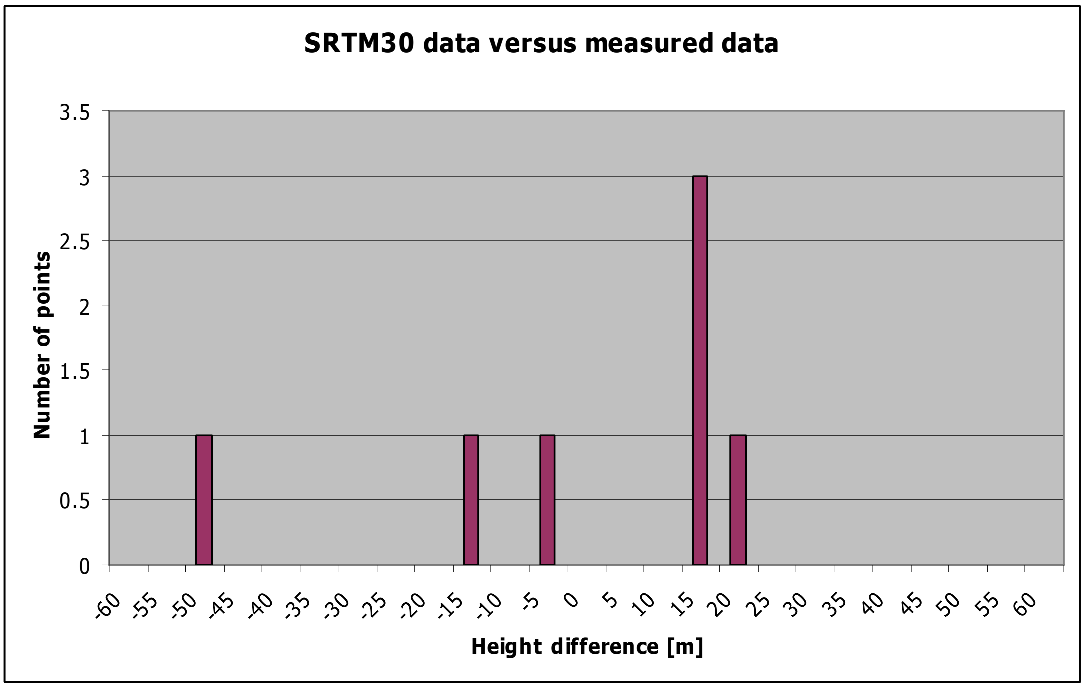


Figure 39 Comparison DataForWind data versus measured data

2.2.4.4. Conclusion

DTED and DataForWind datasets have the highest horizontal resolution and therefore result in the highest accuracy for the terrain modelling of sites.

2.2.5. Database

DTED data is purchasable at the National Geographic Insitutute. The other sources of data (DataForWind, SRTM, GTOPO30 and SRTM30) are available free or charge from the internet.

It is the responsibility of the end user to handle and convert these data sets as required for his own applications.

2.3. References

[5] Wieringa, J., and P. J. Rijkoort, 1983: Windklimaat van Nederland, Staatsuitgeverij, Den Haag, the Netherlands.

[6] Wieringa, J., 1986: Roughness-dependent geographical interpolation of surface wind speed averages. Quarterly Journal of the Royal Meteorological Society 112, 867-889.

[7] Troen, I. and Petersen, E.L. (1989). European Wind Atlas. Published for the Commission of the European Communities, Brussels, Belgium, by Risø National Laboratory, Roskilde, Denmark, ISBN 87-550-1482-8, 656 pp.

[8] Petersen, E.L. e.a. Wind power meteorology. Risoe-I-1206 (EN) December 1997

[9] Mortensen, N.G. e.a. Wind Atlas and Application Program (WAsP). Vol 2. Users Guide. Risoe-I-666 (v.2) (EN), Risoe 1993

[10] European Environment Agency, 2005, reports.eea.eu.int/COR0-part2/en/land_coverPart2.1.pdf

[11] Charnock, H., 1955: Wind stress on a water surface. Q. J. R. Meteorol. Soc., 81, 639-640.

3. Task 3: Model evaluation

3.1. General

The objective of Task 3 is to evaluate a number of existing wind field models for regional wind resource mapping purposes. The models calculate the wind field over a selected area, based on input of meteorological data (wind, solar, radiation, temperature,…) and terrain data (orography, roughness, obstacles, thermal properties,…). The capacity of the selected models to predict the local wind climatology will be assessed by comparison of calculated (simulated) and actual (observed) wind speeds. Existing high quality wind speed measurements are used for this comparison.

This research is particularly useful for hilly regions and complex terrain, for which there is currently a lack of well verified wind modelling methods.

This chapter outlines the methodology and the results of the evaluation of the wind field models. In general, the method is an experimental verification. For this purpose a number of modelling case studies are defined.

3.2. Methodology

Five different models for the prediction of the surface wind climate are investigated. These models can be devided into mesoscale and microscale models, or the combination of the two. The high resolution mesoscale models simulate the regional wind characteristics like flow in presence of large hills and valleys (up to a typical resolution of 1 km). These sophisticated 3 dimensional models are necessary to obtain reliable wind simulations especially in complex terrain. The microscale models calculate the effects of orography, roughness conditions and obstacles on a high resolution mesh.

The models that are tested in this project are summarised in the following table:

Table 14 Tested models

Model	Operated by partner	Model scale	Model Reference
ARPS	VITO	Meso	1
TVM	UCL	Meso/micro	2
MAR	UCL	Meso	3
Maestro Wind	UCL/ATM PRO	Meso/micro	4
WAsP	3E	Micro	5

3.3. Selection of sites for case studies

The validity of the models for the various relevant terrain topologies in Belgium will be evaluated by carrying out case studies. The modelling results are compared with measured data from high quality meteo stations.

Four terrain topologies are investigated. These four topologies represent most of the potential wind turbine sites in Belgium:

- Offshore: offshore site within the Belgian Continental Shelf (BCS), at least 20 km out of the coastline to minimise onshore influences.
- Simple: inland flat site away from coastal influences.
- Medium: inland smooth hilly site, with moderate undulating orography.
- Complex: inland rough hilly terrain with complex orography.

According to these topologies, five different sites have been chosen where good quality wind measurements on site are available. The details are given in the following paragraphs.

The five selected sites are:

Table 15 Selected sites

Site reference	Name	Type of terrain	Measurements
A	Amay	Complex	3E
B	Rumes	Simple	3E
C	Arlon	Medium	3E
D	Mol	Simple	VITO
E	Thorntonbank	Offshore	Meetnet Vlaamse Banken

For every site, the local (site specific) wind climate will be simulated with each model using representative data from synoptic or automatic meteo stations from the RMI.

3.3.1. Details of the sites with meteorological masts of 3E

Table 16 Details of the sites with meteorological masts of 3E

Station Name	Rumes	Arlon	Amay
Terrain type	Simple	Complex	Complex
Lambert Coordinate (m)	76292 (E), 138381 (N)	255604(E), 34174(N)	219207(E),140160(N)
Elevation (m)	62	400	225
Date In (dd.mm.yy)	02/07/2003	16/02/2003	21/12/2001
Date Out (dd.mm.yy)	05/08/2004	26/11/2004	20/06/2002
Mast Height (m)	30	38	27
Height of sensors (m)	30 m: 2 AN & WV 17 m : 2 AN 2 m: T	38 m: AN & WV 20 m: 2 AN 2 m: T & P	27 m: AN &WV 15 m : AN
Averaging period	10 min	10 min	10 min
Data Acquisition	WS : avg, min, max, stdev WD: avg T: avg	WS : avg, min, max, stdev WD: avg T: avg P: avg (hourly)	WS : avg, max, stdev WD: avg
Missing Data (%)	< 1%	< 1%	< 1%
Terrain slope (%)	0%	~15%	~30%
Type of terrain	Simple	Medium	Complex

3.3.1.1. Site Amay

The site of Amay is located in the province of Liège. The site overhangs the river Meuse and the area around the site has a very complex orography. The mast is positioned at an altitude of 225 m above sea level and was placed at the highest point of the excavation site.

Given the complexity of the site, it was necessary to perform a wind measurement campaign to predict the local wind regime. The satellite picture below shows the area of the site of Amay.

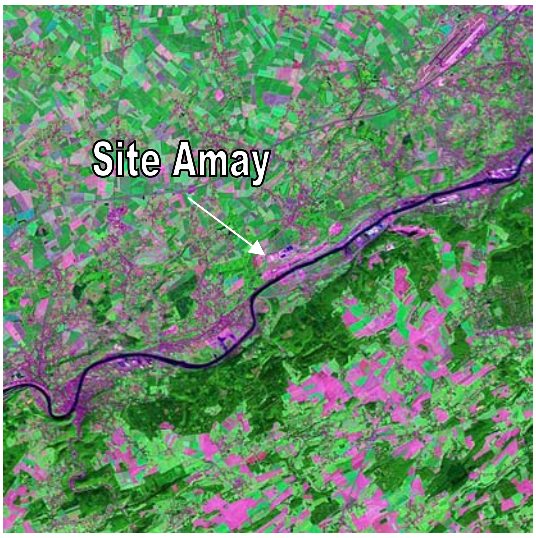


Figure 40 Satellite picture of the site of Amay along the river Meuse

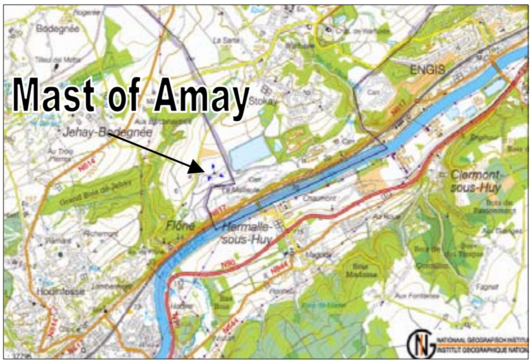


Figure 41 Topographical map of the site of Amay

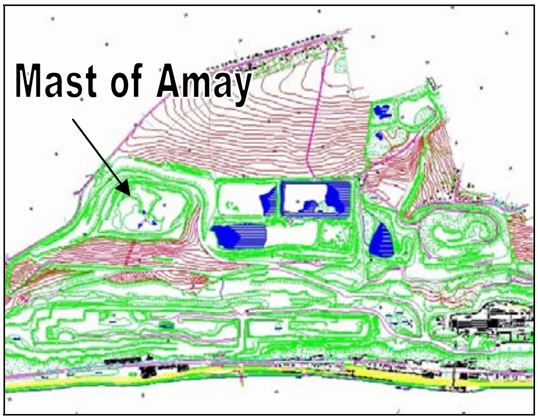


Figure 42 The excavation site of Amay and the position of the wind measuring mast

The mast is placed in the excavation site of Dumont Wautier s.a, located along the roadway Freddy Terwagne.. On Figure 42, one can observe that the undulation is very strong in the neighbourhood of the site: one passes 225 m to 70 m at a distance of hardly 500 m. The mast was placed at the highest point of the site.

Picture 1 Wind measuring mast of Amay

3.3.1.2. *Site Rumes*

The site of Rumes is located in the province of Hainaut, at a few hundred meters of the French border. The position of the mast is indicated at the topographical map below.

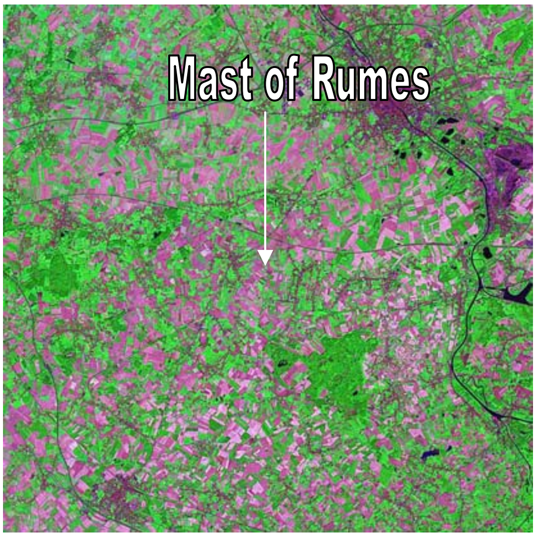


Figure 43 Satellite picture of the site of Rumes

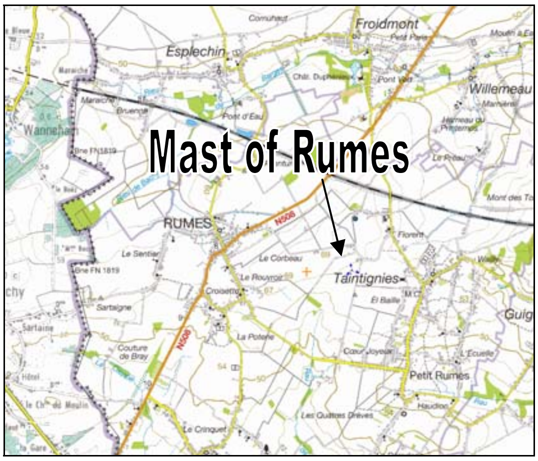


Figure 44 Position of the wind measuring mast of Rumes

Picture 2 The 30 m mast at the site of Rumes

3.3.1.3. Site Arlon

A 40 m wind measuring mast has been installed on the site of Arlon, more in particular between the villages of Messancy and Sélange, in the province of Luxembourg. The geographical position of the mast is indicated on the satellite and topographical maps below.

Figure 45 Satellite picture of the site of Arlon

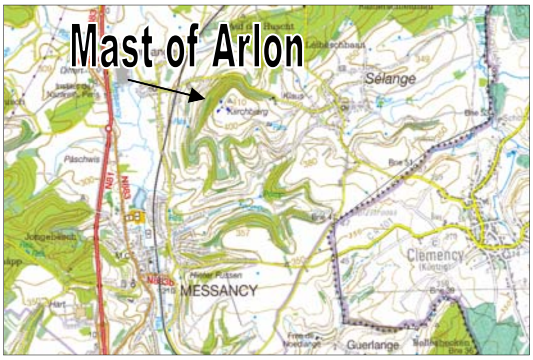


Figure 46 Topographical position of the wind measuring mast of Arlon

Picture 3 Wind measuring site of Arlon

3.3.2. Site with meteorological mast at Mol

Wind speed and direction are measured at an instrumented 114 m tower at the Vito-SCK/CEN domain. The position of the mast is given by Belgian Lambert co-ordinates x = 200393 m, y = 212254 m, which corresponds to a longitude of 5.0887° and a latitude of 51.2186° (decimal degrees). The terrain around the tower is mainly characterised by the presence of pine trees (height around 20 m) and medium-size buildings (most are lower than the trees). Wind speed is measured at 24, 48, 69, 78, and 114 m, and wind direction at 24, 69, and 114 m. Note that these measurement heights are with respect to the forest floor. The measurements are averaged and archived over 10-minute periods.

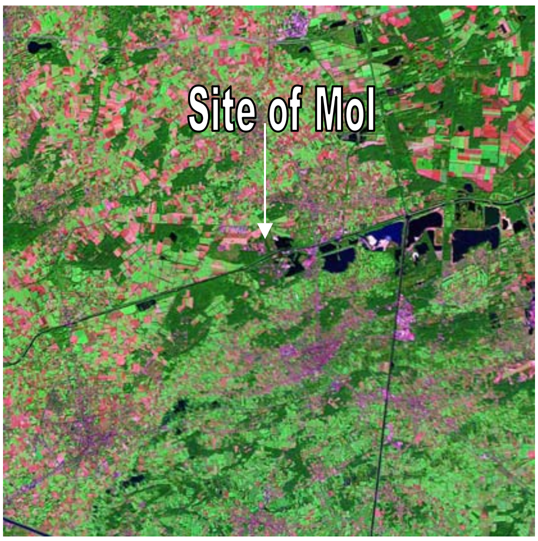


Figure 47 Satellite picture of the site of Mol

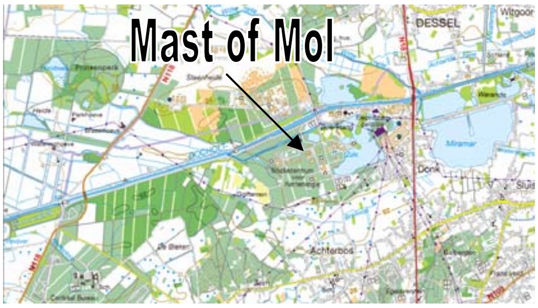


Figure 48 Topographical position of the wind measuring mast of Mol

3.3.3. Site with meteorological mast at Westhinder

RMI does not possess any offshore measuring stations. Offshore meteorology is measured by the "Meetnet Vlaamse Banken" at several positions in the North Sea. One of these is the meteo station "Westhinder", sited almost 35 km offshore from the coast of Middelkerke.

Long term measured data on the meteo station "Westhinder" will be analysed and will be used to calculate the long term wind regime by means of WAsP for the Thorntonbank, which lies within the designated area for the development of offshore wind energy applications (designated area according to the Royal Decree)..

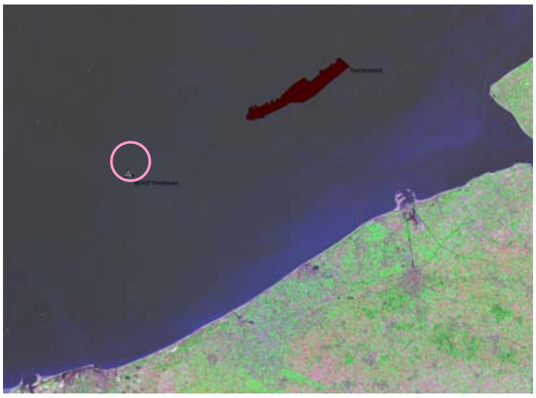


Figure 49 Satellite picture of the position of the meteo measuring mast of Westhinder and the sandbank Thorntonbank

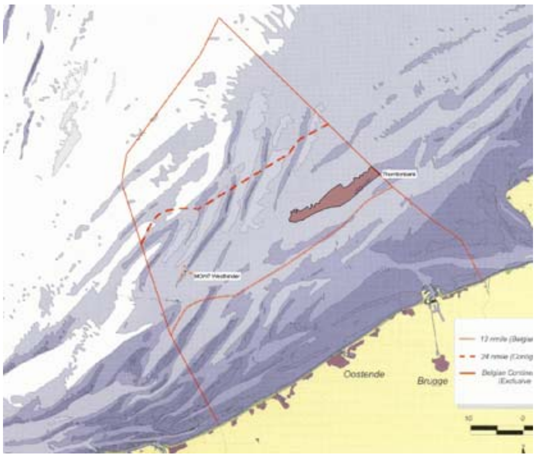


Figure 50 Topographical position of the meteo measuring mast of Westhinder and the sandbank Thorntonbank

3.4. Description of the wind field simulation models

Five models participate to the inter-comparison. These are:

- MAR (Modèle Atmosphérique Régional) developed and used at UCL and at LGGE (Laboratoire de Glaciologie et Géophysique de l'Environnement, Grenoble).
- TVM (Thermal Vorticity Mesoscale) also developed and used at UCL and with JRC-Ispra
- ARPS (Advanced Regional Prediction System) developed at Oklahoma University and used by VITO
- MAESTRO Wind developed at ATM-PRO and UCL and used by ATM-PRO s.p.r.l.
- WAsP (Wind Atlas and Analysis program) developed at Risø National Laboratory in Denmark and used by 3E.

The first four models are 3D grid integrating the atmospheric dynamic equations with time using various assumptions. The WAsP model is a micro scale model

The following table shows the main characteristics of the different meso scale models, their physical properties, and Large Scale (LS) forcing method. More details over each model are given in the next sections. The characteristics of WAsP are not given in the table, because the WAsP model is of a totally different nature than the others. The details of WAsP are given in paragraph 3.6.6.

Table 17 Main characteristics of models used in this wind energy application

Model	ARPS	MAR	TVM	MAESTRO
Project partner	VITO	UCL	UCL	UCL/ATM-Pro
Prognostic variables	P,u,v,w,θ,q_i	P_s,u,v,θ,q_i	Vorticity,θ,q	Vorticity
Hydrostatic/nonhydrostatic	NH	H	NH	NH
Vertical co-ordinate	σ-z	σ-p	σ-z	σ-z
Domain size	20-2000 km	900 x 900 km^2	50 x 50 km^2	10 x 10 to 100 x 100 km^2
Horizontal resolution	0.2-20 km	10 km	1 km	0.25 km
Vertical resolution (min-max)	10-1000 m	10-100 m	10-300 m	10-200 m
Nb of vertical levels	35	60	38	25
Nesting procedure	yes	LS at lateral boundaries (relaxation)	Perturbation on LS	No
Physical packages				
Turbulence	1.5 order TKE	Therry-Lacarère	Therry-Lacarère (1983)	O'Brien (1st order)
IR rad	LW: Chou & Suarez (1994)	Morcrette (1991)	Sasamori	No
Solar rad	SW: Chou (1992)	Fouquart-Bonnel	yes	Yes

Model	ARPS	MAR	TVM	MAESTRO
Project partner	VITO	UCL	UCL	UCL/ATM-Pro
		(1980)		
Surface heat balance	Yes	Yes	Yes	Yes
Surface layer	upgraded from IAGL model		MOST	MOST
Soil sub-model	upgraded from IAGL model	Deardorff (simple force restore type)	Deardorff	No
Clouds (interactive)	Schultz (1995)	Yes	no	No
Input data				
Initial conditions	ECMWF/FNL	ECMWF analysis	Profile from ECMWF analysis	Fixed initial BL
Boundary conditions	ECMWF/FNL	ECMWF analysis	Open boundaries	Open boundaries
Soil characteristics data	fixed (loam)			
Land use data	CORINE	CORINE	CORINE	CORINE
Topography	EDC 30-arcsec SRTM 3-arcsec	GTOPO	GTOPO	NGI
LS forcing	ECMWF/FNL	ECMWF analysis	ECMWF analysis	Synop data
LS data period	6h	6h	6h	1h
Computer platform	PC Pentium	PC & WS	PC	PC
Programming language	Fortran (Intel)	FORTRAN 90	FORTRAN 90	FORTRAN 90
OS	Linux	Linux	Linux	Win

Two types of input data are used in this study by the different models:

- ARPS, MAR and TVM: These models are forced by a large scale meteorological data obtained from the re-analysed fields of the European Centre for Medium-range Weather Forecast (ECMWF, Reading, UK). The large scale wind data from the global models are available every 6 hours. This period of time can sometimes be too long, particularly for rapidly evolving weather situations.
- MAESTRO and WAsP are models forced by meteorological data obtained in a regional observing station. These data are usually available in a continuous way i.e. with a small time increment.

A summary description of each model is given, together with the analysis of the simulation results, is given in the3.6.

3.5. Definition and description of the modelling cases

Four periods of at least one week have been selected as studied cases. A basic requirement is obviously that the observation data are available for the study period. It is also desirable to have at least one experiment in each season. To select time periods appropriate to wind power prediction, the following general criteria were used:

- avoiding large storms (extreme wind events are conditions in which wind turbines may need to be shut down, and these events are by definition rare, thus not representative of a typical week)
- include some days with low wind speeds, but not a majority of such days. The annual wind speed frequency distribution, and the corresponding occurrence of low, medium and high wind speeds, as relevant for the operation of wind turbines should be adequately represented.
- The frequency of occurrence of wind directions should be adequately represented.
-
-

Table 18 Details about the selected modelling time periods

Time period	Sites (data availability)	Comments (wind information: from Beauvechain/Bevekom station)
Spring: April 4-17, 2002	Amay	Various conditions (anticyclonic, mediterranean low, icelandic low), moderate wind speed (daily mean 7->18 km/h, max 40 km/h), various wind directions (ENE -> SW), 1 thunderstorm day

Summer: July 3-9, 2003	Arlon, Rumes, Mol	Various conditions (low over north-sea, then anticyclonic), moderate and low wind speed (daily mean 4-> 14 km/h, max 32 km/h), wind directions NE->SW, 2 thunderstorm days.
Autumn: October 21-27, 2003	Arlon, Rumes, Mol	Wind directions differ from those of the other selected periods (e.g. max wind from east on October 22), rather dry, while rainy weather for the spring period, no thunderstorm days.
Winter: December 22-28, 2003	Arlon, Rumes, Mol	Winter conditions, with snowfall. The first 2 days are cold, quite strong wind, up to 19 m/s, only the beginning of December had low wind speeds, while wind direction was again easterly (conditions would then seem similar to those selected for autumn).

The necessary meteorological information was obtained from the monthly climatological summaries of RMI (including daily information about wind speed and direction). The resulting choice of simulation periods is provided and commented in the Table 18.

The total number of simulation cases is 10 (1 x 1 week Amay plus 3 other sites x 3 weeks). T

3.6. Description and results of the modelling cases

3.6.1. Comparison method of simulations and measurements

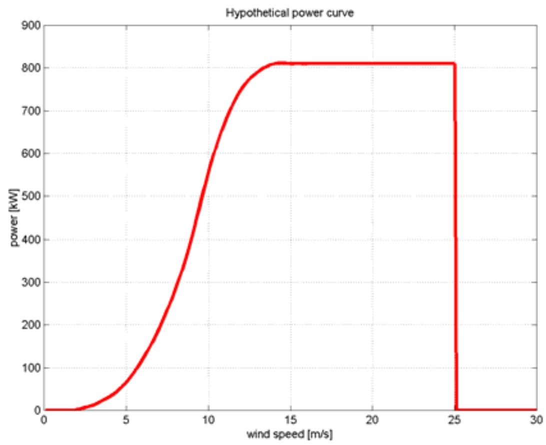
The following methodology for comparison of measured (observed) and simulated data has been applied.

1. Generation of time series and comparing the time series of simulated and measured data. This graphical evaluation is applied on the three parameters: wind speed, wind direction and wind power. For the simulation of the wind power, a hypothetical standard power curve has been defined. See further below. For the evaluation of the time series on wind speed and wind power, the root mean square (RMS) value is calculated.
2. Comparison of the average value of wind speed and wind power, and the total produced energy over the selected time period. The deviation between the observed and the simulated average value is calculated.
3. Regression analysis on wind speed and wind power.

Since the four selected time periods (Table 18) are short term periods, it doesn't make sense to compare the frequency distributions of the different parameters. This evaluation should be applied on long term data.

A dedicated worksheet with pre-programmed cells has been prepared which allows to import results of the simulations and the observations at the various sites.

For the simulation of the wind power, a hypothetical standard power curve has been defined, see following figure.



Wind speed [m/s]	Power [kW]
1	0
2	2
3	12
4	32
5	66
6	120
7	191
8	284
9	405
10	555
11	671
12	750
13	790
14-25	810
>25	0

Figure 51 Hypothetical standard power curve

This power curve has been defined with a cut in wind speed of 2 m/s. The cut in wind speed is the minimum required wind speed for the wind turbine to start operating. This rather low cut in wind speed is selected in order to evaluate the wind power time series even for low wind speed. The cut out wind speed is 25 m/s which is the normal design stop wind speed for the wind turbine. The nominal wind power is 810 kW. The rated wind speed is 14 m/s. This is the wind speed for which the wind turbine reaches its nominal power.

3.6.2. The ARPS model

3.6.2.1. Summary

The Advanced Regional Prediction System (ARPS), a non-hydrostatic mesoscale meteorological model, is used to simulate wind speed and direction near the ground at two experimental sites. One site (Mol) is characterised by flat terrain but very patchy land use, the other site (Amay) is located in hilly terrain with steep slopes. Wind speed simulated at both sites is compared to observed values for periods of the order of 1-2 weeks. For the flat site it is found that the model performs better when allowing several land use types to co-exist within a surface grid cell (mosaic approach), as compared to prescribing the dominant land use type only. Furthermore, the importance of correctly specifying the local roughness length is found to be of paramount importance. For the hilly site, the main conclusion is that accounting for sub-grid scale effects (small isolated hill) at the site improves the results drastically. For both sites, accounting for local site-specific effects (roughness and topography) led to a ten-fold decrease of the bias of the simulated versus the observed wind speed.

3.6.2.2. Introduction

With the increasing demand for renewable energy, methods have been developed to assess the yield of potential energy producing sites. In particular for wind energy, this so-called ‘siting' is of paramount importance, since the yield of a wind mill approximately varies as the cube of the wind speed, hence identifying a site with marginally higher wind speeds may result in a significant increase in expected energy production.

Traditionally, wind energy siting has been done by means of relatively simple but fast numerical models, using observed wind statistics at a nearby meteorological station as input, and accounting for differences in terrain (roughness, orography) between the observation station and the assessment site's position. However, with increasing computing power, mesoscale meteorological models are now becoming a potentially interesting alternative. Indeed, although much heavier to handle and much slower than the station-based models, they represent the atmosphere in a more complete and consistent way, e.g., using the full equations of motion and accounting in a detailed way for atmospheric physics, including radiation transfer, cloudiness, surface energy balance, among others. Another advantage of mesoscale models is that they do not require meteorological data from a local station as input. Instead, they generally use analysis data from regional or global atmospheric models, e.g., from the operational model of the European Centre for Medium-Range

Weather Forecasting. This advantage is perhaps mainly of a practical nature, but it is certainly non-negligible, as station data are often hard to obtain or incomplete (containing data gaps), thus compromising the continuity of the wind yield assessment.

The disadvantage of mesoscale models, apart from their high computational demands, is that at the smallest resolved scales, i.e., the size of the model's grid cells, they represent the atmosphere as a volume average over that grid cell. As the current spatial resolution of mesoscale models is of the order of 1 kilometre in the horizontal and, near the ground, around 10 m in the vertical, it becomes clear that small-scale features such as obstacles or small-scale roughness and orographic variability cannot be accounted for, at least not explicitly, despite their being important for determining the wind speed and direction at a given site.

In this paper we address some of the issues mentioned above. More particularly, it is verified with the ARPS model what improvement can be obtained by allowing sub-grid variability of land cover and associated terrain roughness, and by parameterizing speed-up caused by a sub-grid scale hill at a study site. In Section 2, the ARPS model is described, as well as the input data used in the simulations. Section 3 presents the simulation results, and Section 4 presents the conclusions.

3.6.2.3. Model

The Advanced Regional Prediction System (ARPS) is a non-hydrostatic compressible meteorological model with nesting capabilities developed at the University of Oklahoma (US), and was designed for calculating atmospheric flow over complex terrain. The equations of atmospheric dynamics and physics are discretized on the Arakawa C-grid, employing a terrain-following co-ordinate in the vertical direction. Advection is solved with a 4^{th} order central differencing scheme and leapfrog time stepping. Turbulence is represented with the 1.5 order Turbulence Kinetic Energy (TKE) model. ARPS also contains detailed parameterisations for cloud microphysics, cumulus convection, and radiation transfer. The model was extended with a detailed representation of land surface-atmosphere interactions (De Ridder and Schayes, 1997), in order to account for the effects of soils and vegetation on the atmosphere. For more details regarding the ARPS model, the reader is referred to Xue *et al*. (2000, 2001).

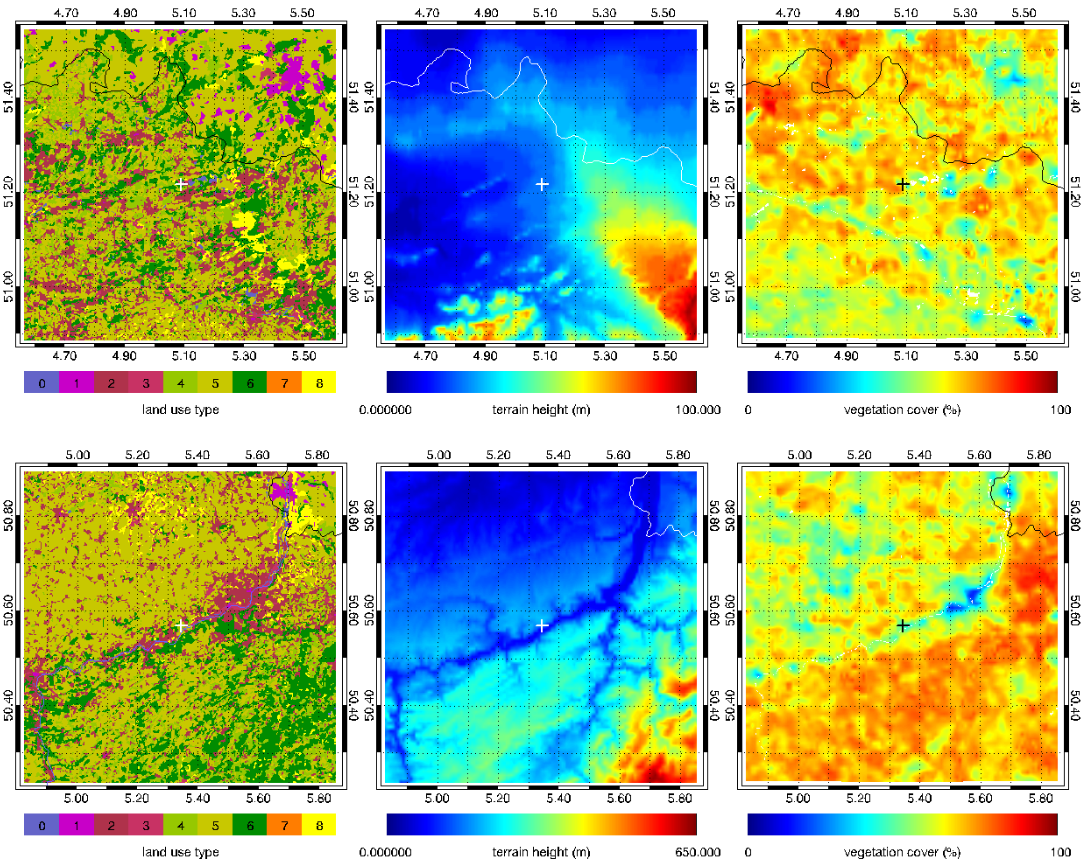


Figure 52. Terrain characteristics for the study domains used in the simulations, for Mol, 20-29 December 2003 (upper panels), and Amay, 6-17 April 2002 (lower panels). The figures show land cover (left), terrain height (centre), and vegetation cover percentage (right), the co-ordinates being in degrees longitude and latitude. The '+' symbol in the centre of each figure indicates the position of the measurement stations. Land use types are numbered in the legend according to Table 19. With respect to terrain height, note the difference in scale used for the two sites.

In the simulations described here nesting is done either within 6-hourly meteorological analysis fields at 0.5° resolution of the large-scale atmospheric model operated by the European Centre for Medium-Range Weather Forecasting (ECMWF, see www.ecmwf.int), or within the 6-hourly NCEP Global Final Analyses on a 1° grid (FNL, see http://dss.ucar.edu/datasets/ds083.2/). (The term 'nesting' refers to the technique used to ingest large-scale meteorological data at a mesoscale model's lateral boundaries. The proper description of the lateral boundary conditions is very important as large-scale atmospheric features, such as depressions, fronts, or anticyclones, do affect the weather even at the smallest scale; hence they are to be accounted for.)

The input data used to specify terrain characteristics are the following:

- land use-dependent parameters (roughness, albedo, stomatal resistance, among others) are specified as a function of land cover, which is derived from CORINE land use raster maps (http://dataservice.eea.eu.int/dataservice/) and aggregated into nine classes, as shown in Table 19;
- terrain height is interpolated from values contained in the EDC 30-arc second Digital Elevation Model (http://edcdaac.usgs.gov/gtopo30/gtopo30.asp), though for certain applications the Shuttle Radar Topography Mission 3-arc second Digital Elevation Model are used (http://www2.jpl.nasa.gov/srtm/);
- sea surface temperature is derived from NOAA/NASA Pathfinder Advanced Very High Resolution Radiometer (AVHRR) SST imagery (http://podaac.jpl.nasa.gov/);
- vegetation cover percentage is taken proportional to the Normalised Difference Vegetation Index (NDVI), which is contained in imagery generated by the VEGETATION instrument (http://www.vgt.vito.be) onboard the SPOT satellite platform.

It should be noted that all input data mentioned above (both terrain and large-scale atmospheric) have at least European and in some cases even global coverage. This means that the ARPS model is geographically very flexible, and can be run almost anywhere without requiring local input data.

Table 19. Surface parameter values as a function of land cover type. The numbering corresponds to that used in Figure 52. The parameters are defined as follows: α *is the albedo,* ε *the emissivity,* z_{0m} *the roughness length for momentum transfer,* r_{st} *the minimum (unconstrained) stomatal resistance, and* β *is the so-called root coefficient, which governs the vertical distribution of the root density in the soil. More details regarding these parameters are provided in De Ridder and Schayes (1997).*

		α (-)	ε (-)	z_{0m} (m)	r_{st} (s m^{-1})	r_p (10^8 m)	β (-)
0	water	0.05	0.99	0.0001	-	-	-
1	urban	0.12	0.95	1.5000	-	-	-
2	sub-urban	0.15	0.95	0.5000	-	-	-
3	industrial	0.15	0.95	0.3000	-	-	-
4	grass	0.20	0.98	0.0100	50.	5	0.961
5	crop	0.20	0.98	0.0100	50.	5	0.961
6	forest	0.15	0.98	1.2000	100.	10	0.961
7	snow/ice	0.70	0.98	0.0010	-	-	-
8	shrub	0.15	0.98	0.1000	100.	10	0.961

The terrain characteristics used for the simulations are shown in Figure 52. Clearly, both sites are characterised by very heterogeneous land cover, consisting of scattered forests and built-up areas mixed with pastures and agricultural fields. Whereas the Mol site is located in relatively flat terrain, the Amay site is located at the edge of the steep and narrow valley of the river Meuse. A particular aspect for this site is that it is located in an actively exploited quarry.

3.6.2.4. Results

Simulations for each site were carried out as specified in Table 20. For the Mol site, a first simulation was performed where only the dominant land cover was specified (M1), the second simulation allowed up to nine land cover types to co-exist within a single surface grid cell (M2). In the latter approach, the so-called mosaic technique, fluxes of energy, water and momentum between the surface and the atmosphere are calculated separately for each sub-grid land cover type, and grid scale fluxes are then calculated as weighted means of the fluxes per cover type, using the percentage of occurrence of each as weights. The third simulation (M3) was identical to M2, except that the local roughness length at the study site was prescribed based on information obtained from the site itself rather than from the land use maps and the associated default parameter values. At the site of Amay, the focus of the simulations was on assessing the effects of terrain height and hilliness. A first simulation (A1) was carried out using the mosaic version of the model, and with default orography (as derived from the 30-arcsecond DEM, 30-arcseconds corresponding to a resolution of around 1 km). In a second simulation (A2), the effects of a sub-grid scale hill present at the site was accounted for by means of a simple parameterization of the speed-up effect associated with the hill.

Table 20. Definition of the simulations: 'no mosaic' refers to the model version in which only one (dominant) land cover type can be specified per surface grid cell, 'mosaic' means that up to eight land cover types (see Table 19) are allowed to co-exist within a surface grid cell. The 'roughness correction' and 'hill speed-up' simulations are defined in the main text.

simulation code	simulation characteristics
MOL	
M1	no mosaic
M2	mosaic
M3	mosaic + roughness correction
AMAY	
A1	mosaic
A2	mosaic + hill speed-up correction

Model performance is quantified using a set of statistical indicators. All are based on time series of wind speed, denoted $U_{sim,i}$ and $U_{obs,i}$ for time step i (= 1, ..., N), for simulated and observed values, respectively. The corresponding means are denoted $<U_{sim}>$ and $<U_{obs}>$, and the corresponding standard deviations are σ_{sim} and σ_{obs}. The indicators used here are the Normalized Mean Difference (NMD), the Normalized Root Mean Square Error (NRMSE), and the Index of Agreement:

$$
\begin{aligned}
NMD &= \frac{<U_{sim}> - <U_{obs}>}{<U_{obs}>}, \\
NMD3 &= \frac{<U_{sim}^3> - <U_{obs}^3>}{<U_{obs}^3>}, \\
NRMSE &= \frac{1}{\sigma_{obs}} \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(U_{sim,i} - U_{obs,i}\right)^2} \\
IA &= 1 - \frac{\sum_{i=1}^{N}\left[\left(U_{sim,i} - <U_{obs}>\right) - \left(U_{obs,i} - <U_{sim}>\right)\right]^2}{\sum_{i=1}^{N}\left[\left|U_{sim,i} - <U_{obs}>\right| + \left|U_{obs,i} - <U_{sim}>\right|\right]^2}.
\end{aligned}
\tag{1}
$$

The NMD represent the fractional bias of the simulated versus the measured wind speed, and good model performance is indicated by values near zero. Here, use is also made of the NMD for the cube of the wind speed (and denoted NMD3), as this quantity is more closely related to wind yield than the wind speed itself. The NRMSE gives an indication of model error compared to the observations, and should be as small as possible, and certainly preferrably smaller than 1. The IA (as defined in Wilmott, 1982) is a number between 0 and 1, with 0 indicating worst agreement, and 1 indicating best agreement.

3.6.2.4.1. Mol simulations

The Mol site is located in the northern part of Belgium, at 51.2186° N and 5.0887° E. Wind observations are obtained from a continuously operated instrumented 114-m tower; here use is made of the measurements obtained at a height of 69 m, the height being defined with respect to the forest floor. The measurements are averaged and archived over 10-minute periods. The terrain around the tower is characterised by the presence of pine trees with a height of approximately 20 m and medium-sized buildings, most of which are lower than the trees.

A simulation was performed for the Mol site, for the period 20-29 December 2003. Use was made of triply nested domains. In a first step, the ARPS model with a 16-km resolution was nested within six-hourly ECMWF analysis data at 0.5° spatial resolution. In a next step, the ARPS model was run over a domain of intermediate size, with a resolution of 4 km and nested in the 16-km simulation. In a final step, the model at 1-km resolution and with 70 × 70 horizontal grid points was nested within the 4-km domain. In the vertical, use was made of 35 grid points with a resolution ranging from approximately 12.5 m at the surface up to more than a kilometre near the model top, located at an altitude of 17 km.

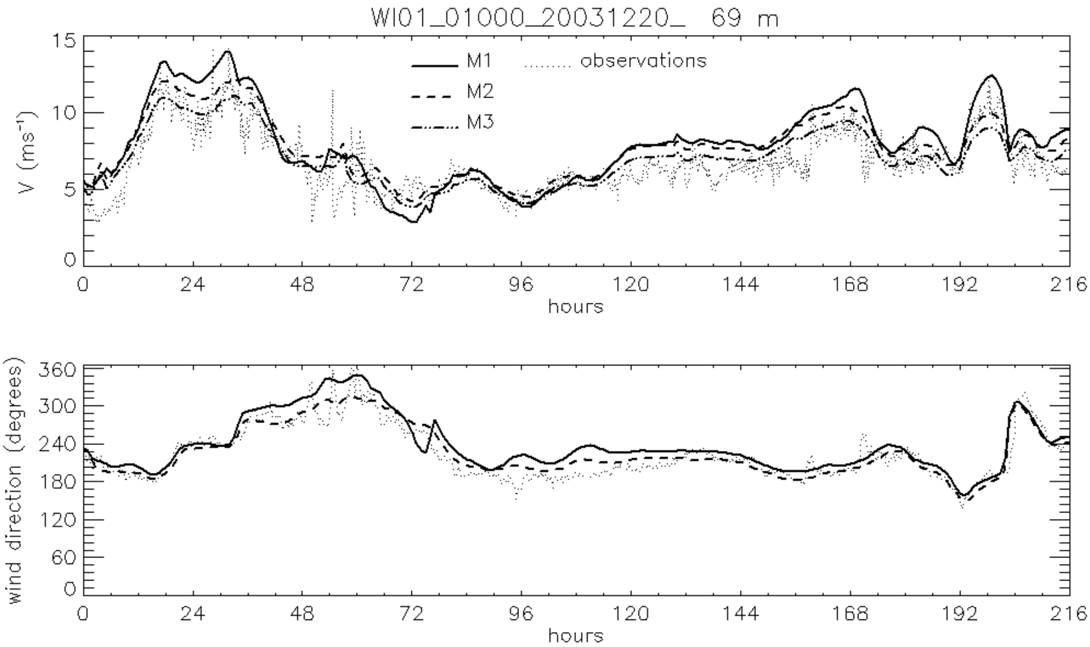


Figure 53. Simulated versus observed wind speed (upper panel) and direction (lower panel) for the site of Mol, 20-28 December 2003.

The observed and simulated wind speed and wind direction for the Mol site are shown in Figure 53. Since ARPS does not have a model level located at the exact 69-m measurement height, simulated values were linearly interpolated from the neighbouring vertical levels. During the period studied here, observed wind speed was relatively high, especially at the start, with values exceeding 12 m s^{-1}. In the middle of the period winds were calmer, to rise again towards the end. Wind directions were dominantly from the south, with some excursions into the westerly direction. Simulation M1 shows a fair agreement of simulated versus observed wind speed and direction. The tendency of calmer winds in the middle of the period is captured, as are the timings of the wind speed peaks. However, as shown in Table 21, there is a moderately positive bias of the simulated compared to the observed values, resulting in a relatively major positive bias (67 % overestimation) when using the cube of the wind speed as a variable. Simulation M2, where the mosaic approach was followed (see above), shows a modest improvement of the bias and a reduced error. From Figure 53 it can be seen that, most of the time, the mosaic approach used in simulation M2 acts to reduce the simulated wind speed. This is not surprising, as the aggregated surface roughness turned out to be higher than in the situation where only dominant land cover (as in M1) was used. Indeed, the area around the Mol site consists of many small forest patches in an otherwise relatively smooth landscape. Many of these small forests are not accounted for when only the dominant cover types are used. In the mosaic approach, however, these small forest patches do contribute to the surface roughness. Even though their fractional area may be low, their contribution to the aggregated roughness is high.

*Table 21. Error statistics for the simulated wind speed at Mol and Amay. The brackets denote a time average of the observed ('obs') versus the simulated ('sim') wind speed (*U*). 'NMD(*U*)' refers to the normalised mean difference of the observed versus simulated wind speed, and 'NMD(*U^3*)' is the same but for the* cube *of the wind speed. The quantities* σ_{obs} *and* σ_{sim} *correspond to the standard deviations of the observed and simulated wind speed, respectively. 'NRMSE' is the normalised (with respect to* σ_{obs}*) root mean square error, and 'IA' is the index of agreement. More details regarding the error statistics used here are provided in Equation (1).*

	$<U_{obs}>$ (m s^{-1})	$<U_{sim}>$ (m s^{-1})	NMD (-)	NMD3 (-)	σ_{obs} (m s^{-1})	σ_{sim} (m s^{-1})	NRMSE (-)	IA (-)
MOL								
M1	6.78	7.95	0.17	0.67	2.00	2.58	0.90	0.68
M2		7.74	0.14	0.40		1.98	0.74	0.70
M3		7.05	0.04	0.06		1.81	0.57	0.89
AMAY								
A1	5.94	3.70	–0.38	–0.76	2.30	1.37	1.15	0.15
A2		5.85	–0.01	–0.07		2.16	0.58	0.90

Even though the use of the mosaic approach improves the simulation result, the bias is not reduced significantly. Therefore, in a next step the local conditions at the site were examined more closely. It was found that the default roughness length of 1.2 m used for forests (see Table 19) is rather inadequate. Indeed, inspection at the measurement site revealed pine trees with a height of 20 m and more. Using the rule-of-thumb that the roughness lenght amounts to about ten percent of the tree height, one can argue that using 2 m as roughness lenght for this site is appropriate. Rather than upsetting the scheme of default roughness values by assigning a new roughness lenght to all forest areas in the domain, a simple roughness correction method was implemented on the available simulated values a posteriori (i.e., without recurring to a new simulation with an adapted site roughness). This correction method is based on the geostrophic drag coefficient (see, e.g., Garratt, 1992), which is defined as

$$C_g = \frac{u_*^2}{G^2}, \tag{2}$$

with u* the friction velocity and G the geostrophic wind speed. Note that, given a wind speed value u(z) and a surface roughness length z0, the friction velocity can also be calculated from the neutral logarithmic wind law, as

$$u_* = \frac{ku(z)}{\ln(z/z_0)}, \tag{3}$$

with k = 0.4 von Kàrmàn's constant. Rossby-number similarity theory states that

$$C_g = \frac{k^2}{\left[\ln\left(\mathrm{Ro}C_g^{1/2}\right) - A\right]^2 + B^2}, \tag{4}$$

where Ro = G / | f | z0 is the Rossby number, with f the Coriolis parameter, and with A ≈ 2 and B ≈ 4.5 empirical constants.

