CA/02

ASPI - Results

Antarctic Subglacial Processes and Interactions: role of transition zones in ice sheet stability

DURATION OF THE PROJECT
15/12/2005 - 30/06/2010

BUDGET
776.300 €

KEYWORDS
Antarctica, ice sheet modelling, subglacial environment, ice core analysis, ice deformation

CONTEXT

The objectives of ASPI met those of the third scientific support plan for a sustainable development (Global change, biodiversity and ecosystems) and the CliC (Climate and Cryosphere) project of the WCRP (World Climate Research Programme). ASPI forms part of international research programs such as the European Project on Ice Coring in Antarctica (EPICA), SCAR-SALE (Subglacial Antarctic Lake Environments, a core project of the Scientific Committee on Antarctic Research), and various ISMIP projects (Ice Sheet Model Intercomparison Project) sponsored by the Numerical Experimentation Group of WCRP/SCAR CliC. ASPI members were closely involved in the drafting of the IPCC Fourth Assessment report (AR4). Finally, the results from the paleoclimatic work are a direct contribution to SCAR-ACE (Antarctic Climate Evolution).

OBJECTIVES

The aim of ASPI (Antarctic Subglacial Processes and Interactions) is (i) to understand the interactions between the ice sheet and the subglacial environment and the processes that control the Antarctic ice sheet, and (ii) to quantitatively determine the stability of the ice sheet in a changing climate and the impact of climatic variations on the coastal ice sheet and vice versa.

A key factor in such quantification and impact assessment is the existence of transition zones within the ice sheet. Such transition zones are examples of specific boundary layers widely found in glaciology. Basically they are parts of the ice sheet that overlie basal transition zones where the flow is anomalous. Typical examples of such transition zones are the grounding lines, i.e. the interface between the ice sheet and an ice shelf, between an ice sheet and a subglacial lake, between an ice shelf and its pinning points as well as, more generally, between areas where the ice sheet switches from cold-based to warm-based conditions and vice versa. These transition zones are probably among the least understood elements of ice sheets, although they determine to a large extent the processes and dynamics of lateral expansion and retreat of ice sheets as well as the stability of marine ice sheets. Apart from their role in ice dynamics and ice sheet stability, processes and interactions within basal transition zones also hamper the interpretation of the paleoclimatic signal as recorded in deep ice cores.

.

Basal deformation is responsible for disturbing this signal and understanding the processes at the base of ice sheets eventually enables such signal recovery. The subglacial environment opens up new frontiers in Antarctic explorations, as this dynamic and extreme interface still needs to be explored in terms of glaciological, geological, geochemical and biological research efforts.

MAIN CONCLUSIONS

We analyzed the response of a marine ice sheet to different perturbations near the grounding line using a numerical ice sheet model that takes into account longitudinal stress coupling and grounding line migration. The model is based on an existing flowline model, but extended with a novel subgrid determination of the grounding line position and migration as a function of the size of the transition zone between the ice sheet and the ice shelf. For instance, a wide transition zone is typical for an ice stream, a small transition zone typical in many areas around the East Antarctic ice sheet where the ice sheet rather suddenly changes into an ice shelf. Model results show that stress transmission or longitudinal coupling across the grounding line plays a decisive role. The grounding line migration is a function of the length scale over which the basal conditions change from frozen to the bed to floating, the "transition zone". Perturbations at the grounding line, such as reduction in buttressing of the ice shelf, substantially thins the grounded ice sheet. Marine ice sheets with large transition zones - such as ice streams - seem highly sensitive to such perturbations, compared to ice sheets with small transition zones, such as an abrupt ice sheet/ice shelf junction.

