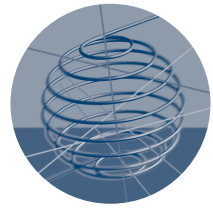
FINAL REPORTS SUMMARIES



SCIENTIFIC SUPPORT PLAN FOR A SUSTAINABLE DEVELOPMENT POLICY SPSD 1

# ANTARCTICA

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

- *"Antarctica"*
- *"Levers for a sustainable development policy"*
- *"Earth observation by satellite" TELSAT 4*
- *"Prenormative research in the food sector"*
- *"Global change and sustainable development"*
- *"Sustainable management of the North Sea"* (available from spring 2003)
- *"Sustainable mobility"* (available from spring 2003)
- *"Supporting actions"* (available from spring 2003)

D/2002/1191/40
Published in 2002 by the
Federal Science Policy
Rue de la Science 8
Wetenschapsstraat 8
B-1000 Brussels
Belgium
Tel : 32/2/238.34.11 – Fax 32/2/230.59.12
http://www.belspo.be (FEDRA)

Contact person :
Mrs Maaike Vancauwenberghe (vcau@belspo.be)
Secr : 32/2/238.36.49

# CONTENTS

## THE BELGIAN SCIENTIFIC RESEARCH PROGRAMME ON THE ANTARCTIC

Together with 11 other countries, Belgium signed the Antarctic Treaty in 1959[1]. Via the possibility of mutual inspection of all activities, this treaty keeps watch over the unique international consensus to use this continent for peaceful purposes only. The Antarctic Treaty provides for the 'freedom' to conduct scientific research and focuses on promoting scientific co-operation. The signing in 1991 of the 'Protocol on Environmental Protection to the Antarctic Treaty' (Madrid Protocol) designated the region as a 'natural reserve, devoted to peace and science'. The Protocol prohibits all non-scientific activities regarding Antarctic mineral resources and prescribes environmental assessments based on scientific data in all other cases. Belgium made an active contribution to the negotiations leading up to the Protocol.

The establishment of scientific research activities remains the cornerstone of the good functioning of the Antarctic Treaty System[2] and constitutes the condition to join the decision-making forums within the System. Scientific research offers the Treaty System the elements needed to pursue an environmental protection and rational management policy. On the other hand, Antarctica offers unique possibilities to tackle major scientific problems and to gain insight in the earth's dynamics – like climate change, ocean level fluctuations, the formation of oceanic deep water or the evolution of continental margins.

In 1985, the Government took the initiative of setting up a structured scientific research programme regarding Antarctica with the will to maximally integrate with the activities of the Antarctic Treaty System. As such, for the first time since the 60s, structural aid was once again offered to the Belgian Antarctic research community. The research programme has continued uninterruptedly up to today.

---

[1] The Antarctic Treaty applies to the entire area south of the 60° south parallel. Such area includes the southern sectors of the Atlantic, Pacific and Indian oceans, constituting a hydrographical entity called the Southern Ocean.

[2] The Antarctic Treaty System is the whole complex of arrangements, including the Treaty itself, made for regulating relations amongst Parties, e. g. the *Madrid Protocol,* the *Convention for the Conservation of Antarctic Marine Living Ressources* and the *Convention for the Conservation of Antarctic Seals*.

These are the broad objectives of the Belgian Antarctic research programmes since 1985:

- Maintain and strengthen Belgium's relevant expertise;
- Increase Belgium's visibility within the Antarctic Treaty System;
- Contribute to a rational management of the Antarctic environment and its natural resources;
- Determine the global consequences of the natural processes that take place in Antarctica and its surrounding oceans.

Four major research areas can be distinguished:

- Marine biology and biogeochemistry;
- Glaciology and climatology;
- Hydrodynamics and sea ice;
- Marine geophysics.

The research takes the form of four-year projects that are entrusted to research teams of universities or (federal) scientific institutions. The emphasis is on a multi-disciplinary approach of the dynamics of the global functioning of Antarctic main natural systems and of their evolution and interactions. The research themes and priorities fully tie in with other important international projects and programmes, such as ANTOSTRAT (Antarctic Offshore Stratigraphy Project), EPICA (European Project on Ice Coring in Antarctica), IGBP (International Geosphere-Biosphere Programme),… As Belgium has no infrastructure of its own in Antarctica (base, appropriate research ships,…), the necessary fieldwork is conducted through participation in scientific expeditions set up by other countries.

All research costs (staff, equipment, travel, functioning and overhead) are defrayed by the Federal Science Policy Office, which is also in charge of the financing, management, co-ordination and dissemination of the Programme. The scientific link with the Antarctic Treaty System is also the responsibility of the Federal Science Policy Office.

A guidance committee with consultative power has the authority to formulate recommendations regarding the Programme's progress. It can also suggest useful measures to better reach the targets.

The period from 1985 to 1996 comprised three consecutive phases of the aforesaid programme. The research budget for the first two phases amounted to ± 2 MEUR, for the third phase it came to ± 4 MEUR.

The fourth phase of the programme (1997 – 2000), of which the project summaries are included in this publication, was integrated into the 'Scientific Support Plan for a Sustainable Development Policy – SPSD I'. Although sustainable development as such is not explicitly mentioned neither in the objectives nor in the strategy of the Treaty System, the underlying concept is in full keeping with the System. This can be gathered from the System's numerous measures and actions aimed at preserving the fauna and flora, establishing protected areas, preventing ocean pollution, eliminating waste or protecting endemic animal species. As Antarctica is recognised by the Madrid Protocol as a ‘natural reserve’, in which all human activities are closely monitored, it can model for the broad-scale implementation of the sustainable development concept.

Apart from the budget for research projects within this phase, which amounted to about 6 MEUR, Belgium also contributed 0,5 MEUR to the cost of working of the European Project on Ice Coring in Antarctica (EPICA).

The continuity of Antarctic research is guaranteed by the current fifth phase (2000 – 2005), which is part of the 'Second Scientific Support Plan for a Sustainable Development Policy – SPSD II'. This plan's budget contribution is comparable to that of phase four and amounts to ± 6 MEUR. Contrary to the previous phases, however, the Antarctic research is no longer categorised under a specific 'Antarctic' subprogramme, but integrated within the broader framework of the second part, 'Global change, Ecosystems and Biodiversity', of SPSD II. Also, the network of financed researchers of each project has been complemented with a 'users committee' (non-financed partners). These non-financed partners can be representatives of relevant international, federal and regional official bodies, scientific experts… They actively contribute to the project with additional data or information and/or the formulation of recommendations regarding ongoing research.

**General overview of the Belgian scientific research programmes on the Antarctic, financed by the Federal Science Policy Office**

| Budget (MEUR) | # Teams | # Institutes | Themes and number of projects |
|---|---|---|---|
| Phase I (1985-1989) | | | |
| 1,7 | 10 | 7 | Plankton Ecology: 3<br>Marine Geochemistry & Geophysics: 2<br>Glaciology & Climatology: 5 |
| Phase II (1988-1992) | | | |
| 1,8 | 10 | 7 | Plankton Ecology & Marine Biogeochemistry: 4<br>Marine Geophysics: 1<br>Glaciology & Climatology: 5 |
| Phase III (1992-1996) | | | |
| 3,6 | 9 | 6 | Marine Biogeochemistry & Ecodynamics: 4<br>Glaciology & Climatology: 3<br>Hydrodynamics & Marine Geophysics: 2 |
| Phase IV (1997-2000) | | | |
| 5,7<br><br><br><br>0,5 | 15 | 8 | Marine Biota & Global Change: 4<br>Dynamics Southern Ocean: 1<br>Palaeoenvironmental records: 4<br>Extra: EPICA |
| Phase V (2000-2005) | | | |
| ± 5,5 | 11 | 8 | Climatology & Atmosphere: 3<br>Marine Biodiversity: 1<br>Terrestrial Biodiversity: - |

More detailed information about the Antarctic research programme and the financed projects is available on the website: http://www.belspo.be/antar.