The actual implementation of the correction method was done as follows:

4. In a first step a friction velocity value was calculated based on the simulated wind speed at 69 m together with the default roughness length of 1.2 m, using (3).
5. From this friction velocity, and together with the roughness lenth of 1.2 m, a geostrophic wind speed *G* was calculated using (2) and (4).
6. Using this geostrophic wind speed *G* together with the site-specific roughness length of 2 m, (2) and (4) were used to yield the corresponding enhanced friction velocity, associated with the higher roughness. Note that this required an iterative solution technique, as (4) is a transcendental equation.
7. In the last step, the logarithmic wind profile (3) was used once again, together with the enhanced friction velcotiy and the 2-m roughness, to calculate the 'corrected' 69-m wind speed.

The ratio of the roughness-corrected wind speed to the initially simulated value (i.e., without correction) was found to be very close to 0.91, meaning that the roughness length of 2 m reduces wind speeds by approximately 9 % as compared to wind speed values simulated over the 1.2-m roughness. The originally simulated values with this roughness correction applied for constitute simulation M3. Both from Figure 53 and Table 21 it can be seen that this roughness correction results in a drastic improvement of model performance. The bias of the simulated versus the observed wind speed is now reduced to 4 %, and the average wind power yield, as represented by the average of the cube of the wind speed, is now limited to only 6 %. The standard deviations of the simulated and observed wind speed time series are very close to each other, which is also good, and the Index of Agreement indicates a value very close to 1.

3.6.2.4.2. Amay simulations

The measurement site at Amay is located in the Meuse valley near the city of Liège, Belgium, at 50.5686° N and 5.34439° E. Measurements of wind speed and direction were performed at a height of 27 m above the ground, the base of the mast being at 225 m above sea level. Measurements were averaged over 10-

minute periods, and the data obtained during the ten-minute period preceding each hour were archived. Note that the site is actually a quarry, and the measurement mast was installed on a temporary hill consisting of piled-up stones. The vegetation surrounding the site is relatively smooth, consisting mainly of grass.

A simulation was performed for the Amay site, for the period 6-17 April 2002. The set-up of the simulations was identical as for the Mol simulations, except that the nesting was done within gridded meteorological fields of the FNL model. In previous exercises, the difference between results obtained with nesting within either ECMWF or FNL data had shown only very minor differences. The observed wind speed and wind direction for the Amay site are shown in Figure 54. During the period studied, observed wind speed was moderate to high (sometimes in excess of 10 m s^{-1}) and coming from the nordeast during the first 8 days, followed by lighter winds from the nordwest during the last 4 days.

Simulation A1 is clearly incapable of reproducing the observed time series of wind speed correctly. The simulated values exhibit a systematic and strong negative bias with respect to observed values. The performance statistics Table 21 show that the average of the cubed wind speed is underestimated by 76 %. The cause of this underestimation becomes evident when comparing 1-km resolution topography data (as those used in simulation A1) with 100-m resolution data, as derived from the Shuttle Radar Topography Mission (SRTM) 3-arc second Digital Elevation Model (Figure 55). Indeed, whereas in the smoothed data the measurement site is located on the slope towards the river Meuse, below an escarpment that acts to reduce wind speed, the high-resolution topography identifies the measurements mast as being located on top of a small (sub-grid scale at 1 km model resolution) hill. In order to account for the speed-up effect that such hills are known to induce, a correction was implemented, treating the wind field over the sub-grid scale hill by means of linear flow theory.

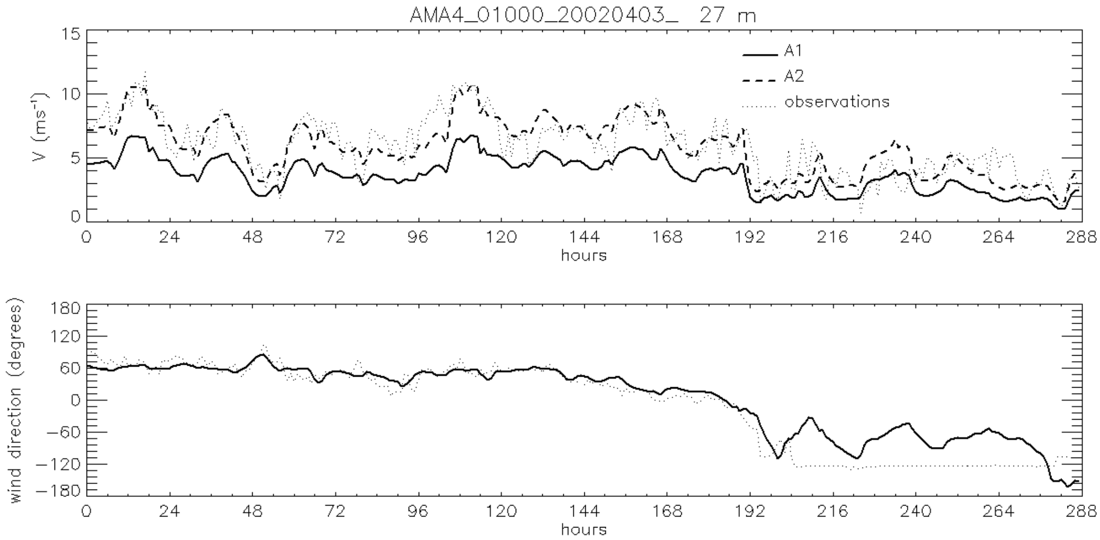


Figure 54. Simulated versus observed wind speed (upper panel) and direction (lower panel) for the site of Amay, 6-17 April 2002.

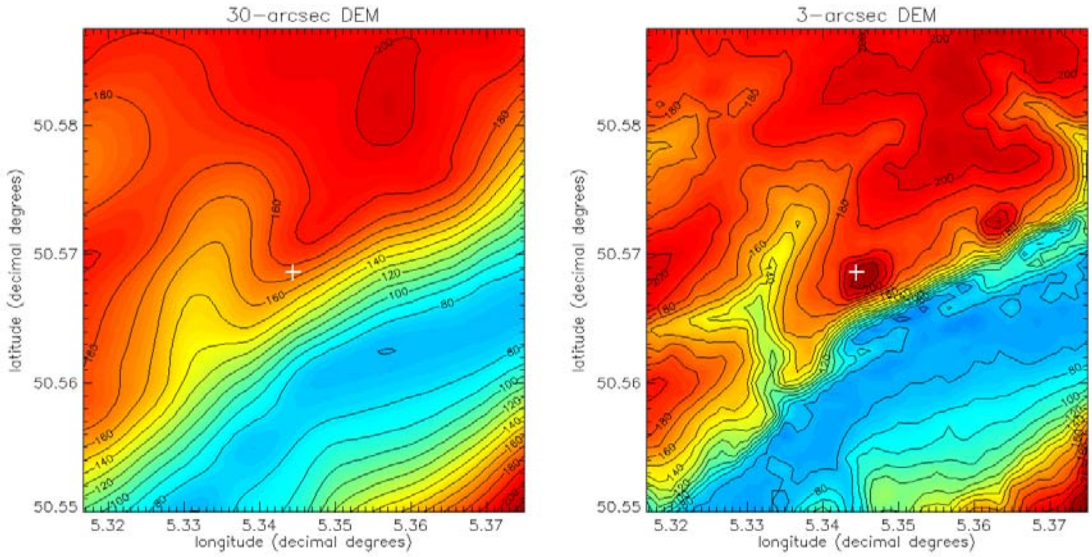


Figure 55. Orography in the vicinity of the Amay site, the observation station being located at the position indicated by the white '+' symbol in the centre. The domain shown is slightly less than 4 km on a side. The left panel shows the orography as contained in the 30-arcsec DEM, and the right panel shows the corresponding orography at a resolution of 3-arcsec. Note that these resolutions roughly correspond to 1 km and 100 m, respectively.

Using linear theory of flow over hills as formulated by Hunt (1988), the following expression can be derived for the wind speed at a height *z* above the top of an axisymmetric hill (see Appendix):

$$U(z) = U_\infty(z)\left[1 + 1.6\frac{H}{L}\frac{\ln^2(l/z_0)}{\ln^2(z/z_0)}\right], \tag{5}$$

with (also refer to Figure 56) U(z) the wind speed over the hill at height z, U∞(z) the wind speed at the same height at inflow, H the height of the hill, L its half-width, z0 the roughness length, and l the depth of the 'inner layer', which is given by the relation

$$\frac{l}{L}\ln\left(\frac{l}{z_0}\right) = 2k^2. \tag{6}$$

Note that this latter expression constitutes an implicit equation for l, which is thus solved for using an iterative method (Newton-Raphson's).

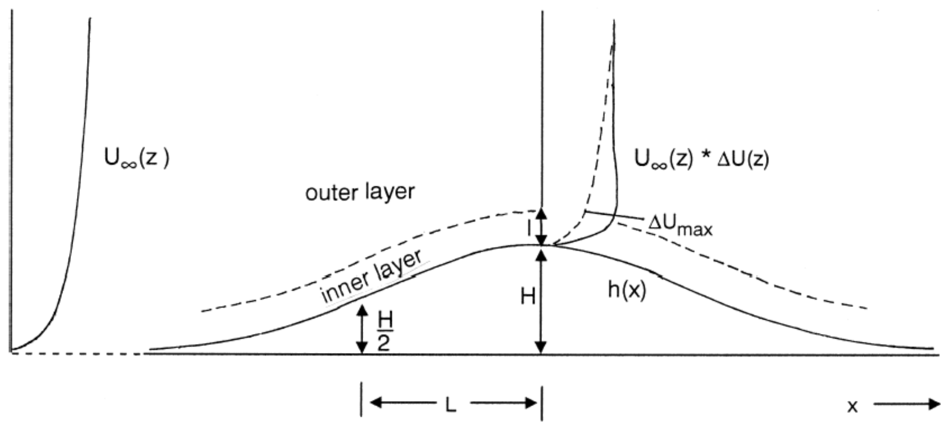


Figure 56. Wind speed-up over a hill, the symbols are explained in the main text.

Available terrain data (as described above), together with data from a local inspection of the measurement site of Amay, yielded the following values for the geometric parameters of the hill: $H \approx 60$ m, $L \approx 100$ m, and $z_0 \approx 0.03$ m. Inserting these values in (5) and (6) resulted in a speed-up factor of 1.58 at the measurement height, that is, $U(z_m) \approx 1.58 \times U_\infty(z_m)$ at z_m =27 m. The resulting corrected wind speed values, constituting simulation A2, show a dramatically improved wind speed prediction for Amay, reducing the bias of the simulated wind speed from -38 % to -1 %, and the corresponding bias for the wind speed cubed from -72 % to -7 %. The IA is seen to increase six-fold from 0.15 to 0.90.

3.6.2.5. *Conclusions*

Simulated wind speed values, obtained with the ARPS meteorological model, were confronted with measured values at two different instrumented sites, located near the towns of Mol and Amay in Belgium. For Mol, a forested site within an otherwise mixed landscape, the main conclusion is that the correct specification of the site-specific roughness length for the pine forest present (2 m), rather than a default value used in the model for this type of land cover (1.2 m), yielded the largest improvement. Another improvement was obtained when the mosaic approach was used, i.e., when several land use types were allowed to co-exist within a single surface grid cell rather than only using the dominant land cover type. For the site of Amay, a major improvement was obtained by accounting for the speed-up effect of a small hill located at the precise position of the measurement mast. This was done by parameterizing the speed-up effect as a sub-grid scale effect, using linear turbulent flow theory. For both sites, accounting for local site-specific effects (roughness and topography), led to a ten-fold decrease of the bias of the simulated versus the observed wind speed cubed.

A general conclusion that may be drawn from the above is that mesoscale models are useful in the context of wind energy assessment studies, provided that proper attention is given to site-specific characteristics. As an alternative, it should be worth considering the use of a combination of mesoscale models and those semi-empirical models that are traditionally used to do site assessments for wind energy. This way, one has the best of both worlds: it would combine the advantages of mesoscale modelling (comprehensive approach, independence of local meteorological data) with those of the site assessment models (advanced accounting for local terrain characteristics, better suited for wind energy yield assessment, users better connected with wind energy industry).

3.6.2.6. *Appendix: Derivation of Eqn. (5)*

The speed-up factor of flow over hills, defined as (for definition of symbols see main text)

$$\Delta S \equiv \frac{U(z) - U_\infty(z)}{U_\infty(z)}, \tag{7}$$

exhibits, for axisymetric hills, maximum values at the inner layer height l of

$$\Delta S_{\max} \equiv 1.6 \frac{H}{L}, \tag{8}$$

(Taylor and Lee, 1987). On the other hand, theory (Hunt, 1988) predicts that the speed-up factor above the inner-layer height (yet below the middle-layer height hm) is given by

$$\Delta S = \frac{H}{L} \frac{U_\infty^2(h_m)}{U_\infty^2(z)} \xi(x), \tag{9}$$

where ξ (x) is a function of order 1. Using the above, and using the neutral logarithmic profile for inflow, it is straightforward to arrive at

$$\frac{\Delta S}{\Delta S_{\max}} = \left[\frac{\ln(l/z_0)}{\ln(z/z_0)} \right]^2, \tag{10}$$

hence

$$\Delta S = \frac{U(z) - U_\infty(z)}{U_\infty(z)} = 1.6 \frac{H}{L} \left[\frac{\ln(l/z_0)}{\ln(z/z_0)} \right]^2 . \tag{11}$$

When inserting z = l in this last expression one retrieves (8), as required. For z > l the speed-up factor decreases with height.

3.6.2.7. References

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3.6.3. The TVM model

3.6.3.1. TVM model description

The TVM (Thermal Vorticity Mesoscale) three-dimensional mesoscale atmospheric model originated from the San Jose State Univ. hydrostatic URBMET PBL model (Bornstein et al. 1987). It solves the dynamic equations in vorticity-mode and has been upgraded to non-hydrostatic and anelastic assumptions (Schayes et al. 1996, Thunis et al. 2000).

The model contains a soil sub-surface layer and the atmospheric surface layer using the usual constant flux surface boundary layer formulation.

Surface temperature and moisture values are computed using surface energy and moisture balance equations, respectively, forced by internally computed solar radiation values. The model has been mainly used for analysing the wind flow in various air pollution studies.

The main characteristics are:

- Density fluctuations are ignored, except in the buoyancy term in the vertical equation of motion. Average density variation with height is allowed. This assumption produces the anelastic form of the continuity equation.
- A hydrostatic or non-hydrostatic version is available. In this project, the non-hydrostatic version is used allowing small horizontal grid cells to be used.
- Sub-saturation specific humidity is a conserved property (no condensation of water vapour allowed in the present application)
- Radiative flux divergence within the PBL occurs only from natural gases (H_2O and CO_2)

The current version of TVM is using a new perturbation formulation. The model solves the equation of the local perturbation over the large scale external forcing. The perturbation is induced by the local topography, surface land use and roughness. The total wind field (i.e. large scale + perturbation) should approximate the real wind field as in a conventional model. This version of the TVM model was developed externally (out of this project) during the years 2003-2004 and tested for the present application during the year 2005.

The terrain topography is obtained from the GTOPO data base adapted for the 1 km resolution. The land use data is obtained from the CORINE data base also at 1 km resolution.

The LS forcing data is obtained from the ECMWF re-analysis data, interpolated for the centre of the domain in the form of a vertical wind and temperature profile updated every 6 h. These forcing profiles are interpolated linearly in time in-between.

3.6.3.2. Analysis of simulation results

The model has been run for the 4 selected sites and the 10 associated periods. The results will be analysed following the seasons.

3.6.3.2.1. Spring : 4-17 April 2002.

The runs have been performed only for the Amay site. As a rule here TVM model results show generally too low winds especially for higher wind speeds. This fact is attributed to the complexity of the local site (close to the Meuse valley).

Experiments have been performed to investigate the effect of spatial resolution (we have been down to 0,5 and 0,25 km grid size) without significant improvement. The table below shows the main figures for this run.

Table 22 TVM results for the Amay test case, Spring 2002

Site	Observed mean WS (m/s)	Calculated mean WS (m/s)	Deviation Mean WS	RMS error (m/s)
Amay	5.93	4.62	- 22 %	2.96

These figures result in much too low predicted power production in this case.

3.6.3.2.2. Summer : 3-9 July 2003

Table 23 TVM results for the Rumes, Arlon and Mol test case, Summer 2003

Site	Observed mean WS (m/s)	Calculated mean WS (m/s)	Deviation Mean WS	RMS error (m/s)
Rumes	3.39	3.68	+ 9 %	1.59
Arlon	3.81	3.16	- 17 %	1.54
Mol 48 m	3.43	3.61	+ 5 %	1.17
Mol 69 m	4.13	4.04	- 2 %	1.27
Mol 114 m	4.40	4.64	+ 6 %	1.33

For Rumes, the wind speed from TVM model is very close to the observed, only showing a little too much wind during the low wind situations. Two wind speed peaks at the begin of the series have no clear explanations. Wind direction is well reproduced. Rumes presents a nearly flat situation.

For Arlon (moderately complex terrain), TVM performs well with a tendency for underestimating the low wind speeds. Note this behaviour is the opposite to the Rumes case.

For Mol, the behaviour seems correct. The average wind is close to the observed one. Surprisingly, the 69 m level wind is under the observations although the other one are above. Mol is a high roughness site as can be seen in the figures, comparable wind speeds to the other sites are found at a much higher height at Mol.

3.6.3.2.3. Autumn : 21-27 October 2004

Table 24 TVM results for the Rumes, Arlon and Mol test case, Autumn 2003

Site	Observed mean WS (m/s)	Calculated mean WS (m/s)	Deviation Mean WS	RMS error (m/s)
Rumes	4.40	4.53	+ 3 %	1.34
Arlon	4.23	3.79	- 10 %	1.63
Mol 48 m	3.96	3.83	- 3%	1.04
Mol 69 m	4.56	4.38	- 4%	1.18
Mol 114 m	5.47	5.30	- 3%	1.57

These simulations look satisfactory. However, for Rumes and Arlon, the first wind speed peak is under estimated, while this is more correct for Mol. Also the three Mol levels show similar slight underestimation. Winds for Rumes are close to observed but for Arlon there is some underestimation. This series is interesting because it exhibits a wider range of wind speeds.

3.6.3.2.4. Winter : 22-28 December 2003

Table 25 TVM results for the Rumes, Arlon and Mol test case, Winter 2003

Site	Observed mean WS (m/s)	Calculated mean WS (m/s)	Deviation Mean WS	RMS error (m/s)
Rumes	7.27	7.06	- 3 %	1.83
Arlon (*)	7.98	7.25	- 9 %	2.13
Mol 48 m	5.77	6.46	+ 12 %	1.99
Mol 69 m	6.45	7.67	+ 19 %	2.53
Mol 114 m	8.00	9.36	+ 17 %	2.96

(*) for this simulation, only 2 days of observations were available.

This series present higher wind speeds. The Rumes series is close to observed with a wide span of wind speeds. Mol runs overestimate the mean wind speed but shows a tendency to underestimate the highest winds. For Arlon, in the limited period for comparison, TVM shows a general underestimation too mainly at the end of the period.

3.6.3.3. General comments over the TVM simulations

First of all, one must make a general remark: this modelling exercise is much too short and restricted to derive any conclusion over the possibilities of mesoscale models in the field of wind energy. Only 4 periods were considered totalising 35 days. The number of different weather situations considered is in this way is too small to derive any valuable statistics.

The exercise was performed to have a view on the potential of this approach.

Over the simpler site of Rumes, TVM performs rather correctly giving a bias on the wind speed of less than 10 % in all cases (average bias -3 %).

Over the site of Arlon which presents a moderate complex topography, the computed wind is in general a little too low (average bias -12 %).

Over the site of Mol, which presents a very high roughness due to the trees but which is otherwise rather horizontally homogeneous TVM shows an average bias of +5.8 %, but much depending on the season (summer and winter runs together average bias about 0 %, but winter run average bias +16 %).

Finally over the site of Amay, which is close to a deep valley, the TVM simulations show an important underestimation (bias of -22 %) but this is only a single experiment and thus we may not draw any firm conclusion from that. This site presents probably local smaller scale features having a typical wavelength smaller than the grid size used in our simulations (1km and 500 m) and thus their influence cannot be represented by the model.

These results show that a potential in using mesoscale models for wind energy exists for sure, but a much longer (in time) and more complete analysis must be performed in order to derive more consistant characteristics.

A last remark is necessary : in these runs, TVM (as ARPS and MAR) was forced by the re-analyses from the European Centre (ECMWF) which delivers data only every 6 hours. This means that meteorological events having a variability in time smaller than 6 hours are not represented in the forcing data and thus cannot appear in the results. A big improvement would already be obtained if the forcing data were available every 3 hours instead.

3.6.3.4. *References*

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3.6.4. The MAR model

3.6.4.1. *Introduction*

The MAR model was initially developed for meso-scale process studies in the Polar Regions. It was later adapted to longer simulation time periods and realistic boundary forcing based on ECMWF reanalysis data, as described in Marbaix et al. (2000). This strategy is similar to that used in other 3D models like ARPS. The ECMWF analysis data does only provide the initial state plus values at the model-domain boundaries, which are several hundred kilometres away from the study site. In this project, we use the hydrostatic version of MAR. The horizontal resolution, 10 km, is approaching the maximum for this version. To reach much higher resolutions, with very detailed topography, it would be desirable to use the non-hydrostatic version. While available in MAR, using this option was not planed here because it would require longer adaptation and testing of the model. The model includes detailed representations of radiation, clouds, convection and turbulence. For clouds, several types of hydrometeors are represented (cloud droplets, cloud ice crystals, rain drops, and snowflakes), with the physical processes that govern the changes from one type to another. For convection, we use a recently developed scheme described in Bechtold et.al. (2001). A convection scheme is needed when the horizontal grid of the model is too coarse (above a few kilometres) to allow the explicit representation of convective motions. This scheme was constructed to provide a general and accurate convective adjustment method, valid for various model and meteorological conditions.

The modelling grid for MAR is 900 km x 900 km large, with a 10 km mesh size (the centre of the grid is at latitude 50.5N, longitude 4.5E). The main model input was modified in order to use surface roughness lengths based on land-use maps from the CORINE database, as for the other models involved in this research. A comparison with older, much less rigorous choice of roughness values showed that the new values based on CORINE provide results which better matches the observed wind speeds.

3.6.4.2. *Analysis of simulation results*

The model has been run for the 4 selected sites and 4 time periods. The results are first analysed following the seasons.

3.6.4.2.1. *Spring : 4-17 April 2002*

Observation data are available only for Amay during this period. The able below shows the main figures for the corresponding run.

Table 26 MAR results for the Amay test case, Spring 2002

	Wind speed			Wind power potential deviation
Site	Modelled (m/s)	Model-obs deviation	RMS error (m/s)	
Amay (27m)	4,37	-26%	2,07	-58%

The mean wind is significantly too low, and the resulting wind energy estimation is severely underestimated. An underestimation of wind speed in this simulation was also obtained with the TVM and ARPS models. The likely explanation was provided by VITO, which noticed that there is a small hill (about 100m large) around the observation site. They computed a correction factor, with an average value of 1.58 (see section 3.5.6.2). With this correction, the results of MAR overestimate the mean with by 16%. The remaining error is most probably connected with the limited resolution of MAR, i.e. 10 km, compared to the width of the Meuse valley near Amay (typically 1 km). The valley is thus not represented, resulting in the overestimation of winds after correction to account for the local details.

3.6.4.2.2. Summer : 3-9 July 2003

The results are reported for the 3 sites in the following table.

Table 27 MAR results for the Rumes, Arlon and Mol test case, Summer 2003

	Wind speed			Wind power potential deviation
Site	Modelled (m/s)	Model-obs deviation	RMS error (m/s)	
Rumes (30m)	3,72	10%	1,46	44%
Arlon (38m)	4,18	10%	1,65	59%
Mol (69m)	4,36	6%	1,78	35%

The model overestimates the wind for all sites. It should be remembered however that correctly representing the wind power, proportional to the cube of the wind, is really difficult for a model. Indeed, even in the worst case, i.e. the simulation for Arlon, the modelled wind speed captures significant features of the observed wind changes (Figure 57). The high variability of the wind speed may also be responsible for some of the model-observation differences (see comments at the end of this section). For Arlon, a significant part of the overestimation is explained by a peak of wind speed at the beginning of the simulation, which was not observed. This might have a connection with the initialisation of the model, but there is probably another explanation, since the ARPS model provided a very similar peak. We also note that at the beginning of the period, the observed wind is relatively weaker at the Arlon site, while this is not the case in Mol and Rumes. In Rumes, the observed wind speed shows a large peak during the first day, as simulated by the model. The problem is thus that the model is simulating a similar peak for the Arlon site, while it was not observed there. The coarse resolution of MAR may explain the absence of such apparently site-specific feature, but a very similar error was obtained with the ARPS model at a much higher resolution. It thus seems possible that the models incompletely represented the mesoscale meteorological features in the area. It is indeed known that predictability is lower in summer. In the present case, thunderstorms where reported in the country. The exact location and details of the associated convection may have been different in the model and in the reality; this may reduce predictability, possibly also on sites not directly hit by the thunderstorms. The wind speed map at the beginning of the peak indeed shows complex geographical variations. However, it should have less impact on long term statistics.

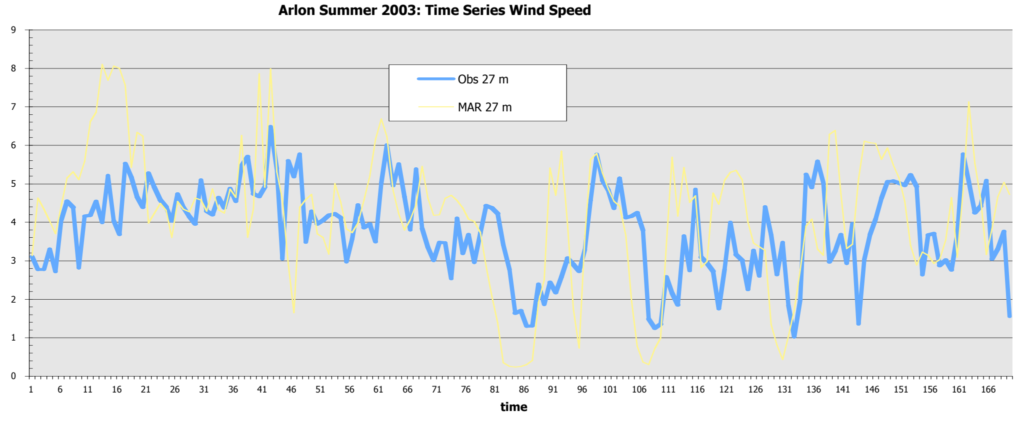

Figure 57: MAR results for the Arlon site, 3-9 july 2003.

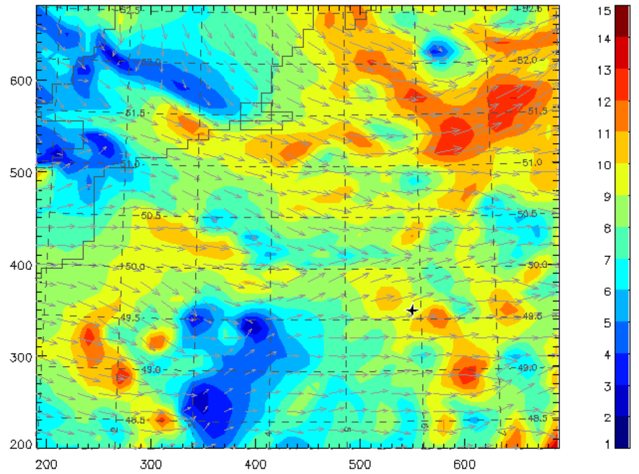

Figure 58: MAR, wind speed (m/s), July 3, 12:00 U.T., 30m above the ground. The black cross locates the site of Arlon. The North-Sea is on the top-left or the map (with a fraction of U.K).

3.6.4.2.3. Autumn : 21-27 October 2004

The results for the autumn period are reported in the following table.

Table 28 MAR results for the Rumes, Arlon and Mol test case, Autumn 2003

	Wind speed			Wind power potential deviation
Site	Modelled (m/s)	Model-obs deviation	RMS error (m/s)	
Rumes (30m)	4,65	6%	1,36	2%
Arlon (38m)	4,32	2%	1,35	1%
Mol (69m)	5,10	12%	1,87	41%

The results for autumn, as well as for winter (below) are much better than for summer. This may partly result of better predictability in this season due to less convective activity, but in the present case the meteorological situation was mostly anticyclonic, so that it is not clear that predictability was much higher. For Rumes and Arlon, the results follows the observations quite impressively (Figure 59), although the computed RMS is still relatively large (see comment at about variability at the end of this section). It is interesting to note that the variability of wind speed is very well represented over Arlon, in spite of the relative complexity of the terrain and the coarse resolution of MAR.

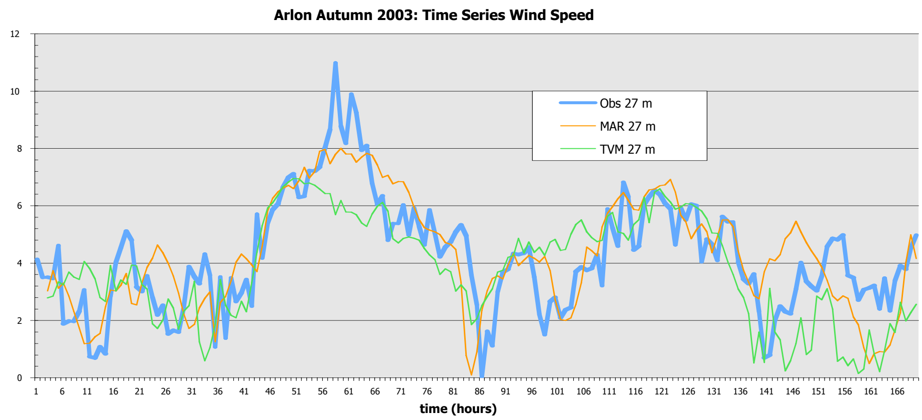

Figure 59 : MAR and TVM results for the period 21-27 October 2004.

3.6.4.2.4. Winter : 22-28 December 2003

Table 29 MAR results for the Rumes, Arlon and Mol test case, Winter 2003

	Wind speed			Wind power potential deviation
Site	Modelled (m/s)	Model-obs deviation	RMS error (m/s)	
Rumes (30m)	7,01	-4%	1,58	-10%
Arlon (38m)(*)	8,24	3%	1,18	15%
Mol (69m)	7,40	15%	1,77	52%

(*) for this simulation, only 2 days of observations were available.

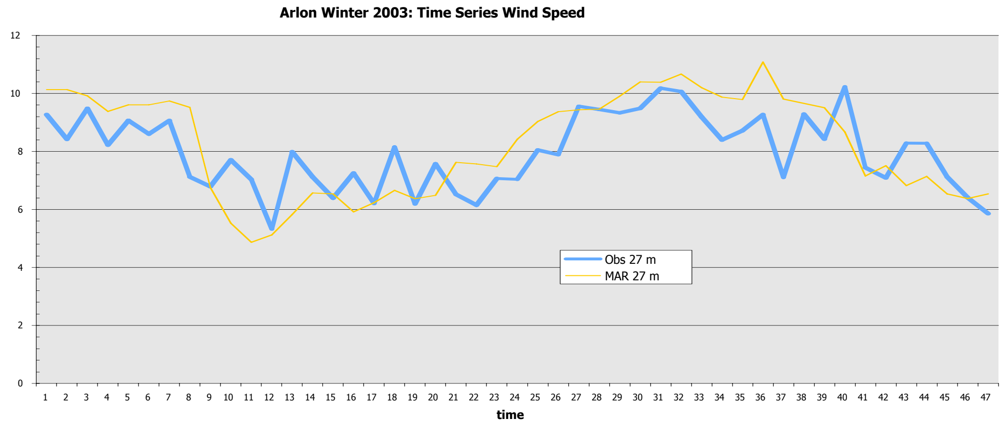

Figure 60 MAR results for Arlon, 22-28 December 2003

As for Autumn, the results are very satisfying for Arlon and Rumes, with more error for the Mol site at 69 m from the ground.

3.6.4.3. General comments on the MAR simulations

3.6.4.3.1. Attempts at improving the results

As the resolution of MAR is quite rough, we paid attention to the procedure used for averaging roughness at the mesh size. However, we did not find a practical way to obtain a better value than the simple (arithmetic) mesh average of roughness values based on CORINE land-use data. As the wind is frequently overestimated in our results, it might be interesting to use an effective roughness length that has some ability to account for the subgrid topography. Although preliminary tests have been done in that direction with MAR, completing this development was not possible within this project and remains a possibility for future work.

A specific issue is the roughness at the model point closest to the observation site. The 10-km average roughness may significantly differ from the site roughness, with large consequences on the results. This was mainly the case for the site of Mol, where the mesh-average CORINE-based roughness is 0.15 m, while the site is mainly covered with high trees. The following table reports results with this mesh average roughness, as well as with an imposed roughness of 1.5 m (only for this mesh, with no other changes).

Table 30 Influence of roughness on the MAR results

	Wind speed			Wind power potential deviation
Roughness	Modelled (m/s)	Model-obs deviation	RMS error (m/s)	
0.15 m	6,92	20%	1,79	74%
1.5 m	6,18	7%	1,31	25%

For the site of Mol, the results are markedly better when the actual local land-use is accounted for. This is illustrated by the reduced deviation from observations in the above table and in *Figure 61*. Note that the results shown in all other figures and tables were obtained with a roughness equal to 1.5 m.

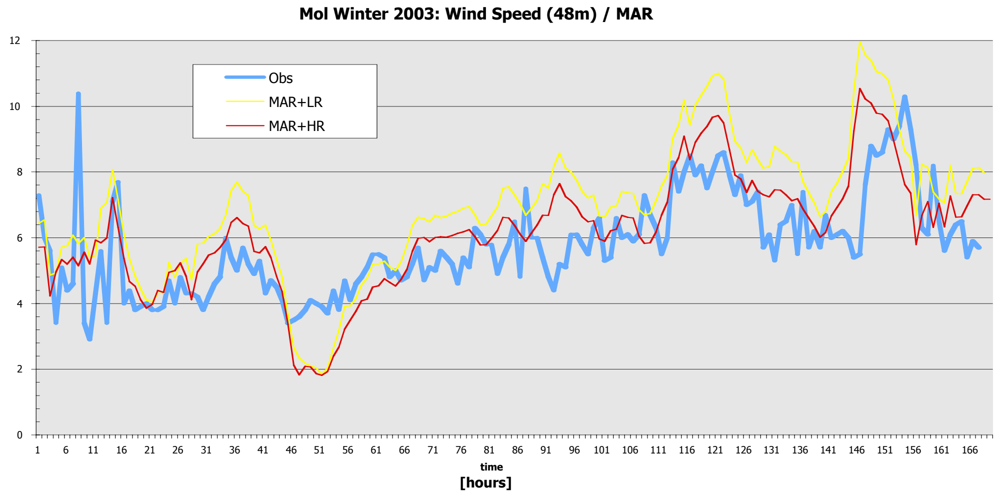

Figure 61 : Wind speed at the Mol site in Winter, effect of roughness length change : standard mesh average roughness (0.15 m, "MAR+LR") and roughness adapted to the local site land-use (1.5 m, "MAR+HR").

3.6.4.3.2. Technical comments

- The MAR results where averaged over the last 10 minutes before each hour, as the observations. Knowing its limited resolution, it may be surprising that the time variability of MAR is quite high, often close to observations. While it provides an apparently realistic variance, the existence of this large variability contributes to increase the RMS error: such rapid changes are largely random in the atmosphere, so that it can not be expected to have a perfect match between model and observations; in such conditions, "smoothed" results would provide lower RMS error. The RMS would not entirely be due to model deficiencies in that case. Further investigations should try to find out to what extent the model variability is realistic, or just represents anomalous model oscillation (noise).
- The large domain size used in MAR (900x900 km) makes the development of mesoscale features possible during the travailing time of air masses from the boundaries to the site. The details of the forcing are thus less important as for TVM. In particular, the fact that the ECMWF analysis provided at the lateral boundaries are available only every 6h should have an impact on the results mostly limited to large and rapidly moving features such as some low pressure systems.

3.6.4.4. Conclusions

The wind speed was generally well simulated, with mean speed errors ranging between 1 and 10% in most cases. Higher error where obtained in Mol (12 and 15% in autumn and winter) as well as Amay. At Amay, the simulated mean wind speed was 26% under the observed value. As noticed by the VITO team, a small hill is surrounding the observation site. When the correction factor computed by VITO is applied, the wind speed is overestimated by 16%: this is most probably due to the coarse resolution of MAR, which cannot capture the nearby Meuse Valley. It is difficult to attribute the somewhat higher error found in Mol (but not in summer), in particular because this result is obtained at 69 m from the ground, while all other sites had only measurements at lower heights and the error is also smaller in Mol at 48 m. It is possible that the details of the land-use (forest), which could not be represented precisely in MAR, also play a role.

For a first set of experiments with MAR in the context of wind energy, and taking into account the limited horizontal scale used (10 km), the results are very satisfying. In some cases, MAR performed as good or better than higher resolution models, while the model resolution probably played a significant role in the inaccurate estimation of wind energy in several other cases. An advantage of this configuration is that it would enable relatively long (months or years) runs over the whole Belgium. Future developments would require a non-hydrostatic model and much higher resolution. While a non-hydrostatic version of MAR has been developed, it would need further testing and coupling to a lower resolution version (nesting). This was outside the scope of this project. Coupling MAR and TVM is also an option that may be considered for future developments, and may use the best characteristics of each model.

3.6.4.5. References

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- Gallée, H. and G. Schayes, 1994. Development of a three-dimensional meso-gamma primitive equations model, Mon. Weather Rev., 122: 671-685.
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3.6.5. The Maestro Wind model

3.6.5.1. Introduction

The modelling exercise proposed in the task 3 aims to provide test cases for modelling systems, such as the meso/micro scale MAESTRO Wind model, which aim to simulate the local climate or local meteorological fields into which wind turbines will be implemented. Evaluation of simulations of the local wind fields and the consequent energy yields is of major importance. Indeed the viability of projects depends on the correctness and reliability of such information.

The set of experiments proposed in task 3 might be considered as too short in time, several periods of time of about 1 week each, with respect to the long term climatology assessment required to investigate the wind potential of a site over the lifetime of the wind turbine. Nevertheless it offers modellers the opportunity to:

-1- Understand physical processes involved,

-2- Investigate the impacts of the terrain complexity on the quality of the model results,

-3- Question about input data sets quality and requirements, and also,

-4- Setup a framework to evaluate and compare correctly simulation and observation.

In this exercise, the MAESTRO Wind model will be forced by hourly meteorological datasets retrieved from one reference weather station. The aim is to analyse model performance over the proposed domains which present various complexity and over the proposed period of time which correspond to various seasons. The analysis of the requirements regarding the selection of the "best" weather station is left for the task 4.4 where various weather stations will be used as reference weather stations.

The selected station is the weather station of Beauvechain which is located is a homogeneous environment and in an almost flat area. Results of Task 1 put in evidence a "variable" wind problem at the station. To deal with this issue, we reconstructed a hybrid dataset taking all parameters required from Beauvechain when wind direction is defined (i.e. wind speed and wind direction at 10m, air temperature at 2m, relative humidity, rainfall, total cloud cover, pressure) and wind direction from Zaventem, Bierset and Gosselies weather stations when the Beauvechain recorded wind direction was "variable". This was performed following the analysis about this station which shows actually defined wind direction in paper records from instruments but which, in the recorded datasets, provides lots of variable winds. These hybrid datasets are then completed over the various periods of simulation. The number of corrected wind direction in the original dataset of Beauvechain for the 4 periods of time is:

-1- Spring (4-17/04/2002): 44 / 288

-2- Summer (3-9/07/2003): 54 / 169

-3- Autumn (21-28/10/2003): 41 / 169

-4- Winter (22-29/12/2003): 4 / 169

The calculations are performed on 25 x 25 km² grids with an horizontal resolution of 250 m. These are centred on the observation sites (see annex 2). The topography is given on the grid from a NGI data base and the land occupation is taken from the Corine Land Cover data base.

The results are given as time series taken at the closest calculation point horizontally and at the altitude of the observation instruments. Further statistical analysis of these time series is then performed to enable model/observation comparison.

3.6.5.2. MAESTRO Wind model description

MAESTRO Wind is a 3D non-hydrostatic meso-meteorological model adapted to determine the wind fields at the local scale on a long term basis (i.e. simulation time period of ~ 1 year). This model solves the Navier-Stokes equations on a terrain following grid using a vorticity formulation. It integrates data (like cloud cover) and models for the atmospheric transfer of solar radiation, energy balance and surface characteristics (like roughness, albedo, emissivity) in order to simulate the boundary layer time evolution and determine realistic local wind fields and other parameters such as the turbulence.

MAESTRO Wind is forced by large scale wind/flow, which can be assessed by a boundary condition called "Geostrophic Wind". This information can either be extracted from large scale modelling results such as the ECMWF re-analysis or from ground observation. Indeed, in the real atmosphere, it is possible to make a "link" between the "geostrophic" wind at ~ 2500 m above ground and the "synoptic" wind available from weather stations at 10 m. To enable this link, it is necessary to ensure that the forcing weather station is representative of the large scale flow. In other words, it is important that the station is not perturbed by "local" terrain effects resulting from a complex topography or a complex land use. This means the weather station has to be "synoptic" or "large scale", not "local" or "perturbed". In the present study the forcing data will be given by a "synoptic" weather station provided by the RMI.

The typical domain extent of MAESTRO Wind starts from a few km to a few tens of km. The horizontal grid resolution that MAESTRO Wind uses corresponds to a mesh size of ~100 m to ~10 km. The standard horizontal resolution used for the Wind Energy Potential Assessment is 250 m.

In order to show the impact of the horizontal grid resolution on the simulation of the local wind fields we show hereafter results obtained using (1) a "large scale" meteorological model (resolution of 10 km which is about the "synoptic" scale) and (2) the MAESTRO Wind model forced by the results of the previous model.

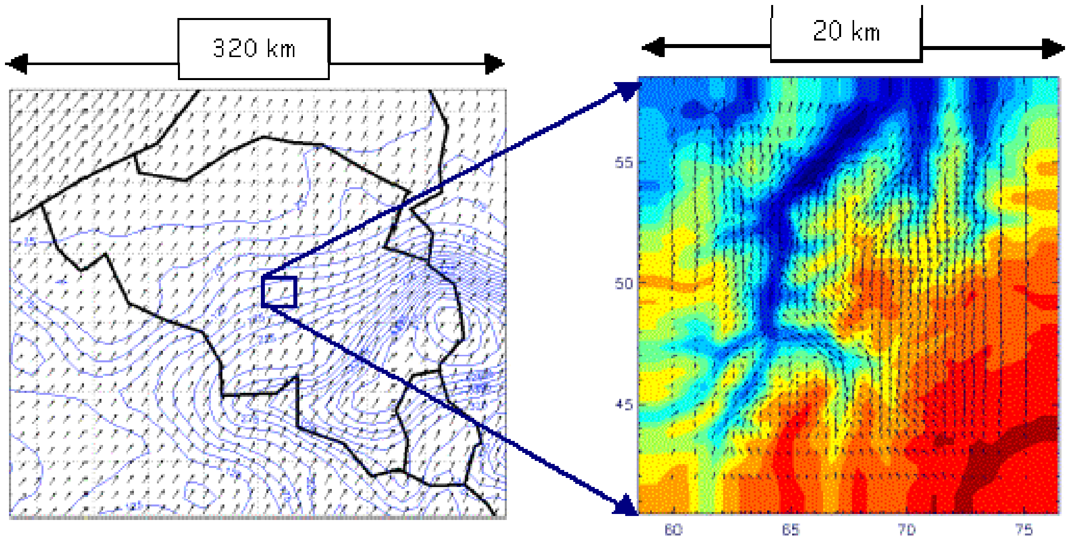


Figure 62 (left): example of meteorological field at the synoptic scale (resolution = 10 km x 10 km). The wind at 10 m is represented by the arrows which give the intensity (length) and direction (orientation) of the wind. The situation corresponds to 2/2/1999 at 20 h. The topography is shown as contour lines. (right): example of meteorological field at the local scale (resolution = 250 m x 250 m). The wind at 10 m is shown. Colour contours provide the topography (blue = valley / red = top of the domain). The local deformation of air movement due to the topography is clearly shown.

An example of MAESTRO Wind validation exercises is given in 3.6.5.5.

3.6.5.3. Analysis of simulation results

The model has been run for the 4 selected sites and 10 associated periods. Focusing on the ability of the models to reproduce the wind fields and energy yields, the variables discussed for the analysis and comparison with observational datasets (see the table hereafter) are:

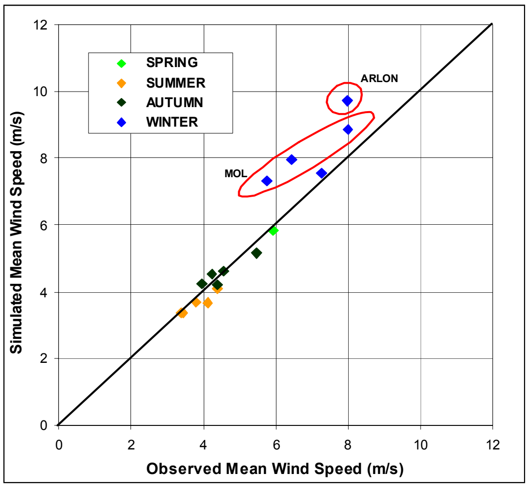
-1- Mean Wind Speed [m/s]

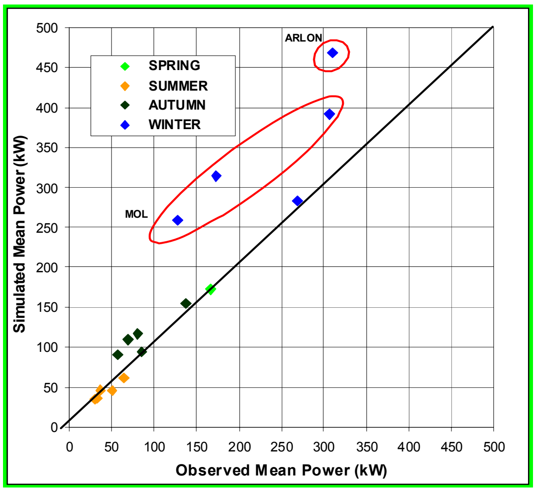
-2- Absolute Deviation in Mean Wind Speed [%]

-3- RMS Error on Mean Wind Speed [m/s]

-4- Mean Power [kW]

To analyse the performance and understand differences between observation and simulation we can draw a synthetic graph showing the Mean Wind Speed and the Mean Power simulated over each of those 10 simulations with respect to corresponding observed ones.





		Zobs (m)	Nb Obs (h)	Obs. MWS (m/s)	Mod. MWS (m/s)	Abs. Dev. MWS (%)	RMS Error (m/s)	Obs. Mean Power (kW)	Mod. Mean Power (kW)
SPRING	*AMAY*	27	288	5.93	5.82	1.9%	1.78	166	173
SUMMER	*MOL*	114	169	4.4	4.09	7.0%	1.77	64	62
	MOL	69	169	4.13	3.67	11.1%	1.71	51	45
	MOL	48	169	3.43	3.37	1.7%	1.44	30	35
	RUMES	30.4	169	3.39	3.37	0.6%	1.40	33	36
	ARLON	37.8	169	3.81	3.7	2.9%	1.79	37	47
AUTUMN	*MOL*	114	169	5.47	5.16	5.7%	2.08	137	155
	MOL	69	169	4.56	4.62	1.3%	1.84	81	117
	MOL	48	169	3.96	4.25	7.3%	1.69	57	91
	RUMES	30.4	169	4.4	4.22	4.1%	1.75	86	94
	ARLON	37.8	169	4.23	4.53	7.1%	2.22	69	109
WINTER	*MOL*	114	47	8	8.86	10.8%	2.25	306	392
	MOL	69	47	6.45	7.96	23.4%	2.38	173	314
	MOL	48	47	5.77	7.31	26.7%	2.25	127	259
	RUMES	30.4	169	7.27	7.56	4.0%	1.98	268	283
	ARLON	37.8	169	7.98	9.72	21.8%	2.59	310	468

The discussion hereafter will be made along the seasons.

3.6.5.3.1. SPRING : 4-17/04/2002

There is only one site analysed during this period which is the site of Amay. This is quite a complex site close to the Meuse valley and inside an excavation site which present different aspects of local topography in time depending on the activities. In order to consider the new configuration of the site, adaptation of the local topography has to be considered.

One can notice that the MAESTRO Wind simulates fairly well this complex case. The deviation on the Mean Wind Speed is only -2 %.

The last indicator, the RMS Error (1.78 m/s), should be considered with care as far as the synoptic systems are changing and passing over the area in some time. The forcing data from Beauvechain might thus be slightly out of phase with the site of observations if this is located at some distances from the reference station. This will result into a shift in time series which will induce higher value of this indicator.