A correct simulation of grounding line migration also requires an additional boundary condition on the ice flux across the grounding line, as recently pointed out in theoretical work from Christian Schoof. His boundary condition was subsequently embedded in numerical experiments in schematic 1D and 2D axisymmetric planform ice flow models that employed a fixed grid. The novel algorithm we devised was thoroughly tested to investigate theoretical requirements such as the reversibility of grounding line migration when subjected to accumulation and sea-level variations and the exact position of the grounding line as compared to analytical expressions. Our scheme was shown to behave well in the time domain and for fixed horizontal grid distances in the range between 2 and 40 km. Further numerical experiments tested heuristic representations for ice-sheet buttressing and for basal sliding. These refinements were implemented in a comprehensive 3D coupled ice-sheet/ice-shelf model of the whole Antarctic ice sheet.

Deformation experiments were conducted to shed more light on how marine ice accretion at the grounding line (and in other weak points of ice shelves) influences the flow properties of the ice sheet system in the transition zone. Therefore, a new analytical facility (pneumatically driven ice deformation unit) was designed, installed and tested at the ULB laboratory. Preliminary experiments clearly demonstrate the importance of such marine ice inclusions on the ice flow: marine ice is harder to deform than meteoric ice in a typical ice-shelf stress field (vertical uniaxial compression with lateral and longitudinal extension) and may therefore exert a stabilizing effect on the whole system. The importance of such result is in conjunction with results from inverse modelling of the transition zone. The latter technique allows for a determination of the ice viscosity properties and/or the basal characteristics in the transition zone, based on observed ice sheet configuration (ice thickness, surface topography) and observed surface velocities. Inverse modelling is therefore capable of determining the size of the transition zone, which is an important factor for predictive modelling. For instance, the application to Pine Island Glacier (WAIS) clearly allows us to determine to position of the onset of the ice stream as well as to delineate areas where stress coupling is essential.

But not only is the ocean influence an important boundary condition. Basal thermal conditions influence to a large extent the behaviour of the Antarctic ice sheet. Whenever the ice reaches pressure melting point, melt water is generated that may lead to enhanced ice flow. Also the presence of subglacial lakes is governed by the basal thermal conditions. Using a 3D thermomechanically-coupled ice sheet model, the influence of spatial variability of the geothermal heat flux on the basal temperature regime of the Antarctic ice sheet was investigated. Results were compared with observations of known basal temperatures (e.g. ice core drill sites) as well as with the spatial distribution of subglacial lakes.

This way it was possible to determine what dataset is more suitable for future model experiments and what basal conditions are more likely to reign underneath the Antarctic ice sheet. Using the most suitable representation of the geothermal heat flux, the same 3D model was furthermore used to reconstruct the current distribution of the age of Antarctic ice. Such qualitative simulations are extremely useful to guide potential deep drilling locations in the quest for ice older than 1 million years. Another model study that combined the large-scale 3D whole Antarctic ice sheet model with a fine scale higher-order model applied to eastern Dronning Maud Land assisted with the dating and interpretation of the EDML ice core drilled at Kohnen station. This work was performed within the framework of EPICA and combined in a unique way the expertise of the VUB modelling group with the ULB glaciology group.

Basal thermal conditions not only strongly control ice sheet flow; they also govern the nature of the interaction between the deep ice and the interface. In turn, this imposes potential restrictions on the validity of climatic and environmental reconstructions in the older ice. The research conducted in the ASPI framework has more specifically looked at the less understood case where melting occurs at the ice bedrock interface without detectable refreezing (EPICA Dome C). We have shown that, in that case, most of the paleoclimatic signatures in the ice are preserved, despite some local (scale of crystal sizes, decimetres) reworking of the chemical impurities under enhanced migration recrystallization at relatively high temperature and changing stress configuration near the bed. However, when noticeable (few hundred meters) bedrock topography changes exist, as in EDC, the time scale can be significantly altered, well above the basal ice (visible solid inclusions) sequence, therefore potentially limiting our exploration capabilities above the one million year range. Previous work of the team has shown that under large scale ice sheets (GRIP, Dye-3), strong mixing occurs between local pre-ice sheet and the active ice sheet ice, when the interface is below the pressure melting point.