The detailed final reports of the different projects within phase 4 of the Belgian scientific research programme on the Antarctic will be available in the beginning of 2003.

# SUMMARIES OF THE PROJECTS WITHIN PHASE 4 OF THE BELGIAN SCIENTIFIC RESEARCH PROGRAMME ON THE ANTARCTIC

A4/02/B01

# MEIOBENTHIC BIODIVERSITY AND FLUXES WITHIN THE ANTARCTIC BIOGEOCHEMICAL ENVIRONMENT

S. VANHOVE, H.-J. LEE, J. VAN DE VELDE,
A. DEWICKE, B. TIMMERMAN, T. JANSSENS
AND M. VINCX

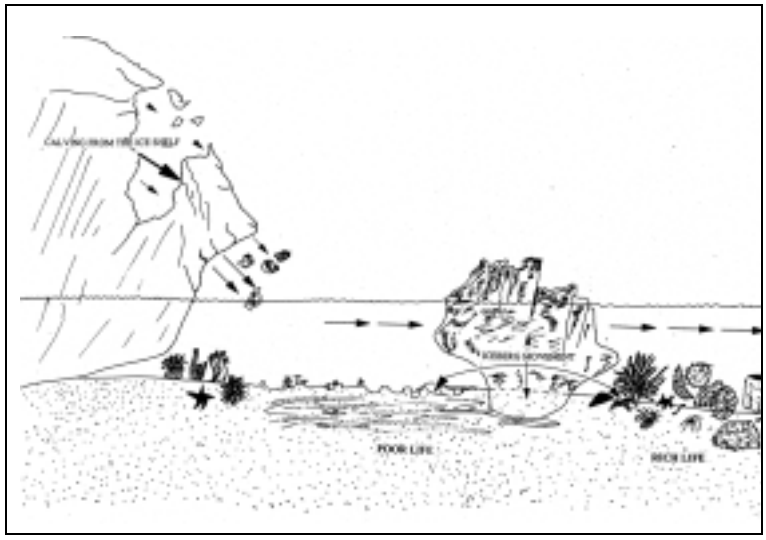
UNIVERSITEIT GENT
MARIENE BIOLOGIE – INSTITUUT VOOR DIERKUNDE
K. L. Ledeganckstraat 35
B-9000 GENT

## INTRODUCTION

The aim of the program is to improve the understanding of the structure and dynamics of the Antarctic coastal and shelf marine ecosystem, the most complex and productive area in Antarctica, and likely the most sensitive to global environmental change. Central themes are the biodiversity and fluxes in the Antarctic ecosystem, with focus on the meiobenthic communities. An answer is searched on the following questions:

Subtheme 1: *The importance of production for meiofaunal biodiversity in the Antarctic coastal zone:* How tight is the temporal variability related to the ambient seasonal environment? Is the variability at Signy Island predictable? Are low Antarctic meiofaunal communities comparable to their high Antarctic counterparts?

Subtheme 2: *Biodiversity and recovery potential in the deep bathyal waters of the Southern Ocean:* What is the impact of ice scouring on the diversity of the meiofauna in iceberg disrupted sediments? How rapid and how does recolonisation processes start and proceed?



Subtheme 3: *The role of Southern Ocean meiobenthos in benthic pelagic coupling:* What is the ecological significance of free-living marine nematodes in Antarctic carbon cycling?

## GENERAL CONCLUSIONS

Primary productivity is the basic resource that fuels life on Earth. It is therefore reasonable to assume that productivity is correlated with standing stock and diversity in many situations. The extremely seasonal input of food from the ice and water column is increasingly considered to be of great importance. Episodic availability of food requires adaptive responses, which impose specific constraints on the types of organisms able to exploit such resources. Here we report on the coupling of the meiobenthos to the seasonal nature of food production in the Antarctic coastal zone (study 1). Distinct peak abundances, lagging with a few weeks behind peak diatom production, and lower stocks during most of the year with immediate and lagged responses to lower quality nanophytoplankton input were observed within the meiofauna communities. Strong reduced stocks with a short duration in mid winter were found when food availability was at its lowest. This seasonal response was, however, variable from year-to-year. Such characteristic makes Antarctic meiofauna less predictable as would be expected. The observed up-side-down control suggest that meiobenthos is strongly influenced by the year-to-year variations in the timing, intensity and duration of phytoplankton blooms.

Despite comparable high meiofaunal abundances in similar circumstances of seasonal food input, fundamental differences were found between the meiofauna communities from Rothera and Signy. Latitudinal differences, such as the Polar Front nearby the South Orkneys, were proposed to be at the base of the variability between high and low Antarctic nematode communities.

A second important ecological agent structuring the Antarctic benthic realm is the disturbance activities related to calving and moving icebergs. Large areas of the sea floor are thus subjected to spatial and temporal disturbances on scales ranging from centimetres to tens of kilometres and from days to decades or longer. Some 15 to 20% of the world's oceans are affected by this phenomenon, yet measurements of the extent of biological destruction from iceberg impacts and subsequent recovery are very rare. Assessing the rates and processes involved in the destruction and recolonisation by in situ fauna is one of the more recent aims of biological investigations as to marine mineral exploitation and the dumping of radioactive and other chemical wastes. Moreover, with reference to the global warming, the calving of icebergs may be a more frequent phenomenon in the future. Moreover, the wide scales of disturbance intensity are thought to add to the overall high levels of Antarctic benthic biological diversity. We studied the impact of iceberg scouring on Antarctic meiofauna, both in the low subtidal

and on the deeper shelf near the Antarctic continent. Data here indicate that the scouring led to more than a 95% decrease in meiofaunal abundance in both areas. The return of major meiofauna groups was accomplished in 30 days in the low subtidal. In spite of this catastrophic destruction, parameters related to nematode community structure, e.g. dominance rank, generation structure, trophic composition and life-traits (r- vs. K-selection) were not affected by the iceberg impact in this area.

Because of major differences of ecological condition between shallow coastal and deep-water habitat, complete nematode community restoration in the latter may take at least some years. An extremely low diversity and a fundamental change in nematode generic composition due to scouring elucidate that the diverse nematode community from the shelf of the Weddell Sea is very fragile against iceberg disturbance. This is in contrast to the findings in the low subtidal where the nematode communities are well adapted to ice disturbance. It was finally concluded that the combined effect of various physical disturbance agents (such as wave action) are structuring the nematode communities at shallow Antarctic coasts while only iceberg disturbance primarily influences the nematode communities in the deep Weddell Sea.

The study of food and feeding habitats of Antarctic benthos has received considerable attention, since they may explain part of the discrepancies between 1) seasonally limited food resources and the existence of a rich benthic life and 2) a low organic carbon content of the Antarctic sediments, despite important sedimentation pulses in summer. Both show that the benthic community, composed of organisms living on and within the sediments of the deep ocean floor, may be an important sink. In particular the meiofauna exhibits high standing stocks in low subtidal and deep sea. Although many fluctuations may be due to factors of unknown nature (for example physical disturbance by storm, macrofaunal activity, biological interactions within the meiofauna etc.) a distinct impact of food supply, as a result of benthic pelagic coupling, is observed in both ecosystems (coastal and deep sea).

Although it is generally accepted that meiofauna as a group are capable of consuming a broad range of microbial food and non-living detrital material, and that meiofauna may specialise on or have preferences for different types of food resources, relatively little is known about how these feeding strategies are manifested under natural conditions. Neither there is exist decisive evidence about the quantitative role of meiofauna in marine food webs. Thus, despite observations of a probable direct uptake of primary food sources by the dominant Epistrate feeding nematodes, the question thus remains

whether the nematodes from the Weddell Sea preferentially incorporate fresh food sources or whether they rely on a mixture of different food sources (as is generally the case for fee-living marine nematodes).