On a short term basis it might be misleading to look at the RMS Error indicator. On a long term basis, the Mean Wind Speed indicator should probably be used as the preferred indicator as far as it will integrate those synoptic fluctuations in the analysis. In this case also the wind speed distribution will another important indicator for the assessment.

Concerning the energy production, MAESTRO Wind provides a very good estimate of the Mean Power resulting in a deviation of only 4 %. It must be said that the analysis period of time is the double of the other ones, i.e. 2 weeks. This is important in order to enable good representation of the wind speed distribution and consequent energy yields resulting from the sequence of few synoptic systems crossing the whole area of concern.

3.6.5.3.2. SUMMER : 3-9/07/2003

The simulations are performed for the Arlon, Mol and Rumes sites. Globally, a fairly good agreement is obtained between the modelling and the observation in what concern the Mean Wind Speed.

On average the absolute deviation on the Mean Wind Speed reaches about 4.7 %. Results indicate also that MAESTRO Wind slightly underestimates the wind speed.

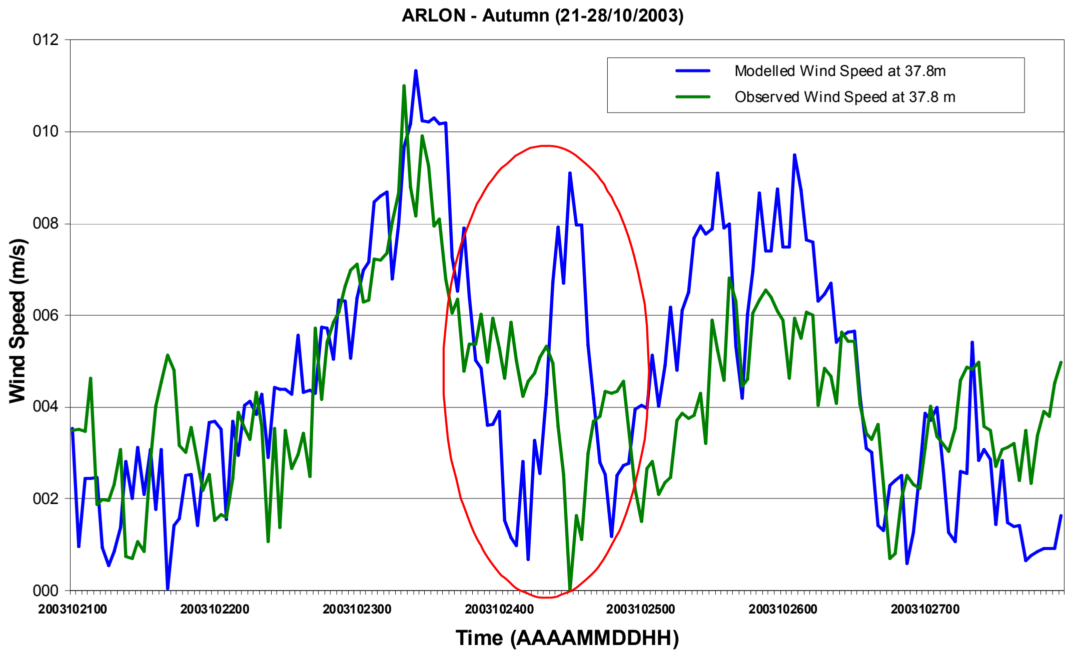
The agreement between observed and model Mean Power seems fairly good but reflects the short time period of analysis.

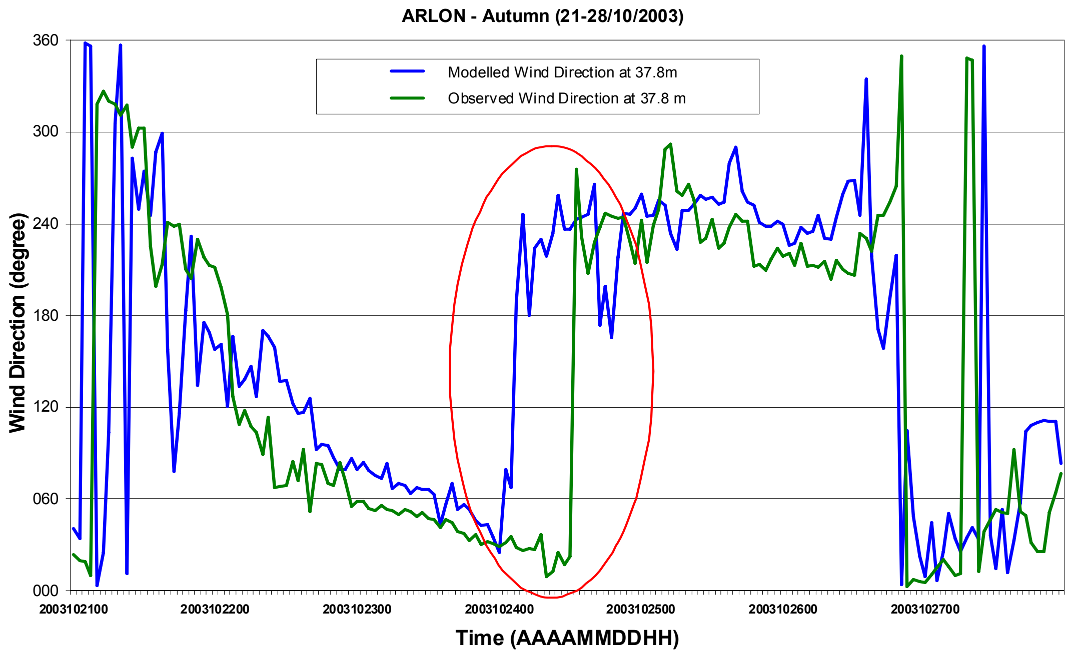
3.6.5.3.3. AUTUMN: 21-27/10/2003

The simulations are performed for the Arlon, Mol and Rumes sites. Globally, a fairly good agreement is also obtained between the modelling and the observation in what concern the Mean Wind Speed.

On average the absolute deviation on the Mean Wind Speed reaches about 5.1 %.

The case of Arlon has been analysed further and provides interesting insights about the origin of the differences between the model results and the observation data. The following graphs point out a change of synoptic situation starting from 23/10 at 20h with a reduction of the wind speed recorded at Beauvechain. The whole synoptic frame moves then slowly towards the Arlon site where a shift is recorded only 12 hours later. Together with the wind speed shift, one can see also that the wind direction changes from the North East towards the South West and that again a delay of about 12 hours is required to observe this shift in Arlon.





This result provides thus some insights about the appropriate location of the reference weather station. Such a station, for the sake of MAESTRO Wind use, should be as representative as possible of the synoptic scale movements of the atmosphere and also the closest one available with respect to the site to investigate. This should ensure a good quality forcing without delays in synoptic scale events.

The agreement between observed and model Mean Power seems fairly good but reflects the short time period of analysis.

3.6.5.3.4. WINTER: 22-28/12/2003

The simulations are performed for the Arlon, Mol and Rumes sites.

For the Rumes site, one observes a good agreement of the MAESTRO Wind simulation and the observation. The deviation on the Mean Wind Speed is 4 %.

For the other sites, Mol and Arlon, one can see that the model overestimates the Mean Wind Speed by 11 % (Mol at 114 m) to 27 % (Mol at 48 m).

It appears from the analysis that during this period of time, the wind speed is generally higher than for the other period of time.

Moreover, the Corine Land Cover data for the area of Mol specifies industrial areas surrounded by forested area. There is a particularity at Mol which is that those sites are located in the forested area itself. So far the parameters associated to industrial areas by the software are not valid. In other words, the land occupation should be updated taking into consideration such particularities. This problem in the database emphasizes the need to combine various datasets of land occupation (Corine Land Cover data base) with other control datasets such as maps, aerial photograph, satellite pictures or any other information coming from a direct on site investigation. While the land cover is adapted to the actual one, the model results might improve.

Another issue for this Mol case is the presence of the forested area surrounding the observation mast. To consider this in the result interpretation, one should consider a displacement height. This means that the anemometer levels in the model are lower than actual ones by about 15m to 20 m. This also reduces the differences between model results and observations.

At Arlon site, a forested area is also located rather close from the observation mast and in the South West direction. This is the direction from which the wind blows mainly during this period. An impact of the forested area is to reduce the wind speed behind it, and in particular at the mast. This should be also considered in the analysis through a displacement height to be used in interpretation of model results. One can also point out the very short period of time, only 2 days, which is far too small to provide firm conclusions.

These issues reflect also in the Mean Power which is exaggerated in those cases where the observation site is in or nearby the forested area.

3.6.5.4. Synthesis on the MAESTRO Wind simulations

All simulations for the Task 3 are using the same weather station, Beauvechain, as a reference to provide the hourly input data for the modelling. Hybrid datasets have been produced in order to deal with some technical issues regarding the variable wind direction (see Task 1).

The main objective of using the same reference weather station is to focus the analysis on the impacts of the terrain complexity, on the impacts of meteorological synoptic conditions / seasons and on the analysis framework that has to be put in place to compare correctly / realistically the simulation results and the observation data.

The model grids used for these simulations are centred on the observation site. Their extent is 25 x 25 km² and their resolution is 250 m horizontally. The vertical grid extent up to 5000 m on a stretched grid with levels at 10, 32, 59, 93, 134, 184, …

A preliminary remark is that short time period analysed here are far too short to be fully conclusive. Instead long term assessment should be made at the end in order to explore and analyse a bigger number of meteorological situations. An attempt in this sense will be addressed within the Task 4.4. .

With respect to the Mean Wind Speed, which can be seen as a long term indicator, most of the results show a good agreement between the simulations and the observations, resulting in absolute deviation of about 5 %. Some results show higher deviations. These correspond to observation sites located in or nearby forested area. Such forested area will reduce the wind speed at level of interest in reality. This effect can be assessed through the introduction of the displacement height concept into the model result analysis.

It appears from this analysis that the location of the observation site is quite crucial when an investigation of the wind potential is performed. Indeed, mast located in or nearby forested area might be influenced by very local effects whose impacts on the wind field might be a function of wind speed, wind direction, forest density, and so on … Extrapolate such data to a wind farm which extends over several km² might result in misleading information on the energy potential of the site.

Analysis of the time series over such short period of time provides nevertheless some useful information. In particular it appears that on a short term basis the location of the reference weather station with respect to observation sites might have an impact on the analysis in the sense that some meteorological events which are passing over large areas, regions or countries, may be seen sooner or later at the reference station with respect to observation site. Short term indicators like the deviation of Mean Wind Speed or the RMS Error indicator will then lead to quite "bad" results even if on the long term basis the overall distribution of the wind speed might be well simulated. Taking care of such shift in time of synoptic scale movements of the atmosphere will improve the comparison.

The choice of the closest synoptic reference weather station is probably more important for short term analysis than for the long term assessment within which many situations will pass over the areas of concern (see also Task 4.4). Moreover such ideal reference station might not exist. Other sources of information might then be investigated such as ECMWF RE-Analysis, but those might be more complex to use and are not provided on an hourly basis for now.

Finally it comes out that validation exercises should be made over long enough periods of time while looking at a fair model/observation comparison of wind speed distribution and the subsequent energy yield. This will ensure that all the synoptic events which last over few days pass over the whole area of concern and avoid misleading analysis. The farther the reference station is located from the observation site, the longer the time period of analysis should be, at least in the case of MAESTRO Wind which is driven by a synoptic reference weather station which can be at some distances from the observation site.

So far we can expect from the modelling exercise performed here that, as far as the period of analysis will be long enough to enable to integrate same number of synoptic events crossing the area in the analysis, i.e. both reference station area and analysis site area, the estimate of wind speed distribution and energy yield using MAESTRO Wind will be very good.

3.6.5.5. Annex 1: Example of MAESTRO Wind validation exercises (ATM-PRO)

As an example of MAESTRO Wind validation, we show hereafter results obtained in the framework of an environmental impact study in the Walloon Region. The results show the wind rose and the wind speed distribution. The results correspond to a one-year simulation at a hourly basis (i.e. 8760 h) and are compared to available local observations. Correlation coefficients of 99.1 and 99.9 % are calculated respectively for the wind speed and the wind direction. The RMS estimated error is about 0.7 m/s for the wind speed and about 5.4 degree for the wind direction. It is important to note that forcing data from synoptic weather station are given with an accuracy of 0.5 m/s for the wind speed and 5 degrees for the wind direction.

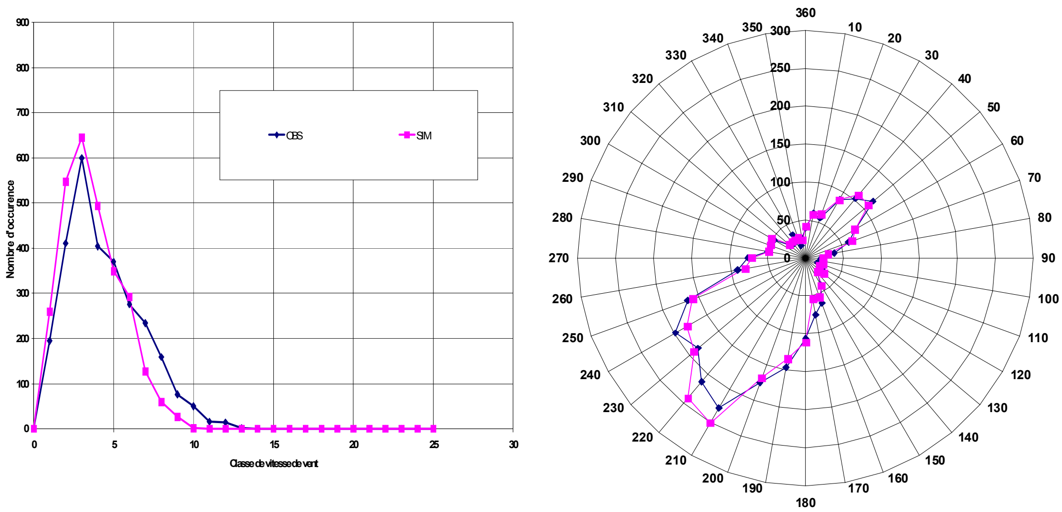
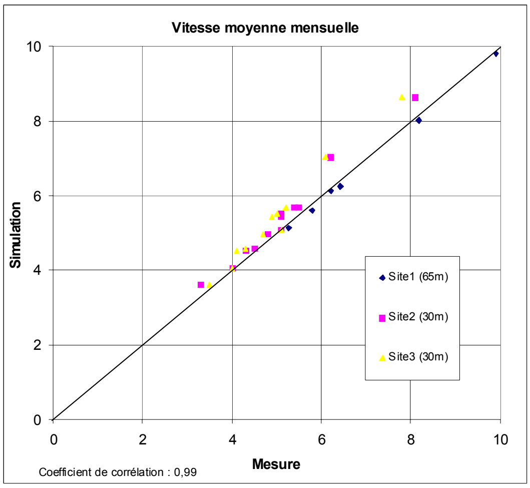
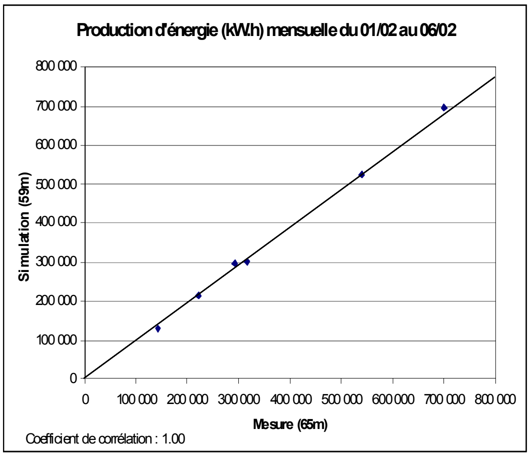


Figure 63 Wind rose. Observation (blue) / Simulation (pink)

Recently, ATM-PRO has conducted another validation project of MAESTRO Wind for the Ministry of the Walloon Region. The main results (see www.atmpro.be for additional information) are summarized in the following graphics showing (1) monthly averaged wind speed at various locations as well as (2) estimates of energy production. On these graphics the observed values are given in abscissa and the simulation results in ordinates



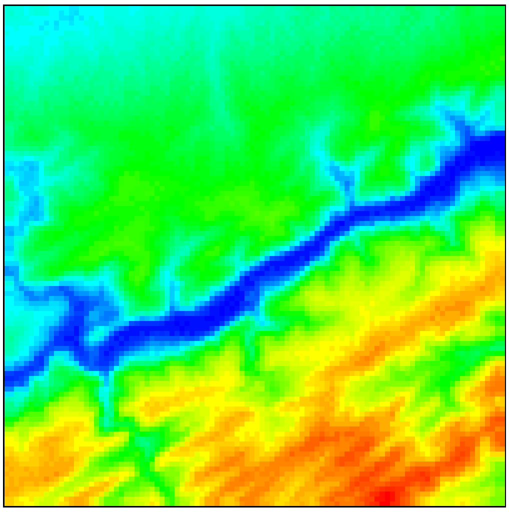


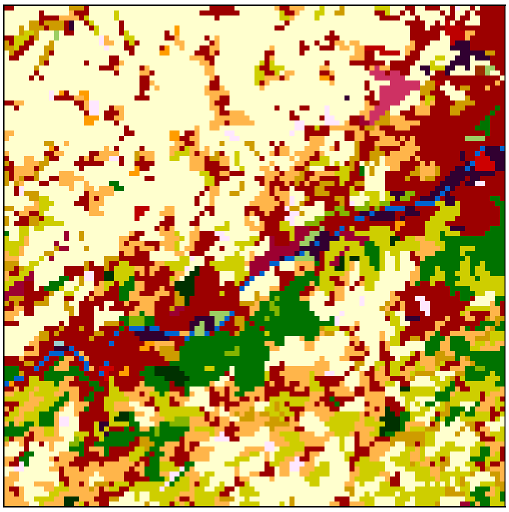
Concerning the wind energy production recent results obtained in other validation exercises aiming to simulate actual energy produced existing wind parks show that when a resolution of 1000 m is used for the modelling one obtains an RMS error estimate of 15 % with respect to actual values from existing wind turbines. At 250 m resolution this error decreases up to 3 – 4 %. This shows the impact of a good representation of the terrain complexity together with an appropriate modelling system.

3.6.5.6. Annex 2: Description of the domain configurations

3.6.5.6.1. Site of Amay

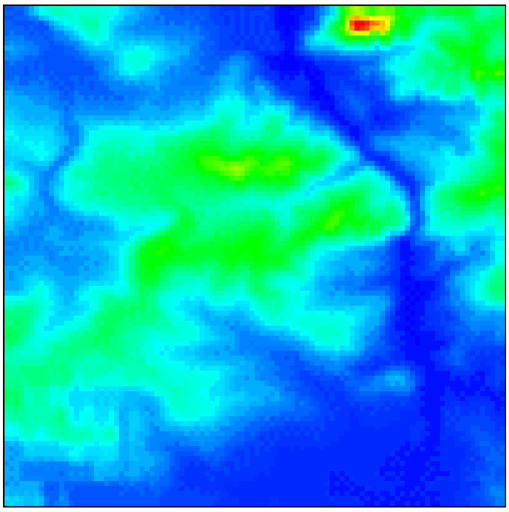
The domain of calculation extends from 206500 to 231500 m Lambert in the West-East direction and from 127500 to 152500 m Lambert in the South-North direction. The figures show the topography (l.h.s.) and the land use (r.h.s.). The star shows the location of the observation mast.

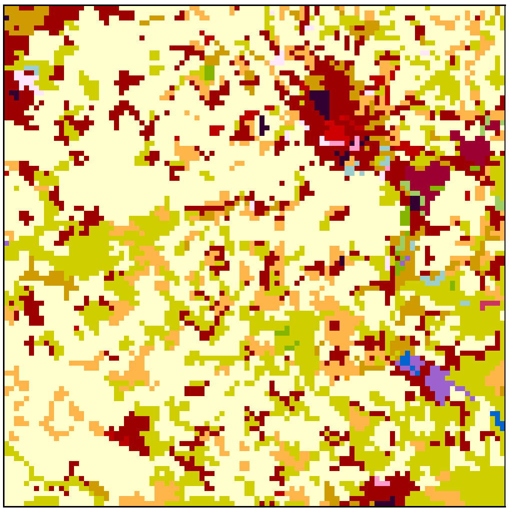




3.6.5.6.2. Site of Rumes

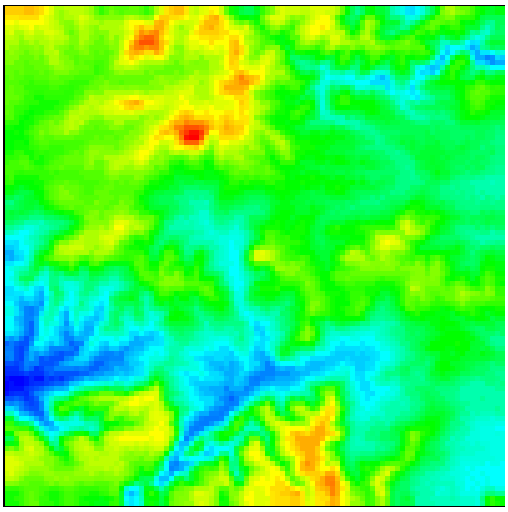
The domain of calculation extends from 63750 to 88750 m Lambert in the West-East direction and from 125750 to 150750 m Lambert in the South-North direction. The figures show the topography (l.h.s.) and the land use (r.h.s.). The star shows the location of the observation mast.

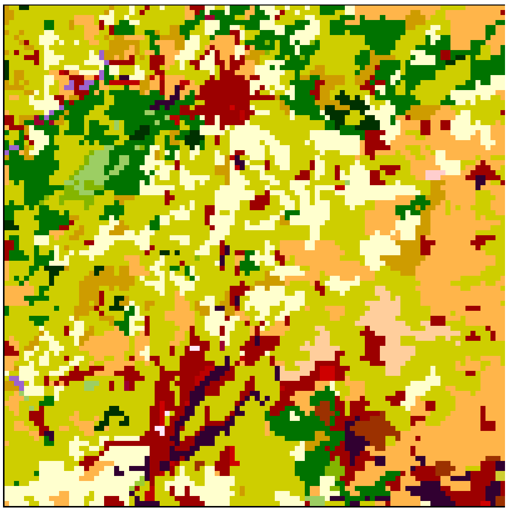




3.6.5.6.3. Site of Arlon

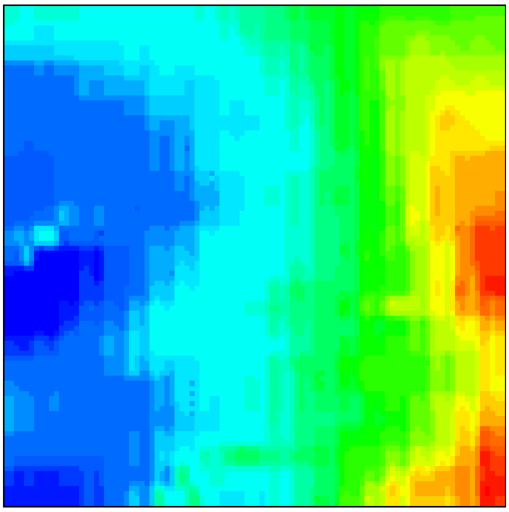
The domain of calculation extends from 243000 to 268000 m Lambert in the West-East direction and from 21500 to 46500 m Lambert in the South-North direction. The figures show the topography (l.h.s.) and the land use (r.h.s.). The star shows the location of the observation mast.

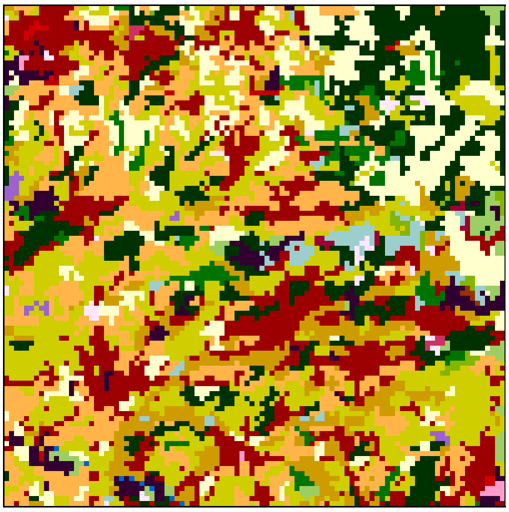




3.6.5.6.4. Site of Mol

The domain of calculation extends from 188000 to 213000 km Lambert in the West-East direction and from 199750 to 224750 m Lambert in the South-North direction. The figures show the topography (l.h.s.) and the land use (r.h.s.). The star shows the location of the observation mast.





3.6.5.7. References

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3.6.6. The WAsP model

3.6.6.1. Introduction

WAsP is a PC program to estimate wind energy resources. The program is described in detail by Troen and Petersen (1989) [7]. The program can generalise a long-term meteorological data series at a (reference) site and may then be used to estimate conditions at a second (predicted) site within certain limits of climate and terrain. The data generalisation is done through the WAsP Analysis procedure, which corrects the measured data series for local effects that only affect the reference site (meteo station), but are not of more general nature. These local effects are:

- shelter from near-by obstacles such as houses and wind-breaks (obstacle model),
- terrain surface roughness (roughness model), and
- orography (BZ orographic flow model).

The generalised data are stored in the Atlas file which may then be used through the reverse process of the WAsP Application procedure in order to estimate the mean wind speeds and wind energy at a second (predicted) site, often referred to as a wind turbine site. A diagram showing the methodology of WAsP is shown in Figure 64.

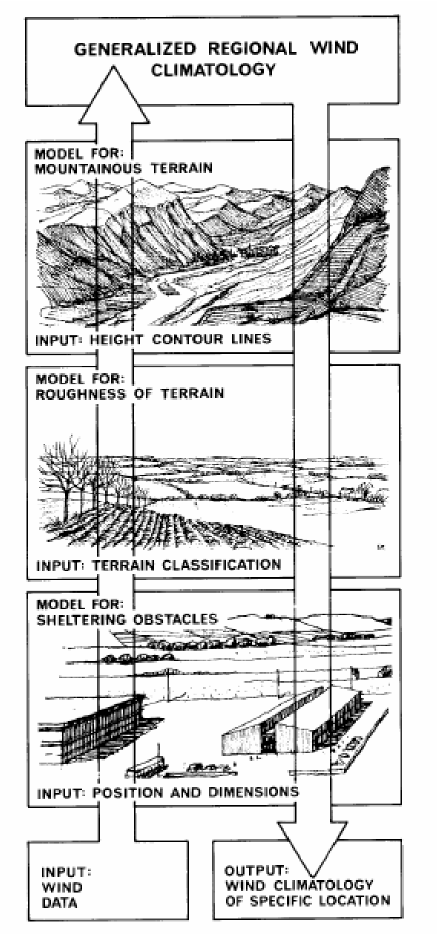


Figure 64 The Wind Atlas methodology used in WAsP. Meteorological models are used to calculate the regional wind climatology from the raw data series. In the reverse process — the application of wind atlas data — the wind climate at any specific site may be calculated from the regional climatology (Troen and Petersen, 1989).

WAsP utilises the 'BZ-model' of Troen (1990, [7]) to calculate the wind velocity perturbations induced by orographic features such as single hills or more complex terrain. The BZ-model belongs to a family of models related to the Jackson and Hunt theory for flow over hills (Jackson and Hunt, 1975). The model was developed with the specific purpose of detailed wind energy siting in mind and has the following general features:

- It employs a high-resolution, zooming, polar grid. This is coupled with a map analysis routine in order to calculate the potential flow perturbation profile at the central point of the model.
- It integrates the roughness conditions of the terrain surface into the spectral or scale decomposition. The 'inner-layer' structure is calculated using a balance condition between surface stress, advection and the pressure gradient.
- It uses an atmospheric boundary layer thickness of approx. 1 km to force the large scale (say, more than a few kilometres) flow around high-elevation areas.

The BZ model is a linear model. The interaction of this model with the roughness change however is non-linear. Also, its hill-flow model assumes neutral stratification, but the mean wind field is for non-neutral stratification. The BZ flow model can handle single digital maps with up to about 500 000 points. If the map contains more points, it should be reduced, e.g. using the Map Editor.

In general, accurate predictions using the WAsP BZ flow model may be obtained (Bowen and Mortensen, 1996) provided:

- the meteorological station and wind turbine site are subject to the same overall weather regime, i.e. that meso-scale effects are not significant,
- the prevailing weather conditions are close to being neutrally stable, however empirical corrections for mildly non-neutral conditions may also be applied through manipulation of the WAsP parameters.

- In view of the practical limitations imposed by climate and terrain, it is recommended that the proper use of the program is confined to terrain which may have low, smooth hills of small to moderate dimensions with sufficiently gentle slopes for areas of flow separation to be insignificant. The latter requirement in particular has a significant impact on the accuracy of WAsP predictions in complex terrain.

Under these conditions, WAsP has been shown to be reliable and accurate. It has been used extensively to develop the European Wind Atlas [7] and similar assessments of the wind energy resources in a number of other countries. Within the project, the WAsP version 8.1 is being used.

In order to perform the short term simulations of Task 3, the WAsP model had to be adapted by 3E. WAsP is designed to generalise a long-term meteorological data series at a (reference) site into a so called wind atlas, which may then be used to estimate the local wind regime at a second (predicted) site within certain limits of climate and terrain. Contrarily to this design emphasis of the model, the WAsP tool should be used here in Task 3 to simulate short term data series. Therefore, it is not possible to use the WAsP software in its original form.

In order to simulate the short term data series, a Matlab based program has been written, based on the original model of WAsP. For both the reference site and the observed site, the terrain description (orography, roughness and obstacles) are defined in the original WAsP tool to generate the site description table (description of roughness values per sector and speed up factors and direction deflections due to orography, roughness and obstacles per sector). These tables are used in the Matlab program to transform the time series of wind speed and wind direction from the reference site to the observed site, by means of the geostrophic drag law and the surface layer similarity laws. The methodology is as described in the European Wind Atlas.

3E wants to stress that it is not the objective of this project to improve or modify the WAsP model.

3.6.6.2. Analysis of the simulation results

The analysis is focused on the simulation for the site of Amay in spring 2002. This site is chosen as it represents a very complex site and it's well knownthat WAsP is developed for flat or slightly hilly terrain.

For this simulation, the observed data of the reference station of Humain, operated by IRM, at the height of 24 m above ground level, was used. The following figures show the main results.

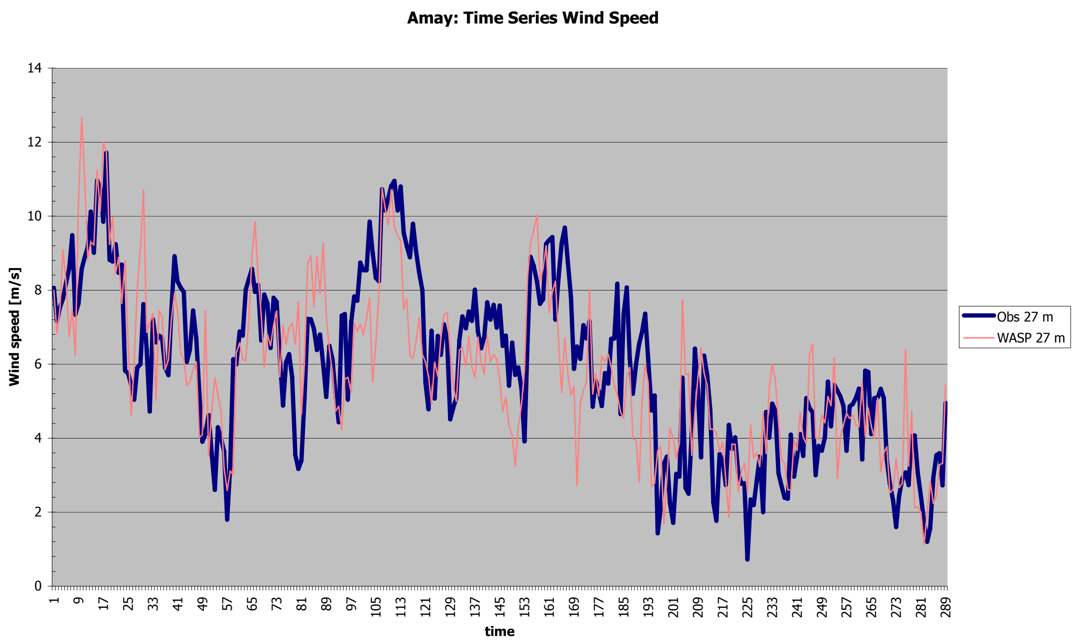


Figure 65 Time series of wind speed for the site of Amay, simulation with WAsP

The simulated wind speed follows quite well the observed wind speed. The deviation in average wind speed is only 2%, while the deviation in energy yield is 8% (predicted too less by WAsP). The rms error of wind speed is 1.53 m/s.

A major difference compared to the approach of other models tested in this project is the selection of the reference station. While the meso-scale models are based on ECMWF or NCEP/NCAR data, the micro scale models use ground reference stations as input meteo data. The Maestro Wind model always uses the same reference station, Beauvechain, from IRM, for the prediction of whatever site in Belgium. For the WAsP model, one normally will select a reference meteo station within the close vicinity of the examined site and having the same terrain characteristics as the examined site.

The following exercises is focused on the test site of Rumes, for which several simulations have been executed based on the reference meteo data of different reference stations of IRM: Beitem, Chièvre, Melle and Semmerzake. The site of Rumes is chosen for this exercise since the terrain characteristics are rather simple: flat terrain, few obstacles and a quite uniform roughness.

Table 31 Reference stations for simulations for Rumes

Name of Obs site	Ref station	Name of Ref site	Distance [km]	Elevation difference [m]
Rumes	6432	Chièvres	36	1
	6414	Beitem	42	37
	6428	Semmerzake	51	25
	6434	Melle	59	50

The following table summarises the results of the simulations on wind speed and wind power.

Table 32 Simulation for Rumes, December 2003, based on different reference stations of IRM

	Wind speed		Wind power	
Reference station	Deviation [%]	Rms error [m/s]	Deviation [%]	Rms error [m/s]
Beitem	4.48%	1.71	15.00%	162
Chièvre	3.78%	1.90	9.64%	149
Melle	-2.20%	1.67	-7.31%	145
Semmerzake	-5.31%	1.79	-13.30%	151

The deviation in wind speed is in the order of +/- 5%, while the deviation in wind power, proportionally with the third power of wind speed, grows up to +/- 15%.

Similar results where found for the other test cases.

3.6.6.3. Thorntonbank

This case represents an offshore simulation for the sandbank called Thorntonbank, located within the designated area for the development of wind energy projects in the Belgian continental shelf. The company C-Power has received permission to start the construction of the first offshore wind park in the Belgian Continental Shelf.

No wind measurements have taken place so far on the Thorntonbank. Therefore, in the frame of this research, no comparison between simulation and observation could be performed.

Long term wind data from the measuring station Westhinder (MOW7) has been used to perform the calculations of the long term wind regime at the Thorntonbank. The meteo data for the measuring station MOW7 Westhinder is delivered by The Monitoring Network Flemish Banks (AWZ – afdeling Kust, Meetnet Vlaamse Banken). The Monitoring Network Flemish Banks was set up for the acquisition of real-time oceanographical and meteorological data along the Belgian coast and on the Belgian continental shelf. The Network is sponsored by the government of Flanders, and set up and maintained by the Waterways and Maritime Affairs Administration (Administratie Leefmilieu en Infrastructuur, Afdeling Waterwegen en Zeewezen: AWK, Vrijhavenstraat 3, 8400 Oostende). Contact person is ir. Guido Dumon, head of Hydrography en Hydrometeo ☐.

The Monitoring Network Flemish Banks consists of a number of measuring pylons, wave boys, meteo parks and tidal measurers. The oceanographic parameters monitored are waves, tidal height, current and water temperature; meteorological parameters are wind, air pressure, air temperature and rainfall.

Data is delivered for the measuring station Westhinder (MOW7) over the period from 30/03/1994 until 30/06/2003, i.e 9 years and 3 months. The availability of the measuring station MOW7 is high (94%) and the measuring period is sufficient long. An overview of the results of the statistical analysis of MOW7 Westhinder is given in the next table.

Table 33 Statistical summary of measuring station MOW7 Westhinder

Measuring station	MOW7, Westhinder
Position (Lambert72)	15596 E, 232624 N
Measuring height [above mean sea level]	25.25
Period	Maa 94–Jun 03
Availability	94%
Number of observations	456230
Number of observations per day	144
Mean wind speed [m/s]	8.52
Weibull A [m/s]	9.618
Weibull k[-]	2.196
Prevailing wind direction	WSW (18.8%)

Figure 49 and Figure 50 show the position of the sandbank Thorntonbank and the measuring station Westhinder in relation to the coast line. The Thorntonbank is situated 27 km out of the coast of Zeebrugge. Measuring station MOW7 lays about 35 km out of the coast of Middelkerke.

The results for the calculations of the wind regime at the Thorntonbank, based on the long term observations at the meteo station Westhinder, are summarised in the following table.

Table 34 Calculated wind regime at the Thorntonbank

Height	Mean wind speed [m/s]	A- parameter [m/s]	k- parameter
25	7,7	8,7	1,99
30	7,9	8,9	2,02
35	8,1	9,1	2,04
40	8,2	9,2	2,06
45	8,3	9,4	2,08
50	8,4	9,5	2,10
55	8,5	9,7	2,11
60	8,7	9,8	2,12
65	8,8	9,9	2,12
70	8,9	10,0	2,13
75	8,9	10,1	2,14
80	9,0	10,2	2,14
85	9,1	10,3	2,15
90	9,2	10,4	2,15
95	9,2	10,4	2,16
100	9,3	10,5	2,16
105	9,4	10,6	2,16
110	9,5	10,7	2,16
115	9,6	10,8	2,16
120	9,6	10,9	2,16

Due to the lack of observed wind data at the Thorntonbank is it impossible to verify the results of these calculations.

Therefore, a second exercise has been performed. The wind climate of measuring station Westhinder (MOW7) has been used to predict the wind climate at the measuring station Wandelaar (MOW0), of which data was made available as well by the Monitoring Network Flemish Banks. Measuring station Wandelaar lays about 10 km out of the coast. The simulation has been executed for the month June 2003. The results are summarised hereafter.

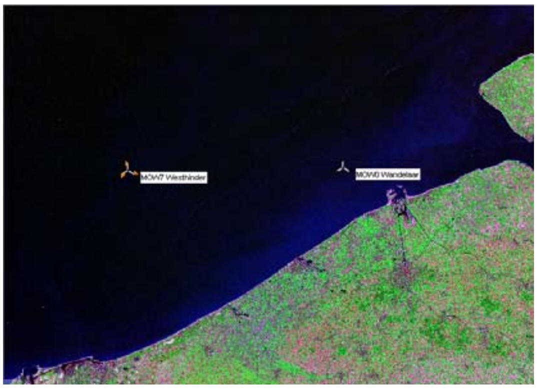
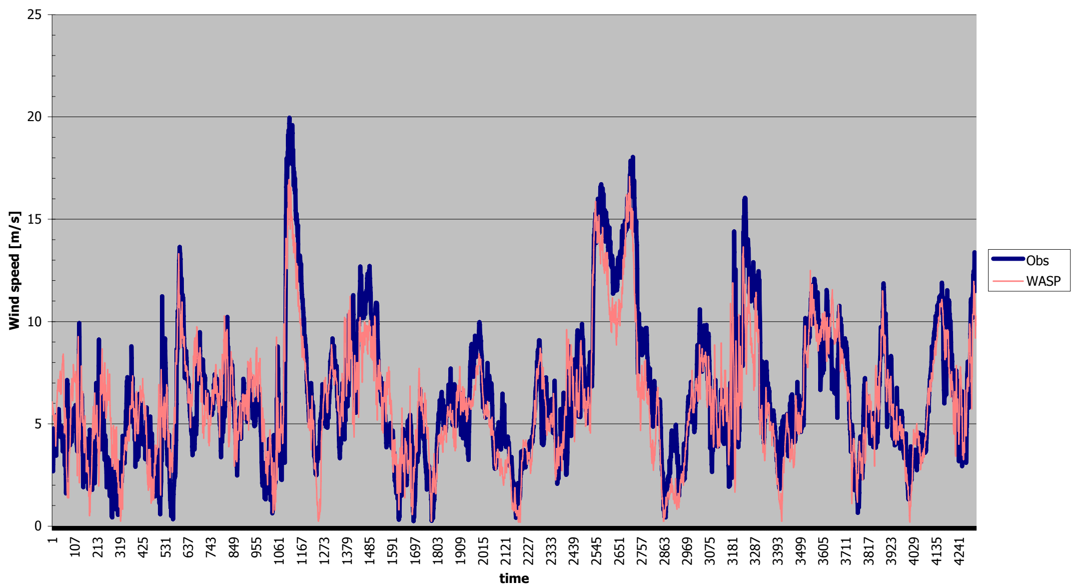


Figure 66 Position of measuring stations Westhinder (MOW7) and Wandelaar (MOW0)

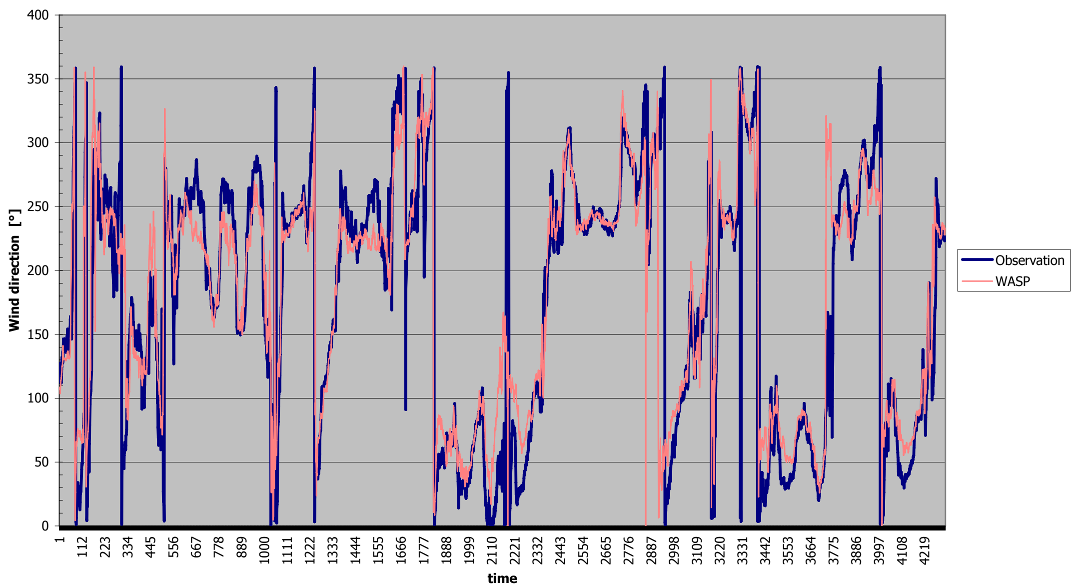
Table 35 Summary table: Prediction of the wind climate at Wandelaar using Westhinder: June 2003

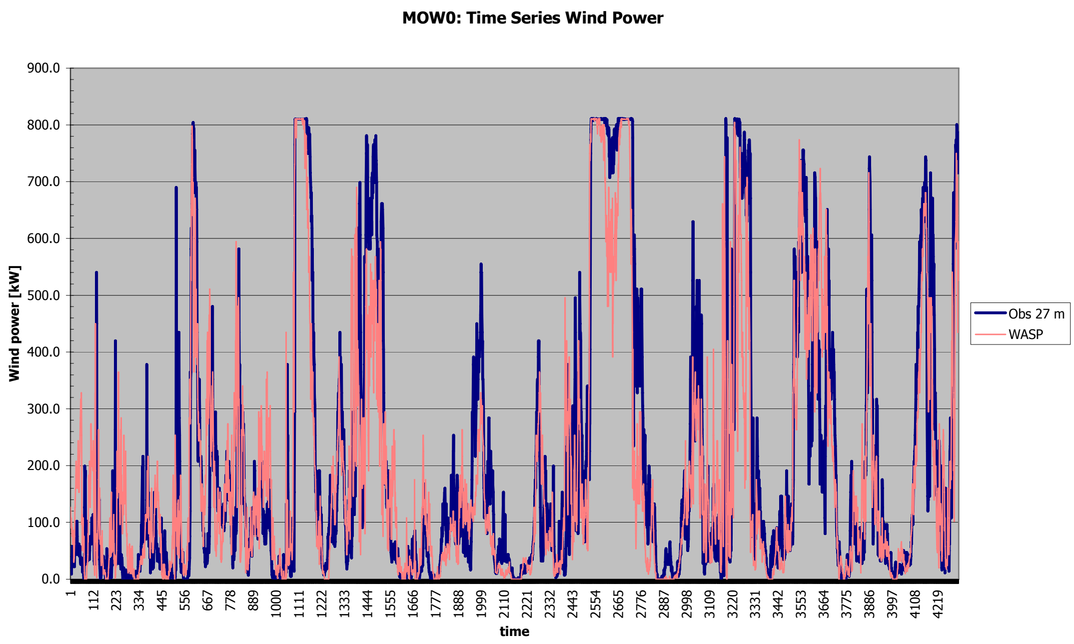
		Observed data	Model 5: WASP (3E)
STATSITCAL VALUES			
Mean wind speed [m/s]		6.41	6.14
St.deviation of wind speed [m/s]		3.48	3.00
Mean power [kW]		213	193
Capacity factor		26%	24%
#data		4320	4320
COMPARISON WITH OBSERVATION			
Deviation wind speed			-4%
RMS wind speed			1.91
Deviation Energy Yield			-9%
RMS Energy Yield			137.84
REGRESSION			
Wind speed		A []	0.7248
		B [m/s]	1.4925
		R^2	0.0053
Wind direction		A []	0.6417
		B [m/s]	71.4079
		R^2	0.4776
Energy yield		A []	-7.0799
		B [m/s]	111.2603
		R^2	0.0026

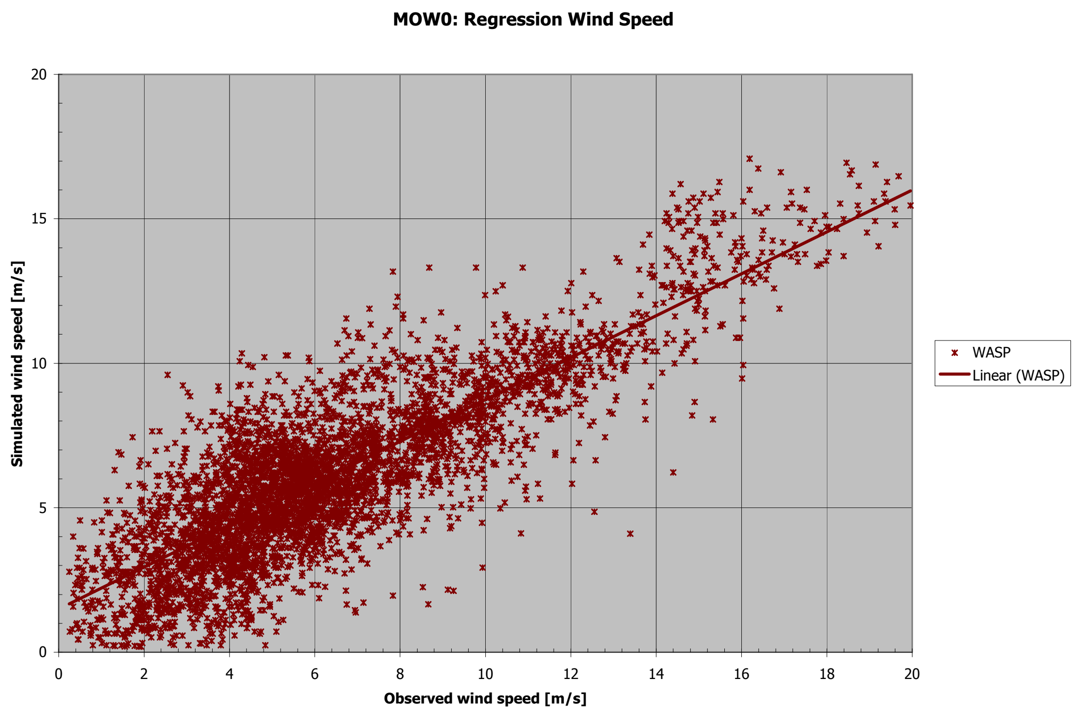
MOW0: Time Series Wind Speed

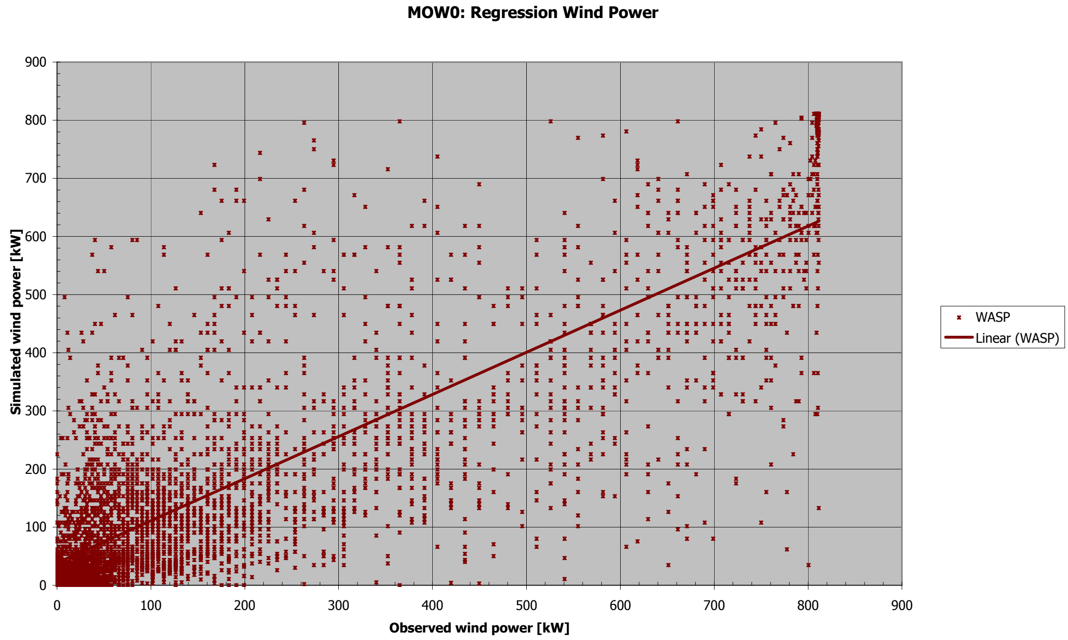


MOW0: Time Series Wind Direction




MOW0: Time Series Wind Power
Wind power [kW]
time
Obs 27 m
WASP


MOW0: Regression Wind Speed
Simulated wind speed [m/s]
Observed wind speed [m/s]
WASP
Linear (WASP)



3.6.6.4. *Conclusions*

It's hard to draw conclusion on these kind of short term simulations since WAsP is essentially a statistical programme which deals with long term (Weibull) probability distribution data of wind speed and wind direction.