ASPI has undertaken the study of the basal ice layer of the medium scale (1000 m) Berkner Island ice cap. Results show that, although the bottom ice has clearly lost its paleoclimatic signature well above the visible debris-rich basal ice layer (biogenic impact), the transition is smooth for all the gas variables and shows no sign of mechanical mixing. This suggests that the ice is of much younger age and has not seen any significant displacement of the ice dome.

Subglacial lakes are yet another type of transition zones that are currently gaining attention. Recent observations demonstrate that subglacial lakes may drain and add significant amounts of basal water to the subglacial hydrological system. Hence, they have the potential of destabilising ice sheets through sudden lake outbursts, of which evidence exist along the coast of the East Antarctic ice sheet. In ASPI we investigate the effect of subglacial lake drainage on the stability of the ice sheet and especially how sensitive the subglacial lake system is towards drainage and flooding. Preliminary experiments show that only slight changes in surface topography might easily lead to partial drainage of such a lake.

Transition zones in the Antarctic ice sheets, whether it be grounding lines, subglacial lakes or the subglacial interface are key elements in the dynamic behaviour of the Antarctic ice sheet and its stability. The ASPI project has considerably improved our understanding of the subglacial processes and interactions that occur at these interfaces. These seem even more important as a controlling factor than was previously thought of.

CONTRIBUTION OF THE PROJECT TO A SUSTAINABLE DEVELOPMENT POLICY

The main contribution of the ASPI project to a sustainable development policy is that it has played a crucial role in keeping a Belgian research capacity operational on both the national and international scale. The teams that participated in ASPI possess at the one hand a unique expertise in glaciological modelling, evident in their state-of-the-art ice flow models including one of the very few comprehensive 3D whole Antarctic ice sheet models available worldwide, and on the other hand a unique expertise in investigating basal ice properties and its paleoclimatic significance. Results and development work performed within this project therefore have found its way in international policy-oriented bodies (IPCC, SCAR, CliC, IPICS) and have set the stage for further participation of both the VUB and ULB modelling partners in EU FP7 research projects such as ice2sea (estimating the future contribution of continental ice to sea-level rise).

CONTACT INFORMATION

Project Website
http://homepages.ulb.ac.be/~fpattyn/aspi

Coordinator

Frank Pattyn
Université Libre de Bruxelles (ULB)
Laboratoire de Glaciologie
Département des Sciences de la Terre et de l'Environnement (DSTE), CP 160/03
Avenue F.D. Roosevelt 50
B-1050 Bruxelles
Tel: +32 (0)2 650.22.27
Fax: +32 (0)2 650.22.26
fpattyn@ulb.ac.be
http://dev.ulb.ac.be/glaciol/index.htm

Partners

Jean-Louis Tison
Université Libre de Bruxelles (ULB)
Laboratoire de Glaciologie
Département des Sciences de la Terre et de l'Environnement (DSTE), CP 160/03
Avenue F.D. Roosevelt 50
B-1050 Bruxelles
Tel: +32 (0)2 650.22.27
Fax: +32 (0)2 650.22.26
jtison@ulb.ac.be
http://dev.ulb.ac.be/glaciol/index.htm

Philippe Huybrechts
Vrije Universiteit Brussel (VUB)
Vakgroep Geografie
Pleinlaan 2
B-1050 Brussel
Tel: +32 (0)2 629.33.84
Fax: +32 (0)2 629.33.78
phuybrec@vub.ac.be
http://www.vub.ac.be/DGGF

SSD SCIENCE FOR A SUSTAINABLE DEVELOPMENT

CLIMATE | ANTARCTICA

belspo
BELGIAN SCIENCE POLICY
Avenue Louise 231 Louizalaan • B-1050 Brussels
Tél. +32 (0)2 238 34 11 • Fax +32 (0)2 230 59 12 • www.belspo.be/ssd
Contact. Maaike Vancauwenberghe