Therefore, the current stable isotope study focussed on the contribution of the meiobenthos community (and especially the most abundant taxon of the nematodes) in the carbon flux of the Antarctic benthic ecosystem. The carbon and nitrogen isotopic composition of the free-living Antarctic nematodes collected during the EASIZ II and III of R.V. Polarstern to the Weddell Sea was studied in a comparative and experimental way. Carbon stable isotope abundances occurred within a large range of variation between –26.5 and –22.5‰ and were situated closely to the natural signals of detritus in the sediments (e.g. between –26.00 and –24.10‰). On the provision that the _13C signature of food is retained in the animal, fresh pennate diatom algae from the settled pelagic phytoplankton and krill faecal strings were indeed proposed as the main carbon source for the nematodes in the Weddell Sea. However, a probable addition of other trophic items could not be excluded. Our earlier suggestion that the meiobenthos responds rapidly and efficiently (as shown by the high standing stock of meiobenthic communities in the deep Weddell Sea) to the episodic food supply characteristic for this part of the Southern Ocean was supported.

**KEY WORDS**

Antarctica, biodiversity, meiofauna, nematodes, temporal changes, temperature and food, disturbance and recovery potential, stable isotopes.

A4/36/B02

# STRUCTURAL AND ECOFUNCTIONAL BIODIVERSITY OF THE AMPHIPOD CRUSTACEAN BENTHIC TAXOCOENOSES IN THE SOUTHERN OCEAN

C. DE BROYER, G. CHAPELLE,
P.-A. DUCHESNE, R. MUNN, F. NYSSEN,
Y. SCAILTEUR, F. VAN ROOZENDAEL AND P. DAUBY

INSTITUT ROYAL DES SCIENCES NATURELLES DE BELGIQUE
LABORATOIRE DE CARCINOLOGIE
Rue Vautier, 29
B-1000 BRUSSELS

## INTRODUCTION

Biodiversity, at its different integration levels –from genes to species and to ecosystems– is a critical element in the evaluation of the resilience of natural systems to environmental changes. In addition, understanding the patterns and processes of biodiversity in relation to production is of fundamental importance for the sustainable management of marine living resources.

Within the Southern Ocean, the Antarctic Coastal and Shelf Ecosystem (ACSE) is the most complex and productive, the richest in species, and likely the most sensitive to global environmental changes. In order to improve our understanding of the ACSE structure and dynamics within the perspective of the global environmental changes, the Scientific Committee on Antarctic Research (SCAR) recently elaborated the programme "Ecology of the Antarctic Sea-Ice Zone" (EASIZ). This programme pays a particular attention to these features that make the biology of this ice-dominated ecosystem so distinctive and to understand seasonal, inter-annual, and long-term changes. For a decade, EASIZ proposed an integrated study of the ice, water column and benthic sub-systems focussing on key processes and key organisms in key communities, in a network of study sites (SCAR, 1994).

In the ACSE, the Antarctic macrozoobenthos is characterized by a relatively high species diversity and richness. Several zoological groups, namely the sessile suspension-feeders such as Porifera and Bryozoa and the endo- or epibenthic Polychaeta and Peracarida, are rich in species. Moreover, a high degree of species endemism has been recorded for many taxa (White, 1984), attaining up to 85% in the case of benthic Amphipoda (De Broyer & Ja_d_ewski, 1993; 1996). Some groups, however, show a moderate species richness (like Bivalvia and Gastropoda), while other groups remain either absent (Stomatopoda, reptant Decapoda) or under-represented (Cirripedia, natant Decapoda) on the Antarctic shelf bottom (Arntz et al., 1997). Circumpolarity in species distribution and extended range of eurybathy (Brey et al., 1996) are common features, as are often high levels of population abundance or biomass. Detailed information on the Antarctic zoobenthos and its diversity can be found in the recent syntheses of Arntz et al. (1994; 1997).

But the latitudinal and vertical patterns of the Antarctic macrobenthos biodiversity in a global perspective, its spatial and temporal variations and the causes of its particular traits remain poorly understood, as well as its roles in the structure and functioning of

benthic systems, in particular their productivity and their resilience in the global warming and ozone depletion context.

In the Antarctic benthic communities, in the quasi-absence of decapods, the peracarid crustaceans (Amphipoda, Isopoda, Tanaidacea, Cumacea, Mysidacea,...) are by far the most species-rich group (De Broyer and Jazdzewski, 1996) and probably one of the most diversified in terms of trophic types, modes of life, habitats and size spectra, thus making a good model group for biodiversity studies. The most numerous, the amphipods, comprise more than 850 species in the whole Southern Ocean, 741 of which are benthic species. It was suggested that this high specific diversity could be related to a high heterogeneity of habitats and a variety of ecological roles which remain to be described and understood.

## GENERAL CONCLUSIONS

Within the Antarctic Coastal and Shelf Ecosystem (ACSE) the peracarid crustaceans constitute the most diverse animal group in terms of species richness, life styles, trophic types, habitats and size spectra.

Using as a model group the amphipod crustaceans –in turn the richest taxon among peracarids with more than 850 species in the Southern Ocean– this study aimed at describing and evaluating the role of the biodiversity of the vagile macrobenthos in the structure and functioning of the Antarctic Coastal and Shelf Ecosystem.

In the framework of the SCAR EASIZ programme some key structural and ecofunctional aspects of biodiversity were investigated.

Different structural biodiversity features were characterised, namely faunal composition, geographic and bathymetric distribution, habitats and microhabitats, bio-ecological traits. Comparative investigations were performed in two EASIZ benthic reference sites, the eastern Weddell Sea Shelf Community in the High Antarctic, and the Maritime Antarctic sublittoral community of Admiralty Bay, King George Island. In the latter site, species abundance was followed during a complete year cycle, allowing to evidence strong seasonal variations.

Gammaridean amphipods appeared ubiquitous in the shelf communities of the eastern Weddell Sea. Their specific habitats were investigated by comparing catches from

different collecting gears and by ethological observations in aquaria. Six main habitats were distinguished: endobenthic, epibenthic, hyperbenthic, benthopelagic, pelagic and cryopelagic. Among epibenthic species, which form the bulk of the fauna, three different strata were detected, together with four symbiotic microhabitats.

The ecofunctional role of biodiversity was approached through the study of trophic diversity and trophodynamics and the significance of the unusually wide size spectra of the Antarctic amphipod crustaceans.

The trophic preferences of 40 dominant amphipod species of the eastern Weddell Sea benthos were deduced from both stomach content analyses and behaviour observations in aquaria. These combined approaches revealed at least eight different feeding types: suspension-feeding, deposit-feeding, deposit-feeding coupled with predation, opportunistic predation, micropredatory browsing, macropredation coupled with scavenging, opportunistic necrophagy and true necrophagy. This feeding type diversity was corroborated by a preliminary analysis of the carbon and nitrogen stable isotopes. Among these eight types, no particular one was dominant. In the same way, types involving microphagy and macrophagy were equally represented. Predatory types (opportunistic or exclusive) accounted for 64% of the analyzed species, while scavenging types (facultative or obligate) accounted for 60%. The overlap suggests that many amphipod species have a wide dietary spectrum and are able to take advantage of different food resources.

The impact of the amphipod community on the eastern Weddell Sea shelf ecosystem was approached using feeding type results and biomass data. It appeared that sedimenting plankton particles, crustaceans and fish carrion were the 3 main items consumed by these crustaceans, accounting respectively for 10-27, 22-32, and 5-18% of the biomass. In addition, a extensive bibliographic investigation was performed in order to estimate the significance of amphipods in the diet of higher trophic levels: 33 species of invertebrates, 48 of birds, 101 of fish and 10 of mammals are regular consumers of amphipods, the share of this type of prey reaching up to 99%.

As the Antarctic amphipod size spectrum appeared to be the widest, after Baikal Lake, precise length data were gathered about more than 2,000 amphipod species from 15 sites world wide, from polar to tropical, and from marine to freshwater environments. It was shown that gigantism was not directly related to water temperature as often stated, but instead to oxygen availability. Maximum size increases dramatically with oxygen, modal size increases less, and minimum size does not increase at all.