Nevertheless, 3E has reprogrammed the formulas behind WAsP in a Matlab tool in order to execute the short term simulations as required in this Task 3.

Attention was focussed on the simulations for Amay, since the site of Amay represents a very complex terrain. For this complex terrain, very good results were found.

The impact of the selection of the reference station was examined for the simulation case of Rumes. It was found that the spacing in deviation of mean wind speed, using different reference stations between 30 km and 60 m from the observation site, lays between plus and minus 5%. Nevertheless, the spacing in deviation of mean wind power, proportionally with the third power of wind speed, lays between plus and minus 15%.

Taking into account the user friendly-ness, the price of the software, the short computation times required, one may conclude that WAsP is still an economic, reliable model for the basic micro siting of wind energy projects.

3.6.6.5. *References*

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3.7. Analysis and discussion of results, inter comparison between the models

A brief description is given here of the results obtained with the models on 10 selected simulation periods. Note that the purpose of this description is not to have a 'beauty contest'. (This would in fact be impossible, given the very different nature of the models involved, their resolutions and input data etc...) Instead, the goal is to try to extract useful information regarding the behaviour of different types of models applied to a variety of simulations, characterized by different weather and terrain characteristics.

It is briefly reminded here that the models ARPS, MAR and TVM are mesoscale models, using analysis data from the ECMWF model as lateral boundary conditions (ARPS and MAR) or as a base state from which a mesoscale perturbation is calculated (TVM). Maestro is also essentially a mesoscale model, adapted to ingest observed wind speeds as input. WAsP is a microscale model that also employs observed wind speed from a nearby station as input. The spatial resolutions used were 1 km for ARPS and TVM, 10 km for MAR, 250 m for Maestro, and down to obstacle-level (buildings, ...) for WAsP. The terrain at Rumes is rather simple, being relatively flat and with little roughness variations. The terrain at Mol is also flat, but characterized by heterogenous roughness. Arlon and Amay are both characterized by very variable topography, especially the Amay site, which is located on top of an isolated small hill in a stone quarry near the edge of the Meuse valley. The Arlon site is also located near a hill top, though a broader one, with heterogenous roughness around it. For all sites, with the exception of Amay, simulations were performed for periods in the summer, autumn, and early winter of 2003. For Amay, the simulation period was in the spring of 2002. For more information regarding the wind field models, the characteristics of the selected sites with respect to terrain and measurements, and the characteristics of the selected simulation periods, the reader is referred to Section 3.4 of the Intermediary Report (January 2005).

Figure 67 – Figure 70 show time series of observed wind speed versus the simulated values, for the different study sites and the selected simulation periods.

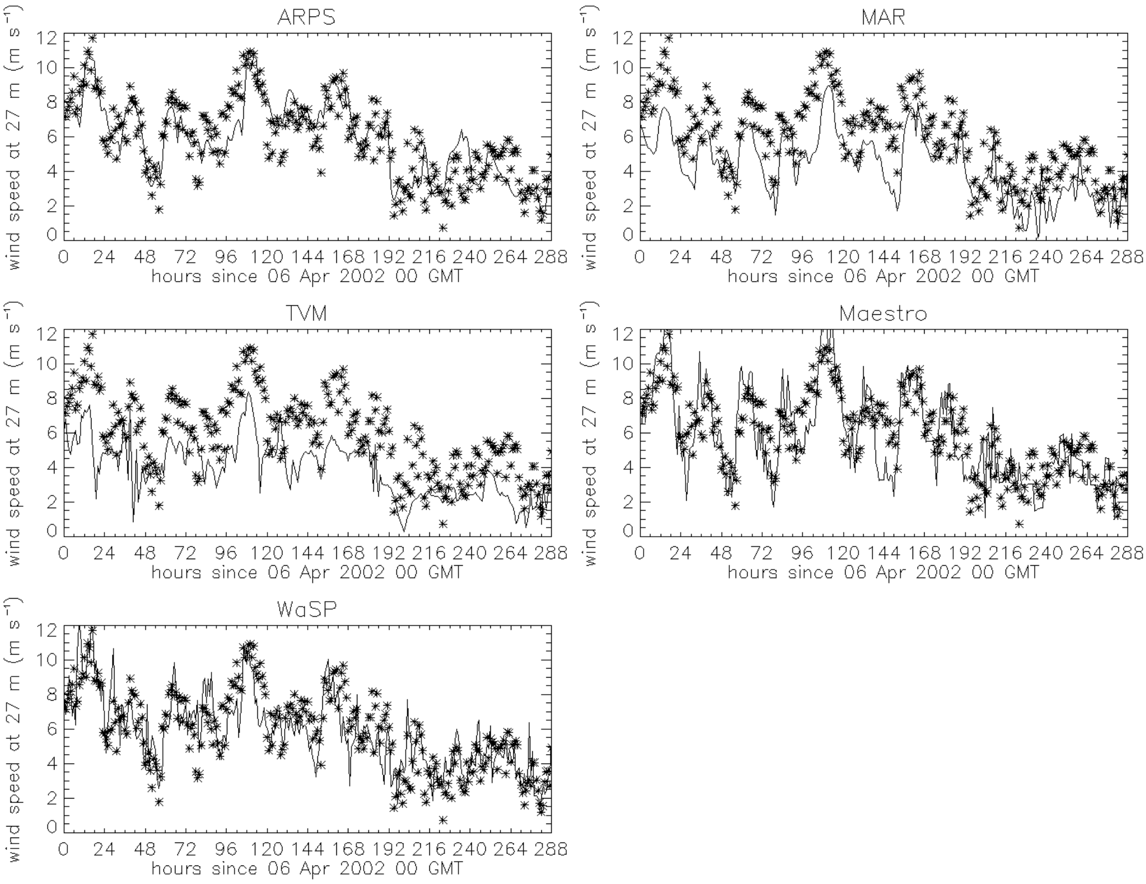


Figure 67. Observed (asterisks) versus simulated (solid line) wind speed at 27 m height for Amay, 6-17 April 2002.

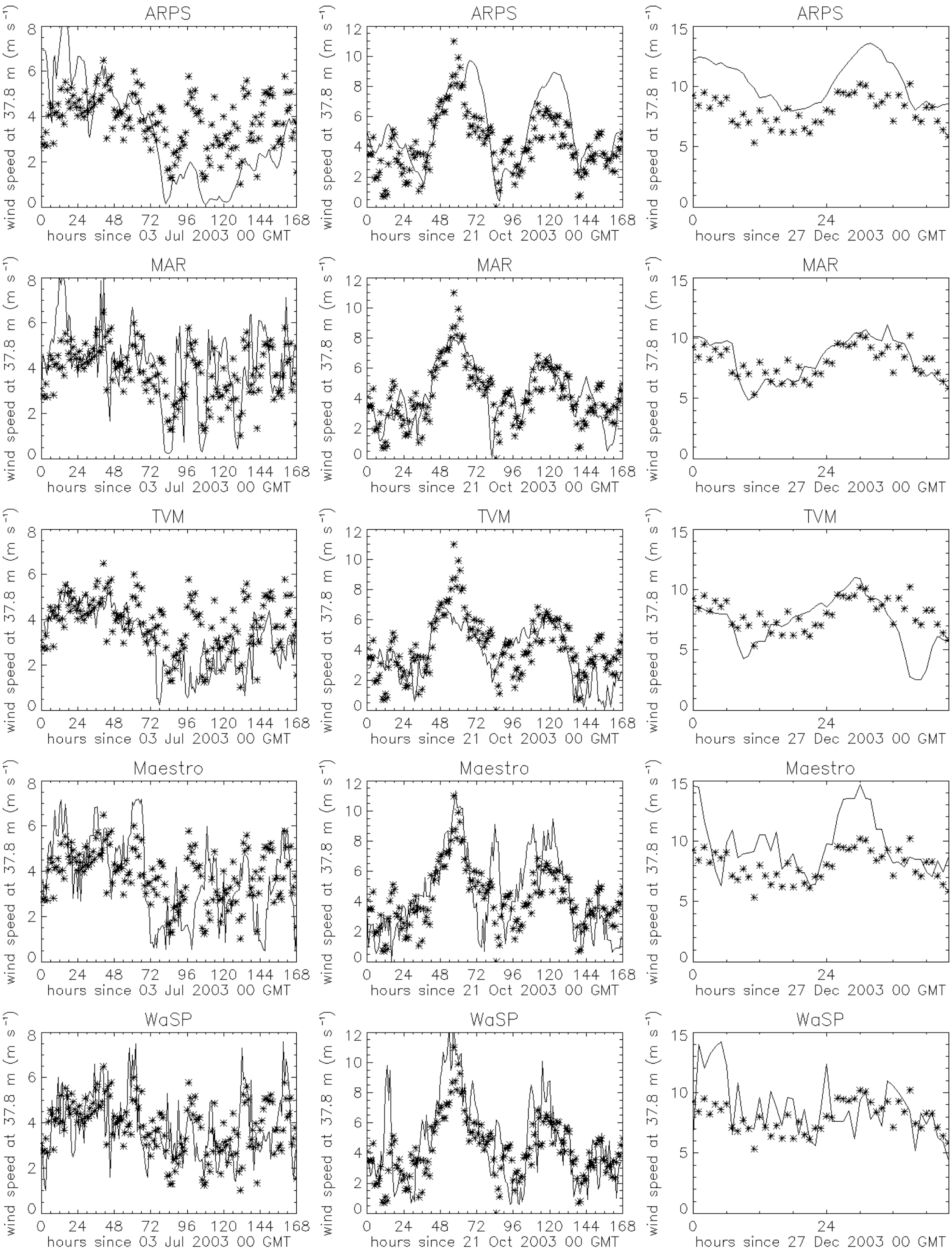


Figure 68. Observed (asterisks) versus simulated (solid line) wind speed at 37.8 m height for Arlon, 3-9 July 2003 (left panels), 21-27 October 2003 (middle panels), and 27-28 December 2003 (right panels).

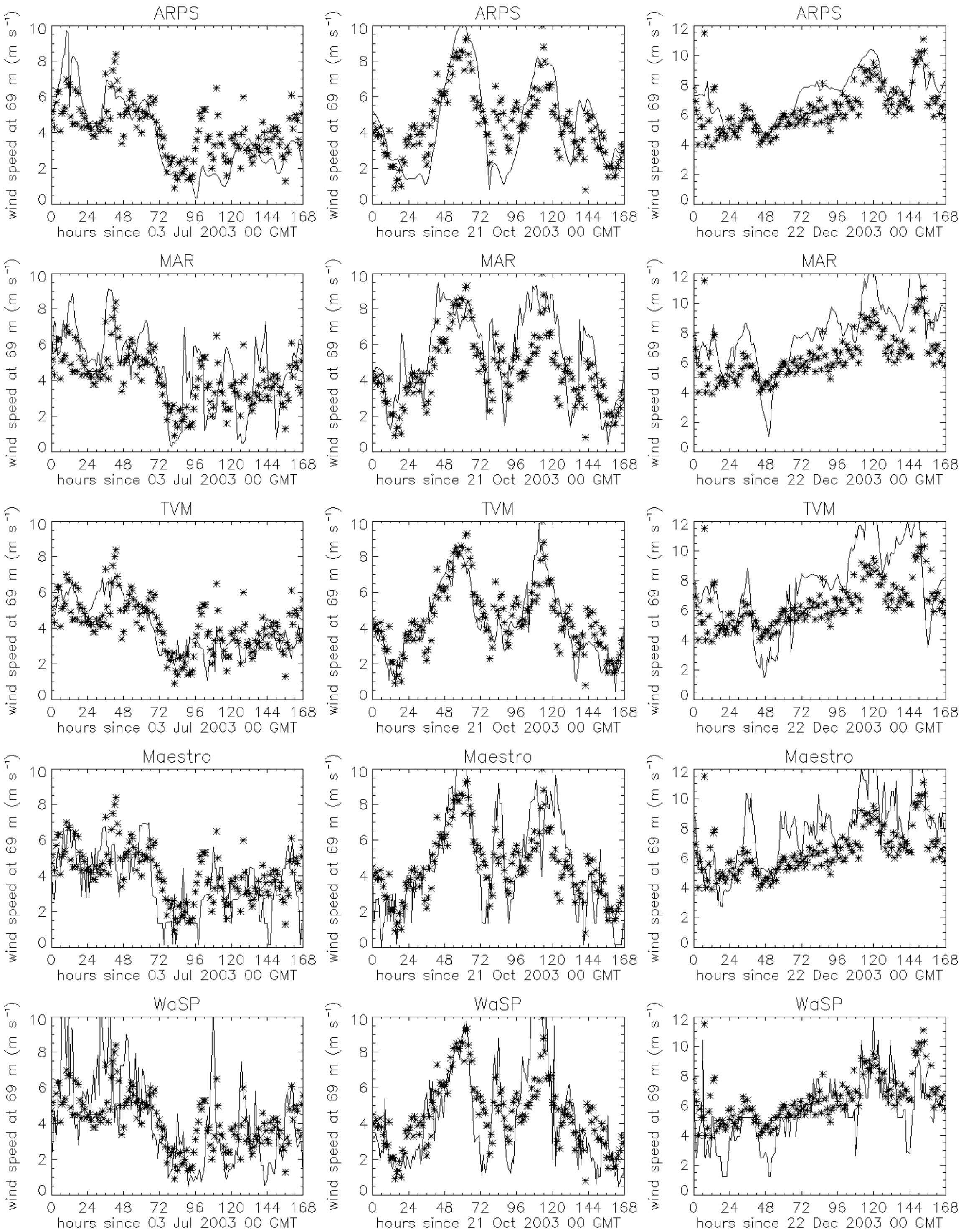


Figure 69. Observed (asterisks) versus simulated (solid line) wind speed at 69 m height for <u>*Mol*</u>*, 3-9 July 2003 (left panels), 21-27 October 2003 (middle panels), and 22-28 December 2003 (right panels).*

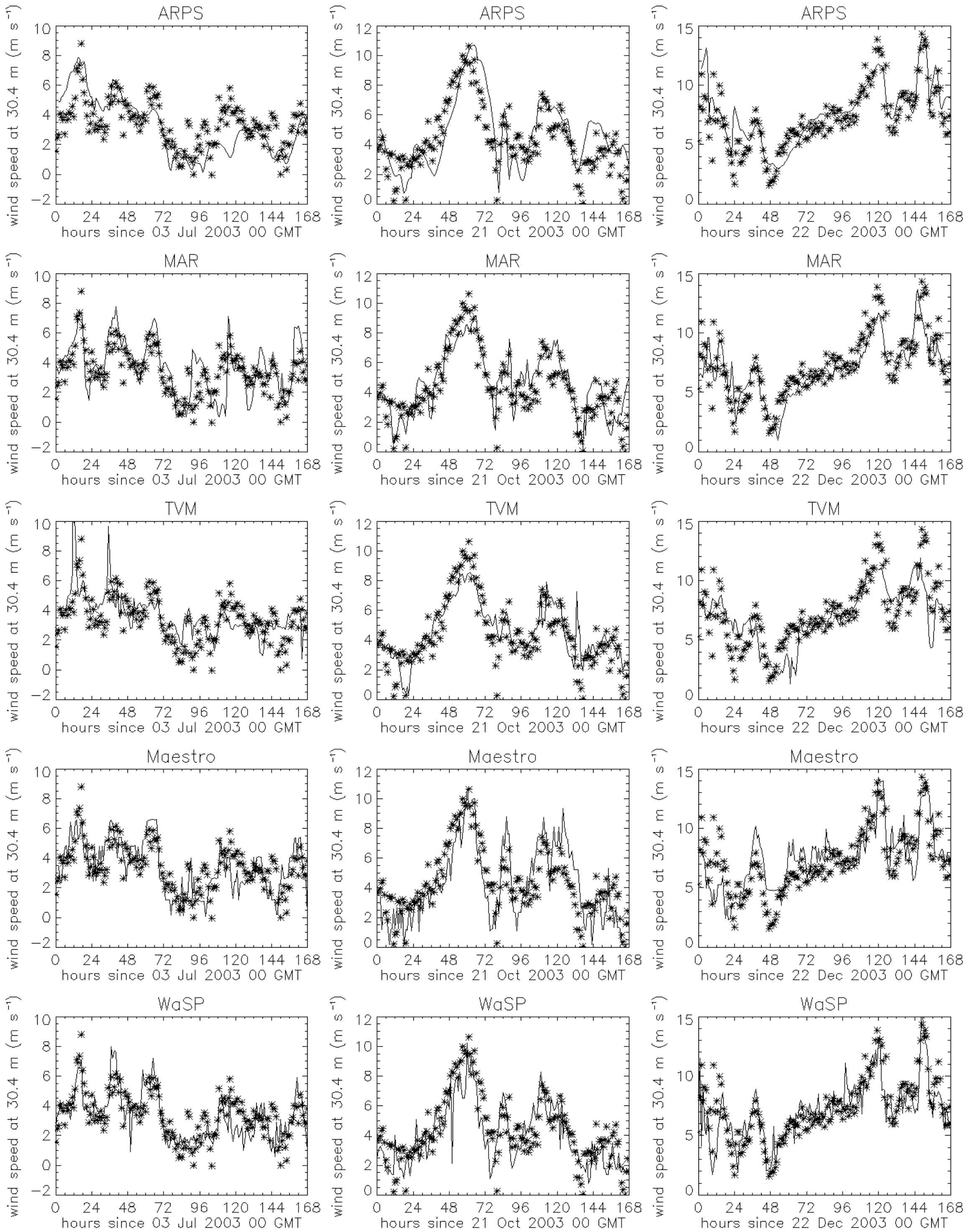


Figure 70. Observed (asterisks) versus simulated (solid line) wind speed at 69 m height for <u>Rumes</u>, 3-9 July 2003 (left panels), 21-27 October 2003 (middle panels), and 22-28 December 2003 (right panels).

Table 36. Summary of the statistics of the results obtained for the ten simulations.

	AMA1	ARL1	ARL2	ARL3	MOL1	MOL2	MOL3	RUM1	RUM2	RUM3
	mean wind speed observed values ($m\ s^{-1}$) and deviations (in percent) by the models									
OBS	***5.9***	***3.8***	***4.2***	***8.0***	***4.1***	***4.6***	***6.4***	***3.4***	***4.4***	***7.3***
ARPS	-1.4	-14.8	20.8	29.9	-8.8	-1.3	13.3	-4.8	6.9	6.3
MAR	-26.4	9.7	2.2	3.3	15.3	19.9	24.2	9.5	5.6	-3.6
TVM	-33.4	-17.1	-10.3	-9.1	-2.2	-4.0	19.1	8.5	3.0	-3.0
Maestro	-1.9	-2.8	7.2	21.8	-11.1	1.3	23.5	-0.6	-4.2	4.0
WaSP	-1.8	-0.2	12.9	9.3	3.9	-1.2	-14.2	-2.8	-10.2	-2.0
	standard deviation of wind speed observed values ($m\ s^{-1}$) and deviations (in percent) by the models									
OBS	***2.3***	***1.2***	***1.9***	***1.3***	***1.5***	***1.9***	***1.5***	***1.5***	***2.2***	***2.7***
ARPS	-5.8	93.9	23.1	45.9	42.8	36.0	0.1	28.4	8.1	-5.0
MAR	-18.7	49.1	-0.9	38.9	43.9	25.0	49.6	20.7	-5.9	-14.2
TVM	-27.5	14.8	-5.7	69.6	-0.1	6.5	87.2	2.9	-16.4	-9.7
Maestro	20.2	59.3	39.7	86.2	22.7	46.5	70.0	14.0	18.3	-4.9
WaSP	-6.0	22.9	46.2	91.3	82.7	70.0	39.0	6.8	-7.1	-7.9
	mean wind power observed values (in kW) and deviations (in percent) by the models									
OBS	***165.7***	***36.3***	***68.2***	***303.8***	***51.9***	***80.4***	***173.4***	***33.0***	***85.7***	***266.0***
ARPS	-6.8	27.3	80.2	82.7	11.8	29.6	39.9	16.8	22.6	12.8
MAR	-57.7	59.0	1.8	14.8	76.7	74.0	87.7	43.7	1.6	-10.1
TVM	-69.4	-34.7	-28.6	-14.2	-5.0	-4.5	78.2	19.8	-11.2	-6.6
Maestro	4.2	29.2	60.2	54.1	-13.6	44.6	80.8	9.1	8.1	5.3
WaSP	-7.9	15.1	83.9	25.3	83.9	39.3	-23.9	2.1	-25.6	-7.7
	RMSE of wind speed expressed as a percentage of the observed standard deviation									
ARPS	59.4	178.0	98.0	219.0	108.0	92.9	92.0	98.7	75.1	59.5
MAR	90.3	143.4	73.4	93.7	134.1	106.8	146.4	96.4	61.0	59.2
TVM	112.3	133.9	88.7	169.5	86.1	61.7	164.7	105.1	60.3	68.8
Maestro	77.8	154.8	113.4	205.7	116.3	96.2	155.2	92.3	78.5	74.3
WaSP	66.8	127.2	116.2	190.0	172.2	128.6	127.8	79.7	69.7	66.8

3.8. Conclusion for the meso scale models

3.8.1. Introduction

The objective of Task 3 was to evaluate a number of existing wind field models in use in Belgium for regional wind resource mapping purposes. These models calculate the wind field over a selected regional area, based on input of meteorological data (wind, solar, radiation, temperature,…) and terrain data (orography, roughness, obstacles, thermal properties,…).

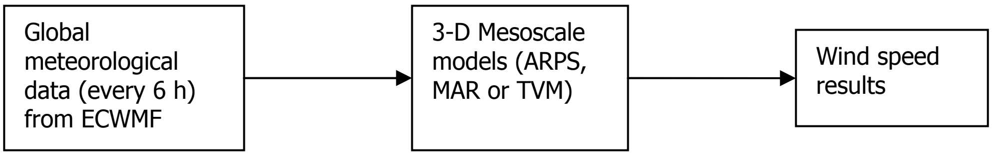
Five different models for the prediction of the surface wind climate were investigated. These models, representing the state of the art in this field, can be devided into mesoscale and microscale models, or the combination of the two.

The high resolution mesoscale models simulate the regional wind characteristics like flow in presence of large hills and valleys (up to a typical resolution of 1 km). These sophisticated 3 dimensional models are necessary to obtain reliable wind simulations especially in complex terrain.

Model	Input data	Local resolution	Intermediate nesting	RM?
ARPS	ECWMF	1 km	yes	
MAESTRO	Surface data	0.25 km	-	
MAR	ECWMF	10 km	No	
TVM	ECWMF	1 km	No	
WASP	Surface data	n/a	No	

The microscale models calculate the effects of orography, roughness conditions and obstacles on a high resolution mesh.

The results commented in this section concern particularly the models ARPS, MAR and TVM which are similar in nature and use the same data flow as is outlined in the figure here below.



The capacity of the selected models to predict the local wind climatology has been assessed by comparison of calculated (simulated) and actual (observed) wind speeds. Existing high quality wind speed measurements were used for this comparison.

Potentially this research is particularly useful for hilly regions and complex terrain, for which there is currently a lack of well verified wind modelling methods.

3.8.2. Global analysis of results - General comments

First of all, one must make a general remark: this modelling exercise is much too short and restricted to derive any conclusion over the possibilities of mesoscale models in the field of wind energy. Only 4 periods were considered totalling 35 days. The number of different weather situations considered is in this way is too small to derive any valuable statistics.

The exercise was performed mainly to derive a view on the potential of this approach.

Pielke in his book "Mesoscale meteorological modeling"[11] gives some indication in its section 12.6 "Comparison [of model results] with observations". Skill of model is demonstrated if at least the following conditions are met

σ-mod ≈ σ-obs

RMS < σ-obs

where σ-mod is the standard deviation of the model results, σ-obs is the standard deviation of the observed data, and RMS is the Root-mean-square deviation between the observations and the model results. These quantities have been determined for the different periods and sites in T3. If one looks over the table of results presented in the Task 3, one may quickly see that the model results sometimes satisfy the above conditions and other not. More this is true for all three (or five) models involved in the exercise.

So we may try to formulate some conclusions at the present stage on the capability of models at small spatial scale in the field of wind energy.

[11] R. Pielke, 2002. Mesoscale Meteorological Modeling (second ed)., *Academic Press*, 672 pp.

Since power output of a wind turbine is very sensitive to the mean wind speed (proportional to the third power of it), it is clear that e.g. a 5 % bias error on the mean wind speed of the model results (as has been frequenly reported in the results) which for meteorological purposes appears to be quite good, but produces a 15 % bias in the power output which is probably for electricity generation an important deviation.

What the 3-D mesoscale models can do most of the time :

- Reproduce the wind variations to about 5 % in mean value over periods of a week or so.
- Reproduce the wind variablity (speed and direction) depending on the large scale meteorological situation
- Reproduce some major effects of the local topography and/or land use on the general behaviour of the wind
- Present most of the time a RMS error which is smaller than the standard deviation of the observed wind speeds.

What the 3-D mesoscale models cannot do for the present time :

- Calculate local mean wind speed with an error less than say 5 %.
- Calculate the mean wind variability showing rapid varying features (with a time span characteristic of less than say 4-5 hours)
- Accurately reproduce the effects on wind of very small scale local topography (less than twice the model grid, i.e. under about 500 m in the current configuration). However, it has been shown in this project that additional site-specific corrections may improve the results, for example by accounting for a 100 m – diameter hill.

These limitations are the consequence of three main facts:

- in all these runs, the models (TVM, ARPS and MAR) are forced by the re-analyses from the European Centre (ECMRF) which delivers data only every 6 hours. This means that meteorological events having a variability in time smaller than 6 hours are not represented in the forcing data. The consequences of this depends on how the model uses the forcing data. TVM is using the forcing data on all its geographical domain (which is relatively small compared to meteorological length scales), and its aim is to add detailed local effects. For this model, using forcing data available every 3 hours or better would be a big improvement. In ARPS and MAR, the re-analysis are used only to provide an initial state and the input of meteorological information at the lateral boundaries. These models have an ability to refine the mesoscale fields which they receive, e.g. they are expected to represent fronts and form their own clouds in a realistic way. In this case, receiving forcing data every 3 hours instead of 6 may still offer an improvement, but mainly when larger-scale features such as low pressure systems are moving rapidly at a boundary of the model domain (this may cause time-interpolation errors).
- the mesoscale models are forced by the large scale data. All errors or imperfections in the large scale data are transmitted in the forcing for the mesoscale models. The models can not compensate all the deficiencies, which appear in the results in a reduced or amplified form (depending on the model and situation).
- the way of taking into account all physical and dynamical aspects of the mesoscale atmosperic features in the models is still far from complete.

These results show that a potential in using mesoscale models for wind energy exists for sure, but a much longer (in time) and more complete analysis must be performed in order to derive more consistant characteristics.

4. Task 4: Verification of the wind prediction quality

4.1. Objectives

The objective of this task is to qualify the reference wind measuring stations for long term prediction purposes. The self-prediction capacity of reference stations are evaluated by comparing measured and calculated wind regime. Cross predictions of reference stations are made. This leads to an overview map of Belgium with the indication of reference stations which can be preferable used for resource predictions.

4.2. Methodology and approach

The analysis of Task 4 consists of 4 subtasks.

4.2.1. Subtask 4.1 Self prediction

For each of the selected long term reference stations, the predicted wind climate is calculated on the basis of the observed wind climate, by using the detailed station descriptions as obtained in Task 1, and the roughness and elevation map of Task 2.

4.2.2. Subtask 4.2 Cross prediction

For selected stations, it is verified how well one station is able to predict the wind climate at the other. The method used for the cross prediction is the same as for the self prediction, whereby the observed wind climate of a selected reference station is used to predict the wind climate at another reference station, using the detailed station description, roughness and elevation maps of both reference stations.

4.2.3. Subtask 4.3 Comparative evaluation

Possible causes for significant deviations between observed and calculated wind regimes are analysed.

4.2.4. Subtask 4.4 Qualification Criteria for reference Weather stations used for Wind Ressource Assessment

This modelling exercise aims to find out which might be the criteria to be considered when choosing a reference weather station, in particular a reference station to use in order to get the required forcing datasets to drive the MAESTRO Wind model.

4.2.5. Remark

From the previous, it is clear that only the micro scale models, which are using the observed wind data from reference stations, are suitable to perform these self and cross predictions. Subtask 4.1, 4.2 and 4.3 are executed with the micro scale model WAsP. Subtasks 4.4 is evaluated by using the MaestroWind model.

4.3. Subtask 4.1 and 4.2: self and cross prediction

4.3.1. Available data

In order to perform the cross prediction analysis, RMI has selected reference stations for which long term data is available over the same period of time. This period of time was determined from January 1st, 1992 until December 31st, 2001.

For this period of time, the following reference stations have a reliable table of frequency.

Table 37 Selected RMI long term reference stations

Reference number	Reference station
1	Beauvechain
2	Bierset
3	Deurne
4	Elsenborn
5	Florennes
6	Gosselies
7	Kleine Brogel
8	Koksijde
9	Middelkerke
10	Saint Hubert
11	Spa
12	Zaventem

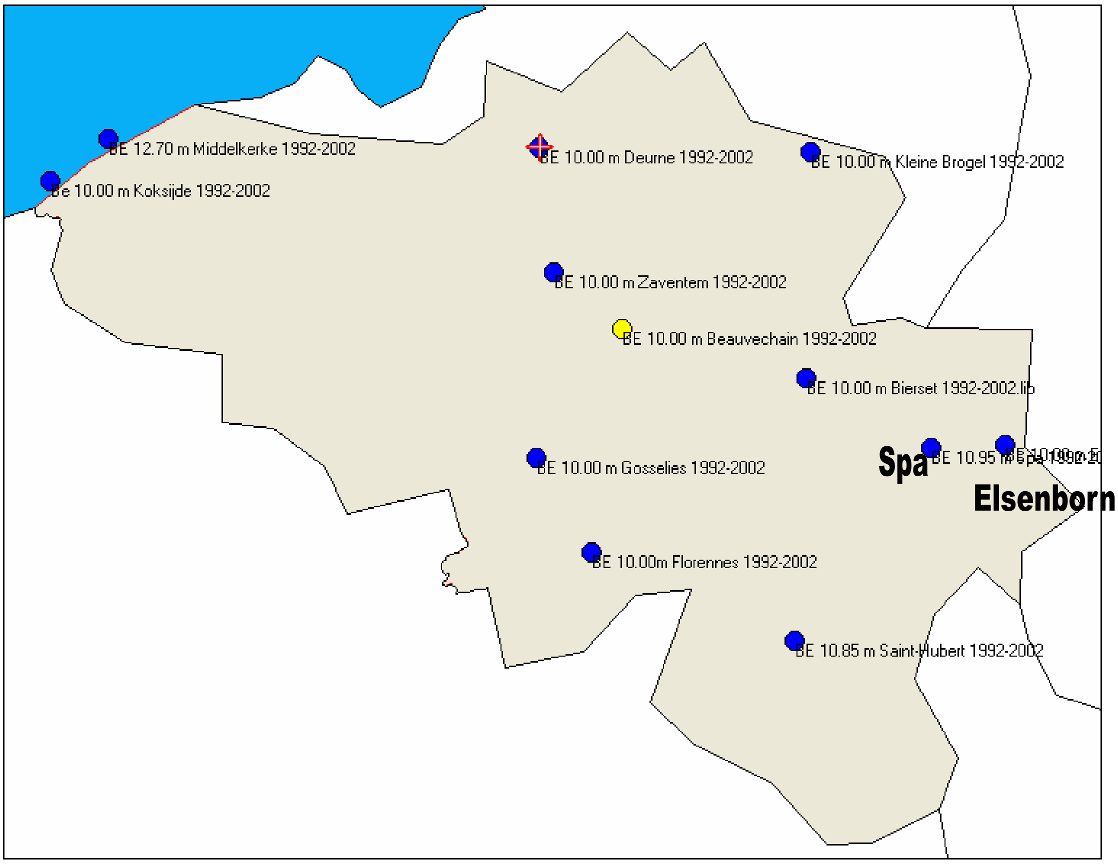


Figure 71 Overvierw of the position of the selected long term reference stations of RMI

The frequency tables, made available by RMI over the period from 1992 until 2001, ie 10 years, have the following information.

Table 38 Example of a long term frequency table for the reference station Deurne

Frequentietabel Deurne
01-01-1992 - 31-12-2001

(VAR = vent de direction variable - veranderlijke richtingen)
(NUL = vent nul - geen wind)
Fréquence dans 12 directions par rapport à toutes les intensités - Frequentie in 12 richtingen en alle intensiteiten
Classe de vent par intensité (m/s) - windklassen per intensiteit (m/s)

	NUL	0	30	60	90	120	150	180	210	240	270	300	330	VAR	Grand Total
0 <=v< 1	3632	182	197	252	407	274	245	144	140	96	66	52	73	140	5900
1 <=v< 2	0	1117	1293	1714	1836	1527	1325	773	836	817	616	362	630	388	13234
2 <=v< 3	0	1241	1783	2076	1729	1472	1426	981	1684	1698	1300	638	1264	60	17352
3 <=v< 4	0	759	1170	1468	1212	866	1060	952	2300	2705	1545	792	1230	9	16068
4 <=v< 5	0	310	562	878	669	420	622	721	2302	2968	1322	806	912	2	12494
5 <=v< 6	0	114	222	388	256	156	301	538	2059	2497	1012	680	536	0	8759
6 <=v< 7	0	33	70	124	91	71	154	382	1658	1907	700	441	217	0	5848
7 <=v< 8	0	7	6	39	46	15	83	203	1171	1224	495	255	91	0	3635
8 <=v< 9	0	2	0	2	8	1	26	130	688	773	265	170	35	0	2100
9 <=v< 10	0	0	1	1	9	2	9	74	315	361	147	85	14	0	1018
10 <=v< 11	0	0	0	0	1	0	1	39	173	245	122	49	9	0	639
11 <=v< 12	0	0	0	0	0	0	1	10	89	106	43	18	1	0	268
12 <=v< 13	0	1	0	0	0	0	0	1	38	51	39	5	2	0	137
13 <=v< 14	0	0	0	0	0	0	0	3	16	21	20	0	0	0	60
14 <=v< 15	0	0	0	0	0	0	0	1	7	11	8	1	0	0	28
15 <=v< 16	0	0	0	0	0	0	0	1	1	4	3	0	0	0	9
16 <=v< 17	0	0	0	0	0	0	0	0	1	4	1	0	0	0	6
17 <=v< 18	0	0	0	0	0	0	0	0	0	2	0	0	0	0	2
Grand Total	3632	3766	5304	6942	6264	4804	5253	4953	13478	15490	7704	4354	5014	599	87557

The measured wind speed values are classified according to wind direction sector and according to the wind speed bin. The wind direction is divided in 12 sectors of 30° each. The wind speed is divided in bins of 1 m/s. The frequency table is created based on hourly mean values of wind speed and wind direction. Wind speed measurements with accompanying variable wind directions over the 1 hour time period are classified in the VAR column of the frequency table.

This frequency table is introduced in the WAsP software and is graphically demonstrated by a so called frequency wind rose. The wind rose for the above frequency table is depicted in the following figure.

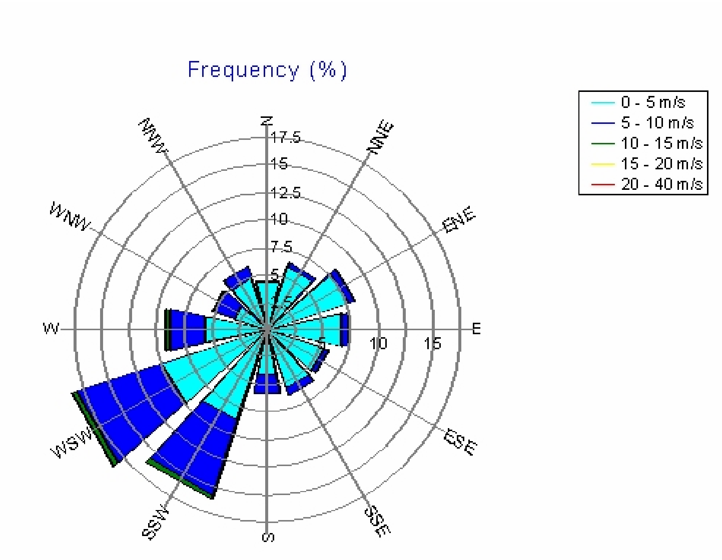


Figure 72 Wind rose of the long term frequency table of reference station Deurne.

Besides this frequency wind rose, the following information is withdrawn from the frequency table:

- The Weibull distribution per sector and for all the sectors together
- The wind rose of the mean wind speed
- The wind rose of the mean energy density

The Weibull distribution and the wind roses for each of the 12 selected long term reference stations are given on the CD-Rom.

4.3.2. WAsP methodology

The self and cross prediction is performed with the WAsP micro scale model. The observed wind climate of a selected long term reference station is used to predict the long term wind climate at another reference station according to the WAsP methodology. This methodology is described more in detail in Task 3.

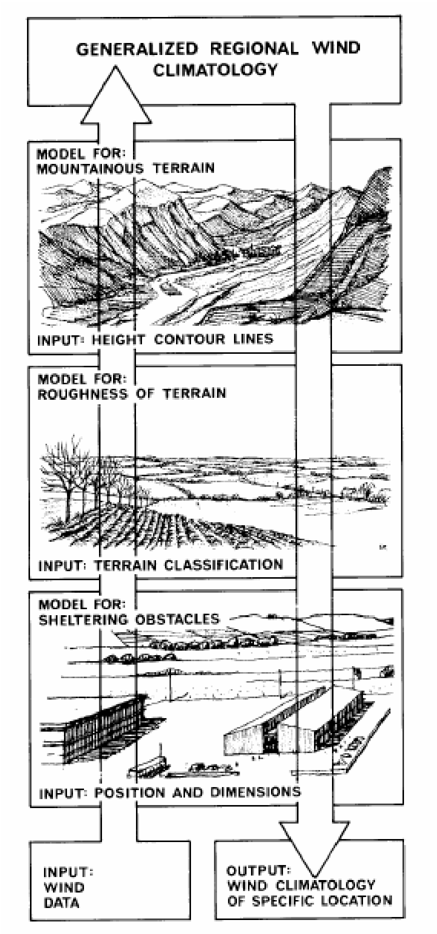


Figure 73 The Wind Atlas methodology used in WAsP

For each selected long term reference station, the generalised regional wind climatology, called a wind atlas, is created based on the input wind data (frequency table) of this station, the site description (sheltering obstacles), the roughness description of the site and environment, and the elevation model.

With this wind atlas of the selected reference station, the wind climate at any other position or reference station can be predicted by applying the reverse process: by using the site description, roughness and elevation map of this second station.

For each of the 12 selected long term reference stations, the corresponding wind atlas have been created using WAsP. The statistical outcome of these wind atlases are given on the CD-Rom.

4.3.3. WAsP analysis

The results of the calculations are shown below in score schemes where the names of the predicted stations are put horizontal and the reference number of the predicting station is put vertically. The diagonal line, with the grey shaded cells, indicates the stations predicting themselves.

Table 39 Comparison of the mean wind speed

	1 Beauvechain	2 Bierset	3 Deurne	4 Elsenborn	5 Florennes	6 Gosselies	7 Kleine Brogel	8 Koksijde	9 Middelkerke	10 Saint Hubert	11 Spa	12 Zaventem
1	4.65	4.51	4.03	3.74	4.22	4.40	4.21	4.73	4.98	3.25	3.00	4.25
2	4.93	4.78	4.28	3.99	4.55	4.63	4.37	5.06	5.31	3.47	3.17	4.58
3	4.74	4.57	3.89	3.85	4.45	4.52	4.32	4.88	5.18	3.61	3.09	4.44
4	5.19	5.02	4.45	4.24	4.83	4.83	4.67	5.32	5.67	3.78	3.44	4.84
5	4.81	4.67	4.19	3.90	4.43	4.50	4.33	4.96	5.26	3.43	3.18	4.46
6	4.60	4.48	3.94	3.70	4.21	4.37	4.11	4.70	4.94	3.21	2.91	4.24
7	4.52	4.38	3.89	3.63	4.09	4.27	4.12	4.59	4.84	3.21	2.93	4.12
8	5.00	4.85	4.18	4.09	4.72	4.74	4.45	5.18	5.47	3.70	3.19	4.71
9	5.12	4.95	4.29	4.17	4.84	4.86	4.52	5.29	5.57	3.75	3.19	4.81
10	6.13	5.97	5.38	5.02	5.75	5.78	5.30	6.31	6.64	4.30	3.85	5.72
11	9.95	9.80	9.08	8.15	9.40	9.35	7.83	10.08	10.22	6.18	5.63	9.32
12	4.75	4.63	4.11	3.83	4.34	4.51	4.26	4.88	5.13	3.32	3.04	4.38

Table 40 Deviation in mean wind speed

	1 Beauvechain	2 Bierset	3 Deurne	4 Elsenborn	5 Florennes	6 Gosselies	7 Kleine Brogel	8 Koksijde	9 Middelkerke	10 Saint Hubert	11 Spa	12 Zaventem
1	0%	-6%	3%	-12%	-5%	1%	2%	-9%	-11%	-24%	-30%	-3%
2	6%	0%	10%	-6%	3%	6%	6%	-3%	-4%	-19%	-26%	5%
3	2%	-5%	0%	-9%	1%	4%	5%	-6%	-7%	-16%	-28%	1%
4	12%	5%	14%	0%	9%	11%	13%	2%	2%	-12%	-20%	10%
5	3%	-2%	7%	-8%	0%	3%	5%	-5%	-5%	-20%	-26%	2%
6	-1%	-6%	1%	-13%	-5%	0%	0%	-10%	-11%	-25%	-32%	-3%
7	-3%	-8%	0%	-14%	-7%	-2%	0%	-12%	-13%	-25%	-32%	-6%
8	8%	1%	7%	-3%	7%	9%	8%	0%	-2%	-13%	-26%	7%
9	10%	3%	10%	-1%	10%	12%	9%	2%	0%	-12%	-26%	10%
10	32%	25%	38%	19%	30%	33%	28%	21%	19%	0%	-10%	31%
11	114%	105%	133%	93%	113%	114%	90%	94%	84%	45%	31%	113%
12	2%	-3%	5%	-9%	-2%	4%	3%	-6%	-8%	-22%	-29%	0%

The self predictions results in mean values equal to those measured, except for the reference station Spa.

Every meso or micro scale model has inherent uncertainties, such as the wind speed measuring errors and the inability of the physical model to model the real flow conditions. The collective effect of the various uncertainties is to diminish the reliability of the regional statistics (wind atlas) and hence their application for predicting wind statistics at sites in their region. Apart from these uncertainties, there is a fundamental problem of determining the flow in hilly and mountainous terrain with the WAsP model. It is obvious that a station located in a deep valley or on the top of a steep slope experiences a wind that has been subject to a considerably channelling or overspeeding effect, as the reference station Spa (channelling) and Saint Hubert (overspeeding) for instance. Stations which are influenced by such a strong orographic effects can only be used as predictors for sites in the vicinity, subject to the same terrain conditions.

There are two distinct types of systematic deviations which can be attributed to measuring errors and/or errors occurring during the extraction of input data for the models from the station information. The first type is characteristic of a reference station which is predicted too low, whereas the station itself predicts the other stations too high. This can be caused by:

- The wind speed measuring instrument reading too high (probably a calibration error)
- The roughness in the roughness map being too high
- The effect of nearby sheltering obstacles being exaggerated
- The calculated effect of the orography underestimating the overspeeding

The second type is characteristic of a reference station which is predicted too high whereas the station itself predicts the other stations too low. This can be caused by the same effects as described above, but with the opposite signs.

Reference stations suffering the first type of characteristic are: Saint Hubert, Spa. Reference stations suffering the second type of characteristic are: Gosselies, Kleine Brogel.

A more complete intercomparison has been performed based on the mean of the third power of the wind speed, which is an indication of the energy density in the wind. The mean of the third power of the wind speed is calculated based on the Weibull parameters A and k according to the following formula:

$$\overline{u^3} = A^3 \cdot \Gamma(1 + \frac{3}{k})$$

Where: $\overline{u^3}$ = mean of the third power of the wind speed

A = Weibull scale factor

k = Weibull shape factor

Γ = the gamma function

$$\Gamma(z) = \int_0^\infty t^{z-1} \cdot e^{-t} dt$$

The following table gives the deviations in mean third power of wind speed for the self and cross prediction, based on the Weibull distribution.

Table 41 Deviation in mean ws³

	1 Beauvechain	2 Bierset	3 Deurne	4 Elsenborn	5 Florennes	6 Gosselies	7 Kleine Brogel	8 Koksijde	9 Middelkerke	10 Saint Hubert	11 Spa	12 Zaventem
1	1%	-11%	13%	-21%	-16%	-2%	16%	-30%	-35%	-49%	-56%	-21%
2	17%	1%	30%	-7%	3%	11%	29%	-18%	-23%	-38%	-49%	-6%
3	15%	-2%	0%	-5%	14%	16%	39%	-15%	-15%	-9%	-49%	2%
4	22%	5%	31%	2%	16%	13%	36%	-13%	-14%	-24%	-43%	4%
5	25%	10%	44%	-2%	3%	18%	46%	-12%	-16%	-39%	-40%	-1%
6	4%	-7%	16%	-20%	-13%	1%	15%	-29%	-34%	-50%	-57%	-18%
7	-10%	-22%	0%	-30%	-25%	-13%	1%	-38%	-43%	-54%	-62%	-30%
8	37%	18%	42%	13%	29%	33%	55%	0%	-4%	-12%	-39%	18%
9	49%	29%	56%	21%	38%	46%	63%	7%	1%	-11%	-38%	26%
10	155%	130%	202%	103%	126%	146%	148%	77%	59%	3%	-9%	105%
11	1657%	1539%	2129%	1346%	1642%	1562%	972%	1105%	815%	317%	197%	1391%
12	31%	17%	49%	0%	4%	29%	50%	-9%	-16%	-41%	-44%	1%

The deviation of the self prediction lays between 0% and 3% when excluding the Spa reference site.

The two figures below shows the frequency of the deviation (a) in mean of wind speed, and (b) in mean of third power of wind speed based on the tables above, excluding the reference stations Saint Hubert and Spa.