To contribute to a more accurate assessment of the Southern Ocean biodiversity new synthetic tools for compiling, increasing, managing, and disseminating biodiversity information were developed, in particular a "Biodiversity Reference Centre", devoted to Antarctic amphipod crustaceans. It is comprised of comprehensive databases (organising the taxonomic, biogeographic and bio-ecological information), validated and operational reference collections, and a network of contributing specialists engaged in the taxonomic revision of the Antarctic amphipod fauna and the preparation of new conventional and electronic identification guides. These efforts will facilitate monitoring biodiversity in selected EASIZ reference sites.

**KEYWORDS**

Antarctica, Southern Ocean, biodiversity, Crustacea, Amphipoda, benthos, habitats, trophodynamics, gigantism.

# AN INTEGRATED APPROACH TO ASSESS CARBON DYNAMICS IN THE SOUTHERN OCEAN

F. DEHAIRS[1], C. LANCELOT[2], L. ANDRÉ[3], M. FRANKIGNOULLE[4], E. DELEERSNIJDER[5]
S. BECQUEVORT[2], D. CARDINAL[3], T. CATTALDO[1], B. DELILLE[4], M. ELSKENS[1], N. FAGEL[3-6], H. GOOSSE[5], E. HANNON[2], J. NAVEZ[1-3], G. PROBST[5], V. SCHOEMANN[2] WITH THE COLLABORATION OF E. KOPCZYNSKA[7] AND A. KOSTIANOY[8]

1- Vrije Universiteit Brussel, Analytische Chemie (Brussels, Belgium)
2- Université Libre de Bruxelles, Ecologie des Systèmes Aquatiques (Brussels, Belgium)
3- Royal Museum for Central Africa, Department of Geology (Tervuren, Belgium)
4- Université de Liège, Unité d'Océanographie Chimique (Liège, Belgium)
5- Université Catholique de Louvain, Unité d'Astronomie et de Géophysique (Louvain-La-Neuve, Belgium)
6- University of Liège, Silicoclastic Sedimentology and Clay Geology (Liège, Belgium)
7- Polish Academy of Sciences, Department of Antarctic Ecology (Warszawa, Poland)
8- Institute of Oceanology P.P. Shirshov, Ocean Experimental Physics Laboratory (Moscow, Russia)

## INTRODUCTION

The Global Ocean plays an important role as a buffer to global warming by absorbing some 40% of the $CO_2$ released annually (Battle et al., 2000). Specifically the Southern Ocean, because of its unique hydrodynamical and ecological features, appears as a potential major $CO_2$ sink. This is not just because of its large size (18% of the World Ocean), but mainly as a result of physical and biological processes including cooling and sinking of surface waters, biological uptake and export of organic carbon from the surface layer.

Dissolved $CO_2$ in surface waters is taken up by photosynthesising algae which require nutrients (phosphate, ammonium/nitrate, and dissolved silica) and trace elements such as iron for their growth. Because of a sustained supply of essential nutrients (N, P, Si) through deep-water upwelling, the Southern Ocean has great potential to further enhance $CO_2$ uptake via the biological pump. However, in the HNLC (High Nutrient Low Chlorophyll) waters of the modern Southern Ocean this does not necessarily occur because of iron limitation (e.g. de Baar et al., 1995; de Baar and Boyd 1999), since this ocean benefits put poorly from inputs by continental erosion (Kumar et al., 1995). There seems to be little doubt today that iron plays a pivotal role in ecosystem structure and food-web export. Iron-enrichment experiments conducted in the HNLC waters of the Southern Ocean, both shipboard (e.g. de Baar et al. 1990, Martin et al. 1990, Buma et al. 1991) and in situ (Boyd et al., 2000) resulted in the stimulation of the large class of algae, in particular chain-forming diatoms (de Baar and Boyd 1999), more prone to sustain carbon export.

Thus, depending on the phytoplankton community and the associated food-web structure, the organic carbon produced is either retained in the surface layer through fast microbial respiration or exported to the deep-ocean as phytoplankton cells, plankton debris or faecal pellets. In the latter case more carbon is retained by the ocean and less returns to the atmosphere. This flux of carbon to the deep ocean is called the biological carbon pump. Its efficiency relies on the one hand on light and nutrient controls of phytoplankton and ecosystem structures and on the other hand on the mineralisation rate of exported carbon when sinking from the surface layer towards the sediment. Mineralisation of sinking organic carbon, in combination with deep ocean circulation, ultimately determines the extent of carbon storage by the ocean. At most of the deep ocean stations where sediment traps were deployed, only few percent of the originally

exported carbon arrived in the ocean's interior (below 1000 m) with the major fraction remineralised by bacterial activity during settling (e.g. Berger et al., 1988).

The importance of organic carbon mineralisation in the mesopelagic layer (100-1000 m) is still poorly known and its prediction requires the full understanding of the mechanisms regulating bacterial degradation of the sinking material as well as the strategy by which bacteria compete for organic matter in these HNLC waters. Quantification of organic carbon mineralisation in the mesopelagic layer can be estimated by comparing the particulate organic carbon (POC) fluxes recorded by deep sediment traps with the primary production and the export flux of carbon at the base of the surface layer, as reconstructed from specific algorithms (e.g. Bishop, 1988). Overall, this approach suffers from a lack of reliability due to the fast and large degradation of the exported organic matter. However, more refractory proxies of organic carbon, such as bio-Ba, barite have been identified (because of their refractory nature) (e.g. Dymond et al., 1992; François et al., 1995). Nevertheless, all approaches based on proxies are potentially affected by biological processes and are also particularly sensitive to spatial and seasonal patterns of POC/proxy ratios (e.g. Dymond and Collier, 1996; Rutgers van der Loeff, 1997; Dehairs et al., 2000a).

In the present study we aimed at elucidating the main factors and processes controlling primary production in different functional environments of the Southern Ocean and at evaluating the impact of this process on atmosphere - ocean exchange of $CO_2$. To further evaluate the efficiency of this biological carbon pump, we also focused our attention on the export of organic carbon to the ocean's interior and on its mineralisation. Finally, a coupled physical biogeochemical model was elaborated to reproduce the inter-linkage between the whole of the physical, chemical and biological processes that are in control of the carbon fluxes.

The applied research methodology involved and combined: (i) Direct estimates of $CO_2$ air-sea exchange and identification of sink-source regions in the Southern Ocean; (ii) Studies of the physico-chemical and biological mechanisms controlling the dominance of key components of the phytoplankton community; (iii) Estimates of the export of organic carbon from the surface mixed layer and the microbial degradation in the subsurface and the deeper water column and (iii) Numerical development of a 1D mechanistic biogeochemical model.

## GENERAL CONCLUSIONS

This work confirms the crucial bottom-up control of phytoplankton production by Fe availability. Our observations for the Atlantic sector confirm the greater sensitivity to Fe limitation for plankton communities composed of larger species, compared to communities with predominance of small cells. Fe limitation appears to be the common condition for the Southern Ocean waters studied, except for specific areas in the vicinity of shelves and influenced by advective input of Fe, such as the Ross Sea and the northern part of the SAZ, west of Tasmania.

Settling rates of individual, autotrophic and heterotrophic cells, colonies and detrital particles during early season in the Ross Sea were £ 8 m $d^{-1}$, similar to observations elsewhere. During mid-summer some increase of export was noticed associated with increased aggregate formation. Since the biomass associated with such slowly sinking particles is relatively large, the carbon fluxes involved become significant and in any case larger than observed for the other Southern Ocean areas. The degradation of sinking particles appeared mainly controlled by attached bacteria. Degradation was relatively low in spring, but it is likely that bacterial activity would have increased with advancing season. Indeed, for a late summer situation in the SAZ and PFZ regions south of Australia, production of ammonium generally exceeded demand, reflecting a decaying bloom with dominance of regenerated production (*f*-ratios <0.5), and probable enhanced bacterial activities.

Inhibition of nitrate uptake and resulting decrease of *f*-ratio due to ambient ammonium increase was high for phytoplankton originally thriving in low ammonium (<0.1 _M) and high iron (>0.4 nM) waters, while it was low, to non-significant in conditions of low Fe (<0.1 nM). Thus, on from a certain level of Fe-depletion the phytoplankton is insensitive to increasing availability of ammonium, as would occur generally along the growth season. In this case, *f*-ratios obtained from short term incubations can be considered as representative for longer time scales, probably of the order of days to weeks, an interesting aspect when trying to link new production to export production.

POM mineralises quickly in the water column and POC flux itself might therefore not be the best parameter to assess export production. Recent publications, in general, emphasise the good potential of excess-Ba – barite is a proxy for organic carbon, and results from this study confirm this. Although full detail about the biogeochemical processes involved with Ba uptake and barite synthesis could not be resolved here, it appeared that phytoplankton uptake of Ba from solution is essentially via adsorption.

This adsorbed Ba adds to an original pool of excess Ba in the plankton that does not seem to exchange with the solution and which we suspect to consist of micro-crystalline barite, a mineral we observed to be an ubiquitous component of the Southern Ocean suspended matter. Diatoms appear to carry a larger pool of excess Ba and adsorb proportionally less additional Ba from the solution. This observation was also confirmed from SAZ and PFZ field data, showing a co-variation between water column excess particulate Ba and diatom abundance. Thus, under diatom dominance a given POM unit produces more excess Ba, than under conditions of Phaeocystis dominance, for instance. When using the Ba proxy to assess export production, this condition must be taken into account via appropriate algorithms.

During the present study it was possible to compare several conceptually and technically entirely different methodologies to assess carbon export from the surface mixed layer (i.e. upper 100m). Direct assessment of the carbon flux was possible from the settling rates of individual, autotrophic and heterotrophic cells, colonies and detrital particles and from new production measurements based on f-ratio and primary production. Carbon export flux obtained from these methods would reflect the short term situation (i.e. days to a few weeks). Seasonally or annually averaged export productions were derived from particulate organic C and $Ba_{xs}$ fluxes in sediment traps and from sedimentary $Ba_{xs}$ rain rates. Clearly, export production estimates obtained from narrow time windows (generally spring and summer) are larger than those based on broader time windows, since the latter have also integrated the signals for the weakly, to non-productive, winter period. It is nevertheless remarkable that the different approaches based on very different and independent methodologies provide converging export production values for the main Southern Ocean areas investigated. Highest export productions are observed for the Antarctic Shelf (Ross Sea) and the Seasonal Ice Zone (80 to 200 mgC $m^{-2}$ $d^{-1}$). The Polar Front Zone (PFZ) in the Indian sector has greater export production than the Permanently Open Ocean Zone (37 and 10 mgC $m^{-2}$ $d^{-1}$, respectively). For the Atlantic sector (6°W), differences between PFZ and POOZ are less pronounced. For the Subantarctic Zone to the west, southwest of Tasmania, export production is higher (70 to 150 mgC $m^{-2}$ $d^{-1}$) than for the PFZ (30 mgC $m^{-2}$ $d^{-1}$), but this might me a peculiar situation due to iron repletedness resulting from the proximity of the Tasmanian shelf. Furthermore, for the PFZ and ACC in the Atlantic sector, comparison of the export production values predicted by the SWAMCO-1D CLIO model with the estimates based on proxy flux (sedimentary Baxs rain rate) show good agreement, providing further weight to the magnitude of the calculated export productions.

In spring and summer, the area between 35° and 50°S in the Indian and Australian sectors was estimated to be a net sink for atmospheric $CO_2$, amounting to between 27 and 86 mgC $m^{-2}$ $d^{-1}$ equivalent to 0.045 and 0.141 GtC, respectively. The fact that such net air to sea fluxes are of the same order of magnitude as the carbon export flux from the surface mixed layer, emphasises the important role of the biological pump, at least during the bloom period, in redistributing atmospheric carbon into the ocean. However, when giving these data a closer look, the question is raised on how to reconcile them with the observation of low *f*-ratios (<0.5; at least for late summer in the SAZ), which suggest less than 50% of primary production is available for export. Clearly, such a comparison requires further improvement of the spatio-temporal resolution of the production process and the export production regime in the Southern Ocean.

**KEYWORDS**

Antarctica, Southern Ocean, air-sea $CO_2$ fluxes; biological pump; micronutrient limitation; phytoplankton composition; new production; export production; subsurface bacterial degradation; trace elements as proxies; coupled physical-biogeochemical modelling.

**A4/DD/B21-B23**

# SOUTHERN OCEAN GLOBAL ECOSYSTEM RESPONSE TO PHYSICAL AND TROPHIC CONSTRAINTS

J.-H. HECQ[1] AND A. GOFFART[1] WITH THE COLLABORATION OF V. DEMOULIN[3], A. NORRO[2], G. PICHOT[2] AND A. WILMOTTE[3]

[1:] UNIVERSITÉ DE LIÈGE, UNITÉ D 'ECOHYDRODYNAMIQUE, INSTITUT DE PHYSIQUE B5, Sart Tilman, B-4000 LIÈGE

[2:] MANAGEMENT UNIT OF THE NORTH SEA MATHEMATICAL MODELS (MUMM),Gulledelle 100, B-1200 BRUSSELS

[3:] UNIVERSITÉ DE LIÈGE, DÉPARTEMENT DE BOTANIQUE B22, Sart Tilman, B-4000 LIÈGE

## INTRODUCTION

The purpose of the present contribution was the conceptualisation, the parameterisation and the validation of a coupled numerical modelling system integrating the physical and trophic processes which govern the equilibrium and changes of biodiversity in the Southern Ocean global ecosystem.

The research consists of a multidisciplinary study of the biodiversity and productivity of the global ecosystem of the Southern Ocean, in a context of variation of the environmental and climatic conditions. The main objective was to develop inside an interdisciplinary network a coupled physical/biological model able to simulate the multiparametric variability of the Ross Sea, with a particular attention to the variability connected with climate. The analysis of sub-ecosystems at specific time and space scales and the interconnection of these systems were developed by means of a proper modelling.

The studied sub-ecosystems are:

1. the planktonic ecosystem, which is the target of the study of the processes relating to biodiversity, dynamics and phyto-zooplanktonic interactions;

2. the pelagic ecosystem, with which is associated the macrozooplankton and in particular the krill;

3. the ecosystem of the higher trophic levels.

The final objective was the valorisation of the research by implementation of a quantitative decision tool for the Southern Ocean global ecosystem management.

## GENERAL CONCLUSIONS

The coupled model, based on our previous experience in the Ross and Weddell Seas was based on experimental implementation or parameterisation of some specific processes.

- Phytoplankton responses (determined by its pigment contents) to the Southern Ocean physical constraints (irradiance, vertical structure of the water column,

structural and thermal properties of the ice) and to the trophic control (grazing by zooplankton, biodegradation, bio-sedimentation).

- Picophytoplankton biodiversity approach with emphasis on new molecular tools for the study of picoplankton.

- Parameterisation of ice melting and formation and resolution of three-dimensional, time-dependent, non linear Navier-Stokes equations describing the conservation of mass, momentum, temperature and salinity, forcing the Southern Ocean global ecosystem.

- The data for forcing functions, initial values of variables and for validation of the model were issued from oceanographic cruises and from all published information. Publications, workshops with other networks, participation to formatted data bank for Antarctic Global ecosystem applications and organisation of a congress on Hydrodynamical and Ecosystem processes in ice covered seas in southern and northern hemispheres in 1998 was a valorisation objective of the project.

- The conceptualisation, the parameterisation and the validation of a coupled numerical modelling system integrating the physical and trophic processes which govern the equilibrium and changes of biodiversity in the Southern Ocean global ecosystem were developed.

Salinity and temperature fields for the Ross Sea and surrounding areas were extracted from the monthly climatology Levitus data for the period particularly relevant for biological activities, from November to February. Available bathymetry data, wind stress data, sea-ice data (concentration and thickness) and Eulerian and Lagrangian data on water masses circulation have been formatted for the calibration and the validation of the model. Hydrological and nutrient data obtained by the authors in the Ross Sea during various oceanographic cruises were treated as an illustration of the water column structure and variability in the Ross Sea. The spatial and temporal distributions of phytoplankton pigments sampled in the western and south central Ross Sea during austral spring 1994 and summer 1990 were investigated. The different plankton assemblages were identified in the Ross Sea and correspond to local particularities and seasonal succession of different phases of the whole Southern Ocean seasonal ice zone ecosystem controlled by specific physical conditions. They are not to be taken as different ecosystems but more realistically as different states of a typical ecosystem locally controlled by specific constraints or progressing from pack-ice to ice-free waters.