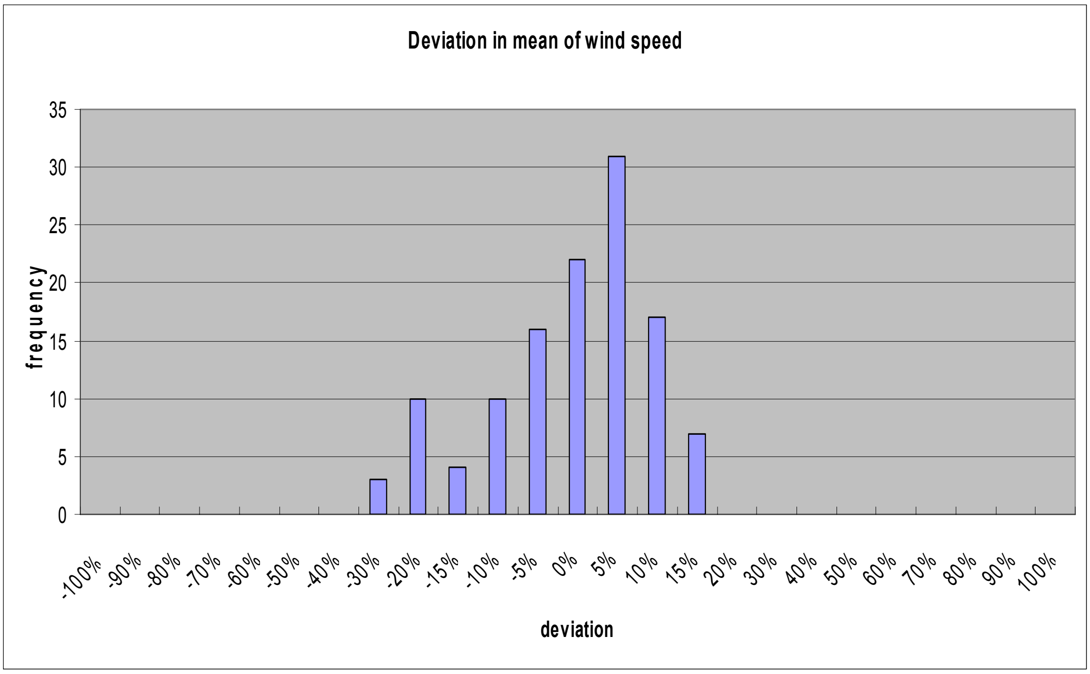


Figure 74 Frequency of deviation in mean wind speed

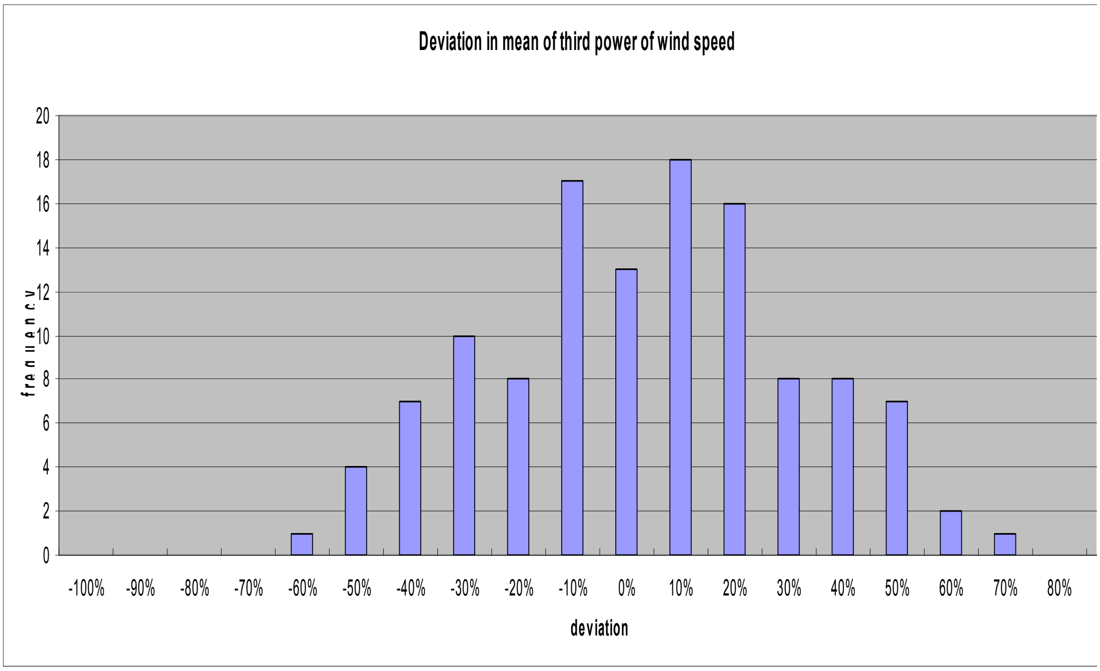


Figure 75 Frequency of deviation in mean third power of wind speed

44% of the cross predictions of mean of wind speed lay between –5% and +5%. 26% of the cross predictions of the mean of third power of wind speed lay between –10% and +10%.

4.4. Subtask 4.3 Comparative evaluation

Accurate predictions using the WAsP package may be obtained provided that both the reference and predicted sites are clearly:

- subject to the same weather regime, defined by the typical scale of the prevailing synoptic weather systems,
- the prevailing weather conditions are close to being neutrally stable, and
- the surrounding topography is not too steep, i.e. sufficiently gentle and smooth to ensure predominantly attached flows and minimal large-scale terrain effects such as channelling.

The prediction accuracy also depends on the quality of the reference data, the methods used by the user for preliminary data processing and the correct use of the WAsP program.

A detailed description of the accuracy of WAsP calculations is given in [12].

The analysis from the previous chapter reveals the following conclusions.

- For regions near the coast, it is clear that only the reference stations Koksijde and Middelkerke should be used. Due to the typical coastal effects (sea breeze), inland reference stations result in an underestimation of the wind energy density at the coastal stations. There is quite a difference between the two measured mean wind speeds. The reason is that the reference station Middelkerke is really very close to the sea while the reference station Koksijde is more inland. This is clear when comparing the roughness of both sites (roughness class 0.9 for Middelkerke while 1.6 for Koksijde). So for really coastal sites, use Middelkerke as a reference site, for more inland coastal sites, use Koksijde.
- Reference stations Spa and Saint Hubert should be excluded for predictions to other sites with different orographic effects.
- For the reference station Spa, one can conclude that the WAsP model is not powerful enough to guarantee a good self prediction. The site conditions at Spa outcome the boundary conditions of the WAsP tool.
- The reference stations of Gosselies and Kleine Brogel are always predicted too high whereas these stations themselves predict the other stations too low. The possible reasons for this phenomena were mentioned in the WAsP analysis.
- The reference station Zaventem seems to underestimate the other inland stations; while reference Zaventem itself is mostly overestimated by other reference stations. Zaventem is located at the north-east of the city of Brussels. The influence of the city of Brussels on the climatology of Zaventem may be an explanation for the rather poor prediction results from Zaventem.
- The reference stations Beauvechain, Bierset, Deurne, Elsenborn and Florennes are predicting each other quite well.
- There is clearly a gap in reference stations for the inland of West Vlaanderen, Oost Vlaanderen and Hainaut.
-
- General conclusions that can be drawn are:
- Although the deviations in wind speed may seem rather small, the deviations in mean third power of wind speed can become quite important.
- The self and cross prediction analysis of this chapter is done for reference stations with a typical measuring height of 10 m. The relative impact of sheltering obstacles becomes more important on this low level measurement. The sheltering impact of these obstacles is not very easy to model. This impact diminishes when modelling for higher measuring levels, like the hub heights of wind turbines which are typically between 50 m and up to 100 m or even more. It is expected that a prediction based on a reference station for a high level measuring mast will be better. Even so, using a reference site with a higher measuring level would result in better accuracy.
- In selecting reference stations for predictions of the wind climate at a certain site, limit the distance between the predicting site and the predicted site to maximum 100 km.
- The wind atlases in WAsP lib format of these selected reference stations are given on the CD-Rom. The end user is responsible for the correct use of this data. These wind atlases can be seen as an extension of the data given in the European Wind Atlas.

4.5. Subtask 4.4 Qualification Criteria for reference Weather stations used for Wind Ressource Assessment

4.5.1. Introduction

The modelling exercise proposed here aims to find out which might be the criteria to be considered when choosing a reference weather station, in particular a reference station to use in order to get the required forcing datasets to drive the MAESTRO Wind model.

As a reminder (see Task 3), the meso/micro scale meteorological model MAESTRO Wind is driven by the large scale or synoptic flow represented by a top level boundary condition representing the geostrophic wind. This information is not measured as such and must be estimated either from large scale modelling, like ECMWF Re-Analysis modelling or other large scale modelling system, or from ground level weather stations. This last option is investigated in the present work.

We will try to understand and confirm some ideas that the reference weather station should be located in an area where the topography is almost flat and the land occupation rather homogeneous. If this would not be the case some local terrain influences will be measured at the station and will be reflected into the geostrophic wind estimate. This would induce errors in the simulated local wind field as far as MAESTRO Wind produces itself the local winds. In other words, using a locally perturbed station would lead to "double" simulate the local effects or lead to purely wrong estimates of the local winds. Another criterion to investigate is the distance between a reference station and a site to be analysed. In other words this leads to the question: is the reference station is too far away from the analysis domain (see Task 3).

Looking at the situation in Belgium and in particular at the synoptic weather stations available, one can say that there are not too many stations and that some are obviously influenced by local phenomena like sea-shore and valleys. An analysis of wind roses (see task 1 also) will, for example, show that the Spa weather station seems influenced by the local topography. Moreover other problems of station consistency in time or technical problems at station might also reduce the number of good quality data from those weather stations (see Task 1 for detailed analysis of Belgian synoptic weather station network).

In order to understand a little more those issues, we have chosen to run the model for long time period, 3 months, using various reference station candidates. Therefore, we have defined an analysis domain within which some datasets were available within the same period of time. The period of simulation is enlarged with respect to task 3 modelling exercises in order to enable to get more realistic statistics about wind speed distributions and energy yields.

The input data have been controlled in order to ensure that the site description is correct with respect to topography and land occupation. Moreover an analysis of both observational datasets and meteorological forcing datasets has been performed.

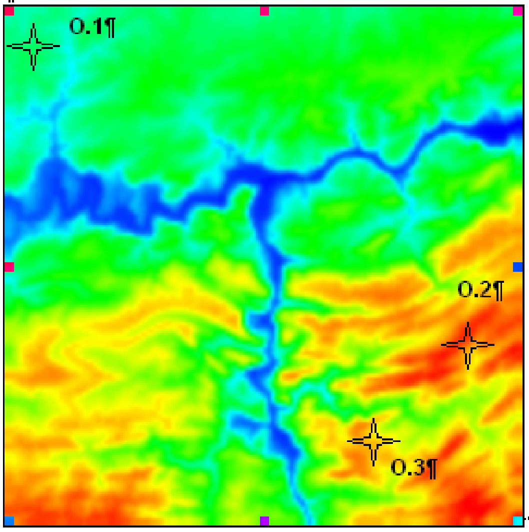
The comparison of the simulation results and observational datasets will use the similar variables as the ones used for the task 3: (1) Mean Wind Speed, (2) Deviation of Mean Wind Speed, (3) Mean Power and (4) Deviation of Mean Power.

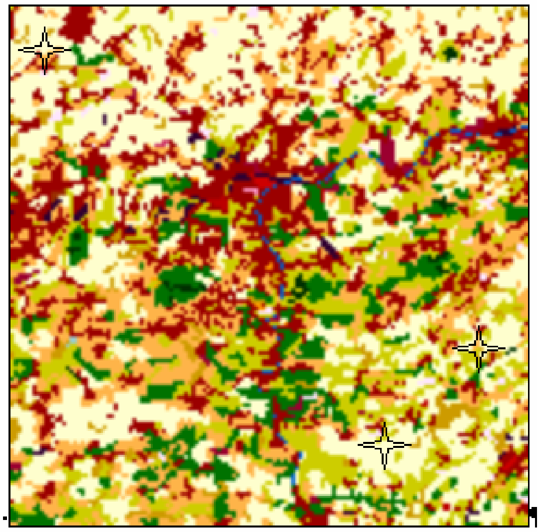
The results of the simulation will be taken at the closest horizontal point of calculation and at the level of the observation. Time series over the simulation time period will be produced in order to enable statistical analysis and comparison with observational datasets.

4.5.2. Calculation Domain Description

The calculation domain extends over 35 x 35 km², from 168000 to 203000 m Lambert in the West-East direction and from 105000 to 140000 m Lambert in the South-North direction. It is centred on the Namur City. The resolution of the horizontal grid is 250 m.

The following figures show the topography (l.h.s.) and the land use (r.h.s.). The stars show the location of the observation masts (see 4.4.3).





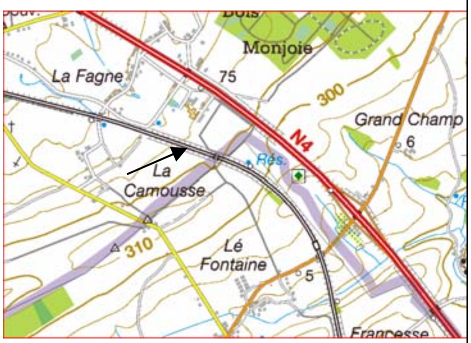
4.5.3. Observation datasets

In order to analyse the model results three observation datasets have been used : Gembloux, Assesse and Spontin. The time period of simulation will be from 1st of June 2002 up to 31st of August 2002.

4.5.3.1. Site of Gembloux (O.1)

Name :	Gembloux
X Lambert :	170464 m
Y Lambert :	137652 m
Z (a.s.l.) :	168 m
Z obs. (a.g.l.) :	65 m
Time Period :	01/06/2002 – 27/06/2002
Nb. Data :	648 hours
Nb. Missing Data :	0 hours (0 %)

4.5.3.2. Site of Assesse (O.2)



Name :	Assesse
X Lambert :	198806 m
Y Lambert :	116986 m
Z (a.s.l.) :	300 m
Z obs. (a.g.l.) :	30 m
Time Period :	01/06/2002 – 31/08/2002
Nb. Data :	2208 hours
Nb. Missing Data :	79 hours (3.6 %)

4.5.3.3. Site of Spontin (O.3)

Name :	Spontin
X Lambert :	193157 m
Y Lambert :	110419 m
Z (a.s.l.) :	250 m
Z obs. (a.g.l.) :	30 m
Time Period :	01/06/2002 – 31/08/2002
Nb. Data :	2208 hours
Nb. Missing Data :	43 hours (2 %)

4.5.4. MAESTRO Wind forcing datasets

In order to drive the model, four different synoptic weather stations have been used : (S.1) Beauvechain, (S.2) Ernage, (S.3) Gosselies and (S.4) Bierset. The station of Ernage is the only one which is an automatic weather station which provides the wind speed and direction observation at an accuracy of 0.1 m/s and 1 degree, respectively. The other stations provide classical WMO standard data at the resolution of 1 m/s for the wind speed (accuracy of +/ 0.5 m/s) and of 10 degrees for the wind direction (accuracy of +/- 5 degrees).

The distances (in km) between reference weather stations and the observation sites are given in the following table:

	Gembloux	Assesse	Spontin
Beauvechain	23.0	47.3	51.3
Ernage	4.2	35.7	37.1
Gosselies	17.9	44.6	41.4
Bierset	56.9	41.5	50.2

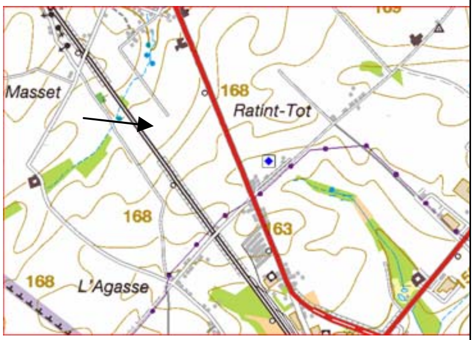
The distances between the reference weather stations and observation sites range from 4 km (Ernage, Gembloux) up to 57 km (Bierset, Gembloux).

4.5.4.1. Weather station of Beauvechain (S.1)

Name :	Beauvechain
X Lambert :	178020 m
Y Lambert :	159436 m
Z (a.s.l.) :	127 m
Z obs. (a.g.l.) :	10 m
Time Period :	01/06/2002 – 31/08/2002
Nb. Data :	2208 hours
Nb. Missing Data :	618 hours (28 %)

The high number of missing data is again linked to the "variable" conditions recorded in the datasets.

4.5.4.2. *Weather station of Ernage (S.2)*



Name :	Ernage
X Lambert :	172608 m
Y Lambert :	141302 m
Z (a.s.l.) :	159 m
Z obs. (a.g.l.) :	10 m
Time Period :	01/06/2002 – 31/08/2002
Nb. Data :	2208 hours
Nb. Missing Data :	0 hours (0 %)

4.5.4.3. *Weather station of Gosselies (S.3)*

Name :	Gosselies
X Lambert :	155527 m
Y Lambert :	127754 m
Z (a.s.l.) :	187 m
Z obs. (a.g.l.) :	10 m
Time Period :	01/06/2002 – 31/08/2002
Nb. Data :	2208 hours
Nb. Missing Data :	105 hours (4.8 %)

4.5.4.4. *Weather station of Bierset (S.4)*

Name :	Bierset
X Lambert :	~226460 m
Y Lambert :	~147928 m
Z (a.s.l.) :	191 m
Z obs. (a.g.l.) :	10 m
Time Period :	01/06/2002 – 31/08/2002
Nb. Data :	2208 hours
Nb. Missing Data :	71 hours (3.2 %)

4.5.5. Analysis of simulation results

The MAESTRO Wind model has been run for a three months period extending from 1st of June 2002 to 31st of August 2002. Four weather stations have been used to provide the forcing datasets.

In order to ensure a as consistent as possible comparison between observations and simulation results, the data corresponding to missing data from observational datasets or forcing datasets have been removed from the resulting time series used for the analysis. This procedure might have some effect on the analysis. Indeed, as mentioned in the Task 3, synoptic scale events last for few days and cross the whole area of interest in few days also. To remove some data "sparsely" in time series might reflect similar problems than observed in Task 3 exercise.

Nevertheless it seems very difficult to obtain complete and consistent datasets from observational data to be used as forcing data or validation data. Moreover on a long term basis, looking at 10, 20 or 30 years back in order to build a "local wind climatology", the number of stations available to drive the model decreases tremendously. It has to be noticed that even if they appear as good candidates for the future, automatic weather stations are quite recent in Belgium and provide only data for a few years.

Before exploring the criteria that might be used to recommend a weather station as a reference one, we will first focus our analysis on the ability of the model to reproduce the wind fields and energy yields. Therefore, the variables discussed for the analysis and comparison with observational datasets (see the table hereafter) are:

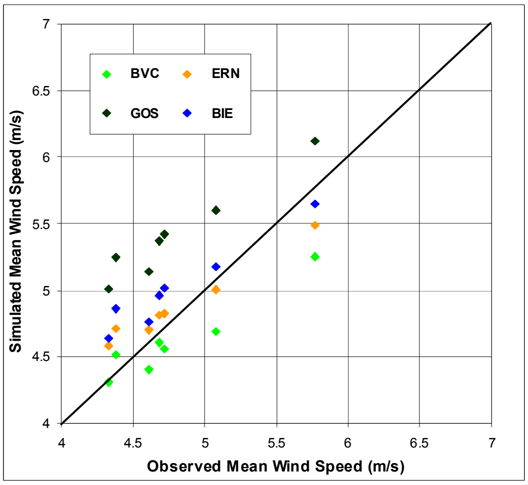
-1- Mean Wind Speed [m/s]

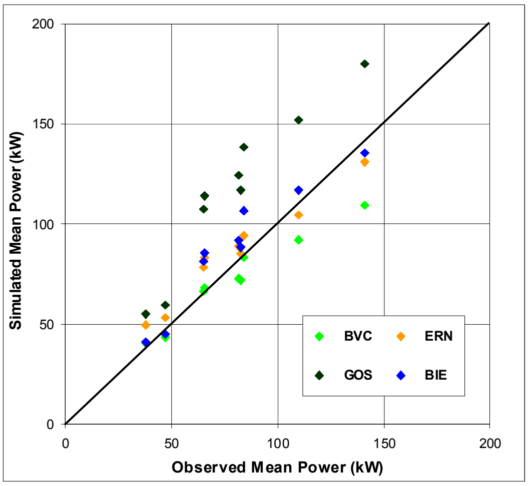
-2- Absolute Deviation in Mean Wind Speed [%]

-3- Mean Power [kW]

-4- Absolute Deviation in Mean Power [%]

To analyse the performance and understand differences between observation and simulation we can draw synthetic graphs showing the Mean Wind Speed and the Mean Power obtained from each simulations with respect to corresponding observed ones. Monthly averages are plotted as well as averages over the whole three months period.





The following table provides the synthesis of the results.

Forcing	Observ.	Time	Obs. MWS (m/s)	Mod. MWS (m/s)	Abs. Dev. MWS (%)	Aver. Dev. MWS (%)	Obs. MP (kW)	Mod. MP (kW)	Abs. Dev. MP (%)	Aver. Dev. MP (%)
BVC	GBX	JUN	5.8	5.3	9.0	3.7	141	110	22.2	9.3
	ASS	JJA	4.3	4.3	0.5		65	67	2.2	
		JUN	4.4	4.5	3.1		66	68	3.6	
		JUL	4.7	4.6	3.5		84	84	0.5	
		AUG	3.7	3.7	0.7		38	40	7.3	
	SPT	JJA	4.6	4.4	4.6		83	72	13.1	
		JUN	4.7	4.6	1.7		82	73	10.9	
		JUL	5.1	4.7	7.6		110	92	16.3	
		AUG	3.9	3.8	2.9		47	43	7.7	
ERN	GBX	JUN	5.8	5.5	4.9	4.8	141	131	7.1	14.1
	ASS	JJA	4.3	4.6	5.8		65	78	20.4	
		JUN	4.4	4.7	7.7		66	83	26.8	
		JUL	4.7	4.8	2.2		84	94	12.3	
		AUG	3.7	4.1	8.9		38	49	30.9	
	SPT	JJA	4.6	4.7	2.0		83	85	2.8	
		JUN	4.7	4.8	2.6		82	89	8.8	
		JUL	5.1	5.0	1.5		110	105	4.7	
		AUG	3.9	4.2	7.5		47	53	13.3	

GOS	GBX	JUN	5.8	6.1	6.1	12.5	141	180	27.7	48.3
	ASS	JJA	4.3	5.0	15.7		65	108	65.0	
		JUN	4.4	5.2	19.8		66	114	73.5	
		JUL	4.7	5.4	14.8		84	139	64.9	
		AUG	3.7	4.1	10.7		38	55	45.6	
	SPT	JJA	4.6	5.1	11.5		83	117	41.3	
		JUN	4.7	5.4	14.6		82	124	51.9	
		JUL	5.1	5.6	10.2		110	152	38.3	
		AUG	3.9	4.2	9.3		47	60	26.8	

BIE	GBX	JUN	5.8	5.7	2.1	4.6	141	136	3.9	13.8
	ASS	JJA	4.3	4.6	7.2		65	82	25.2	
		JUN	4.4	4.9	11.0		66	85	30.2	
		JUL	4.7	5.0	6.2		84	107	26.8	
		AUG	3.7	3.8	2.1		38	41	8.4	
	SPT	JJA	4.6	4.8	3.3		83	88	6.8	
		JUN	4.7	5.0	5.8		82	92	12.0	
		JUL	5.1	5.2	1.9		110	117	6.5	
		AUG	3.9	3.9	1.5		47	45	4.1	

From the table here above, one can say that globally the Beauvechain weather station seems to be the best candidate as a reference station to provide the forcing data to the MAESTRO Wind. On average, the absolute deviation of the Mean Wind Speed is less than 5 % (~3.7 %). Moreover the assessement of the Mean Power looks also very good with an average Absolute Deviation on the Mean Power less than 10 % (~9.3 %). The values obtained in the simulations are slightly underestimated with respect to the observed values.

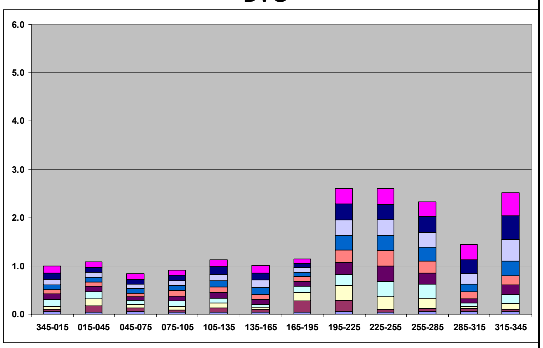
Concerning the Ernage and the Bierset weather stations, the average Absolute Deviation on the Mean Wind Speed is ~5 %. The average Absolute Deviation on the Mean Power is ~14 %.

The Gosselies weather station lead to overestimated results as compared to the observations. The average of the Absolute Deviations of the Mean Wind Speed is ~12 %. The average of the Absolute Deviations of the Mean Power is ~48 %. These large differences are probably due to the presence of a quite complex topography and heavily populated / urbanised areas around the weather station which would not be considered then as a synoptic / large scale flow representative.

The analysis of the area around the forcing weather stations indicates that the roughness length or terrain complexity exerts an influence on the measurements and the extent to which it can be used to produce the actual forcing of the MAESTRO Wind model.

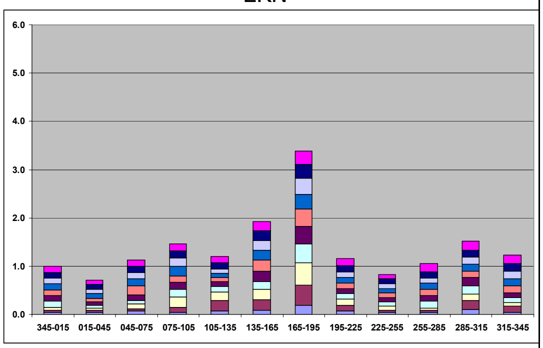
It is interesting to look at the roughness length with respect to the distance from the measurement site in the range of 1 to 10 km and also with respect to sectors. To visualize the information we design the "Cumulative Roughness Length" indicator ("CRL"). The following graphs show the "cumulative roughness length" with respect to distance and sector for the 4 weather stations used for the forcing of the model. One can observe a great variability and high values for Ernage, Gosselies and Bierset. Beauvechain shows the lowest values ranging from 0.8 to 2.6 m, i.e. a total range of 1.8 m.

BVC

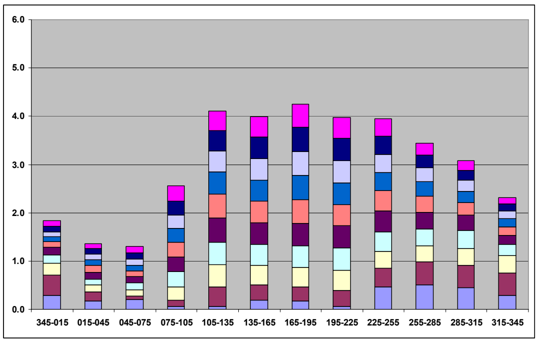
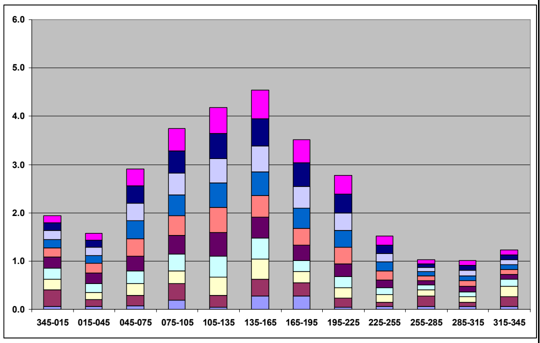


CRL range : 0.8 – 2.6 m
ΔCRL = 1.8 m

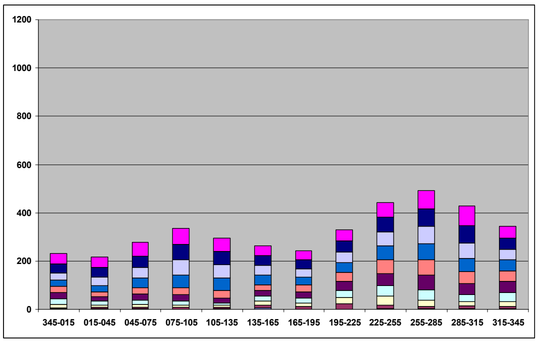
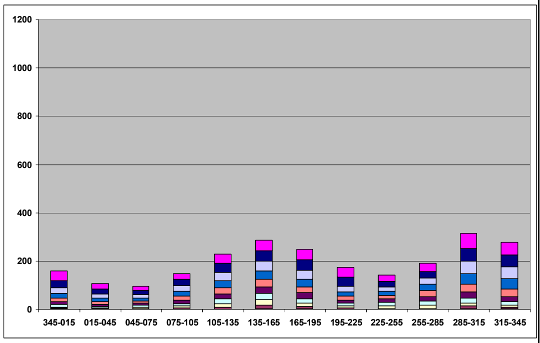
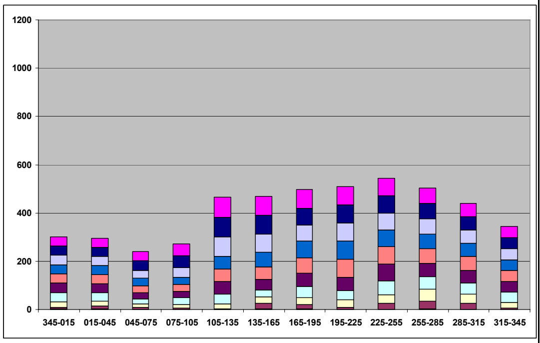
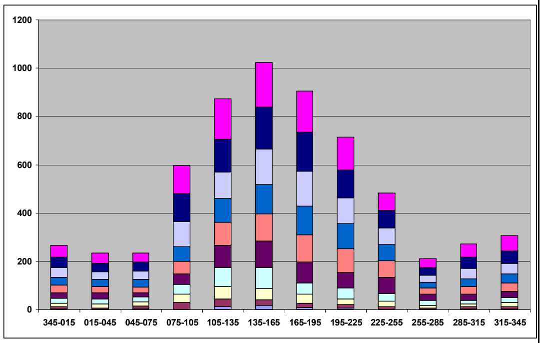
ERN



CRL range : 0.7 – 3.4 m
ΔCRL = 2.7 m

GOS	BIE
	
CRL range : 1.3 – 4.2 m ΔCRL = 2.9 m	CRL range : 1.0 – 4.5 m ΔCRL = 3.5 m

To complete this local area analysis one can also look at the variations of the topography with respect to distance from the measurement site and also with respect to the sectors. This can be assessed from the range of altitude that is obtained in circular zones within 1 to 10 km from the site. Again we design a "Cumulative Altitude Range" indicator ("CAR") to enable the visual representation of this information. The following graphs show the "CAR" indicator with respect of the sectors for the 4 weather stations used as reference in this exercise.

BVC	ERN
	
CAR range : 216 – 490 m ΔCAR = 274 m	CAR range : 96 – 315 m ΔCAR = 219 m
GOS	BIE
	
CAR range : 239 – 543 m ΔCAR = 304 m	CAR range : 212 – 1024 m ΔCAR = 812 m

It appears that the lowest range of the CAR indicator is obtained for Ernage (219 m) and the highest one for Bierset (812 m).

Looking at the 4 weather stations used in this modelling exercise, we can see that the best candidate as "synoptic reference" weather station is probably the station of Beauvechain. The Ernage weather station looks like being a good second choice as well. Gosselies and Bierset look very complex and probably strongly influenced by the complexity of the terrain within the surrounding areas.

Both indicators "Cumulative Roughness Length" ("CRL") and "Cumulative Altitude Range" ("CAR") within an area extending up to 10 km can be seen as good indicators of local influences that could decrease the synoptic skill of a weather station.

4.5.6. Synthesis on the MAESTRO Wind simulations

The aim of the exercise proposed in the task 4.4 is to understand or find out criteria that might be used to select a reference weather station that will provide forcing datasets for the model.

In order to reach this objective, four simulations were performed on the same calculation domain, but using 4 different datasets obtained from 4 weather stations of the RMI network: (1) Beauvechain, (2) Ernage, (3) Gosselies and (4) Bierset. The simulations were made for a three months period of time.

Within the domain and over the selected time period, 1st of June 2002 to 31st of August 2002, three observational datasets were available for the validation exercise. These are located at: (1) Gembloux, (2) Assesse and (3) Spontin.

The analysis of the observational datasets used as forcing or validation shows that there are quite a great number of missing data or "variable" wind conditions resulting in "missing data" in the modelling results because no wind direction is defined as forcing in such a case. Those hours where "missing" data appear were removed from the observation and result time series for the analysis. This procedure might lead to similar problems as described previously in task 3. Ideally one would prefer complete datasets in both validation and forcing datasets. This appears to be rarely achievable in reality.

So we first analyse simulations performed with respect to the various forcing datasets looking at the model results in terms of Mean Wind Speed and Mean Power variables. This analysis shows that the Beauvechain station provides rather good results over the various sites of observation. On average a deviation of the MWS of 3.7 % is calculated and a deviation of 9.3 % is obtained for the Mean Power. The results obtained using the other reference stations show higher deviation. The simulation using Gosselies as a reference leads to 12 % of deviation for the Mean Wind Speed and 48 % of deviation for the Mean Power.

To understand why Beauvechain might be a better reference than the other stations, we analyse the surroundings of the stations in terms of roughness and topography. Two indicators were defined "Cumulative Roughness Length" and "Cumulative Altitude Range" in order to visualise and quantify the local complexity of the area. Again, Beauvechain shows the lowest variation of Roughness length with respect to distance and sectors and shows also not too high variations of topography ranges in its surroundings. The analysis shows also that Ernage might be quite a good second choice. Gosselies and Bierset leads to high complexity in the surroundings of the stations and are suspected to be influenced strongly by those local features.

It appears also, as a consequence, that the distance between the reference station and the analysis domain is less important than the quality or the "synoptic" skill of the weather station. Indeed over long period of time the actual distribution of synoptic events should be correctly reproduced by the simulation.

Other criteria should be considered as well, even if one site seems to be a very good candidate with respect to its synoptic skill, it might be very difficult to be used as a reference when too many data, like "variable" winds, lead to missing data in the results. One should encourage those in charge of the collection of wind or meteorological data to strongly improve their quality control procedures in order to provide end-users with complete and consistent datasets which will lead to realistic and good quality forcing datasets.

Finally, as far as long term assessment of the wind potential is concerned, one should also focus on long time series of observations which will enable to develop a realistic climatology of local winds required for the wind farm project viability assessment. With this respect, automatic weather station, providing measurements of higher accuracy, seems to be good candidates for the future, but provide only short time series which might be insufficient to develop long term climatology of local winds.

To conclude this exercise with some perspectives, one should also look at the large scale model results as providers of the required synoptic forcing for the MAESTRO Wind model. Some issues about the quality of the modelling themselves, the resolution of the calculation, the timing or the availability of the datasets would need to be address to understand if this alternative can be realistically used for the wind potential assessment. Indeed, long term re-analysis might be influenced by the quantity of the data assimilated in time and in space and might also lead to inconsistent data sets. These datasets might also become very expensive and difficult to use in a practical way for end-users.

For the time beeing and as a concluding remark, to define a reference weather station for such a model as the meso/micro scale meteorological model "MAESTRO wind", we should thus focus on:

-1- the availability of observational data sets or long term observation records (cf. network)

-2- the synoptic skill of the site where the station is located (cf. "CRL" and "CAR" indicators)

-3- the quality of the recorded data and their completeness (cf. missing or so data)

-4- the availability of long term series of observations (10, 20 or 30 years) (cf. "climatology")

-5- the distance between the reference site and the analysis domain (cf. synoptic circulation)

4.6. References

[12] Risø National Laboratory, ISBN 87-550-2320-7, December 2004, 65 p.

5. Task 5: Evaluations, recommendations and guidelines

In this Task, some recommendations and guidelines are given for the accurate performing of model based predictions and wind measurements campaigns.

5.1. Evaluations

5.1.1. Observation evaluation

The analysis of the datasets available from the Belgian Network reveals that to measure atmospheric variables in a consistent way over long time period is quite a difficult task.

Indeed, observations are integrating in their records the modifications of site location, the modifications of instruments, the defects of instruments, the modifications of data record methodologies. All these "problems" resulting from the life of observation sites might affect the quality of a weather station with respect to the quality of the data obtained and thus its skill to be used as a reference station for the wind resource assessment.

Moreover, weather stations are located in sites which might be optimized for a local observation or a large scale observation depending on the complexity of the surrounding terrain. Topography, urbanisation and landscape modifications might modify the behaviour of the atmosphere around the observation site in time and influence data long term analysis.

Using those data sets as reference to correlate short term measurements should be made only with the best quality measurements. Further analysis of the data bases and understanding of problems should be a continuous process leading to best quality datasets.

Concerning the on site data, these are generally based on a short period of time of about one year. As they are performed with instruments, they are not immunised against defects or bad locations which will not lead to results representative to the area.

As a consequence, and similarly to the synoptic network, we strongly recommend to improve the quality control procedures in the installation phase and running phase of the measurements in order to avoid any missing or fault data.

Another issue with the observational network will be the altitude at which the measurements are performed, generally 10 m for the synoptic network, which is most of the time not the altitude at which the wind turbines will be implemented. Care should be taken then while extrapolation algorithms are used in order to ensure that the vertical and horizontal structures of the atmospheric flows are well reproduced.

In general, observations will be used either as input data for some modelling system or as validation datasets. For such purposes attention must be paid on the quality of the records and on the quality of the site in which the observations are performed.

An ideal reference station will depend on the requirements of the modelling system and or on the validation purpose. In any case, time series should be without missing data or defect.

5.1.2. Site Input datasets evaluation

The modelling exercises performed in the framework of the project reveal that the input datasets used might be wrong.

Indeed, one of the test case proposed in the region of Amay points out that the topography recorded in the NGI database does not take into account the topography modifications related to excavation sites. An adaptation of the local topography within the model grids have to be performed.

Another test case proposed in the region of Mol points out that the Corine Land Cover database might be misleading because of the classification performed. Indeed in this particular case, land occupation in the surroundings of the measurement station is identified as industrial area which will be linked in models with some surface parameters (albedo, emissivity, roughness length, in particular). In this case this industrial areas is within the forested area. As a consequence defining the surface parameters in the model setup should consider these particularities as far as they would lead to very different interactions between the surface and the atmosphere.

As a conclusion for the site setup in models, one should performed again further analysis and quality control using various sources of information to ensure the correct representation of the surface characteristics in the models. Such NGI topography or Corine Land Cover data bases should be coupled with maps, aerial photos, detailed topography of industrial sites, site visits and so on …

5.1.3. Model evaluation

Each one of the 5 models used in the framework of the project has its own capabilities, limitations and purposes. In order to assess wind resources on a long term basis, i.e. wind climatology, at a local level the models should be able to reproduce the wind speed and direction distribution at the focused location. This will impose to represent correctly the variability of the wind resulting from (1) synoptic / large scale atmospheric flows and (2) local terrain complexity influences on the wind fields.

The meso scale models such as MAR or ARPS use the global climate model outputs to force their boundary conditions. These models intend to reproduce the synoptic scale movements of the atmosphere inside a large area (few hundreds of km). Multiple nesting methods enable to reach some resolution like 10 km or 1 km. The TVM model used in a perturbation mode takes the global climate model outputs as a reference state and produces local perturbations of the wind fields at a resolution of typically 1 km.

Using the ECMWF Re-Analysis datasets provided at 6 hours resolution in time might be good for the models using large areas as far as they will calculate the evolution in time of the meso scale atmospheric features, but in the case of the perturbation mode used within the TVM model, this resolution in time might be insufficient as far as the input data are only interpolated in between the 6 hour intervals. This interpolation in time will not reproduce the synoptic flow modifications in time as such.

The meso/micro scale model MAESTRO Wind uses the synoptic forcing as inputs and requires the most synoptic representative reference station to be used as forcing on an hourly basis. The issue for this model will be more linked to the selection of the most appropriate reference station to ensure good quality assessment of the wind resources.

The WASP model is developed mainly to focus on statistical approach over long period of time (at least one year) using speed up factors and input data coming from observations obtained at various levels. To obtain the wind assessment at level and location of interest some extrapolations will be required. This model does not intend to reconstruct the wind fields as such, but intends to reproduce a statistical distribution of wind starting calculation from a reference station statistics.

Model requirements and capabilities will thus depend on the methodologies implemented.

The validation exercise performed in Task 3 intended to provide some insight of the capabilities of those models to provide or improve the quality of the wind resource assessment for Belgium sites. Test cases have been proposed for 4 sites and 4 seasons. Time periods of 1 week were proposed.

The main output of this exercise is that the time period seems far too short to provide good validation conclusions. This is mainly due to the fact the the typical time scale for synoptic flows is 4 to 5 days and that there is not enough situations analysed within period of time of one week.

Another issue related to the short period of time is that the observations used either as forcing or as validation datasets presents some defect and or missing or so data. This will reduce the number of data available for the comparison.

Finally, depending on the modelling approach, one have noticed that the synoptic flows crossing the areas of interest sooner or later might induce misleading conclusions when looking at some analysis variables such as deviations or RMS error which are analysis of simultaneous datasets, even if on average the modelling results are good. Looking at distribution of wind speeds and directions would be probably better. Nevertheless over a one week period of time this is not relevant. Short term indicators like the deviation of Mean Wind Speed or the RMS Error indicator will then lead to quite "bad" results even if on the long term basis the overall distribution of the wind speed might be well simulated. Therefore validation should focus mainly on long term variables such as mean wind speeds or mean power.

It appears also from this analysis that the location of the observation site is quite crucial when using the data for a validation exercise. Indeed, masts located in or nearby forested area might be influenced by very local effects whose impacts on the wind field might be a function of wind speed, wind direction, forest density, and so on … Therefore these kind of station should not be installed as they will only provide a very local information which may not be extended to larger areas. Apart from a validation exercise issue, extrapolate such data to a wind farm which extends over several km², for example, might result in misleading information on the energy potential of the site.

As a conclusion, validation exercises should be made over long enough periods of time while looking at a fair model/observation comparison of wind speed distribution and the subsequent energy yield. This will ensure that all the synoptic events which last over few days pass over the whole area of concern and avoid misleading analysis. The farther the reference station is located from the observation site, the longer the time period of analysis should be, at least in the case of MAESTRO Wind which is driven by a synoptic reference weather station which can be at some distances from the observation site.

5.1.4. Reference station evaluation

The criteria that should respect a weather station to get the status of "reference" weather station for wind resource assessment depend of course on the modelling approach and the purpose of the modelling.

Focusing hereafter on the meso/micro scale meteorological model MAESTRO Wind, one has identified some criteria or procedure to be followed in order to select a station as reference to be used for the forcing of the model. This stands in the following points:

-1- availability of observational data sets or long term observation records

-2- synoptic skill of the site where the station is located

-3- quality of the recorded data and their completeness

-4- availability of long term series of observations (10, 20 or 30 years)

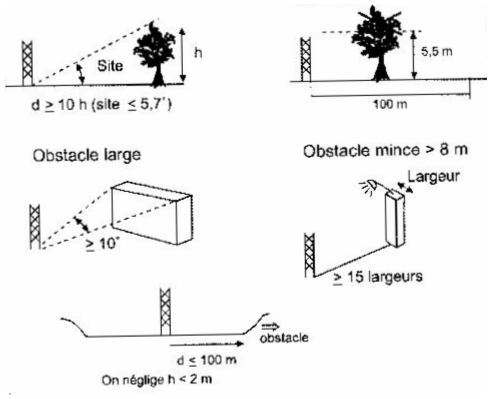
-5- distance between the reference site and the analysis domain

When these are correctly installed with respect to their synoptic skill, automatic weather stations, providing measurements of higher accuracy, seems to be good candidates for the future. Nevertheless, at this stage, they provide only short time series which might be insufficient to develop long term climatology of local winds.

5.2. Recommendations for wind measurement campaigns in general

5.2.1. Site

- Wind measuring masts should be located over level, open terrain
- The measuring mast must be positioned at a distance of at least 10 times the height of the obstacles in its vicinity
- An object is considered as an obstacle when its angular width is superior to 10°.
- The obstacles may not be higher than 5.5 m within a radius of 100 m around the measuring mast.
- Obstacles with a height inferior than 2 m may be neglected.
- A change in relief (orography) within a radius of 100 m is considered as being an obstacle.
- The sensors must be located at a minimal distance of 15 times the width of a thin obstacle (mast, thin tree) exceeding a 8 m height.



5.2.2. Sensors, instruments

5.2.2.1. Wind speed

Anemometers must be robustly constructed using weather resisting plastics, anodised aluminium and stainless steels enabling them to withstand continuous exposure to the weather including marine environments.

The speed of rotation is proportional to the wind speed, providing the speed is steady and is sufficient to overcome the bearing friction. Rotation of the cup is sensed and the instrument can be configured to produce either an analogue output (proportional to wind speed) or a pulse train with each pulse representing a fixed amount of rotation, equivalent to a fixed run of wind. The rate of pulsing gives the wind speed. Counting pulses is an attractive approach because the ideal integrated values of the wind run are directly measured.

Options include anti-icing heaters, mounting adaptors and anti-surge protection

The time response of cup anemometers is specified in terms of a *distance constant*, d. This is the length of wind run for the output, in response to a step change in wind, to reach (1-1/e) of its final value. For a given wind speed, v this gives a time constant, τ, equal to d/v seconds. Unfortunately, cup anemometers respond more rapidly to increases in wind than decreases. This results in the so-called overspeeding effect resulting in an over-estimate of the wind speed. In order to limit this effect, a sufficiently fast response anemometer should be used. Generally, a value of d = 5 m is considered acceptable. A further source of measurement error arises because the cup also responds to some extent to vertical wind components.

5.2.2.2. Wind direction

The wind vane which is essentially a device mounted on a vertical shaft free to rotate with changes in wind direction. In general this instrument produces an analogue output corresponding to direction. There is inevitably a discontinuity in the output at 0/360 degrees, and this is usually aligned to be away from the prevailing wind direction. There is a second type of wind vane which uses a series of switches at around typically 3 degree intervals which does not have a discontinuity at 0/360 degreees. However, this has the disadvantage that the direction is only resolved to a resolution of 3 degrees.

5.2.2.3. Temperature

Ambient temperature has conventionally been measured using a platinum resistance thermometer (PRT) or a thermocouple, although simple semiconductor devices can now be used which are sufficiently accurate. The PRT or thermocouple are normally appropriately shielded from direct radiation from the sun in order to give an accurate reading of the air temperature. Suitable signal conditioning circuitry is supplied with proprietary instruments.

5.2.2.4. Pressure

Compact commercial pressure transducers are available for the measurement of atmospheric pressure. These instruments normally come supplied with appropriate signal conditioning.

5.2.2.5. Datalogger

Dataloggers store data in RAM on storage cards, ready for downloading to a PC at regular intervals. Some loggers are available with modems for data transmission. Some data acquisition systems have been specifically developed for wind site assessment, and these usually come supplied with the appropriate transducers and software.

Wind speed and direction, temperature, humidity and pressure averages over ten minute intervals are recorded, together with maximum and minimum value over this 10 minute interval and the standard deviation.

The measuring frequency is preferably 1 Hz.

5.2.3. Calibration

An error of 3 % in the wind speed measurements leads to an error of about 10 % in the annual energy production which is of course unacceptable. An individual anemometer calibration before, after and at regular time intervals during a measurement campaign is therefore absolutely necessary.

Calibration happens in a wind tunnel according to the IEC 61400-121 and Measnet (Measuring Network of Wind Energy Institutes) standard, by measuring the anemometer velocity at different reference velocities, plotting a graph of one against the other and using linear regression to find the calibration coefficient. It should also be noted that cup anemometers will tend to have a degree of inertia at low wind speeds and hence will not have a linear response at these low wind speeds.

5.2.4. Mast

Open-lattice towers or thin tubular towers with guy wires are preferred.

5.3. Recommendations for the wind measurements of IRM

The purpose of the recommendations should be focused on the improvement of the predictions of wind power in Belgium. Important inputs therefore are the anemometric data of the synoptic reference stations, operated by Belgocontrol, Meteo Wing and RMI. The following recommendations are given.

- A first and important demand is to improve the precision and the frequency of the delivered synoptic data. The AWS stations, operated by RMI already have data with a high precision. Since Belgocontrol and Meteo Wing are having or going to have also automatic weather stations in the future, it should be possible to do this. The RMI proposes to start up a data bank on anemometric data with higher frequency and higher precision. The parameters as mentioned in 6.5, Table 65 are already in use at RMI since the introduction of its AWS. It could perhaps be recommended to extend some parameters. For example, the bins which are chosen according to Table 66, can be extended towards the calm winds. The bins only start until now from wind gusts speed from 40 km/h onwards.
- A bottleneck, which is inherently linked to an automatic weather station is the control on the quality of these data. The WMO proposes to perform a certain quality control check on the gathered data from automatic weather stations (referentie). RMI has already a certain expertise in this domain. When the data is entering the oracle database, it is first subjected to a quality control. If a certain pre-programmed criterion isn't fulfilled, the data is stocked as "suspicious". A staff member of RMI is then informed to check this. If he approves aborts or changes the "suspicious" data, the original data is saved, together with the co-ordinates of the responsible person who treated the data. The difficulty here is to find efficient criteria to find as much as possible errors, tendencies or even malfunction of the instruments (the immobilisation of a wind vane for example can be easily detected if the standard deviation of the wind vane is close to zero). RMI could take the lead to centralise a database on high precision anemometric data

from automatic weather stations with a time resolution of 10 minutes in collaboration with Belgocontrol and Meteo Wing.

- It would be recommended to use more or less the same algorithm for the definition of variable wind for the synoptic code for automatic weather stations. According to the WMO regulations, the recommended criterion is that the standard deviation is equal or greater than 30 degrees and/or the wind speed is smaller than 2 m/s.
- During this project, it has been obvious that there is a certain gap in the history of instrumentation, mast location, interruptions of instruments, calibration of the instruments, etc… Also if there is a change in the surroundings around the mast, like a construction of a building within a range of 500 m, it would be informative to communicate this information. It would be interesting to document these things in a more standard way. The design of a "standard report document" could be a solution.
- The Installation of a mast of 50 m or higher, to be used as a reference mast would be a good option.

5.4. References

- Leroy M, 1999, Météo France, Classification d'un site, note technique
- Measnet. (1997). "Cup Anemometer Calibration Procedure".

6. Task 6: Evaluation of the measuring stations

6.1. Introduction

Since 1952, RMI started to receive hourly synoptic messages from some of these stations. Every hour, a wind direction with a precision in tens of degrees and a wind speed rounded to unity [knots] were transmitted to the RMI besides other meteorological parameters like temperature, surface pressure, cloudiness,… Nevertheless, RMI only stored the synoptic data every 3 hours in a digital format. Since 1985, RMI started to receive written reports from the synoptic data 3 times a month and started also to save the data hourly in a digital format. This was also the case for the gust speed wind data.

Also the homogeneity of the wind time series will be thoroughly checked by applying some statistical tests; since the 1st of July, 1996, the reporting unit for wind speed changed from knots [kt] into [m/s]. Since then, the precision of the delivered wind speed data decreased since the numbers after the digit are not reported and are therefore rounded to the next integer number.

In addition, the automatic weather stations of RMI will be reviewed (12 stations).

There were 28 anemometric stations that have been visited (Figure 3, page 13). These stations are also synoptic stations; 7 stations are managed by Belgocontrol (red in Figure 3), 9 stations by Meteo Wing (green in (Figure 3) and 12 AWS stations by RMI (blue in Figure 3). A detailed description of these stations can be consulted Task 1 "description of the sites".

6.2. Analysis of the wind data

6.2.1. Introduction

The statistical analysis on the wind time series focuses on the time period 1985 – 2004. Since 1985, the RMI receives written reports (three times a month) from the hourly observed synoptic data at the stations operated by Belgocontrol and Meteo Wing.

The observations are hourly recorded in the RMI database since 1985 while they used to be recorded 3 hourly in a digital format before 1985. The written reports give the RMI the opportunity to check eventually erroneous data in the transmitted hourly data. It should be emphasised that this data is considered as "official" data.

During the last 20 years, there have been some changes in used instrument type, mast location, registration methods (manual → automatic) and there has also been a change for all the stations in reporting the unit of measurements for wind speed (conversion from knots [kt] to [m/s] on 01/07/1996).

Most of the changes in instrument type and mast location have been reported in Task 1 in the description of the sites for the time period 1985-2004.

Meteo Wing decided in the beginning of the nineties to start with the installation of semi automatic stations (referred as the FMA-system), including a data collection platform and a data presentation system. Since then, the software automatically records in the synoptic code dd (= wind direction in tens of degrees), ff (=wind speed), ff 911 (=highest gust speed (3 seconds) within the previous hour), ff 912 (=highest 10 minutes averaged wind speed within the previous hour). The observer needs only to fill in the synoptic data afterwards.

Since 2001, Meteo Wing changed from the FMA system into the AWS-system (Automatic Weather Station). RMI started with its AWS network in December 2000 (Dourbes). Since February 2004 the anemometric data for the station of Zaventem are inserted in an automated way in the synoptic reports. This automation will be applied at al the stations, operated by Belgocontrol in the future.

6.2.2. Synoptic code

In this chapter we will briefly discuss the purpose of different types of national and international codes. Also the anemometric parameters mentioned in the synoptic code will be described. Also a discussion about how to encode "variable wind" in the synoptic reports will be made.

"The synoptic code is the WMO standard method for transmitting surface weather information via communications circuits. It is universal in that there are formats for data collected in several units (for wind speed), contains no plain language information (i.e., it is entirely numeric), is always in the same format, etc. There are allowances for each individual country to include national data which are not necessarily of interest to the rest of the world. This code has its own tables, etc., which are for the most part different from those used in the airways code, but is much more systematic... The official reference for taking the surface observation for any observer in Belgium is: "Manuel des codes" , published by WMO. [13][14][15].

The METAR code is the national and international code to report routine, hourly weather conditions at air terminals. METAR contains a report of wind, visibility, runway visual range, present weather, sky condition, temperature, dew point, and altimeter setting collectively referred to as "the body of the report". In addition, coded and/or plain language information, which elaborates on data in the body of the report, may be appended to the METAR. Aviation Selected Special Weather Report (SPECI) is an unscheduled report taken when any of the specified criteria have been observed. SPECI shall contain all data elements found in a METAR plus additional plain language information, which elaborates on data in the body of the report. The Federal Meteorological Handbook No. 1, "Surface Weather Observations and Reports (FMH-1)," is the authoritative source of observing, reporting, and coding standards for surface-based meteorological reports.

In this report, the focus will be on the parameters in the synoptic code, which are linked to the parameter wind. Every hour, 4 variables are communicated with regard to the parameter wind:

- dd: mean wind direction during 10 minutes reported in tens of degrees. (Rounded to the nearest decimal, i.e.,10º=5º→14º)
- ff: mean wind speed during 10 minutes reported in [m/s] and rounded to unity.
- 911 ff: gust speed during the last hour, 3 hours (referred as the intermediate hours: 03, 09, 15, 21 U.T.) or 6 hours (referred as the main hours: 00, 06, 12 and 18 U.T.), reported in function of the hour of the day, also reported in [m/s], rounded to unity.
- 912 ff: mean maximal 10' averaged wind speed during the last hour, 3 hours or 6 hours, reported in function of the hour of the day (idem as 911 ff).

In the next subsection the problems encountered with regards to the detection of variable wind for the different stations will be discussed.

6.2.2.1. Detection of variable wind

The definition for variable wind in the synoptic code, meeting the WMO regulations is the following: the code 99 (variable wind) is addressed to the wind direction (dd) when the wind direction cannot be determined. In the Netherlands for example dd=99 may be encoded if the wind speed (ff) is smaller than 2 m/s and the wind direction (dd) is not detectable, i.e. if the standard deviation of dd is more than or equals 30º.

Other definitions of variable wind direction are found in the METAR and SPECIES reports [ICAO,Doc 9837,2004].

- "when the total variation is between 60º and 180º and the wind speed is less than 6 km/h (3kt), the wind direction shall be reported as variable with no mean wind direction"; or
- "when the total variation is 180º or more, the wind direction shall be reported as variable with no mean wind direction;"

When automatic weather stations are introduced, algorithms are programmed in data loggers to calculate the parameters dd and ff. This calculation approach can be scalar or vector. This calculation approach was scalar until February 2004 for the three networks (RMI, Belgocontrol, Meteo Wing).

Since February 2004, Belgocontrol changed this scalar calculation into a vector calculation with the introduction of a Thies anemometer at the meteo station of Zaventem. The other stations will follow in the future. Belgocontrol follows the ICAO recommendations [ICAO,Doc 9837,2004].

For the parameter wind speed, the **International Civil Aviation Organization** (ICAO) and the WMO (World Meteorological Organisation) have not yet provided recommendations on the calculation method, probably since both practices are used throughout the world and a vector calculation would cause problems in several areas. With modern systems, vector calculations are not a problem, especially since they are required for the mean direction. Differences in results between both calculations are minimal when there are few changes in wind direction, but are greater when the wind direction shows great variability. If the speed is over 10 [kt], there is a marked discontinuity. If the speed is less than that, the differences (in absolute values) between both methods remain minimal.

Concerning the parameter wind direction, it is recommended by ICAO that a vector calculation is performed, which can be done using two methods:

- By calculating the mean wind vector and its direction and
- By calculating the mean wind vector using the instantaneous vectors of a unit modulus and the direction equal to the measured direction. This method of calculation is somewhat simpler than calculating the actual mean wind vector. Unless there are significant variations in wind speed, it gives equivalent results, while significant variations in wind speed produce marked discontinuity."

Since the introduction of the automatic weather stations, the number of encountered "variable wind directions" changed progressively. Figure 76 shows the general positive trend over the years in detecting "variable wind" (99) for the Belgian synoptic network (14 selected stations), starting in 1991-1992 since the introduction of the FMA system by Meteo Wing. Figure 77 shows the number of hits for this 14 synoptic stations over a time period of 20 years of hourly data (10' average) in which it is obvious that the stations which are or has been operated by Meteo Wing since 1991-1992 ((Beauvechain, Bierset, Chièvres, Elsenborn, Florennes, Kleine-Brogel, Koksijde en Semmerzake) had much more hits of variable wind (code 99) compared with the other stations, operated by Belgocontrol, although the anemometers for this stations are well located and well exposed. The station of Bierset resumes well the influence of introducing an AWS on detecting variable wind: Figure 78 shows that indeed since 1991-1992, the number of "variable wind" hits is increasing for Bierset. Since 1998, when Belgocontrol took over the synoptic reporting from Meteo Wing, the number of encountered variable wind directions is comparable with the number of hits before the introduction of the FMA-system at Bierset, although the mast only moved a few hundreds of meters to the northeast and the mast location can still be considered as sufficiently open. This can only be explained by an algorithm problem. When visiting the station of Beauvechain, the graphical output of the wind direction of the Vaisala instrument has been compared with the output, generated automatically by the AWS for the synoptic reports. The graphical output shows that it is possible to assign a wind direction although in the synoptic reports a direction 99 is noted.

If we look at the trend at Beauvechain in detecting variable wind (Figure 79), it is observed that in 2003 almost 23 % of the yearly-generated data for wind direction is variable (code 99).

RMI does not have since the introduction of its AWS until now an operational algorithm running to detect variable wind. Therefore there is every 10 minutes always an averaged 10 minutes wind direction reported in the database. Since the RMI also calculates simultaneously the standard deviation on the wind direction according to the Yamartino algorithm, it would be easy to reconstruct the detection of a variable wind direction according to the WMO regulations: "if the standard deviation is greater than or equals 30º, the wind direction can be considered as variable."

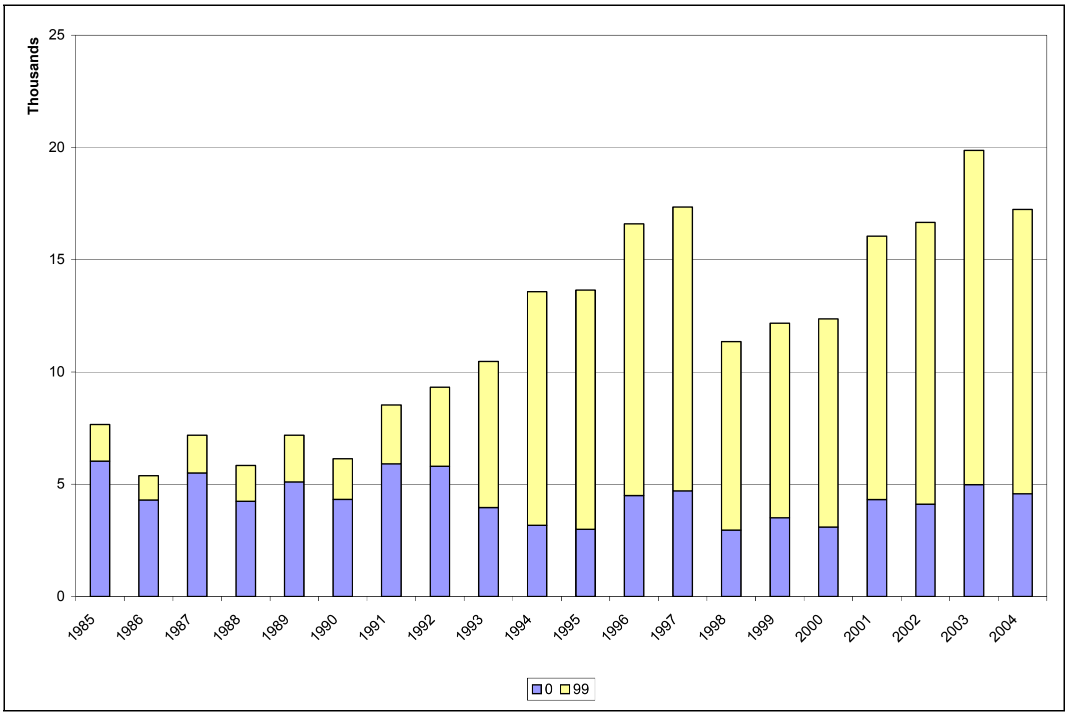


Figure 76: Number of encountered cases of variable wind direction (99) and calms (0) for the time period 1985-2004 for 14 selected synoptic stations (see figure below)

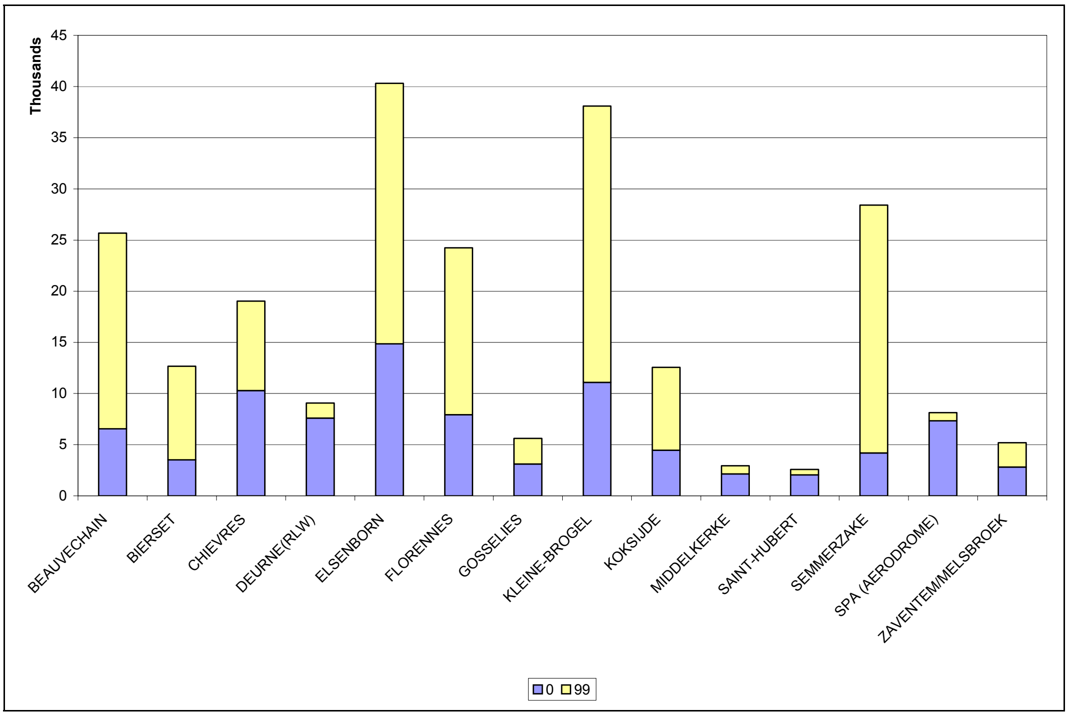


Figure 77: Total number of encountered cases of variable wind directions (99) and calms (0) for the time period 1985-2004 for 14 selected synoptic stations

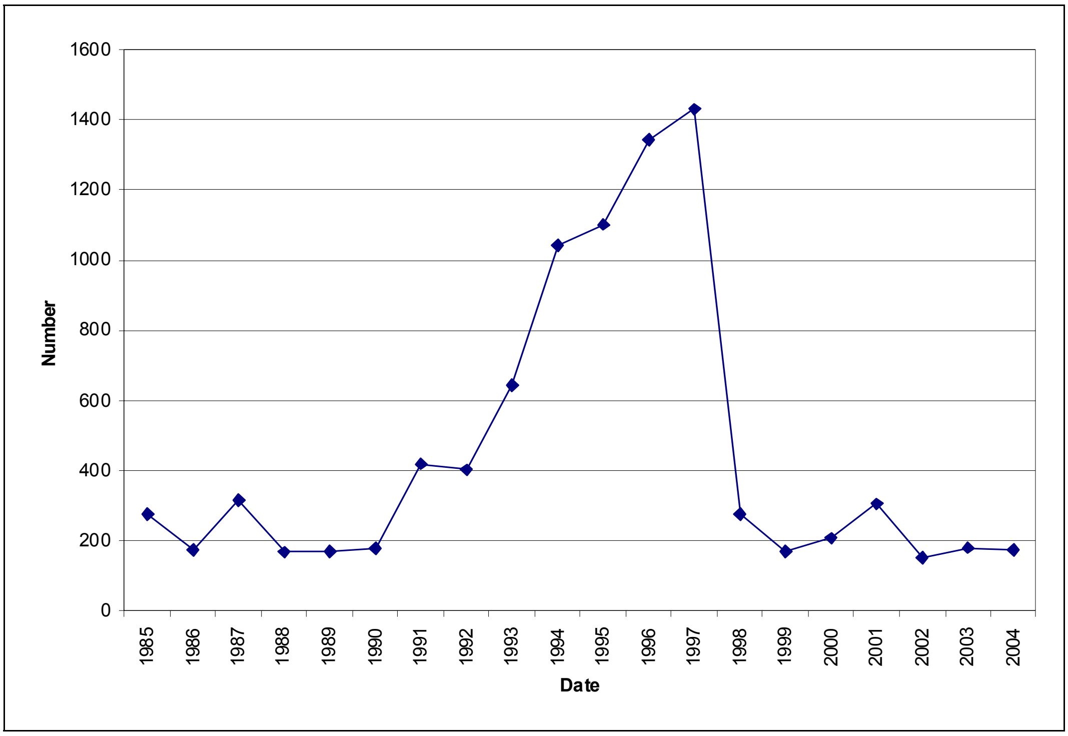


Figure 78: Number of encountered cases of variable wind direction (99) for the time period 1985-2004 for the synoptic station of Bierset

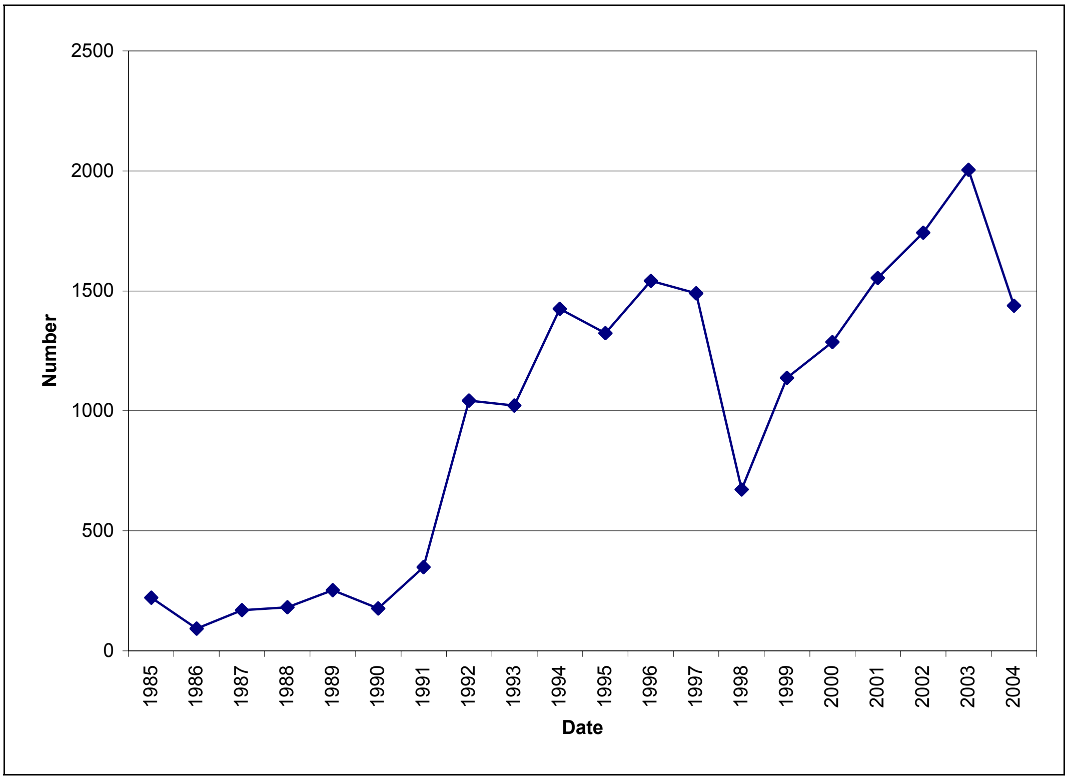


Figure 79: Number of encountered cases of variable wind direction (99) for the time period 1985-2004 for the synoptic station of Beauvechain

Table 42, Table 43, and Table 45 give an overview of the number of encountered variable winds and null winds for all of the 14 reference stations in function of the year and the operated network:

Table 42: yearly percentage of detected variable wind direction for the stations operated by Meteo Wing

	BEAUVECHAIN	CHIÈVRES	ELSENBORN	FLORENNES	KLEINE-BROGEL	KOKSIJDE	SEMMERZAKE	SCHAFFEN
1985	2.52	0.83	2.07	2.27	2.95	1.26	1.69	1.44
1986	1.05	0.39	2.33	1.68	1.19	1.31	0.92	0.96
1987	1.93	0.35	4.91	2.07	1.61	1.84	0.92	1.51
1988	2.07	0.19	6.08	1.78	1.25	1.30	2.04	1.17
1989	2.89	0.40	7.44	2.47	2.37	1.14	2.57	1.48
1990	2.02	0.63	5.78	1.40	1.64	1.16	2.73	1.39
1991	3.98	1.79	6.97	2.34	3.58	0.62	2.37	1.66
1992	11.87	3.19	7.41	2.76	3.56	0.63	1.84	4.37
1993	11.67	2.34	12.18	4.89	15.54	2.75	11.78	5.24
1994	16.27	2.90	22.39	11.62	23.74	2.44	22.18	7.85
1995	15.11	2.73	23.28	12.66	23.84	3.30	23.48	4.16
1996	17.55	6.45	22.53	11.50	24.66	6.19	27.33	5.69
1997	17.01	9.75	23.48	18.45	23.82	3.93	25.39	5.70
1998	7.67	8.85	18.01	14.54	19.32	2.68	17.10	3.84
1999	12.99	4.10	16.79	12.93	20.02	5.21	19.76	4.25
2000	14.65	2.78	21.79	11.84	23.13	6.26	17.27	4.76
2001	17.74	10.78	19.76	14.66	26.79	11.11	22.76	17.19
2002	19.90	12.83	22.69	15.65	29.99	9.52	23.07	14.54
2003	22.88	15.10	24.28	21.78	31.31	16.39	25.59	14.97
2004	16.37	13.43	20.22	18.78	27.77	13.27	25.38	18.44

Table 43: yearly percentage of detected null winds for the stations operated by Meteo Wing

	BEAUVECHAIN	CHIÈVRES	ELSENBORN	FLORENNES	KLEINE-BROGEL	KOKSIJDE	SEMMERZAKE	SCHAFFEN
1985	6.84	6.75	3.09	7.16	7.76	1.97	2.47	9.39
1986	3.22	4.28	3.56	9.08	5.62	5.41	1.03	1.42
1987	3.06	9.73	14.19	4.61	5.74	5.95	1.40	0.71
1988	4.59	6.17	12.33	4.70	6.34	1.54	1.90	0.50
1989	3.74	8.66	15.39	4.29	8.66	3.52	1.76	0.55
1990	4.50	6.97	8.37	4.87	7.45	1.61	1.52	0.82
1991	5.47	8.76	11.82	4.14	9.49	1.93	2.00	1.58
1992	2.87	23.62	10.02	4.72	6.92	1.63	1.09	1.22
1993	3.62	4.86	8.74	4.73	3.46	0.86	1.39	1.35
1994	2.51	4.10	4.41	2.59	5.11	2.60	1.06	0.88
1995	2.24	3.37	4.86	2.85	4.05	1.38	0.27	0.72
1996	2.65	5.00	7.57	8.98	3.94	1.56	0.48	1.08
1997	3.24	7.71	8.85	4.35	5.35	2.60	0.41	2.40
1998	2.18	1.15	6.20	1.92	3.82	2.85	0.22	5.14
1999	3.34	2.36	8.57	1.97	5.99	1.13	0.79	1.75
2000	1.59	1.79	4.80	3.03	4.93	0.98	0.22	4.44
2001	3.97	4.47	7.64	6.37	6.08	2.29	1.77	3.32
2002	2.93	1.62	8.09	2.73	7.59	5.26	0.73	3.60

	BEAUVECHAIN	CHIÈVRES	ELSENBORN	FLORENNES	KLEINE-BROGEL	KOKSIJDE	SEMMERZAKE	SCHAFFEN
2003	4.58	3.09	12.26	3.74	9.90	2.65	1.00	4.30
2004	7.58	2.81	8.71	3.68	8.25	3.32	1.13	2.69

Table 44: yearly percentage of detected variable wind direction for the stations operated by Belgocontrol

	BIERSET	DEURNE	GOSSELIES	MIDDELKERKE	SAINT-HUBERT	SPA	ZAVENTEM
1985	3.15	1.08	0.39	0.32	0.00	0.06	0.07
1986	1.99	0.90	0.25	0.10	0.00	0.17	0.09
1987	3.61	1.29	0.30	0.10	0.02	0.16	0.15
1988	1.91	0.91	0.18	0.11	0.03	0.15	0.13
1989	1.94	1.15	0.25	0.25	0.00	0.41	0.42
1990	2.02	1.36	0.32	0.25	0.05	0.58	0.70
1991	4.78	1.26	1.06	0.18	0.07	0.72	0.21
1992	4.58	1.53	1.08	0.15	0.08	1.31	0.14
1993	7.34	1.24	0.96	0.31	0.48	1.10	1.64
1994	11.88	0.56	1.26	0.40	0.81	0.54	1.86
1995	12.58	0.29	0.99	0.17	0.82	0.39	2.01
1996	15.30	0.54	1.32	0.30	0.73	0.47	2.89
1997	16.32	0.33	1.56	0.54	0.50	0.50	2.79
1998	3.14	0.30	2.23	0.26	0.29	0.32	1.20
1999	1.93	0.48	1.89	0.49	0.29	0.42	1.74
2000	2.36	0.52	2.50	0.64	0.34	0.26	1.23
2001	3.48	1.05	1.97	0.40	0.63	0.39	2.44
2002	1.74	0.32	2.40	0.76	0.37	0.40	3.63
2003	2.05	1.05	3.86	2.12	0.34	0.35	2.84
2004	1.97	0.56	3.83	1.20	0.24	0.16	0.97

Table 45:yearly percentage of detected null winds for the stations operated by Belgocontrol

	BIERSET	DEURNE	GOSSELIES	MIDDELKERKE	SAINT-HUBERT	SPA	ZAVENTEM
1985	1.84	6.48	3.09	2.53	1.82	6.11	3.90
1986	1.61	3.06	3.40	1.46	1.31	3.87	1.74
1987	1.53	3.68	7.32	2.21	0.71	2.26	1.10
1988	2.16	2.96	2.36	1.71	0.33	1.38	1.23
1989	1.40	4.85	1.36	2.21	0.74	1.56	1.32
1990	2.95	3.65	0.84	1.53	0.42	3.72	1.68
1991	3.70	4.68	1.31	1.86	0.53	10.24	1.86
1992	2.61	4.10	1.14	1.68	1.23	3.11	1.13

	BIERSET	DEURNE	GOSSELIES	MIDDELKERKE	SAINT-HUBERT	SPA	ZAVENTEM
1993	5.39	3.56	0.73	0.73	1.60	4.05	1.55
1994	2.12	3.87	0.80	0.39	1.27	4.03	1.46
1995	1.83	4.67	1.18	0.65	1.07	3.68	1.56
1996	3.95	5.34	1.55	1.05	1.26	5.56	1.68
1997	2.61	4.67	1.43	1.05	1.23	5.73	2.39
1998	0.38	2.31	1.12	0.47	1.85	3.54	0.76
1999	0.32	5.42	1.28	0.95	1.43	3.74	1.67
2000	0.44	3.69	1.21	0.67	2.28	4.49	0.85
2001	0.45	3.80	1.86	1.13	1.11	5.29	1.45
2002	0.51	5.65	1.14	0.72	1.56	4.35	1.16
2003	0.98	5.56	1.21	0.68	1.21	5.00	1.64
2004	3.53	4.80	1.26	0.77	0.47	2.12	2.09

6.2.3. Descriptive statistics

To illustrate the Belgian wind climate, some contour plots are plotted in the next figures (Figure 80, Figure 81 and Figure 82). They reflect some descriptive statistics for the station of Zaventem averaged over a time period of 20 years (1985-2004). To design those contour plots, hourly data of wind speed and wind direction have been used. It is obvious from Figure 80 that the predominant wind direction is southwest (more generally from S to WSW) through the whole year and particularly during winter. Less dominant are east-, northeast- and northwest winds. Northwest winds occur more generally during spring and summer season. East northeast winds occur during the entire year.

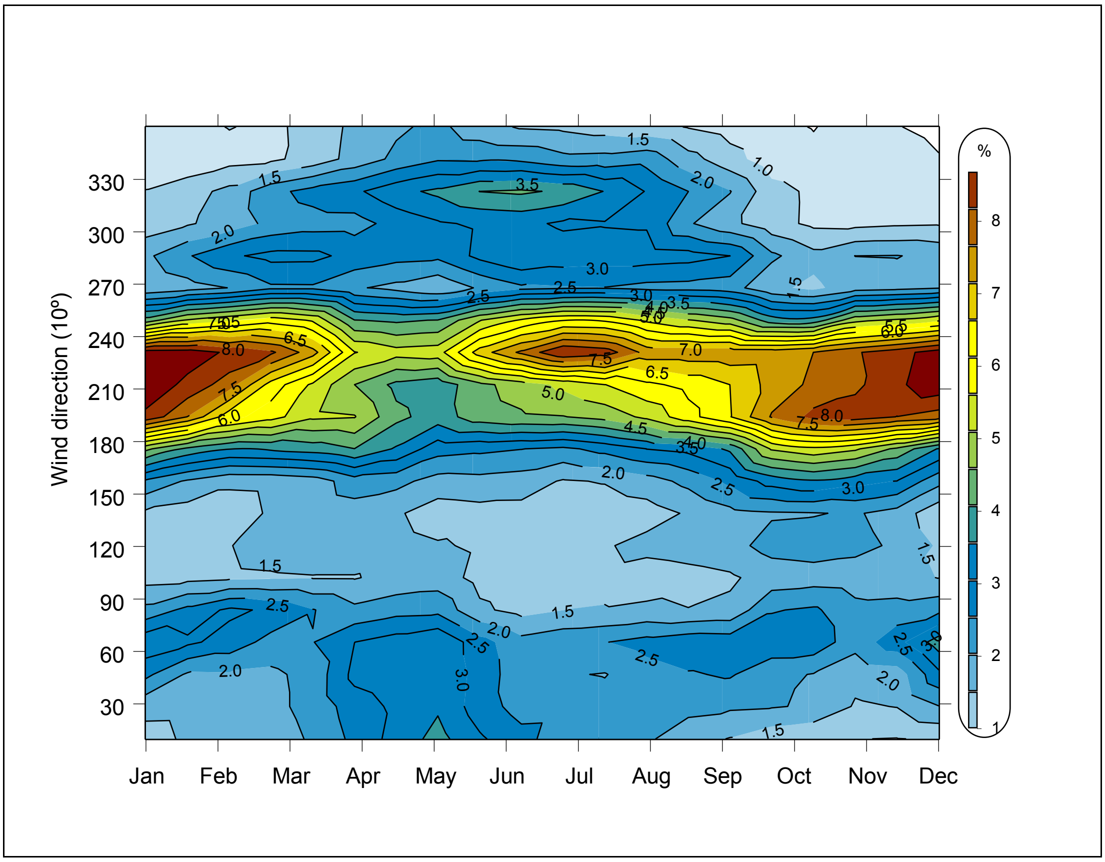


Figure 80: Monthly percentage of wind direction according to 36 wind directions for Zaventem from 01/01/1985 – 31/12/2004

Figure 81 shows the climatology of averaged wind speed for the synoptic station of Zaventem in function of the wind direction and the month for the time period 1985–2004. This shows that the highest wind speeds occur for the most prevailing wind directions (i.e. southwest, east northeast and northwest). The lowest wind speeds are related to wind blowing from directions east → southeast.

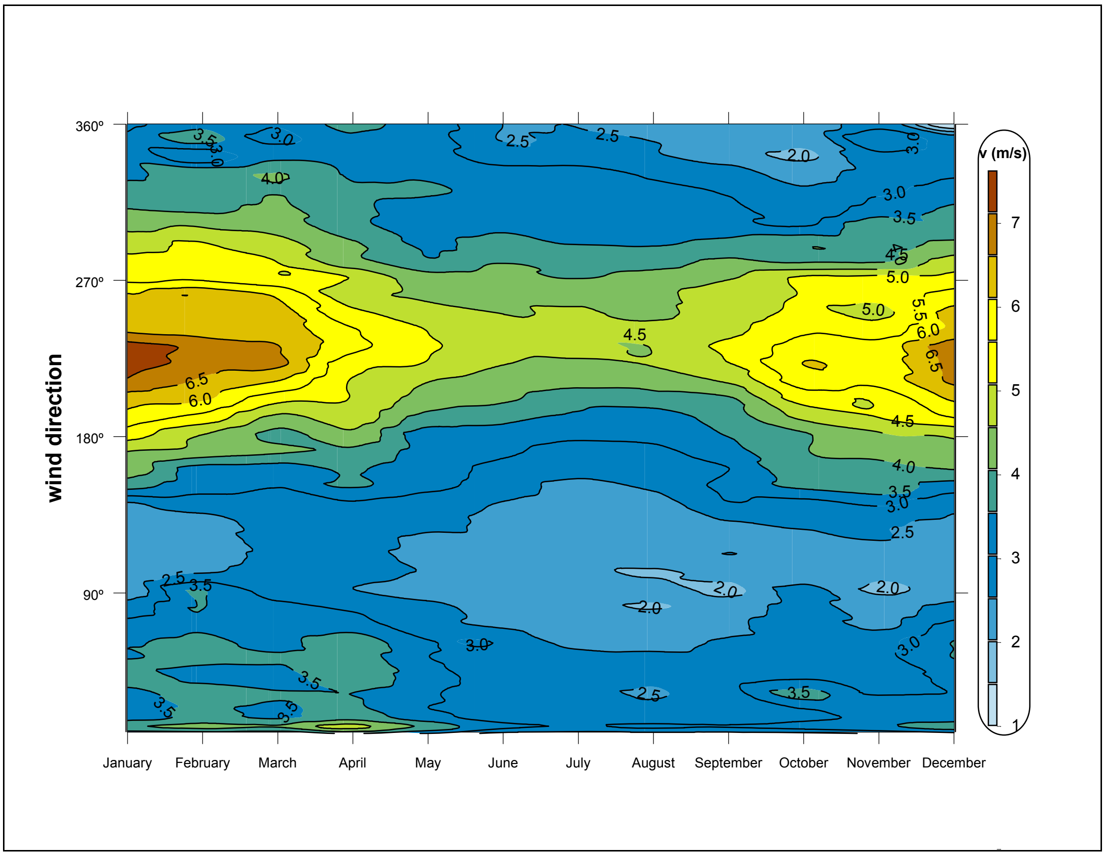


Figure 81: Monthly averaged wind speed climatology for Zaventem in function of the wind direction for the time period 01/01/1985 – 31/12/2004

The next figure below illustrates the climatology of the averaged wind speed in function of the hour of the day and the month of the year. It is obvious that there is a diurnal cycle present through the whole year, but more pronounced during summer.

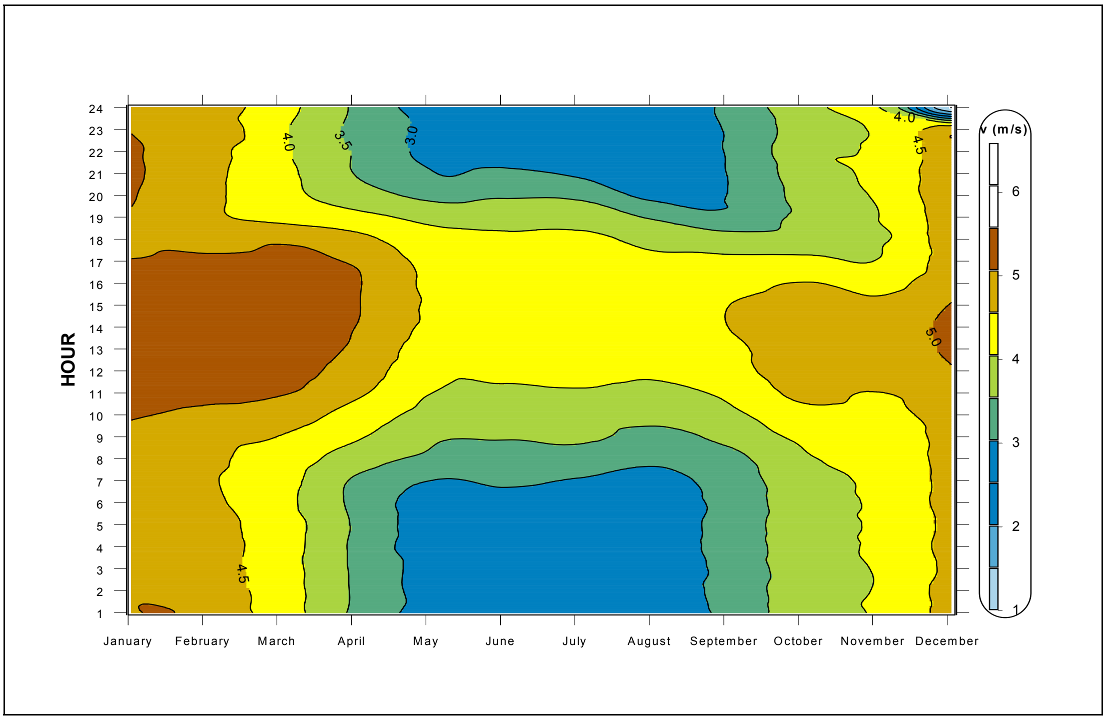


Figure 82: Hourly averaged wind speed climatology for Zaventem in function of the month for the time period 01/01/1985 – 31/12/2004

6.2.4. Homogeneity of the wind time series

To test the homogeneity of the time series, some statistical tests have been applied on the time series of monthly mean values of wind speed. In the following subsection, an explanation on the usefulness of the Pettitt-Man-Whitney test is given to find discontinuities in time series. After this description, the results of these tests on 13 selected reference stations are briefly discussed.

6.2.4.1. Mann-Whitney U-test

The non-parametric Mann-Whitney U-test tests the hypothesis that two populations X and Y have the same mean of distribution against the hypothesis that they differ. When a time series is divided in two shorter series at time T, these sub series can be seen as independent populations X and Y. When the results of the test show that the mean of the two populations X and Y do not differ from each other, this will mean that no change occurred at time T.

The Mann-Whitney statistics for X and Y are defined as follows (Zar,1999; McCuen, 2003):

$$U_x = N_x \cdot N_y + \frac{N_x \cdot (N_x + 1)}{2} - W_x$$

$$U_y = N_x \cdot N_y + \frac{N_y \cdot (N_y + 1)}{2} - W_y$$

where N_x and N_y are the number of elements in X and Y , respectively and W_x and W_y are the rank sums for X and Y, respectively. The test statistic Z which closely follows a normal distribution for sample sizes exceeding 10 is defined as follows:

$$Z = \frac{U_x - (N_x \cdot N_y)/2}{\sqrt{(N_x \cdot N_y \cdot (N_x + N_y + 1))/12}}$$

When the calculated probability is smaller than the 0.05 significance level, the hypothesis that the two populations X and Y have the same mean of distribution is rejected.

For example, a wind speed time series is divided into two new partial series with the elements (x1, . . ., xT) and (xT +1 , . . ., xN). Each of these two series must contain at least ten elements. When the calculated Mann-Whitney test statistic Z at time T is smaller than 0.05, this means that a change in wind speed occurred around time T. To detect all the possible change-points in the anemometric time series, the Z statistic is calculated for every time T in the series and a plot is made of its evolution. Because this Mann-Whitney U-test is not that powerful in detecting changes in a time series, the results will be discussed together with the results of the Pettitt-Mann-Whitney test.

6.2.4.2. Pettitt-Mann-Whitney test

Consider a time series (x1 , x2, . . ., xN), then the time series is said to have a change-point at τ if xt ∈ x1, . . . , xτ is from a distribution function F1(t) and xt ∈ xτ +1 , . . . , xN is from a distribution function F2(t) and these two distribution functions F1(t) = F2(t). The approximation of the non- parametric Pettitt-Mann-Whitney test for continuous data is used to test the null hypothesis of no change, H0 : τ = N against the alternative of change, H1 : 1 ≤ τ < N (Pettitt, 1979).

The indices V (t) and U (t) are calculated from:

$$V(t) = \sum_{j=1}^{N} \operatorname{sgn}(x_t - x_j)$$

$$U(t) = \begin{cases} U(t-1) + V(t) & \text{for t} = 2, \text{N} \\ V(t) & \text{for t} = 1 \end{cases}$$

where

$$\operatorname{sgn}(x) = \begin{cases} 1 & \text{for x} > 0 \\ 0 & \text{for x} = 0 \\ -1 & \text{for x} < 0 \end{cases}$$

The most significant change-point is found where the value |U(t)| is maximum:

$$K = \max\left|U(t)\right|$$

The approximate significance probability p(t) for a change-point is:

$$\text{p(t)} = 1 - \exp\left(\frac{-6 \cdot \text{U(t)}^2}{N^2 + N^3}\right)$$

A significance level of 0.90 is chosen for p(t).

In the next subsections, the results of the application of the above mentioned tests will be discussed for 13 reference stations.

Every figure consists of 3 subfigures; on top there is the time series itself, in the middle there is the Pettitt-Mann-Whitney test and the bottom figure shows the results of the Mann-Whitney-U test.

The second graph, showing the results of the Pettitt-Mann-Whitney test, shows a red and a black colored line. The red line is the |U(T)|, which is normalized. This has as a consequence that the point on the graph which has a value of 1 can be defined as the most significant change-point. This moment is printed on the graph as a date (month/year). This change-point is only statistically significant if the probability p(t) black line exceeds the 0.90 level. When the line on the bottom figure (Mann-Whitney U-test) is below the significance level (0.05), a change-point or period is present, according to the described test statistics.

6.2.4.2.1. Beauvechain (Bevekom)

The most significant change-point for Beauvechain is March 1988. The significance level of the Pettitt-Mann-Whitney test doesn't exceed the 0.90 level. No significant discontinuities are detected. The Mann-pettit U-test shows that there is no significant difference in averaged wind speed between 1992 and 2004.

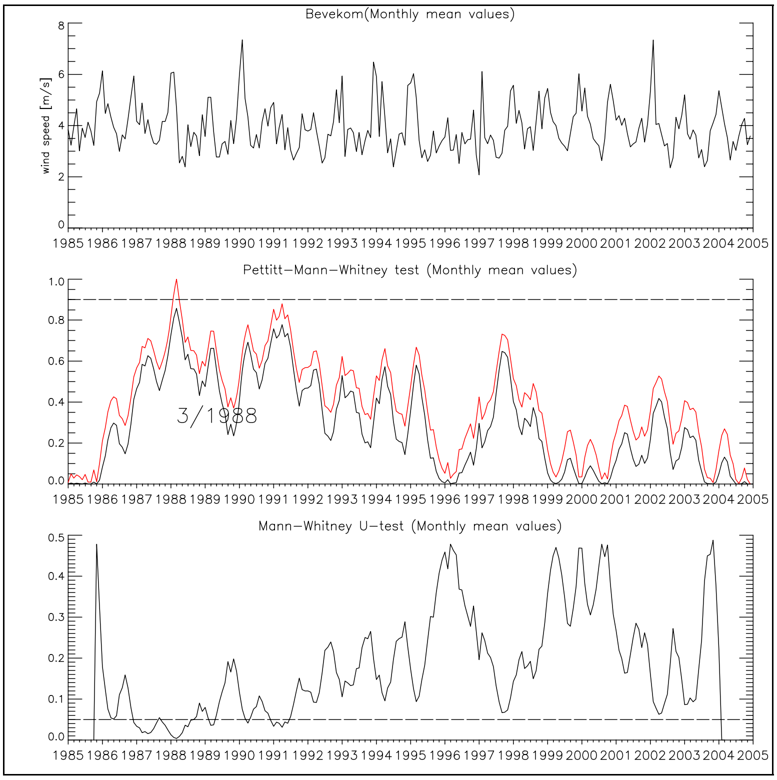


Figure 83: Monthly averaged wind speed time series, Pettitt-Mann-Whitney test and Mann-Whitney U-test for the station of Beauvechain

6.2.4.2.2. Bierset

Bierset has the same most significant change-point as Beauvechain, i.e. March 1988. The Pettitt-Mann-Whitney test exceeds the 0.90 level twice, the first time on March 1988 and the second time around November 1997. There is an indication that the mean averaged wind speed values before and after November 1997 are significantly different.

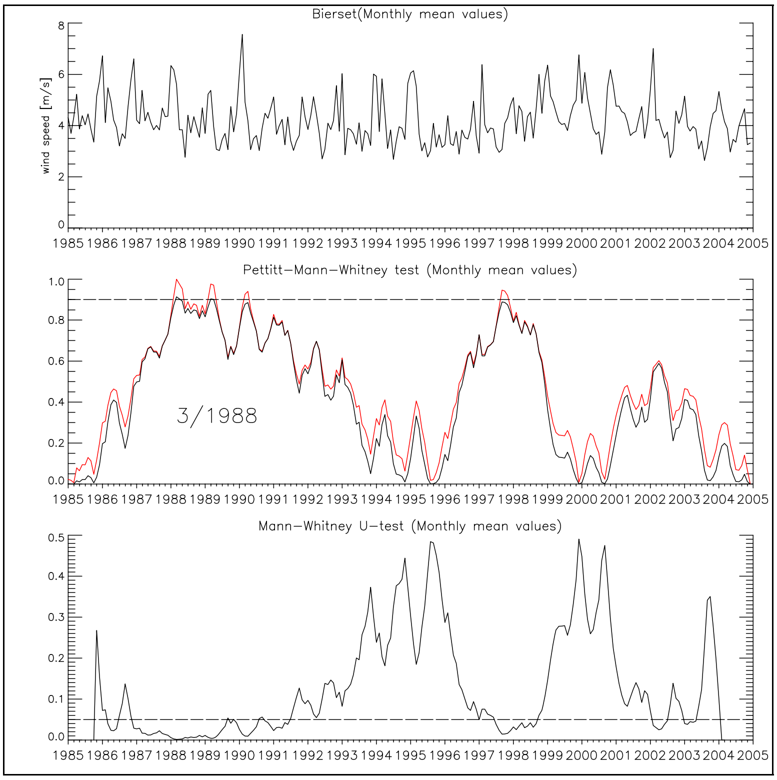


Figure 84: Monthly averaged wind speed time series, Pettitt-Mann-Whitney test and Mann-Whitney U-test for the station of Bierset

6.2.4.2.3. Chièvres

Chièvres has its most significant change-point on August 1993. During our station visits, it has been reported that on September 1st of 1993, a temporary anemometer has been installed on the roof of the traffic tower. Between 1992 and 1994, many problems have been encountered at the station of Chièvres with the detection of the wind direction and the wind speed. Since 16-12-1993, the FMA system became operational at Chièvres. Since 1999, this station isn't staffed anymore on a 24 hour bases. Consequently, less data is received from this station (Table 63). A good reference period for this station is from1994 till 1998. Still, this station is very important for the Belgian synoptic network, since if this station is out of use, there is a spatial gap in the reference stations around Chièvres (Figure 3). Therefore it should be emphasized in the recommendations that it would be appreciated to receive more data from Chièvres.