In the framework of a more comprehensive study of the picophytoplankton in the Southern Ocean, the genotypic diversity of the different types of organisms present in the size fraction 0.2-2 _M was developed. From the picoplanktonic fraction of two water samples taken at a depth of 20 and 30 m in the Southern Ocean, 16S rDNA sequences from different types of organisms were retrieved: eubacteria, plastids of eukaryotic algae, and cyanobacteria. The cyanobacterial sequences appear almost identical to sequences obtained from the picoplanktonic fraction (Synechococcus sp.) of temperate and tropical oceans. Thus, a lineage of taxa defined on the basis of 16S rDNA but with diverse pigment compositions has adapted to different environmental conditions and can be observed from temperate and tropical to Subantarctic regions.

The sea ice model computes the temperature, the thickness and the concentration of the ice deduced from heat exchanged vertically through the ice-air and ice-ocean interfaces and horizontally through the leads.

A numerical model of the upper trophic levels of the Antarctic food chain was developed to simulate the impact of whaling activities in the Southern Ocean. The model validates the hypothesis of krill limitation by the whale stocks before the whaling period and the control function of whaling on Antarctic birds and seals.

A mechanistic modelling approach (ECOHYDRO-MVG) of the Ross Sea Seasonal Ice Zone ecosystem was used to test the influence of the physical constraints on the variability of the plankton ecosystem. This model parameterises explicitly the water column vertical structure and mixing and takes into account the importance of the ice melting the atmospheric constraints and the presence of ice algae. A standard run is developed and an application to various local situations is discussed in relation with data acquired during the cruises.

In the aim to compute the role three-dimensional circulation and the turbulence diffusivities on biological variables dynamics, a version of the Princeton Ocean Model (POM) (Mellor, 1998) was applied to the Ross Sea. In this model, the classical three-dimensional, time-dependent, non-linear equations describing the conservation of mass, momentum, temperature and salinity are solved on a C-grid (Arakawa, 1972) and transformed into a _-coordinates system. The model has a free surface and a split time step. A second moment turbulence closure (Mellor and Yamada, 1974) provides the vertical mixing coefficients.

Particular attention have been given to the following aspects:

- Parameterisation of phytopigment modification by light control in ice algae in relation with physical processes in ice.
- Qualitative and semi-quantitative analysis of the picoplankton of the Southern Ocean.
- Application of the model at specific conditions of the Ross Sea
- Hypotheses test concerning the atmospheric forcing in the Ross Sea (the influence of wind and lighting conditions)
- Application of the 1-D model at a spatial scale and at a 3D vision of the Ross Sea
- Application of the 1-D model in the sub-polar regions limited in nutriments
- Coupling of the three-dimensional model of the Ross Sea with the ecosystem model and application of the model to the Ross Sea ecosystem (numerical development). Calibration and simulation of the key assemblages variations in standard conditions.
- Simulation of natural variability and spatial heterogeneity of key species (coastal zone, ice edge, polynya). Simulation of critical levels for biota extinction.

**A4/36/HO1**

# STUDY OF CONVECTIVE MOVEMENTS IN THE SOUTHERN OCEAN

G. PICHOT

MANAGEMENT UNIT OF THE NORTH SEA MATHEMATICAL MODELS (MUMM)
Gulledelle 100
B-1200 BRUSSEL

## INTRODUCTION

The Southern Ocean is characterised by specific oceanographic processes. More precisely, the Weddell Sea has been identified, together with the Greenland Sea in the Arctic Ocean, as one of the main locations of bottom water formation for the world ocean. The Weddell Sea is also one of the rare oceanic regions presenting deep vertical mixing. The dense water, generated by complex processes related to the geometry, to the presence of ice pack, to meteorological forcing as well as to the resulting heat and salt fluxes, spreads into the world ocean.

To simulate these processes, the approach followed at MUMM is the building of a coupled ocean/ice model at the regional scale of the Weddell Sea. A particular attention is needed for the zones around the Filchner-Ronne Ice shelf and the Maud Rise, which are renowned, one, for contributing to the production of Antarctic bottom water, the other, for undergoing vertical movement (upwelling) of relatively warmer water.

## GENERAL CONCLUSIONS

To reach such a goal:

- a sea ice model has been coupled to a three-dimensional circulation model.
- Available data sets have been analysed and relevant information extracted.

Specific meteorological forcing is applied to the model and comparison between results and observation is conducted.

It has been shown that the model satisfactorily reproduces the main characteristics of the annual ice pack evolution: the computed ice thickness is in the range of observed values. This model is a useful tool to investigate the separate roles of each parameter influencing the ice formation.

The model still overestimates the ice thickness along the Antarctic Peninsula because the coastal winds are too weak to push offshore the ice produced in this area. This is because the climatological atmospheric forcing fields fail in correctly representing the strong influence of katabatic winds along the coasts of the Antarctic continent. The climatological dataset of Taljaard et al. (1969) underestimates the air temperatures responsible for the overestimate of ice production in the Weddell Sea.

The model simulates an evolution of the oceanic mean flux in good agreement with the in-situ observations.

As observed, the perennial ice is located along the Antarctic Peninsula and the Filchner-Ronne ice shelf (the southern part of the Weddell Sea).

The general circulation of the Weddell Sea has been successfully reproduced by the model as enhanced by the analysis of the ice movements. Small-scale simulations have been conducted on the Maude Rise region and permitted to show the strong three-dimensional character of the flow around the seamount. Moreover, strong upwelling velocities have been obtained. Hence no direct measurements of the vertical velocity are available, such results are in good agreement with the presence of warmer upwelled water in the vicinity of the Maud Rise.

Different available datasets (T, S, density, ice concentration and thickness, current meter and drifters, etc...), have been used and analysed to produce maps of the Weddell Sea. Data have also been extracted from these datasets to calibrate and validate the sea ice and hydrodynamic models.

Finally, the analysis of the produced map has allowed to identify regions and periods of water vertical motion.

**KEY WORDS**

Antarctica, Southern Ocean, sea ice, rheology, modelling, high-resolution simulation

# MASS BALANCE OF THE ANTARCTIC ICE CAP (A CONTRIBUTION TO EPICA)

J. NAITHANI[1], H. GALLÉE[2], A. DUTRIEUX[1], AND G. SCHAYES[1]

[1] UNIVERSITÉ CATHOLIQUE DE LOUVAIN (UCL)
INSTITUT D'ASTRONOMIE ET DE GÉOPHYSIQUE GEORGES LEMAÎTRE
Chemin du Cyclotron 2
B-1348 LOUVAIN-LA-NEUVE

[2] INSTITUT DE RECHERCHES POUR LE DÉVELOPPEMENT
LTHE
BP 53
F-38041 GRENOBLE CEDEX 9
FRANCE

## MARINE AIR INTRUSION

Marine air intrusion and subsequent cloud formation plays a dominant role in the energy budget and mass balance of the Antarctic. However, the intrusion is very difficult to understand using the ground-based measurements alone.

In this paper we present simulations of marine air intrusion into the Adelie land, East Antarctica, using the Modèle Atmosphérique Régional (MAR), for July 1994 and January 1995. The model is nested into the ECMWF analyses.

The simulations show a strong influence of large-scale disturbances, over the ocean, which helped in the penetration of marine air into the interior and the formation of clouds. Each marine air intrusion episode resulted in cloud formation in July 1994. Blocking anticyclones have also been found to be responsible for much of the moisture transport far into the interior elevated locations. MAR simulations, as well as ECMWF analyses, show influence of cyclones in strengthening and prolonging the surface layer flow. The study also indicated that the influence of depressions on surface winds is pronounced during the period when the depression is approaching the Adelie Land coast.