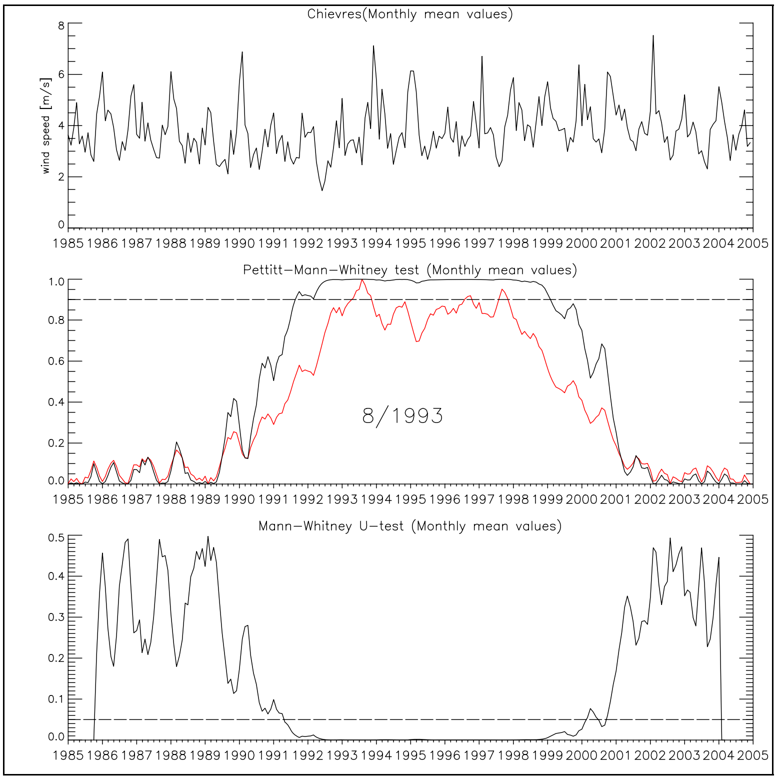


Figure 85: Monthly averaged wind speed time series, Pettitt-Mann-Whitney test and Mann-Whitney U-test for the station of Bierset

6.2.4.2.4. Deurne

The most significant change-point for Deurne occurs on October 1997. This could be due to the rounding of knots [kt] to [m/s] since July 1996. The Mann-Whitney U-test confirms the results of the Pettit-Mann-Whitney test and also shows a moment in time where a significant change in averaged wind speed took place (06-1996→ 1999)

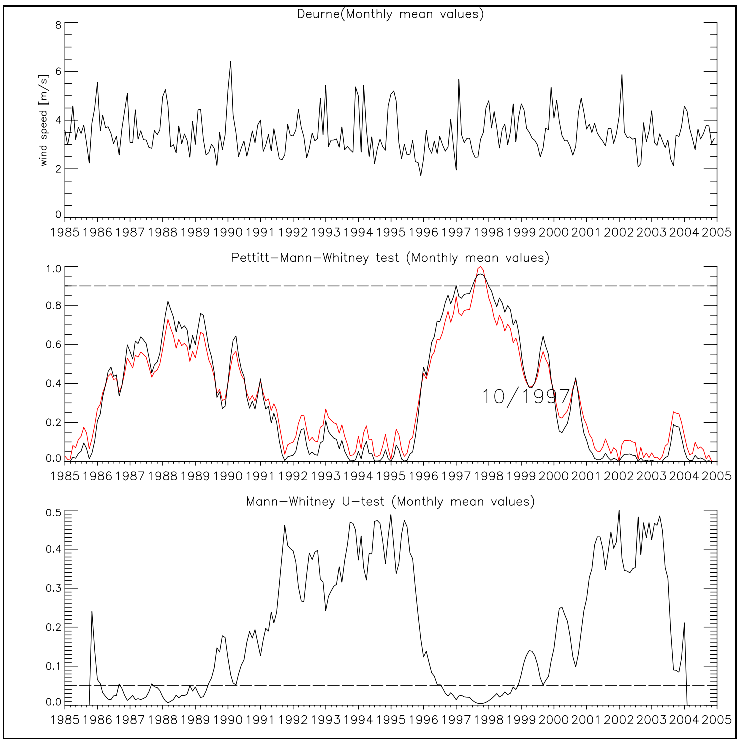


Figure 86: Monthly averaged wind speed time series, Pettitt-Mann-Whitney test and Mann-Whitney U-test for the station of Deurne

6.2.4.2.5. *Elsenborn*

This military aerodrome also shows its most significant change-point on March 1988. The significance level of the Pettitt-Mann-Whitney test doesn't exceed the 0.90 level. The Mann-Whitney U-test shows that there is no significant difference in averaged wind speed between 1990 and 2004.

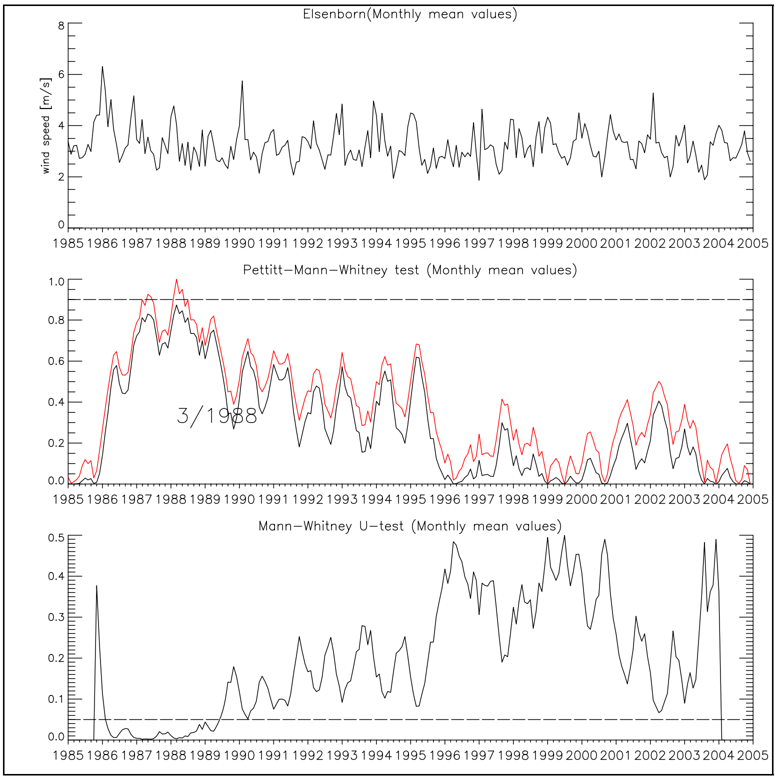


Figure 87: Monthly averaged wind speed time series, Pettitt-Mann-Whitney test and Mann-Whitney U-test for the station of Elsenborn

6.2.4.2.6. *Florennes*

Florennes has its most significant change-point around November 1997. The significance level of the Pettitt-Mann-Whitney test doesn't exceed the 0.90 level. The Mann-Whitney U-test shows that there is a difference in averaged wind speed before and after November 1998, but according to the severe test, this is not significant.

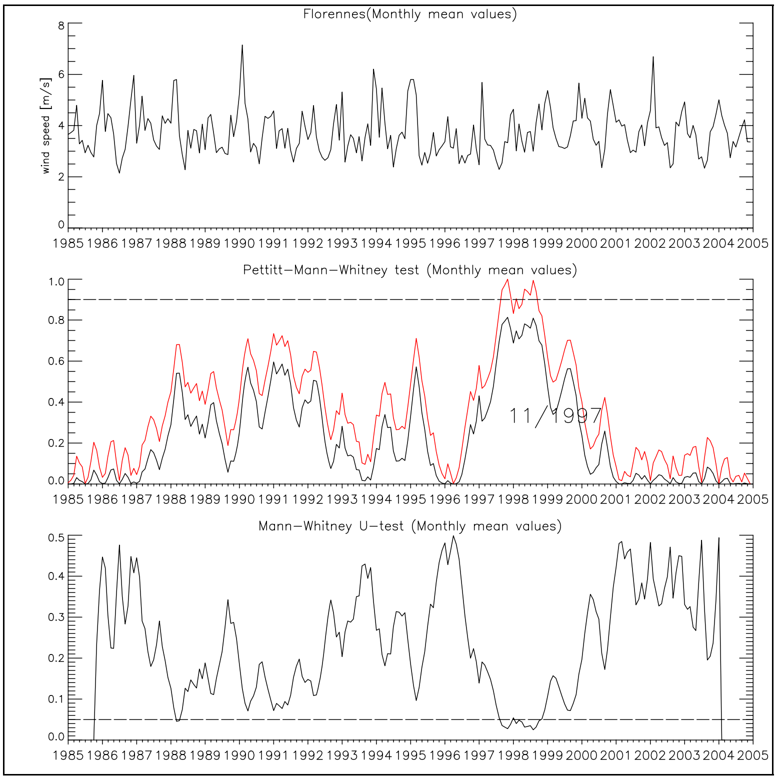


Figure 88: Monthly averaged wind speed time series, Pettitt-Mann-Whitney test and Mann-Whitney U-test for the station of Florennes

6.2.4.2.7. Gosselies

The wind speed time series for Gosselies shows its most significant change-point around September 1997. The significance level of the Pettitt-Mann-Whitney test exceeds the 0.90 level between 1996 and 1999. Here there is a clear significant change-point present in the wind speed time series, which could be due to the change in unit since July 1996 ([kt] → [m/s]). The Mann-Whitney U-test confirms the results of the Pettitt-Mann-Whitney test and also shows a moment in time where a significant change in averaged wind speed took place (1996-1999)

After the description of all the stations, Gosselies will be further discussed.

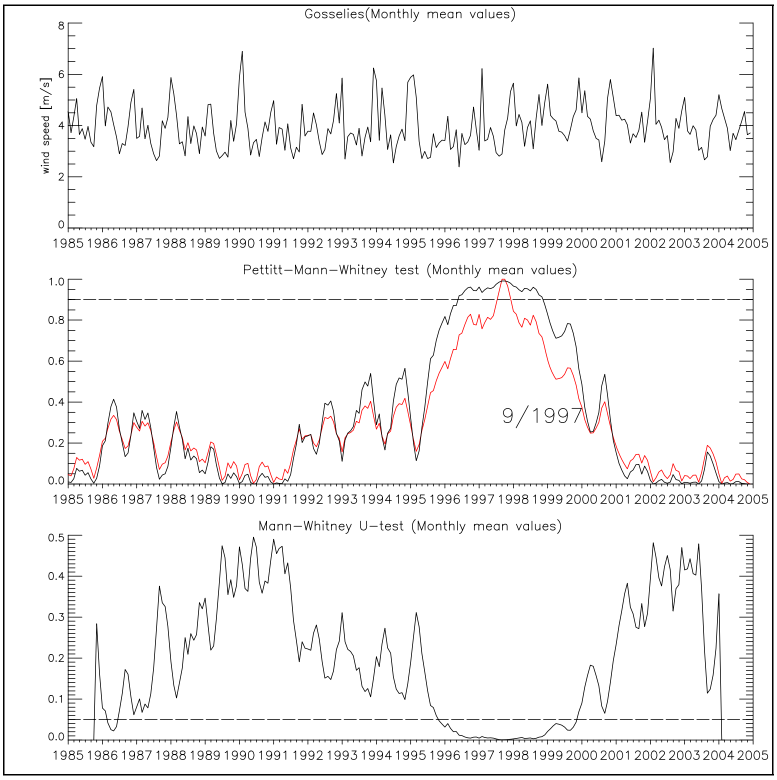


Figure 89: Monthly averaged wind speed time series, Pettitt-Mann-Whitney test and Mann-Whitney U-test for the station of Gosselies

6.2.4.2.8. Kleine-Brogel

The wind speed time series for Kleine-Brogel shows its most significant change-point around November 1997. The significance level of the Pettitt-Mann-Whitney test doesn't exceed the 0.90 level. For Kleine-Brogel, there are no significant change-points detectable. The Mann-Whitney U-test shows a change in averaged mean wind speed around November 1998 and March 2002.

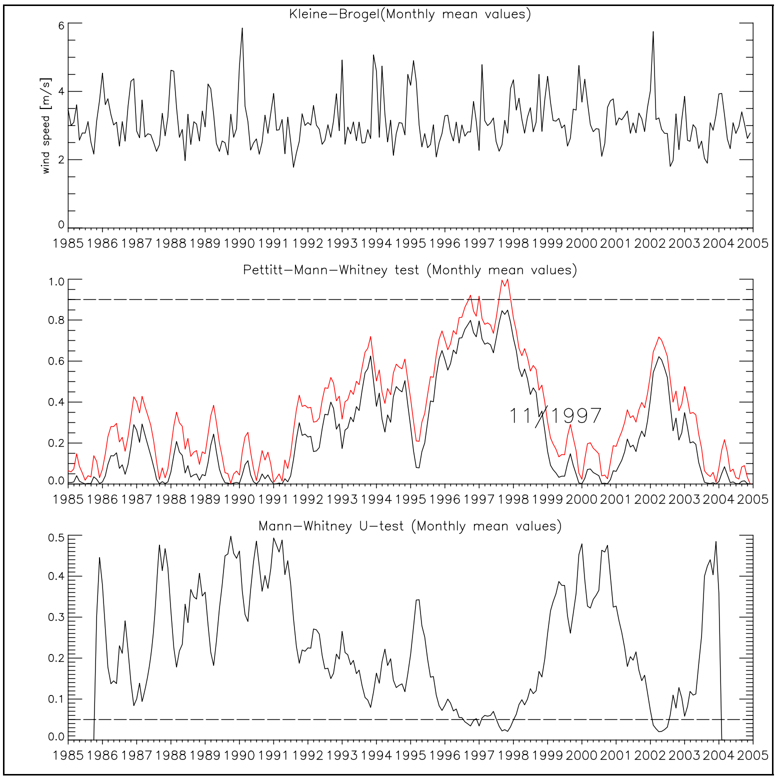


Figure 90: Monthly averaged wind speed time series, Pettitt-Mann-Whitney test and Mann-Whitney U-test for the station of Kleine-Brogel

6.2.4.2.9. Koksijde

The wind speed time series for Koksijde shows its most significant change-point around April 1997. The significance level of the Pettitt-Mann-Whitney test doesn't exceed the 0.90 level. For Koksijde, there are no significant change-points detectable.

The Mann-Whitney U-test shows a statistical significant change in averaged wind speed around March, 2002. Overall, this time series can be considered as homogeneous.

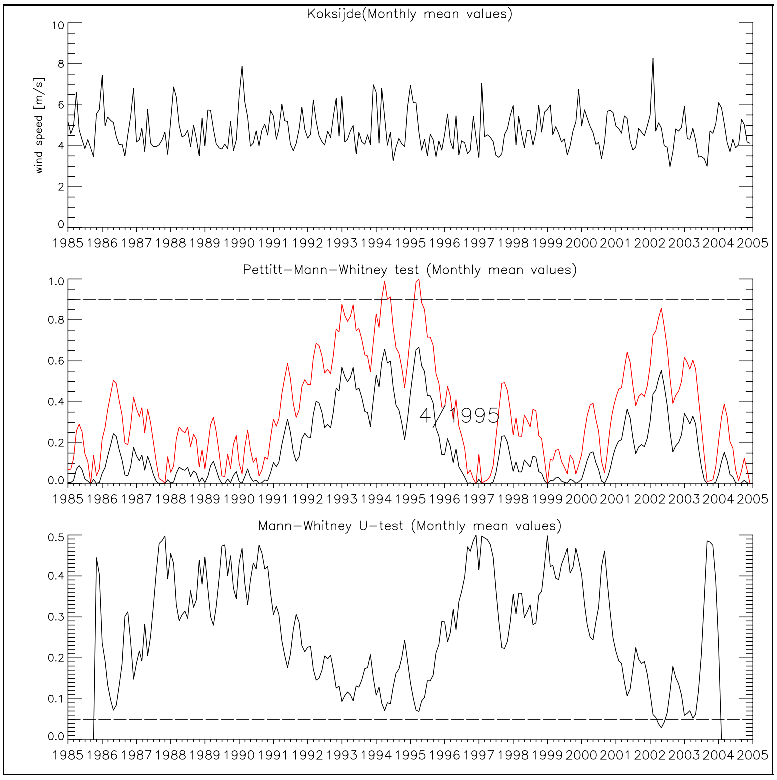


Figure 91: Monthly averaged wind speed time series, Pettitt-Mann-Whitney test and Mann-Whitney U-test for the station of Koksijde

6.2.4.2.10. Middelkerke

When applying the Pettit-Mann-Whitney test on the wind speed data for the reference station of Middelkerke, there is a statistical indication that for the time period 1991-1997 a discontinuity is present in this time series. The most significant change-point, according to the Pettit-Mann Whitney test took place around April 1995. This is due to a change in instrument type and a change in installation height. The installation height at Middelkerke changed from 12.7 m into 10.0 m; meeting the WMO regulations. This change took place on 26/06/1995.

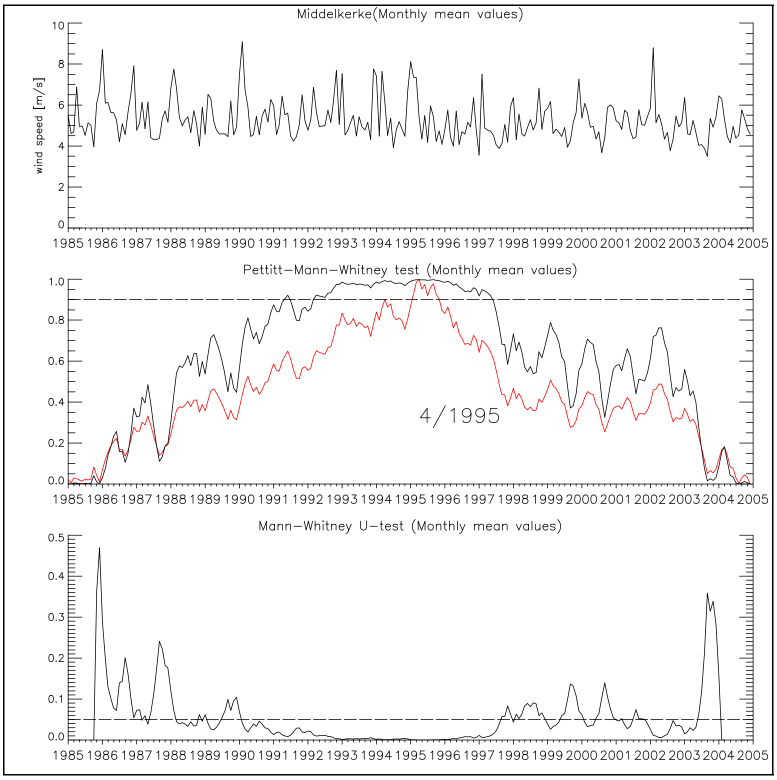


Figure 92: Monthly averaged wind speed time series, Pettitt-Mann-Whitney test and Mann-Whitney U-test for the station of Middelkerke

6.2.4.2.11. Saint-Hubert

For Saint-Hubert, there are no significant changes detectable in the wind speed time series for both tests.

Saint-Hubert should be considered as a station with specific properties and only representative for this particular location. This station is located on a plateau, at one of the highest points in Belgium. Therefore, also a very specific wind regime is present here, especially during winter (e.g., presence of catabatic winds)

Saint-Hubert is the only station, which didn't change its mast location and its instrument type since 1968. Even today, the same instrument, a Fuess 90 Z, is operational at Saint-Hubert. Nevertheless, it should be mentioned that we don't receive since 2004 data during the night, which influences the average of the wind speed. These data are introduced afterwards into the RMI database from the received written reports, which contain the complete anemometric hourly wind speed time series.

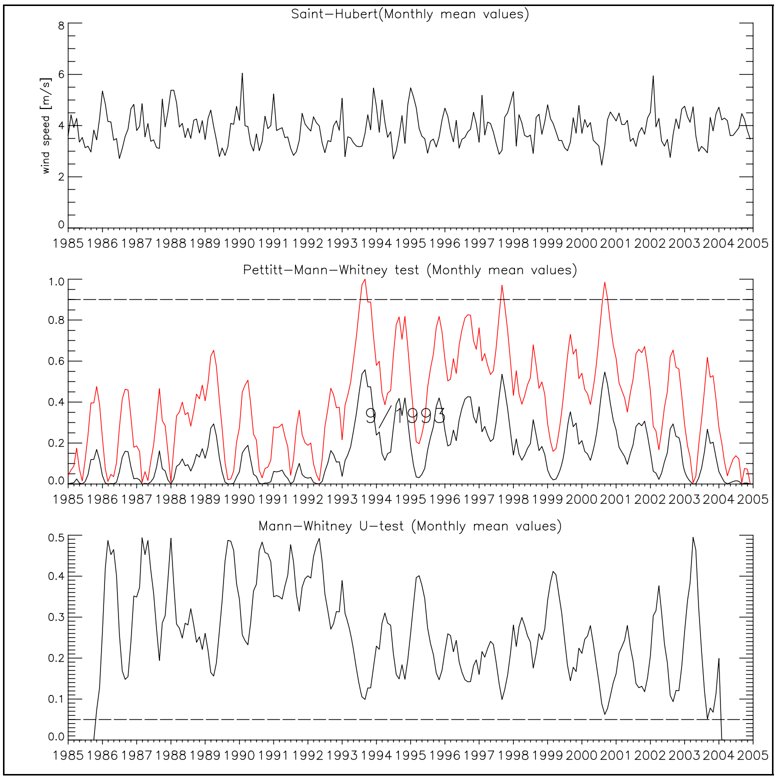


Figure 93: Monthly averaged wind speed time series, Pettitt-Mann-Whitney test and Mann-Whitney U-test for the station of Saint-Hubert

6.2.4.2.12. Spa

The wind speed time series for Spa shows its most significant change-point around November 1997. The significance level of the Pettitt-Mann-Whitney test doesn't exceed the 0.90 level. For Spa, there are therefore no significant change-points detectable.

The Mann-Whitney U-test shows a difference in averaged wind speed around November 1998 and March 2002.

Spa is a very particular station since it has a different wind regime compared with the other stations in Belgium. The most prevailing wind direction at Spa is southeast. This can be explained by the specific topographic properties of this site; the mast of Spa is located nearby the top of a hill with a rather steep slope (See Task 1.)

This specific wind regime can be explained by two phenomena:

- The ventury effect: When a high pressure system is present above central Europe and continental air is coming from direction eastsoutheast, the wind is forced over the top of the hill and therefore results in higher wind speeds because of this funnelling effect.
- Catabatic winds: Due to a temperature difference between the valley (Spa) and the top of the hill, catabatic winds (wind, caused by the downward motion of cold air) can occur with elevated wind speeds in direction (140), i.e. the orientation of the hill towards the valley (Spa). This station can be considered as complex terrain and is only representative for this particular zone, i.e. 5 km long and 2 km large.

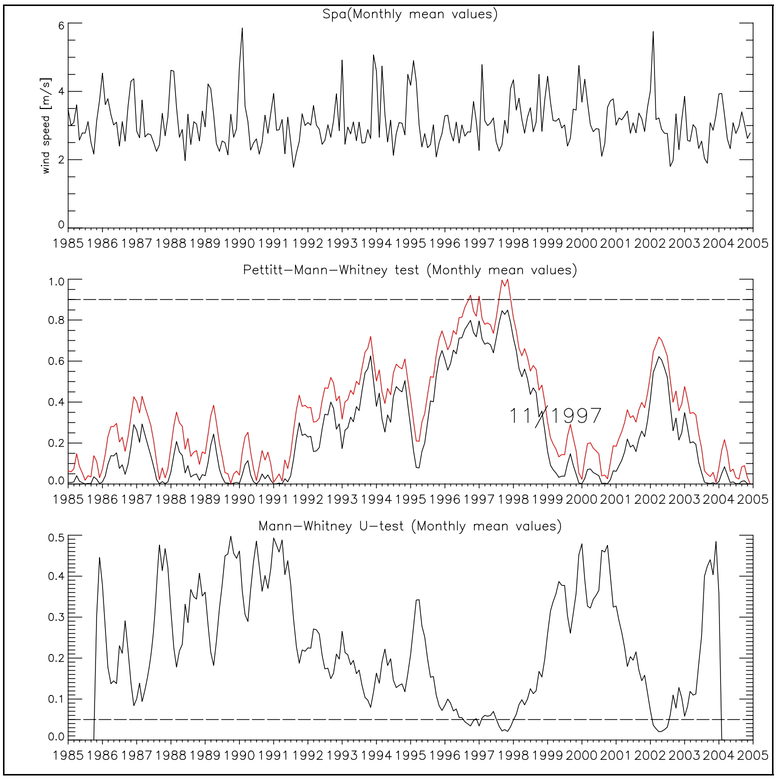


Figure 94: Monthly averaged wind speed time series, Pettitt-Mann-Whitney test and Mann-Whitney U-test for the station of Spa

6.2.4.2.13. Zaventem

The wind speed time series for Zaventem shows its most significant change-point around September 1997. The significance level of the Pettitt-Mann-Whitney test reaches the 0.90 level, which indicates that the mean averaged wind speed before and after September 1997 is significantly different.

The Mann-Whitney U-test shows a significant change in averaged wind speed around November 1997 and March 2002.

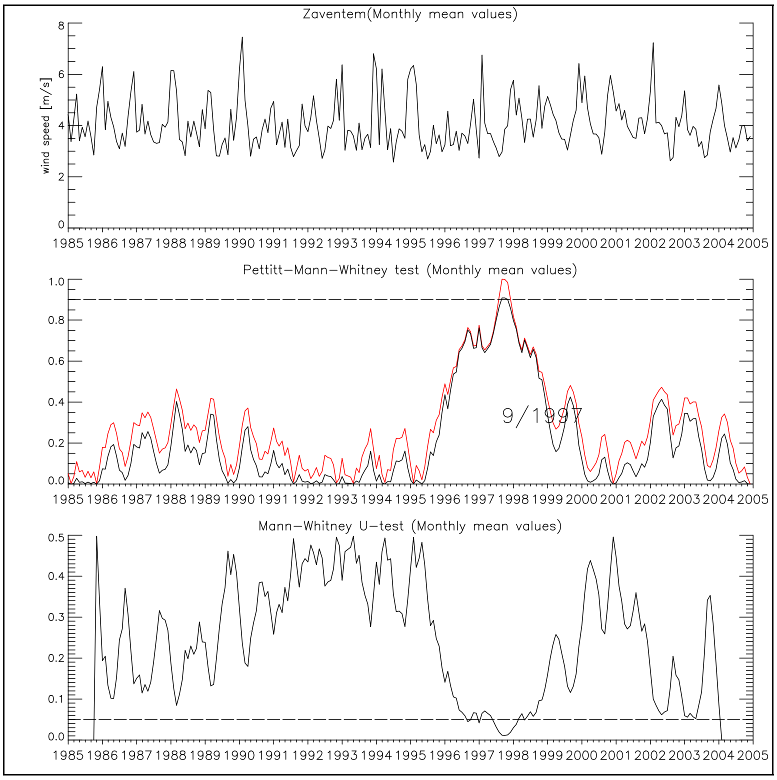


Figure 95: Monthly averaged wind speed time series, Pettitt-Mann-Whitney test and Mann-Whitney U-test for the station of Zaventem

6.2.4.3. Discussion of the results

It is shown that the above-mentioned tests are effective in finding discontinuities in time series. It should be clarified that a change-point, detected for example in April by the Pettitt-Mann Whitney test, can be due to a real change two months later (in June). A detected change-point by the above described test, can also be explained besides instrumental changes, changes in mast location, changes in installation height by a climatologically change.

Table 46 Overview of detected change-points, according to the above-mentioned tests

Station	Change-point
Bevekom	March, 1988
Bierset	March, 1988; November 1997
Chièvres	September, 1993
Deurne	October, 1997
Elsenborn	March, 1988
Florennes	November, 1997
Gosselies	September, 1997
Kleine-Brogel	November, 1997
Koksijde	April, 1995
Middelkerke	April, 1995
Saint-Hubert	-
Spa	November, 1997
Zaventem	September, 1997

It is obvious from the results from these tests that a marked discontinuity occurred in the wind speed time series for practically all the stations around September till November 1997. This cannot be directly linked with the moment of change in reporting ([kt] → [m/s]). It should also be noted, that August and September 1997, were months with very low wind speed.

To show the influence of this measure (the change in unit), the same test has been performed on the wind speed time series for the stations of Gosselies and Zaventem. The difference with the previous test (Figure 89) is that the input data used for this test has been rounded to unity, supposing that the conversion took already place since 1985. The results of this supplementary test show that there is no significant change-point present anymore in the wind speed time series for Gosselies (Figure 96) and Zaventem.

If the same principle of rounding all the data since 1985 is applied on other wind speed time series, a significant change point occurs in time series where there was no significant change-point present when treated with the original data.

Therefore these time series should be treated with care, concerning its homogeneity. Just rounding the data works well for Gosselies and Zaventem.

Stations, which are operated with analogue instrumentation, don't show a significant change point (Saint-Hubert and Spa).

This results show that it is impossible to homogenise these time series by just rounding the data if it is not well documented how the rounding has been treated.

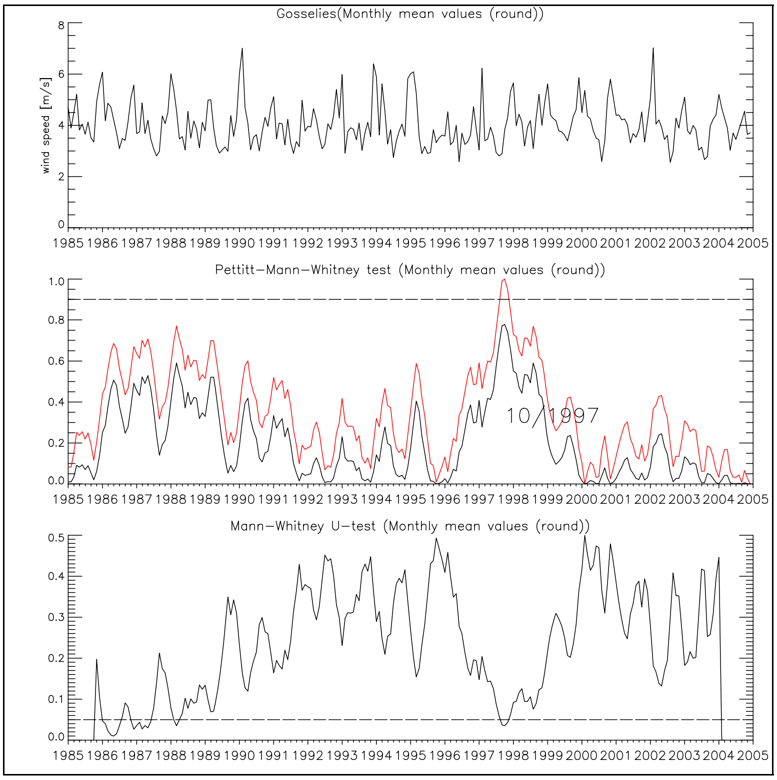


Figure 96: Monthly averaged wind speed time series, Pettitt-Mann-Whitney test and Mann-Whitney U-test for the station of Gosselies with rounded data

To show the influence of rounding the data in wind speed time series in numbers, a paired t-Test and a Standard Two-Sample t-Test has been calculated on the wind speed data for Zaventem for the time period 01-01-1985→ 31-06-1996. Both tests show a statistically significantly difference at the 95 % level (p=0). The mean difference between the rounded wind speed time series for Zaventem and the original data is + 0.17 m/s.

Another example where the influence from the change in unit for wind speed is detectable is in the representation of wind speed data in histograms, in the next figure (Figure 97), an example of a histogram of the wind speed distribution for Zaventem is shown. Comparing the histogram for the time period 1985-1991 and 1992-1996 shows no significant difference. For the time period 1997-2004, a significant difference between this time period and the previous mentioned time periods

('85-'91 and '92-'96) is present. The red arrow shows a marked shift to the right in the histogram. If the data for the time period 1985-1996 is also rounded, no significant difference is detectable anymore between this *"rounded"* histogram and the histogram with the original data for the time period 1997-2004. Both histograms (cyan and orange) almost perfectly match each other.

This result shows that there are some important repercussions when no attention is drawn to the change-over in unit from knots to [m/s]. It is clear that an overestimation is introduced of the wind climate if the following bins are used:

0<= v [m/s]<1; 1<= v [m/s]<2, when the measuring unit is [m/s].

Therefore it should be recommended to define new bins, which are chosen in function of the "rounding" function:

(i.e. 0.5<= v [m/s]<1.5; 1.5<= v [m/s]<2.5). This reduces the influence of the rounding.

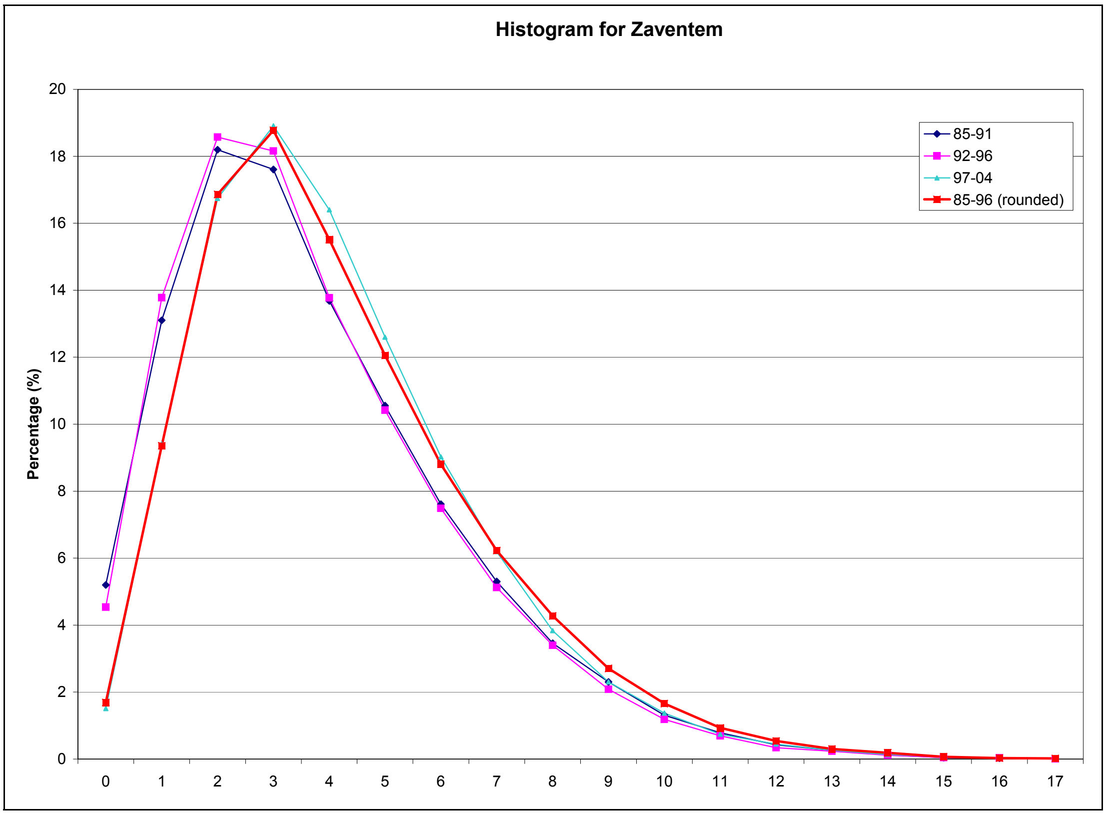


Figure 97: Histograms for the time periods 1985-1992, 1992-1997, 1997-2005 and 1985-1997 with rounded wind speed data for the station of Zaventem

6.2.5. Long term wind climate in Belgium

The longest wind speed time series, present at the RMI, besides the synoptic reports, are the climatological time series. Since 1931, 2 hourly averaged wind speed data have been kept. The history of these data is well documented (Sneyers et al., 1988). At the plateau at Uccle, two masts are operational. The northern mast (28 m.) represents the climatological mast, the southern located mast (30 m.) is operational for the synoptic reports.

To check if there were any changes detectable for the long-term wind climate in Belgium, the statistical tests as described above (i.e., Pettitt-Mann-Whitney test and Mann-Whitney U-test) have also been applied on these time series. According to Sneyers et al., it is shown that since 1969 the averaged wind speed decreased systematically. This is confirmed by the above-mentioned tests (Figure 98). This significant negative trend can be explained by the changes of the environment since then, provoked by the construction of a nearby building and the growing of the nearby trees.

The long-term data should be treated with care, when it is to be used for long-term trends:

When the Pettit-Mann-Whitney test is applied on this climatological wind speed time series, together with the synoptic long-term wind speed time series of Saint-Hubert and Zaventem for the time period 1965-2005, it is shown that these wind speed time series show a significant change-point around February 1984. The wind speed time series of Saint-Hubert has been chosen since there were also no changes reported as mentioned above since 1968. For Zaventem there were some changes in instrument type, mast dislocation and changes in height reported.

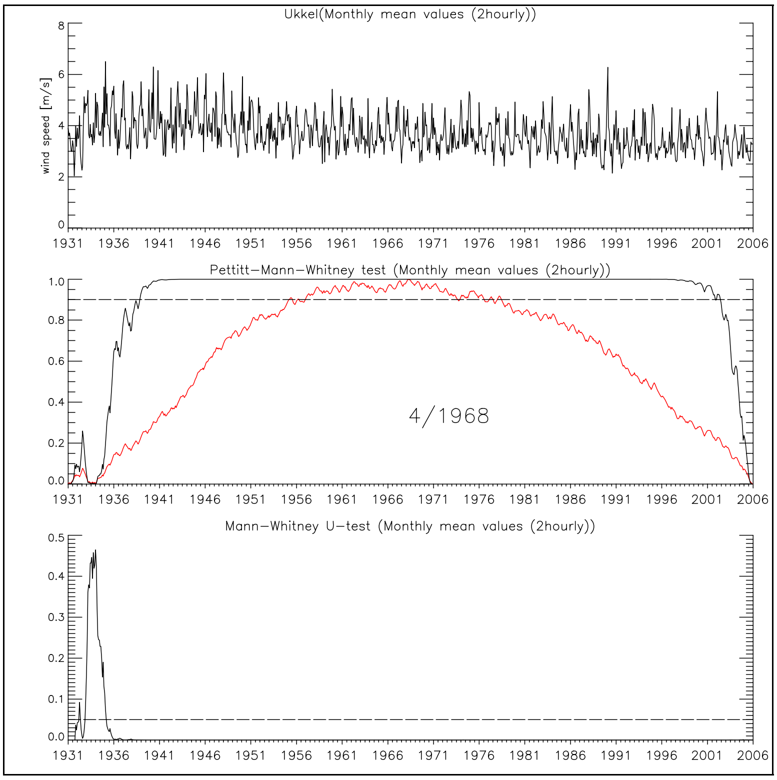


Figure 98: Monthly averaged wind speed time series, Pettitt-Mann-Whitney test and Mann-Whitney U-test for the climatological station of Uccle since 1931

When the same test is applied on the longest representative time series operated by Meteo Wing, i.e. Koksijde since 1975, there is no significant change-point present in the data. Over more than thirty year of measuring wind speed at Koksijde, the averaged wind speed didn't change significantly here. Therefore, it cannot be concluded that the averaged wind speed in Belgium significantly decreased over the last decades.

Figure 99 illustrates some wind roses from three synoptic stations (Saint-Hubert, Zaventem and Koksijde) for two different time periods. When comparing the wind roses for these stations for different time periods (the time period 1965-1985 against the time period 1985-2005) it can be concluded that there is no marked difference between both wind roses

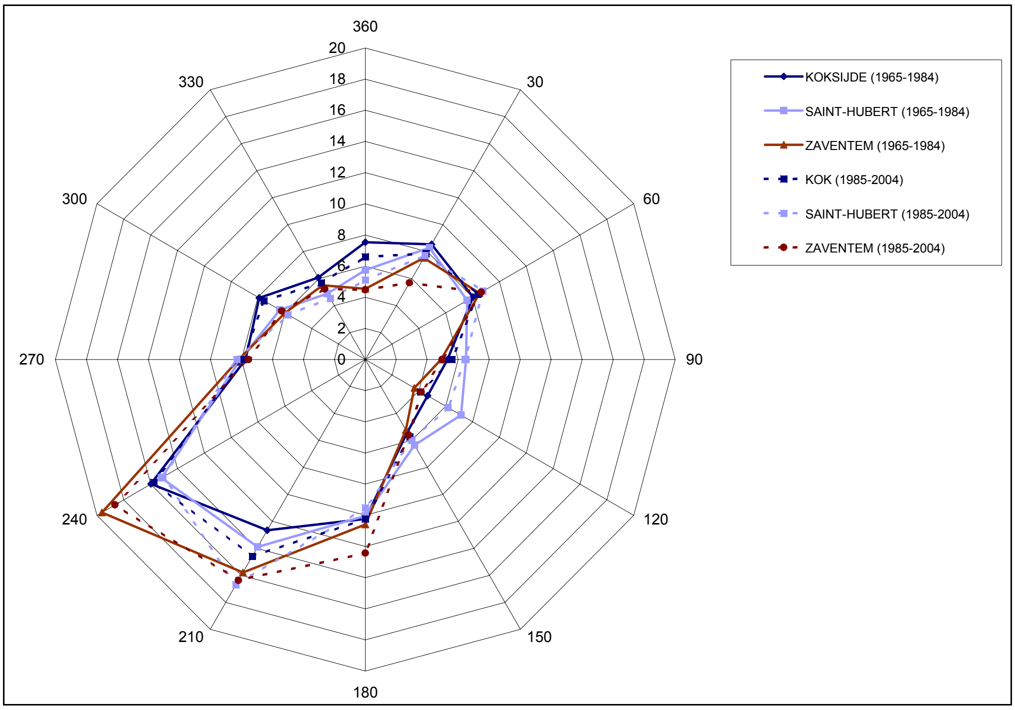


Figure 99: Overview of a wind rose ([%] in 12 directions) for three selected long-term stations (Saint-Hubert, Zaventem and Koksijde)

6.3. Extreme value analysis of gust wind speeds

In this section an extreme value analysis of 13 selected anemometric time series measured at the synoptic stations is performed. Two types of methodologies, the maximum annual method (MA method) and the Peak-Over-Threshold (POT) methodology, have been followed. The first methodology uses the set of maximum annual values (one value every year), whereas the second one uses for each year extreme values exceeding a fixed threshold.

In the next subsections, a description will be made of the methods applied. The best results were achieved by applying the adjusted law of Gumbel, since for this law there are only two parameters to be estimated. The input data are the hourly reported gust speed data from the synoptic stations during the considered time period. Table 47 gives an overview of all the stations considered in the analysis, together with the number of complete years available and used in the analysis for each station.

Table 47: Number of available years of complete wind gust speed time series at the station of interest for the time period 1985-2004

Station name	Number of years
Bevekom	20
Bierset	20
Chièvres	14
Deurne	20
Elsenborn	18
Florennes	20
Gosselies	20
Kleine-Brogel	20
Koksijde	20
Middelkerke	20
Saint-Hubert	20
Spa	15
Zaventem	20

6.3.1. MA Methodology

In the case of the MA methodology, the maxima are often modelized by the Gumbel law or, more generally, by the GEV law (for General Extreme Value). This last law possesses an additional parameter, and for a particular value of this parameter (the zero value) the GEV law reduces to the Gumbel law. These two laws find their origin in the extreme value theory (see for example Beirlant *et al.*, 1996).

6.3.1.1. The Gumbel law

The cumulative distribution function of this law is described by the following formula:

$$F(x) = \exp(-\exp(-\frac{x-\mu}{\sigma}))$$

This law presents two parameters to be estimated, a localization parameter μ as well as a scale parameter σ. These two parameters can be estimated by many ways. Amongst others let us quote the moment's estimators as well as the maximum likelihood estimators. We have decided here to use the L-Moments estimators. Those are described in particular in chapter 18 of Maidment (1992) and have the advantage of being robust, which is hardly needed here because of the relatively short length of the wind speed time series. Figure 100 shows an example of the Gumbel density adjusted for the station of Beauvechain whereas Figure 101 shows the same information, but in the form of a QQ-plot.

A QQ-plot (see for example Beirlant *et al.*, 1996) is a plot showing the observations (in our case the daily annual maximum wind speeds) versus a corresponding reduced probability as well as a function of the estimated parameters of the fitted distribution versus a well-chosen reduced variate. This function is chosen in such a way that it is close to the observations when the fitted distribution corresponds to the true distribution and when the parameters of this distribution have been correctly estimated. QQ-plots can be used to see visually if our sample of daily maximum values is likely to be drawn from the fitted distribution (i.e. if the fit is good enough). QQ-plots can also be used to explore graphically the relation existing between the values (wind speeds) of the observations and their frequency of occurrence or return period.

Let us notice that the QQ-plot represents here a straight line whose two coefficients are precisely the parameters μ and σ.

6.3.1.2. The GEV law

The cumulative distribution function of this law is described by the following formula:

$$F(x) = \exp(-(1+\gamma\frac{x-\mu}{\sigma})^{-\frac{1}{\gamma}}) \text{ for } 1+\gamma\frac{x-\mu}{\sigma} \succ 0 \text{ et } \gamma \neq 0$$

This function presents 3 parameters to be estimated. The two first parameters are similar to those described for the Gumbel law. The third parameter, γ, is called the curvature parameter. Typically, the parameter γ is positive because otherwise the wind speed would be bounded from above and this seems not to be the case. Figure 102 shows an example of a GEV density adjusted for the station of Beauvechain by mean of the L-moments method and Figure 103 shows the same information but in the form of QQ-plot. Let us notice that contrary to the QQ-plot obtained for the Gumbel law, the QQ-plot for the GEV law is not anymore a straight line, but a curve whose curvature is measured by the third parameter γ. When this curvature parameter is positive, the quantiles given by GEV law are systematically higher than those given by the Gumbel law.

6.3.2. Computing the extreme values

Mathematically, an extreme value is also called a quantile. Let us suppose that our data follow a distribution *F*. For a series of annual maximum quantities, the quantile (extreme wind speed) having one return period *T* is defined by value *q* verifying the equality:

$$F(q^*_T) = 1 - \frac{1}{T}$$

One then finds the quantile by reversing this relationship:

$$q^*_T = F^{-1}(1 - \frac{1}{T})$$

A confidence interval on this quantile can be found by means of analytical formulas resulting from the asymptotic theory or by means of resampling methods (bootstrap), these last methods being in general more precise although more expensive in computing times. We decided here to compute the confidence intervals via the simplest bootstrap scheme, where the bootstrap samples are drawn with replacements from the original sample. A good introduction to the bootstrap theory can be found in Efron and Tibshirani (1993).

6.3.3. POT Methodology

We present briefly below the laws used within the framework of the POT methodology. These laws are entitled Generalized Pareto Distributions (or GPD) and model the statistical distribution of the peaks above the fixed threshold. The L-moments estimators also exist for these laws and can for example be found in Hosking et al. (1985). A Poisson law classically models the temporal distribution of the events. The combination of the two laws (GPD + Poisson) will allow, in fine, the derivation of estimators for the quantiles.

6.3.3.1. Generalized Pareto law with 2 parameters

The cumulative distribution function of this law is described by the following formula:

$$F(x) = 1 - \exp(-\frac{x-\mu}{\sigma}), \qquad \text{with } x \geq \mu$$

6.3.3.2. Generalized Pareto law with 3 parameters

The cumulative distribution function of this law is described by the following formula:

$$F(x) = 1 - (1 + \gamma\frac{x-\mu}{\sigma})^{-1/\gamma}, \text{ with } x \geq \mu \qquad \text{et } \gamma \succ 0$$

or

$$F(x) = 1 - (1 + \gamma\frac{x-\mu}{\sigma})^{-1/\gamma}, \text{ with } x - \mu \in \left[0, -\frac{\sigma}{\gamma}\right] \text{ et } \gamma \prec 0$$

6.3.4. Choice of a law

The M Methodology investigates the Gumbel as well as the GEV model. Also a L-moment version of the estimators of the GPD with 3 parameters has been implemented in order to compare the methodologies MA and POT. The first conclusion is that the data series are not long enough to allow a correct estimate of the curvature parameter γ. Indeed, γ strongly varies from one series to another and is sometimes positive, sometimes negative. The confidence interval associated with this parameter is relatively large. For this reason it is more reasonable to limit us to two parameters and it is decided to use the Gumbel law. The use of the POT methodology allows us to take into account a larger dataset but also raises the question of the choice of the threshold. Various thresholds were tested (the ones that permit (on average) 1 to 6 values per year to be selected) and it seems that the choice of on average two values per year is optimal with regard to the bias-variance trade off issue. But even for this choice, it appears that the estimation of the curvature parameter remains too difficult. Let us note however that the study of the GPD law with two parameters was not carried out and should be realized in order to decrease the amplitude of the confidence intervals on the estimates.

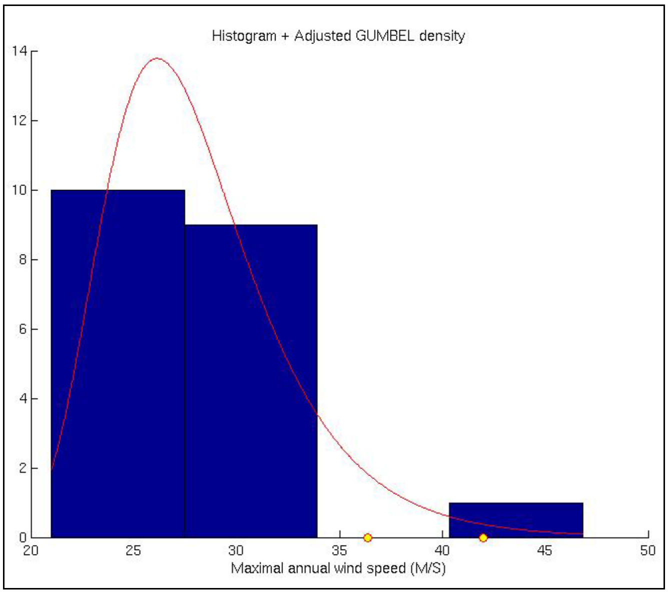


Figure 100: Histogram and adjusted Gumbel density for data of maximum gust speed [m/s] for the station of Beauvechain

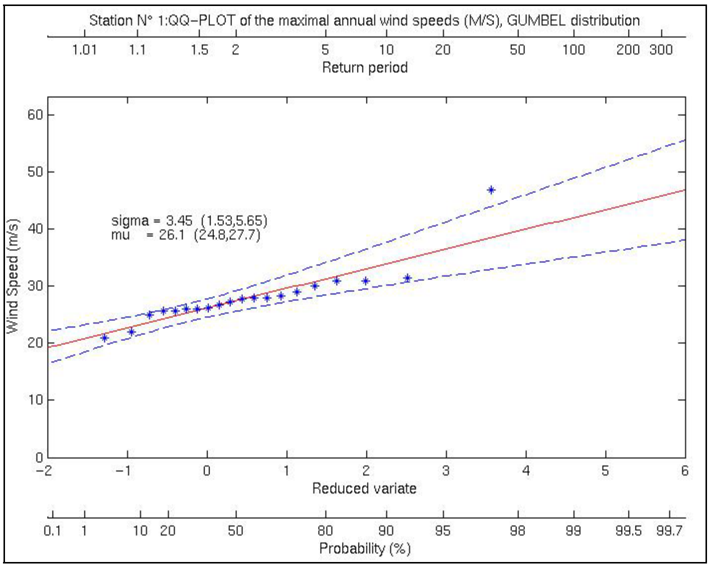


Figure 101: QQ-plot of the maximum annual gust speed [m/s] for a Gumbel distribution for the station of Beauvechain

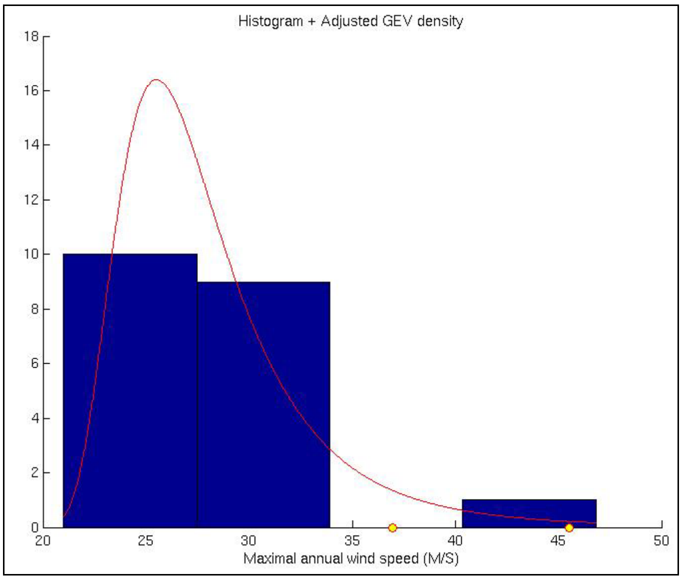


Figure 102: Histogram and adjusted GEV density for data of maximum gust speed [m/s] for the station of Beauvechain

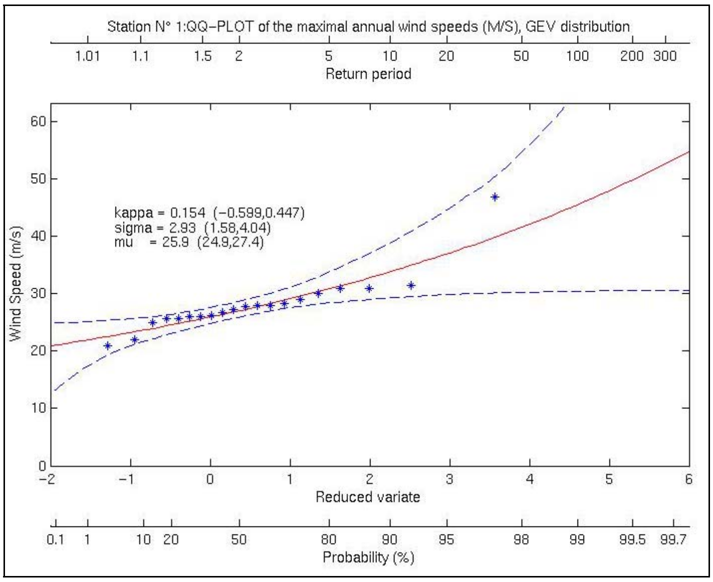


Figure 103: QQ-plot of the maximum annual gust speed [m/s] for a Gumbel distribution for the station of Beauvechain

The next table below gives an overview of the results for the three applied techniques for the station of Zaventem. For Zaventem the three methods give comparable results.

Table 48: Overview of the results of the extreme values analysis for three adjusted laws for the station of Zaventem for the period 1985-2004.

Unit : m/s								
Adjusted law	Return Periods (years)							
	2	6	10	20	25	30	50	100
Gumbel	29	33	34	36	37	37	39	41
Gev	29	32	34	37	37	38	40	43
POT	29	33	35	37	38	39	42	45
Unit : km/h								
Adjusted law	Return Periods (years)							
	2	6	10	20	25	30	50	100
Gumbel	104	117	123	130	132	134	139	146
Gev	103	116	123	132	135	137	145	156
POT	105	119	125	135	138	141	150	162

For the other stations, the results for the adjusted Gumbel law are tabulated in table 5:

Table 49: Overview of the results for thirteen stations of interest according to Gumbel:

Station	parameters Gumbel		Maximum wind speed [km/h] for different return period (years)							
	x_0	alpha	2	6	10	20	25	30	50	100
Bevekom	26.1451	3.4473	99	115	122	131	134	136	143	151
Bierset	26.1399	3.8348	99	118	125	135	138	141	148	158
Chièvres	26.6493	3.8	101	119	127	137	140	142	149	159
Deurne	25.9609	3.182	98	113	119	127	130	132	138	146
Elsenborn	23.8328	3.2557	90	106	112	121	123	125	132	140
Florennes	25.5984	3.3719	97	113	119	128	131	133	140	148
Gosselies	26.2448	3.168	99	114	120	128	131	133	139	147
Kleine-Brogel	23.8452	3.3275	90	106	113	121	124	126	133	141
Koksijde	28.5317	3.6892	108	125	133	142	145	148	155	164
Middelkerke	29.7305	3.0103	111	125	131	139	142	144	149	157
Saint-Hubert	25.7902	3.3516	97	113	120	129	131	134	140	148
Spa	26.9646	4.2451	103	123	131	142	146	149	157	167
Zaventem	27.8698	2.7786	104	117	123	130	132	134	139	146

In Table 50, detailed results are shown for a return period of 2 years. The other detailed results for every return period can be consulted in the annex (Table 51, Table 52, Table 53, Table 54, Table 55, Table 56, Table 57 for respectively a return period of 6, 10, 20, 25, 30, 50 and 100 years).

In these tables, the lower and upper confidence limits (in the tables referred as respectively L.C.L. and U.C.L.) of the confidence interval are tabulated. A confidence interval gives an estimated range of values, which is likely to include an unknown population parameter, the estimated range being calculated from a given set of sample data. If independent samples are taken repeatedly from the same population, and a confidence interval calculated for each sample, then a certain percentage (confidence level) of the intervals will include the unknown population parameter. The width of the confidence interval gives us some idea about how uncertain we are about the unknown parameter (see precision). A very wide interval may indicate that more data should be collected before anything very definite can be said about the parameter. Confidence intervals are therefore more informative than just mentioning the most expected maximum annual wind speeds [km/h] in function of the return periods. They reflect more the uncertainty on the estimated value.

Table 50: Overview of the results for thirteen stations of interest according to Gumbel for a return period of 2 years:

Station	maximum wind speed [km/h]	% of the confidence interval					
		70		90		95	
		LCL	UCL	LCL	UCL	LCL	UCL
Bevekom	99	95	102	93	104	92	105
Bierset	99	96	103	94	106	93	108
Chièvres	101	97	105	95	107	94	108
Deurne	98	95	101	93	103	92	104
Elsenborn	90	87	93	86	96	85	97
Florennes	97	93	100	92	102	90	102
Gosselies	99	96	102	94	105	93	105
Kleine-Brogel	90	87	94	86	96	84	97
Koksijde	108	104	111	103	113	102	114
Middelkerke	111	108	114	107	117	106	118
Saint-Hubert	97	94	100	92	102	90	104
Spa	103	98	107	95	109	93	110
Zaventem	104	102	107	100	108	99	110

6.3.5. Detailed results

Table 51: Overview of the results for thirteen stations of interest according to Gumbel for a return period of 6 years:

Station	maximum wind speed [km/h]	% of the confidence interval					
		70		90		95	
		LCL	UCL	LCL	UCL	LCL	UCL
Bevekom	115	106	124	104	129	103	131
Bierset	118	110	124	108	128	105	129
Chièvres	119	111	125	106	129	105	131
Deurne	113	109	115	107	116	105	117
Elsenborn	106	100	110	96	112	94	114
Florennes	113	107	118	105	121	104	123
Gosselies	114	109	118	107	121	106	122
Kleine-Brogel	106	101	111	98	112	98	114
Koksijde	125	118	132	115	137	114	140
Middelkerke	125	120	130	118	132	117	133
Saint-Hubert	113	106	120	104	124	103	126
Spa	123	118	127	115	129	114	129
Zaventem	117	112	121	110	125	108	126

Table 52: Overview of the results for thirteen stations of interest according to Gumbel for a return period of 10 years:

Station	maximum wind speed [km/h]	% of the confidence interval					
		70		90		95	
		LCL	UCL	LCL	UCL	LCL	UCL
Bevekom	122	110	132	107	136	105	141
Bierset	125	114	133	111	141	110	146
Chièvres	127	119	133	113	139	110	141
Deurne	119	115	121	112	123	111	124
Elsenborn	112	106	117	101	120	101	122
Florennes	119	112	126	110	131	108	133
Gosselies	120	115	124	113	127	111	129

Station	maximum wind speed [km/h]	% of the confidence interval					
		70		90		95	
		LCL	UCL	LCL	UCL	LCL	UCL
Kleine-Brogel	113	107	117	104	120	103	122
Koksijde	133	122	138	117	144	114	150
Middelkerke	131	126	137	121	140	120	141
Saint-Hubert	120	111	127	108	132	107	134
Spa	131	125	134	121	137	120	138
Zaventem	123	116	129	112	132	110	134

Table 53: Overview of the results for thirteen stations of interest according to Gumbel for a return period of 20 years:

Station	maximum wind speed [km/h]	% of the confidence interval					
		70		90		95	
		LCL	UCL	LCL	UCL	LCL	UCL
Bevekom	131	116	144	112	154	111	155
Bierset	135	122	144	119	152	114	156
Chièvres	137	122	144	114	149	111	151
Deurne	127	123	130	120	132	119	133
Elsenborn	121	111	125	107	129	105	132
Florennes	128	118	136	115	141	113	143
Gosselies	128	120	134	118	139	117	139
Kleine-Brogel	121	115	127	110	130	108	132
Koksijde	142	130	152	125	158	124	161
Middelkerke	139	131	145	129	149	127	150
Saint-Hubert	129	117	137	113	144	112	147
Spa	142	134	146	128	150	126	151
Zaventem	130	122	137	117	142	115	144

Table 54: Overview of the results for thirteen stations of interest according to Gumbel for a return period of 25 years:

Station	maximum wind speed [km/h]	% of the confidence interval					
		70		90		95	
		LCL	UCL	LCL	UCL	LCL	UCL
Bevekom	134	117	148	114	160	112	162
Bierset	138	125	150	120	158	119	161
Chièvres	140	126	146	120	153	118	156
Deurne	130	124	133	123	135	121	136
Elsenborn	123	114	129	111	133	109	136
Florennes	131	120	137	118	143	116	147
Gosselies	131	121	136	119	141	117	144
Kleine-Brogel	124	117	130	112	134	107	136
Koksijde	145	130	158	125	168	124	173
Middelkerke	142	133	148	130	153	129	156
Saint-Hubert	131	118	139	115	146	112	149
Spa	146	137	150	132	152	128	153
Zaventem	132	123	139	119	144	117	146

Table 55: Overview of the results for thirteen stations of interest according to Gumbel for a return period of 30 years:

Station	maximum wind speed [km/h]	% of the confidence interval					
		70		90		95	
		LCL	UCL	LCL	UCL	LCL	UCL
Bevekom	136	118	149	115	160	114	166

Station	maximum wind speed [km/h]	% of the confidence interval					
		70		90		95	
		LCL	UCL	LCL	UCL	LCL	UCL
Bierset	141	126	149	122	157	120	163
Chièvres	142	127	151	120	159	117	162
Deurne	132	126	135	123	137	122	137
Elsenborn	125	116	131	110	135	108	137
Florennes	133	121	142	119	148	118	154
Gosselies	133	123	139	121	143	119	146
Kleine-Brogel	126	116	132	111	136	110	137
Koksijde	148	132	157	129	170	124	172
Middelkerke	144	134	151	131	156	130	157
Saint-Hubert	134	121	145	118	152	115	154
Spa	149	141	153	135	156	133	159
Zaventem	134	125	140	120	145	118	147

Table 56: Overview of the results for thirteen stations of interest according to Gumbel for a return period of 50 years:

Station	maximum wind speed [km/h]	% of the confidence interval					
		70		90		95	
		LCL	UCL	LCL	UCL	LCL	UCL
Bevekom	143	122	156	118	168	117	174
Bierset	148	133	160	127	169	123	173
Chièvres	149	133	160	123	169	121	172
Deurne	138	133	141	129	143	127	144
Elsenborn	132	121	137	117	143	112	144
Florennes	140	127	149	123	157	122	161
Gosselies	139	128	145	125	152	123	157
Kleine-Brogel	133	121	138	117	145	114	146
Koksijde	155	136	166	132	176	130	181
Middelkerke	149	137	156	134	162	131	163
Saint-Hubert	140	123	150	119	156	119	163
Spa	157	146	162	141	166	138	168
Zaventem	139	126	148	121	153	120	155

Table 57: Overview of the results for thirteen stations of interest according to Gumbel for a return period of 100 years:

Station	maximum wind speed [km/h]	% of the confidence interval					
		70		90		95	
		LCL	UCL	LCL	UCL	LCL	UCL
Bevekom	151	128	170	123	182	122	188
Bierset	158	136	172	130	183	127	190
Chièvres	159	143	172	131	180	127	182
Deurne	146	139	149	136	152	135	153
Elsenborn	140	128	148	120	152	116	154
Florennes	148	134	159	128	164	126	168
Gosselies	147	135	155	129	163	128	165
Kleine-Brogel	141	130	148	125	151	121	153
Koksijde	164	144	178	139	189	136	194
Middelkerke	157	145	166	139	170	136	174
Saint-Hubert	148	131	162	125	174	123	176
Spa	167	157	173	152	179	149	184
Zaventem	146	133	155	125	163	121	166

6.3.6. Conclusions

An extreme value analysis of 13 synoptic gust speed series has been performed. After comparison with other more elaborate models, the Gumbel law was finally chosen for its simplicity and robustness. The results tabulated in table 5 look at first sight homogeneous for all the stations. After applying a divisive hierarchical cluster analyse on the maximum wind speed [km/h] results for the Gumbel law for different return periods (years) (see table 5), three clusters could be identified:

- Koksijde and Middelkerke show the highest values followed by Spa, Chièvres and Bierset. Middelkerke and Koksijde have indeed the highest values because these stations are situated near the coastline. For Spa and Chièvres less data has been used (15 and 14 years respectively), which influences the uncertainty of the higher return periods. Especially Spa shows very high values. This could be explained by the specific location of the mast on a hill. It has to be stressed that the synoptic station of Chièvres is well exposed.
- In the second cluster the following stations are retained: Bevekom, Zaventem, Deurne, Gosselies, Florennes and Saint-Hubert.
- The third cluster contains the stations with the lowest return periods: Kleine-Brogel and Elsenborn. This could also be explained by the geographical locations of these sites. Pine trees shelter the mast at Kleine-Brogel and Elsenborn is located at the lee side of the highest geographical point of Belgium: "Signal de Botrange" with an altitude of 694 m a.s.l.

6.3.7. References

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[13] WMO, Volume I.1 -- Codes internationaux : Partie A -- Codes alphanumériques, 1995; ISBN : 92-63-25306-4, Prix : CHF 130.-

[14] WMO, Volume I.2 -- Codes internationaux : Partie B -- Codes binaires et Partie C -- Eléments communs aux codes binaires et alphanumériques, 2001; suppléments; ISBN : 92-63-26306-X, Prix : CHF 120.-

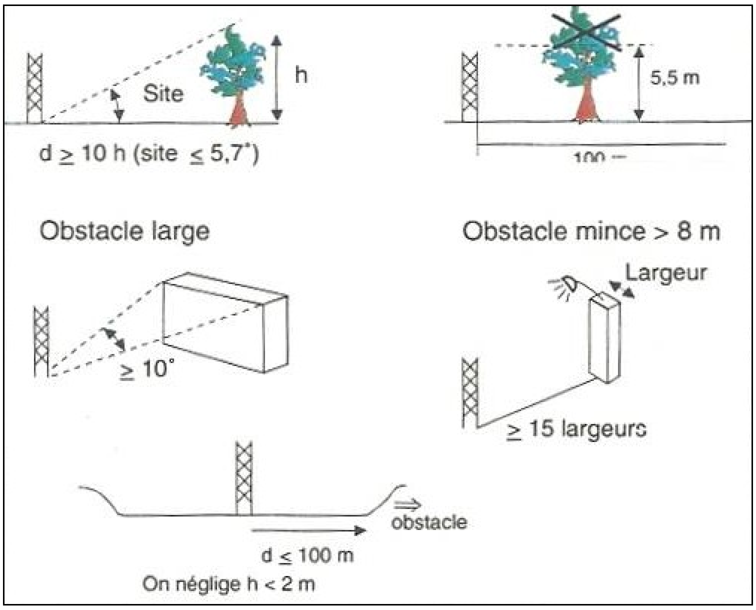
[15] WMO, Volume II -- Codes régionaux et pratiques nationales de chiffrement, 1998; suppléments; ISBN : 92-63-25306-3, Prix : CHF 128.-

6.4. Classification of the stations, according to Meteo France

A well-exposed anemometer, far from buildings and other obstacles, should be installed at 10 m above ground level (a.g.l.) according to the WMO rules. A well-exposed terrain is a terrain where the obstacles are located at a distance of at least10 times the altitude of the obstacle (more details in the description of Class 1). Also the roughness of the terrain should be taken into account. According to the WMO, the value of the roughness should not exceed 0.03. So this classification method is two folded: one for the roughness of the terrain and the other concerning the nearby obstacles and the environment. For the environment, a detailed description of the criteria which should be fulfilled to assign a certain class level to a station (according to Meteo France) will be listed. After the enumeration of the properties, the stations will be mentioned which meet these criteria. It will also be explained why a certain station is classified in a certain class.

6.4.1. Environment

6.4.1.1. Class 1



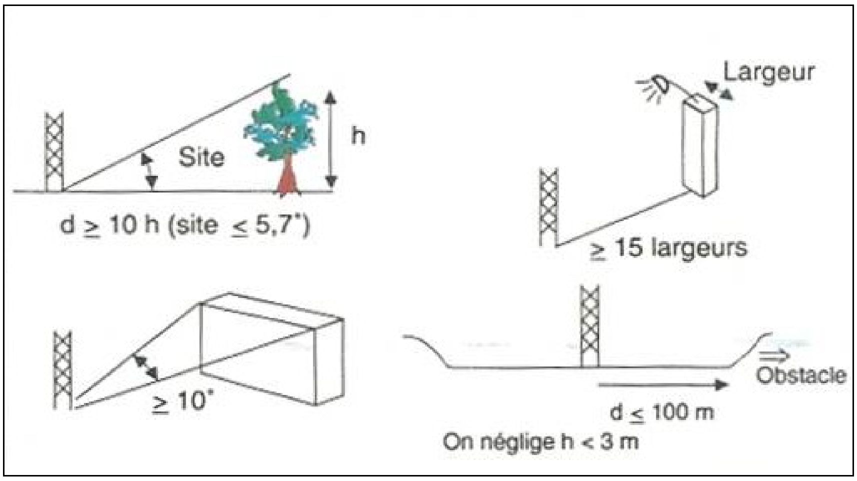
- The mast should be installed at a distance of at least 10 times the height of a nearby obstacle.
- An object is considered as an obstacle if it presents an angular width of more than 10º.
- The obstacles should not be more than 5.5 m in height within a range of 100 m.
- Obstacles, less than 2 m in height can be ignored as an obstacle.
- A change in topography within a range of 100 m can also be considered as an obstacle.
- The anemometer should be installed at a distance of at least 15 times the width of a thin obstacle, which is higher than 8 m.

Seventeen stations meet these criteria: Chièvres, Middelkerke, Koksijde, Beauvechain, Elsenborn, Oostende, Zaventem, Beitem, Florennes, Humain, Schaffen, Saint-Hubert, Melle, Bierset, Diepenbeek en Kleine-Brogel.

Diepenbeek meets this criterion closely, since in direction NNW the height of some trees in this direction is close to the "10 times the height rule of a nearby obstacle". What is important for the station of Diepenbeek is the small cultivation of fir trees in direction SSW. In the near future they can influence the anemometric measurements.

Kleine-Brogel is surrounded by pine trees, which are on the limit too close to the mast in southern directions. The distance between the mast and the trees is ± 150 m, while the height of the trees is estimated to be 12-15 m.

6.4.1.2. Class 2 (10 % error ?)

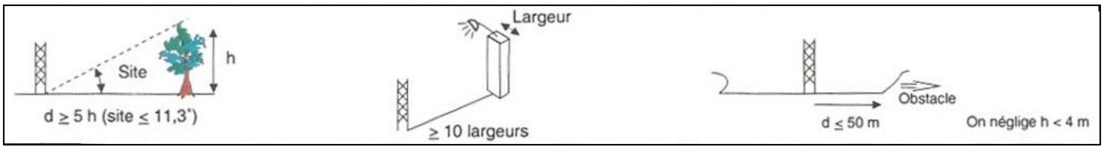


- The mast should be installed at a distance of at least 10 times the height of a nearby obstacle.
- An object is considered as an obstacle if it presents an angular width of more than 10º.
- Obstacles, less than **3** m in height can be ignored as an obstacle.
- A change in topography within a range of 100 m can also be considered as an obstacle.
- The anemometer should be installed at a distance of at least 15 times the width of a thin obstacle, which is higher than 8 m.

Retained station: Deurne

Deurne is retained, since an obstacle is located within a range of 100 meters in northern direction of the mast not fulfilling the condition 3 from class 1. In the near future this mast will be moved towards the centre of the aerodrome, meeting the conditions of class 1.

6.4.1.3. Class 3 (20 % error ?)



- The mast should be installed at a distance of at least 5 times the height of a nearby obstacle.
- Obstacles, less than **4** m in height can be ignored as an obstacle.
- A change in topography within a range of 50 m can also be considered as an obstacle.
- The anemometer should be installed at a distance of at least 10 times the width of a thin obstacle, which is higher than 8 m.

Selected stations: Semmerzake, Spa, Buzenol, Mont-Rigi, Ernage and Dourbes

Semmerzake: In the direction (90), a building is too close to the mast.

Spa: The topography is the main cause since there is a strong gradient present at this site.

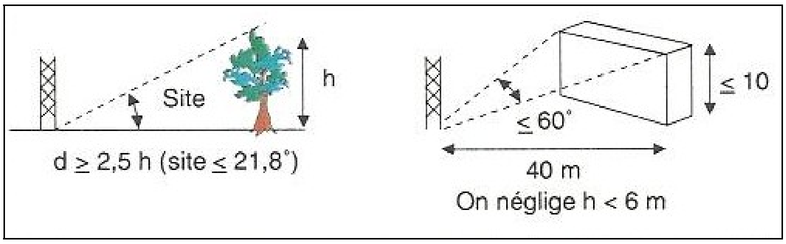
Buzenol: Only in the western direction, there are a few trees too high according to the WMO regulations (the mast should be located at least at 10 times the height of the obstacle).

Mont-Rigi: In the directions N, NNE, NE, some trees are too close to the anemometer

Ernage: A small house is situated too close from the mast. If this house could be pulled down, this station would be classified in class 1.

Dourbes: There are trees and obstacles too closely located from the mast.

6.4.1.4. Class 4 (30 % error ?)



- The mast should be installed at a distance of at least 2.5 times the height of a nearby obstacle.
- Obstacles, less than **6** m in height can be ignored as an obstacle.
- Obstacles with an angular width of more than 40º and a height of more than 10 m within a range of 40 m.
- The anemometer should be installed at a distance of at least 10 times the width of a thin obstacle, which is higher than 8 m.

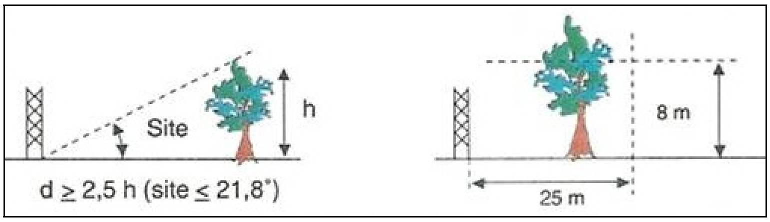
selected stations: Gosselies, Retie, Zelzate

Retie: Only in northern direction, there are trees too closely located from the mast.

Zelzate: Also here, some trees are located too close from the mast.

Gosselies: This is due to topography, namely the presence of a ridge, too closely situated from the mast.

6.4.1.5. Class 5 (error 40 % ?)



- The mast should be installed at a distance of at least 2.5 times the height of a nearby obstacle.
- The obstacles should not be more than 8 m in height within a range of 25 m.

Uccle is the only station, which meets these properties. Therefore, the anemometer has been installed at an height of 30 m.

6.4.2. Classification of the reference stations

The next tables (Table 58, Table 59 and Table 60) resume the classification of the reference stations according to the above discussed classification in function of the operated network:

Table 58: Classification of the reference stations according to Meteo France for the stations, operated by Belgocontrol:

Station	Class number according to Meteo France
Bierset	1
Deurne[12]	2
Gosselies	4
Middelkerke	1
Saint-Hubert	1
Spa	4
Zaventem	1

[12] will become class 1 in the near future

Table 59: Classification of the reference stations according to Meteo France, operated by Meteo Wing:

Station	Class number according to Meteo France
Bevekom	1
Chièvres	1
Elsenborn	1
Florennes	1
Kleine-Brogel	1
Koksijde	1
Schaffen	1
Semmerzake	3

Table 60 Classification of the reference stations according to Meteo France, operated by RMI:

Station	Class number according to Meteo France
Beitem	1
Buzenol	3
Diepenbeek	1
Dourbes	4
Ernage	3
Humain	1
Melle	1
Mont-Rigi	3
Oostende	1
Retie	4
Zelzate	4

6.4.3. Missing data

For the missing data, the focus is on the time period 1985-2004. In the next subsection, the stations will be discussed in function of the operated network again (Belgocontrol, Meteo Wing and RMI). The following tables (Table 61 (Belgocontrol), Table 62 (Meteo Wing) and Table 63 (RMI)) elucidate the percentage of missing data (dd, ff) for every station in function of the year. For RMI, only three stations are mentioned. The AWS network will be discussed separately since this subsection only focuses on the long term.

Table 61 Percentage of missing data for wind direction (dd) and wind speed (ff) for the stations operated by Belgocontrol

Year	BIERSET		DEURNE(RLW)		GOSSELIES		MIDDELKERKE		SAINT-HUBERT		SPA (AERODROME)		ZAVENTEM	
	dd	Ff	dd	ff	dd	ff	dd	ff	dd	ff	dd	ff	dd	ff
1985	0.00	0.00	0.00	0.00	0.11	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.23	0.23	0.00	0.00	0.00	0.00	0.13	0.13	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	45.47	45.47	0.00	0.00
1988	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00	0.16	0.16	47.34	47.34	0.00	0.00
1989	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	47.16	47.16	0.00	0.00
1990	0.18	0.18	0.14	0.14	0.17	0.17	0.17	0.17	0.17	0.17	0.45	0.43	0.17	0.17
1991	0.03	0.03	0.08	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.15	0.15	0.00	0.00
1992	1.13	1.13	0.31	0.31	0.18	0.18	0.00	0.00	0.00	0.00	0.17	0.17	0.02	0.02
1993	0.09	0.09	0.01	0.01	0.00	0.00	0.00	0.00	0.56	0.56	0.87	0.87	0.00	0.00
1994	0.00	0.00	0.26	0.26	0.42	0.42	0.00	0.00	0.15	0.15	0.26	0.26	0.00	0.00
1995	0.09	0.08	0.05	0.05	0.31	0.31	0.00	0.00	0.46	0.46	0.37	0.37	0.00	0.00
1996	0.00	0.00	0.13	0.13	0.35	0.34	0.01	0.00	0.20	0.19	0.30	0.28	0.00	0.00
1997	0.16	0.16	0.03	0.03	0.06	0.06	0.00	0.00	0.29	0.29	0.34	0.34	0.00	0.00
1998	11.14	11.14	0.02	0.02	2.33	2.33	0.00	0.00	0.88	0.88	0.30	0.27	0.00	0.00
1999	0.03	0.02	0.00	0.01	2.82	2.82	0.01	0.00	0.26	0.26	0.15	0.15	0.00	0.00
2000	0.43	0.41	0.03	0.00	0.10	0.03	0.06	0.00	0.48	0.43	0.28	0.26	0.06	0.00
2001	0.41	0.00	0.46	0.08	0.37	0.01	0.42	0.00	5.42	5.10	0.38	0.08	0.43	0.00
2002	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.53	0.53	0.46	0.46	0.00	0.00
2003	0.19	0.19	0.02	0.02	0.02	0.02	0.01	0.01	6.72	4.77	6.80	5.08	0.02	0.02
2004	2.45	2.45	1.13	1.13	1.57	1.57	1.76	1.76	48.13	48.13	44.35	44.35	0.96	0.96

Table 62: Percentage of missing data for wind direction (dd) and wind speed (ff) for the stations operated by Meteo Wing

Year	BEAUVECHAIN		CHIÈVRES		ELSENBORN		FLORENNES		KLEINE-BROGEL		KOKSIJDE		SCHAFFEN		SEMMERZAKE	
	Dd	Ff	dd	ff	dd	ff	dd	ff	dd	ff	dd	ff	Dd	ff	dd	ff
1985	0.02	0.02	0.00	0.00	64.22	64.22	0.00	0.00	0.01	0.00	0.24	0.23	43.00	43.00	0.47	0.47
1986	0.01	0.00	0.00	0.00	46.13	46.13	0.55	0.55	0.00	0.00	0.00	0.00	42.57	42.57	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.00	0.00	7.07	7.07	0.00	0.00	0.10	0.10	43.36	43.36	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.01	0.00	1.25	1.25	0.01	0.00	0.01	0.00	42.69	42.69	0.44	0.44
1989	0.00	0.00	0.00	0.00	0.00	0.00	0.21	0.21	0.00	0.00	0.00	0.00	43.53	43.53	0.48	0.48
1990	0.21	0.19	0.16	0.16	0.47	0.47	0.82	0.82	0.16	0.16	0.17	0.17	45.22	45.22	0.17	0.17
1991	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	45.84	45.84	0.00	0.00
1992	0.00	0.00	0.00	0.00	0.44	0.44	0.00	0.00	0.85	0.85	0.00	0.00	46.80	46.80	0.00	0.00
1993	0.01	0.01	1.24	1.24	0.00	0.00	1.02	1.02	0.00	0.00	0.00	0.00	46.05	46.05	0.00	0.00
1994	0.01	0.00	0.19	0.19	0.00	0.00	0.27	0.27	0.01	0.01	0.02	0.02	43.79	43.78	0.00	0.00
1995	0.00	0.00	0.00	0.00	0.05	0.05	0.08	0.08	0.00	0.00	0.03	0.03	64.02	64.02	0.00	0.00
1996	0.00	0.00	0.00	0.00	0.02	0.02	0.17	0.19	0.00	0.00	0.00	0.00	67.52	67.52	0.00	0.00
1997	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	63.40	63.40	0.00	0.00
1998	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	62.47	62.58	0.02	0.02
1999	0.00	0.00	42.65	42.99	0.05	0.05	0.06	0.06	0.00	0.00	0.01	0.00	63.39	63.80	0.00	0.00
2000	0.11	0.07	57.05	57.10	0.98	0.97	0.77	0.75	0.06	0.01	0.05	0.00	61.59	61.67	0.05	0.00
2001	0.42	0.02	22.33	22.36	0.43	0.00	0.61	0.23	0.46	0.00	0.41	0.01	14.74	14.67	0.39	0.00
2002	0.00	0.00	24.83	25.22	0.00	0.00	0.08	0.08	0.00	0.00	0.00	0.00	18.80	18.88	2.11	2.12
2003	0.14	0.14	24.79	25.35	0.05	0.03	0.11	0.11	0.13	0.13	0.11	0.11	29.67	29.94	0.73	0.72
2004	4.37	4.37	25.25	25.25	6.10	6.10	3.59	3.59	3.84	3.86	2.87	2.86	15.22	15.22	8.69	8.69

In the following table below, a short description of the missing data of three long-term RMI stations is given:

Table 63 Percentage of missing data for wind direction (dd) and wind speed (ff) for the stations operated by RMI (synoptic data)

Year	OOSTENDE		UCCLE		ZELZATE	
	dd	ff	dd	ff	dd	ff
1985	67.2	67.2	66.7	66.7	67.5	67.5
1986	40.3	40.3	40.5	40.5	67.0	67.0
1987	1.4	1.4	0.6	0.6	67.3	67.3
1988	0.1	0.1	65.6	65.6	67.2	67.2
1989	1.4	1.4	63.7	63.7	67.0	67.0
1990	1.0	1.0	64.3	64.3	66.9	66.9
1991	0.4	0.4	62.4	62.4	68.0	68.0
1992	3.1	3.1	56.5	56.5	66.9	66.9
1993	0.5	0.5	57.0	57.0	67.0	67.0
1994	12.8	12.7	58.3	58.3	66.8	66.8
1995	40.4	40.4	62.3	62.3	66.8	66.8
1996	62.5	62.6	63.8	63.8	66.8	66.8
1997	5.5	5.5	63.2	63.2	66.9	66.9
1998	82.0	82.1	63.5	63.6	66.8	66.8
1999	11.2	12.6	63.8	63.9	66.8	66.8
2000	64.4	64.4	64.2	64.1	67.1	67.0
2001	14.2	14.2	69.6	69.6	69.3	69.3
2002	0.7	0.8	65.9	65.9	33.8	33.9
2003	0.3	0.5	59.9	60.1	5.2	5.7
2004	0.2	0.2	0.1	0.1	1.9	1.9

6.5. AWS network, operated by RMI

The AWS network, operated by RMI, is operational since the end of 2000. Until then, there has only been few problems encountered.

There has been an interuption in May 2004 with the anemometer of Humain: The wind vane was blocked at 360 degrees during one month. Since the introduction of the different AWS stations, only small interruptions have been encountered so far. This means that there are for the other stations almost no missing data (0.01%).

The next table gives an overview of the available 10 minutes anemometric data retrieved with the AWS stations of RMI together with the beginning of the data:

Table 64: Overview of the available anemometric data of the RMI since the introduction of its AWS network

NAME	BEGINDATE	2001		2002		2003		2004		2005	
		dd	ff	dd	ff	dd	ff	dd	Ff	dd	ff
BEITEM	26-7-2003 0:10	0.00	0.00	0.00	0.00	43.45	43.45	99.99	99.99	100.00	100.0
BUZENOL	27-3-2003 12:20	0.00	0.00	0.00	0.00	76.55	76.55	99.37	99.37	100.00	100.0
DIEPENBEEK	30-6-2004 0:50	0.00	0.00	0.00	0.00	0.00	0.00	50.54	50.54	100.00	100.0
DOURBES	15-12-2000 10:50	98.83	98.83	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.0
ERNAGE	7-5-2002 14:20	0.00	0.00	65.32	65.32	100.00	100.00	100.00	100.00	100.00	100.0
HUMAIN	6-3-2002 13:40	0.00	0.00	81.99	81.99	99.20	99.20	88.16	99.33	99.63	99.6
MELLE	23-8-2002 0:10	0.00	0.00	35.89	35.89	99.48	99.48	99.99	99.99	99.55	99.5
MONT RIGI	23-1-2001 14:40	90.84	90.84	99.17	99.17	99.52	99.52	99.91	99.91	100.00	100.0
OOSTENDE[1]	4-4-2001 13:00	74.37	74.37	100.00	100.00	99.97	99.97	99.93	99.93	100.00	100.0
RETIE	23-1-2002 13:40	0.00	0.00	93.47	93.47	100.00	100.00	100.00	100.00	100.00	100.0
ZEEBRUGGE	18-8-2005 19:00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	37.03	37.0
ZELZATE	19-3-2001 13:00	69.33	69.33	100.00	100.00	98.81	98.81	100.00	100.00	100.00	100.0

[1] Oostende end date: 12-01-2006 9:50

The products, which are generated by the AWS stations concerning wind data, are summarized in the following table:

Table 65: Overview of anemometric parameters, obtained from the RMI AWS network

Parameters	Unit	Description
WIND_SPEED_AVG_2M	[m/s]	wind speed at 2 m. (10 'average)
WIND_SPEED_AVG_10M	[m/s]	wind speed at 10 m. (10 'average)
WIND_SPEED_AVG_30M	[m/s]	wind speed at 30 m. (10 'average)
WIND_SPEED_MAX	[m/s]	wind speed maximum (1' average)
WIND_DIRECTION	[degrees]	wind direction
STANDARD_DEVIATION[13]	[degrees]	standard deviation of wind direction
WIND_GUSTS_SPEED	[m/s]	maximum gust speed
WIND_GUSTS_TIME	[h:min.]	time of the maximum gust speed
WIND_GUSTS_DIRECTION	[degrees]	direction of the maximum gust
WIND_GUST_HISTORY (HOURLY)	%	History on the gust speed within the last hour

The data logger RMI uses is "Campbell Scientific". The anemometric parameters are obtained with a scalar calculation.

Every 10 minutes, an averaged wind speed is obtained on different altitude levels (2 m, 10 m and 30 m (Uccle, Melle) or 24 m (Humain)), together with a maximum wind speed value, the maximum gust speed within 10 minutes, with the time of occurrence simultaneously reported (*wind_gusts_speed*, *wind_gust_time*).

Wind speed is recorded every second. After 1 minute, an averaged wind speed is calculated. After 10 minutes, an averaged wind speed over 10 minutes (*wind_speed_avg_**) is obtained by using the last 10 *averaged wind speed 1 minute* values. The highest wind speed within these 10 minutes is also saved under the parameter *wind_speed_max*.

The parameter wind gust history is reported every hour. It reflects the distribution of 3600 recorded 3 seconds moving average gust wind speed data in 10 bins. This gives us the opportunity to identify the spread of the gust wind speed within the passed hour. The bins are chosen according to a scale of [km/h] (see table below). Also the highest gust speed in agreement with

[13] This standard deviation on the wind direction is calculated according to the Yamartino algorithme

the gust direction and the gust time (exact moment in U.T. this event took place) are reported every hour and every 10 minutes.

Table 66: bins in km/h for the wind gust history with an example:

Interval (km/h)	Percentage (%)
v ≤ 40	27.17
40< v ≤ 50	59.89
50< v ≤ 60	12.32
60< v ≤ 70	0.57
70< v ≤ 80	0.05
80< v ≤ 90	0
90< v ≤ 100	0
100< v ≤ 110	0
110< v ≤ 120	0
v > 120	0

The wind direction is recorded every second. After 10 minutes an averaged value is calculated, together with its standard deviation. To calculate the averaged wind direction, a vector approach is used. The standard deviation is calculated according to the Yamartino algorithme.

6.6. Recommendations

The purpose of the recommendations should be focused on the improvement of the predictions of wind power in Belgium. Important inputs therefore are the anemometric data of the synoptic reference stations, operated by Belgocontrol, Meteo Wing and RMI. What could we do, suggest or recommend?

- A first and important demand is to improve the precision and the frequency of the delivered synoptic data. The AWS stations, operated by RMI already have data with a high precision. Since Belgocontrol and Meteo Wing are having or going to have also automatic weather stations in the future, it should be possible to do this. The RMI proposes to start up a data bank on anemometric data with higher frequency and higher precision. The parameters as mentioned in 6.5, Table 65 are already in use at RMI since the introduction of its AWS. It could perhaps be recommended to extend some parameters. For example, the bins which are chosen according to Table 66, can be extended towards the calm winds. The bins only start until now from wind gusts speed from 40 km/h onwards.
- A bottleneck, which is inherently linked to an automatic weather station is the control on the quality of these data. The WMO proposes to perform a certain quality control check on the gathered data from automatic weather stations (referentie). RMI has already a certain expertise in this domain. When the data is entering the oracle database, it is first subjected to a quality control. If a certain pre-programmed criterion isn't fulfilled, the data is stocked as "suspicious". A staff member of RMI is then informed to check this. If he approves aborts or changes the "suspicious" data, the original data is saved, together with the co-ordinates of the responsible person who treated the data. The difficulty here is to find efficient criteria to find as much as possible errors, tendencies or even malfunction of the instruments (the immobilisation of a wind vane for example can be easily detected if the standard deviation of the wind vane is close to zero). RMI could take the lead to centralise a database on high precision anemometric data from automatic weather stations with a time resolution of 10 minutes in collaboration with Belgocontrol and Meteo Wing.
- It would be recommended to use more or less the same algorithm for the definition of variable wind for the synoptic code for automatic weather stations. According to the WMO regulations, the recommended criterion is that the standard deviation is equal or greater than 30 degrees and/or the wind speed is smaller than 2 m/s.
- During this project, it has been obvious that there is a certain gap in the history of instrumentation, mast location, interruptions of instruments, calibration of the instruments, etc… Also if there is a change in the surroundings around the mast, like a construction of a building within a range of 500 m, it would be informative to communicate this information. It would be interesting to document these things in a more standard way. The design of a "standard report document" could be a solution.
- The Installation of a mast of 50 m or higher, to be used as a reference mast would be a good option.

7. General conclusions and recommendations

This report describes the work carried out under SPSD-CP54 carried out in the framework of scientific Support Plan for a Sustainable Development (SPSD II).

The general objective of the work is to improve the basis for wind predictions in Belgium. With predictions is meant the long term annual energy yield for a certain site. The long term wind characteristics in terms of average wind speed and frequency distribution need to be well known. As input data for such an assessment wind speed and wind directions from reference stations is used, roughness maps and orography is needed.

In a first phase the different (28) meteorological stations have been visited and thoroughly described in order to assess the quality of the data measured at the different stations but also as important reference for everyone working in resource assessment. A number of stations could not be used (eg SPA) for such assessments. In addition the stations have been classified according to criteria like nearby obstacles and roughness. It is recommended to use the nearest station to the site under study taking into account similar characteristics of the site and the reference station.

Table 67: Classification of the reference stations

Station	Class number according to Meteo France
Bierset	1
Middelkerke	1
Saint-Hubert	1
Zaventem	1
Bevekom	1
Chièvres	1
Elsenborn	1
Florennes	1
Kleine-Brogel	1
Koksijde	1
Schaffen	1
Beitem	1
Diepenbeek	1
Humain	1
Melle	1
Oostende	1

In order to verify the quality of the calculations based on reference stations cross correlation's should be performed for a the used stations and it also recommended to use the different stations one by one for the site under study.

In a second step, the roughness maps for the whole of Belgium have been produced including the boundary parts of the neighbouring countries. For a site under study it is crucial to take the roughness maps in the vicinity of 20km around the site.

This roughness maps are an important result of the present work. They are based on the Corine database and verified with zoning maps, aeral photography or NGI maps. It is strongly recommended to verify this maps with the real situation as roughness might change during the course of time. Also a refinement of the map close to the site is necessary. The roughness map is an important factor in the vertical extrapolation of wind speeds and the main source of errors especially when extrapolating from 10m measuring height. For the classification of the roughness standard values have been used as described in literature.

A third important input parameter for resource assessment is the relief or height contour maps. Different sources have been used and validated and the 'dataforwind' site where SRTM data are freely available is giving good results. Another possible source is the Digital Elevation Model from the NGI. In forest areas special the accuracy of the dataforwind data should be verified with the NGI Maps since this data is obtained through remote (satelite) sensing.

All models use these sources of data in order to arrive at specific wind conditions at the site and hub height. The following models have been evaluated.

Table 68 Tested models

Model	Operated by partner	Model scale	Model Reference
ARPS	VITO	Meso	1
TVM	UCL	Meso/micro	2
MAR	UCL	Meso	3
Maestro Wind	UCL/ATM PRO	Meso/micro	4
WAsP	3E	Micro	5

They can be classified in two series eg. Mesoscale models and Microscale models.

WasP is the wind industry standard and has been used in many countries. The methodology is simple, for each selected long term reference station, the generalised regional wind climatology, called a wind atlas, is created based on the input wind data (frequency table) of this station, the site description (sheltering obstacles), the roughness description of the site and environment, and the elevation model.

With this wind atlas of the selected reference station, the wind climate at any other position or reference station can be predicted by applying the reverse process: by using the site description, roughness and elevation map of this second station. Wasp is performing well in relatively simple terrain. The advantage is the simple approach making it also possible to run the program on a PC within a few minutes. It is advised to run this program as a basis an check the validity of the results with the RIX value.

Recent years new models have been developed based on mesoscale and CFD techniques.

The high resolution mesoscale models simulate the regional wind characteristics like flow in presence of large hills and valleys (up to a typical resolution of 1 km). These sophisticated 3 dimensional models are necessary to obtain reliable wind simulations especially in complex terrain.

An important parameter for the classification of a site for wind energy is the extreme wind speed that might occur once in 50 year.

An extreme value analysis of 13 synoptic gust speed series has been carried out. After comparison with other more elaborate models, the Gumbel law was finally chosen for its simplicity and robustness. Koksijde and Middelkerke show the highest values because these stations are situated near the coastline.

The availability of quality input data for wind resource assessment and the description and classification of the reference stations makes this work very useful assessing the site characteristics for wind turbine location. It would be very useful in the future to standardize measuring equipment and measuring systems of meteorological stations and calibrate the instruments on a regular basis.

Although in the framework of the WMO a standard height of 10 m is recommended, some reference data at higher altitude should be envisaged in view of the ever increasing hub height of wind turbines.