## STRONG WIND EVENTS

Strong wind events over Dumont d'Urville (DdU), an east Antarctic coastal station, and Dome C, an interior station, have been studied to determine the the role of large scale disturbances on them. Strong wind events for the years 1993-1999 have beed studied using the MSLP fields of the ECMWF analyses.

It has been found that these events are associated with the approach of a depression from the west towards the DdU coast. The wind increases in response to the approaching depression and decays once the depression moves past the DdU coast. The response of wind to the approaching depression is not the same for all the events and depends upon the strength of the anticyclone over the continent, the high pressure ridge or a blocking anticyclone over the northeast of the Adelie land coast and the downslope pressure gradient.

The presence of the blocking high to the east of DdU renders the approaching depression to the west slow-moving, which intensifies in the process. These intensifying

slow-moving blocked depressions start to penetrate inland if the central high of the anticyclone over the plateau happens to be shallow. The winds at Dome C increase to as high as 17 m/sec in response to these penetrating depressions. It is concluded that the strong surface winds in the coastal East Antarctic station, DdU, are governed by the katabatic and the synoptically forced winds operating together.

A4/11/E02

# BASAL ICE FROM EAST ANTARCTICA (EPICA)

R. LORRAIN, S. SLEEWAEGEN,
R. SOUCHEZ AND J.-L. TISON

UNIVERSITÉ LIBRE DE BRUXELLES - CP 160/03
DÉPARTEMENT DES SCIENCES DE LA TERRE ET DE L'ENVIRONNEMENT
Avenue F.D. Roosevelt, 50
B-1050 BRUXELLES

## INTRODUCTION

In order to be able to understand the behaviour of the East Antarctic Ice Sheet, the interactions between the ice sheet and its substratum must be well known. The study of the composition of basal ice can shed light on the processes acting or having acted at the ice-bedrock interface.

Basal ice can only be reached in three circumstances:

Figure 1 : The research program will focus on the study of basal ice from different sites in Antarctica (see text).

1. A deep drilling reaching the bedrock under the ice sheet is undertaken at one specific place like the deep drilling of the European Program of Ice Coring in Antarctica (EPICA project) at Dome C in the central part of an ice dome in East Antarctica. In such a situation, basal ice can be perforated and sampled like at the location represented by site A in figure 1.

2. Basal ice can leave the ice-rock interface at the grounding line and be included in the ice shelf bordering the ice sheet where a backstress is exerted. This requires that basal melting is not occurring in the contact zone between the ice sheet and the ocean. Such a situation can prevail in areas protected from the influence of high salinity shelf waters (HSSW) which promote melting at the ice-ocean interface. Due to the ablation resulting from the action of katabatic winds at the ice shelf surface, basal ice can ultimately appear at or close to the surface where it

can be more easily reached. Such a situation is depicted on site B in figure 1 and presently occurs in Terra Nova Bay near the Italian station of the same name.

3. Due to special environmental circumstances, the ice coming from the central part of the ice sheet does not completely fill the valleys of a marginal mountain range. Some of these valleys are even devoid of an ice cover and are called dry valleys. At the border of the ice sheet or at the margin of its outlet glaciers, basal ice is outcropping and can be sampled. Site C in figure 1 represents such a situation. The region called the Dry Valleys area in South Victoria Land in the vicinity of the two permanent stations of MacMurdo (USA) and of Scott Base (New Zealand) is such a favorable place.

The strategy set up to gain substantial information within this context is based on the study of the composition of basal ice, mainly the composition in the stable isotopes of oxygen and hydrogen from the ice crystals, the total gas content and gas composition in the principal atmospheric gases ($O_2$, $N_2$, $CO_2$) and in methane and also the crystallographic properties. In some circumstances, chemical analyses of major anions and cations are also conducted to derive additional information. Specific techniques are required for the analysis of basal ice, because it is rich in debris and poor in gases. Some of the techniques are already used on a routine basis in our laboratory; others have been developed during the first part of this contract while the efficient use of the helium trap for concentrating gases in the case of an ice sample extremely poor in gas content (less than 0.01 ml / g) is still under development.

Radio-echo-soundings in East Antarctica have revealed the existence in numerous areas of subglacial lakes. The more extensive of these lakes is lake Vostok near the Russian station of the same name which has dimensions comparable to lake Ontario in North America (about 14000 $km^2$). Smaller subglacial lakes are numerous in East Antarctica and present in the immediate vicinity of Dome C. The presence of such lakes is important to consider as far as the interactions of the ice sheet with its substratum are concerned, these interactions playing a major role in ice deformation. A study of basal ice deformation is indeed of paramount importance to be able to develop a flow model for the entire ice sheet in the Dome C area, flow model required to establish an age-depth relationship for the deep ice older than 100000 years which will be reached by the EPICA drilling. Retrieval of reliable palaeoclimatic information from before the last major climatic cycle is thus dependent on the knowledge of basal boundary conditions.

Therefore, the emphasis in this antarctic research contract is put on studying situations where the East Antarctic Ice Sheet is interacting with water bodies in order to be able to interpret correctly the basal ice sequence from Dome C. Furthermore, we have shown that, in Central Greenland, basal ice preserves information revealing genetic processes of the ice sheet, for instance, the incorporation by mixing at the ice sheet base of ice formed at the ground surface, or within the upper part of the ground.

## GENERAL CONCLUSIONS

The presence of numerous subglacial lakes, some of them of great extent like lake Vostok, under the East Antarctic Ice Sheet has certainly important consequences on the ice sheet behaviour. Meltwater at the base implies that the pressure melting point is reached in the bottom part of the basal ice. Liquid water has the potential to induce glacier sliding which would modify the age-depth relationship of the ice at depth.

The EPICA project has as one of its major objectives to derive palaeoclimatic and palaeoenvironmental information from a deep drilling now conducted at Dome C in the central part of East Antarctica. In order to retrieve such an information, a reliable flow model able to date ice at depth must be constructed. Numerous small subglacial lakes have been detected in the vicinity of the Dome C site by radio-echo-soundings. Therefore a study of the interactions between the ice sheet and subglacial water bodies has to be made to help to fulfill the objectives of the program.

Basal ice composition study is a powerful tool for the investigation of the interactions of the ice sheet with its substratum. Isotopic composition in _D and _$^{18}$O, gas content and gas composition, crystallographic and chemical properties of the ice are all affected by phase changes and by the presence of liquid water.

In order to be able to interpret correctly the analyses which will be done on the basal ice from the EPICA ice core at Dome C, some sites where the ice sheet is in contact with water bodies have been and are studied within this research contract.

In two circumstances, basal ice originated in the contact zone between an ice sheet and a water body can be easily studied since outcroppings are present at the ice sheet margin or at its surface.

In the Dry Valleys area of South Victoria Land, glaciers below the pressure melting point at their base are flowing into lakes. It can be shown that transient wet-based conditions occur in such circumstances as ice flows into the unfrozen sediments of the lake bottom, creating conditions favourable to the entrainment of debris and to ice accretion by water freezing.

In Terra Nova Bay, ice formed at the grounding line where a glacier enters into contact with the ocean in areas protected from the influence of high salinity shelf waters. Such ice is now outcropping at the ice shelf surface because of strong ablation due to katabatic winds. An upward velocity component thus exists and ice previously at depth reaches the ice shelf surface. Ice composition studies indicate that freezing at the grounding line occurs by a double-diffusion effect, diffusion of heat being an order of magnitude higher than salt diffusion. Double-diffusion freezing at the grounding line is a newly discovered process. Its implications on a larger scale must still be envisaged.

The ice at the bottom of the Vostok ice core is lake ice. It is formed as a result of water circulation in subglacial lake Vostok. Supercooling as a consequence of rising waters and a possible contrast in water salinity gives rise to fragile ice crystals. Subsequent consolidation of the loose ice crystals developed results in the accretion of ice at the ceiling of the lake.

The consequence of the presence of such an extensive subglacial lake and of lake ice formation on the behaviour of the ice sheet must still be considered.

**KEY-WORDS**

Antarctica, Dry Valleys, Terra Nova Bay, Vostok, Glaciology, Basal ice, Grounding Line, Lake ice, Stable isotopes, Gases in ice.

A4/03/E03

# DYNAMICS OF THE ANTARCTIC ICE CAP AND CLIMATE CHANGES (A CONTRIBUTION TO EPICA)

F. PATTYN AND H. DECLEIR

VRIJE UNIVERSITEIT BRUSSEL (VUB)
DEPARTMENT OF GEOGRAPHY
Pleinlaan 2
B-1050 BRUSSEL

## INTRODUCTION

EPICA 1 (European Project on Ice Coring) is a long-term (7 years) European project in Antarctica to derive high resolution records of climate and atmospheric composition through several glacial-interglacial cy-cles. During the second phase of the project a core will be obtained from Dronning Maud Land (DML), in that part of Antarctica which faces the Atlantic Ocean and where more detailed information might be obtained about rapid climate oscillations that have been detected across Greenland throughout the last glaciation. The Dronning Maud Land area is also one of the least explored sectors of Antarctica. Therefore, several reconnaissance surveys were carried out during the first phase 2 of the EPICA project – which coincided with this project - providing the necessary data for both drillers and modellers.

During the former (third) phase of the Belgian Program on Antarctic Research the Department of Geography of the Vrije Universiteit Brussel (VUB) has developed a flowline model capable of simulating the ice cap behaviour on a regional scale. Ideally, such flow line model has the potential to link the detailed information obtained from ice core drilling with the sedimentation and erosion records near the ice margin (ice free areas, marine glacial deposits), although the latter records are notoriously meagre in Antarctica. By doing so the dynamics of the ice cap in response to the climatic signal can be reconstructed and understood. This is necessary, as at present we lack knowledge to explain the seemingly rapid variations of the climate on the one hand and the presumed stable behaviour of the ice cap on the other hand. The solution might be found in trying to understand the very different behaviour of ice streams, which are rapid flowing ice masses within the relative stagnant ice cap and where the basal mechanisms might resemble more ice shelf conditions than those pertaining to grounded ice.

Where some studies of the physical mechanisms in the boundary regions of the ice cap, such as the relation with mass balance and the shift of ice divides, are preferably treated by means of 3-D modelling, others such as those questions related to grounding line shift and basal sliding can best be tackled by flowline modelling on a very refined scale. Moreover, the two-dimensional flow line model is the only feasible method presently available to simulate outlet glaciers and ice stream evolution in the marginal area of Antarctica. Furthermore, it has the potential to produce a maximum resolution and precision in interpreting deep ice core and borehole data, and provides particle paths, stresses, strain rates, temperature profiles and several other derived parameters. For the purpose of this study, the aforementioned flowline model was improved in order to

reconstruct the glacial history of the ice sheet in Dronning Maud Land in relation to climatic parameters, and to investigate the influence of coastal ice dynamics on the central parts of the ice sheet.

While new data necessary for the glacier dynamics in Dronning Maud Land are and will be obtained by collaboration with different countries involved in EPICA and Dome Fuji, the dynamics of outlet glaciers might be inferred from SAR interferometry. In collaboration with the Centre Spatial de Liège, where an interferometric SAR processor was developed, detailed data on the ice flow field of a major outlet glacier in Dronning Maud Land was obtained, and the role of this glacier in the stability of the Antarctic ice sheet was investigated. In addition we participated in field work during the 41st Japanese Antarctic Research Expedition (1999-2000), assembling data on coastal glacier dynamics. The bulk of these research results is expected to become available in the near future.

## GENERAL CONCLUSIONS

The East-Antarctic ice sheet is primarily drained by large outlet glaciers which play a decisive role in the dynamic behaviour of the ice sheet with changing climate. Monitoring of these outlet glaciers is one of the prime objectives of the glaciological community. The knowledge of the ice dynamics of these glaciers is necessary for interpreting ice cores, especially when they are not drilled at a major ice divide, but within their drainage area, as is the case with the future EPICA–DML drilling site. However, a significant amount of information – both glacial-geologic and ice dynamic – stems from those parts of the ice sheet which reacts differently to the climatic signal (such as the outlet glaciers, the local glaciers and the ice sheet in mountain areas). Unravelling the complex behaviour is the keystone for understanding the dynamics of the ice cap in response to the climatic signal.

In view of these needs we developed a high-resolution second-order numerical ice-sheet model with full thermo-mechanical coupling, and capable of simulating the ice-sheet response to the climatic signal. Numerical model experiments were carried out along several flowlines in Dronning Maud Land, one flowline passing through the central part of a coastal mountain range (Sør Rondane), one along a major outlet glacier (Shirase Glacier), and one in the area of a future deep drilling site within the EPICA project. These model experiments revealed different response patterns of the East

Antarctic ice sheet to the climatic signal, strongly related to subglacial conditions, such as the presence of subglacial mountain ranges. A similar differentiation in ice-sheet response is also observed in the field, such as the dynamic ice sheet in the downstream part of the Shirase drainage basin and the stable ice sheet in the nearby Sør Rondane Mountains. Experiments along a flowline in western Dronning Maud land gave an idea of the basic ice-dynamical features of the drainage area in the vicinity of the future EPICA–DML drilling site and the ice-stream dynamics in the Jutulstraumen area.

A more profound study on the ice-dynamical behaviour near the grounding line of fast-flowing outlet glaciers showed the importance of longitudinal stresses at the ice-sheet/ice-shelf interface at different grid sizes, and the importance of basal drag vs driving stress in basal sliding laws. When sliding becomes dominant, this transition zone considerably widens. Furthermore, the longitudinal stress deviator is found to vary considerably with depth due to the thermo-mechanical coupling.

Finally, interferometric processing of ERS Synthetic Aperture Radar images led to the determination of the surface velocity field of Shirase Glacier. A large-scale vertically-integrated force budget calculation then allowed for the determination of the major stress components in the floating ice tongue, near the grounding line and on the in-land slope. In the grounded part, more than 80% of the total velocity seems due to basal sliding. A comparison with a balance-flux distribution of the Antarctic ice sheet (Huybrechts et al., 2000) suggests a thinning of the ice sheet in the downstream area of the Shirase Glacier drainage basin as well as a high sub-ice tongue melting rate.

**KEYWORDS**

Antarctica, Ice-sheet modelling, Fast-flowing glaciers, Interferometry, ERS, EPICA

A4/02/G01

# ANTARCTIC SHELF-SLOPE DYNAMICS: AN INNOVATIVE GEOPHYSICAL APPROACH

M. DE BATIST EN J.-P. HENRIET

UNIVERSITEIT GENT
RENARD CENTRE OF MARINE GEOLOGY
Krijgslaan 281 – S8
B-9000 GENT

## INTRODUCTION

The project was conceived with three main project goals in mind:

1. Analysing the various depositional and erosional processes controlling Antarctic shelf-to-slope sediment transport.

2. Further unravelling the glacial record contained in Antarctica's margin sediments, and using this record to contribute to a reconstruction of the glacial history of Antarctica.

3. Developing an innovative geophysical methodology for obtaining good-quality, high-resolution seismic records of Antarctic margin deposits.

In order to achieve the above-defined project goals and to fulfil the project tasks, the following research strategies and methodological approaches were adopted:

1. To acquire, process and interpret new grids of reflection seismic profiles and multi-beam bathymetry data from the shelf and slope domains along various parts of the Antarctic continental margin, especially in areas with well-developed trough-mouth fan systems, and/or affected by large-scale gravitational instabilities.

2. To remain actively involved in the Weddell Sea ODP drilling proposal, either by following-up the course of the proposal within the ODP system, or by participating to the actual drilling leg or to new site surveys (depending on externally imposed planning strategies and selection procedures).

3. To design a new concept of a deep-tow reflection seismic system, to analyse the potential of new sources and receivers, to develop a prototype of the new system, and to use it to acquire high-resolution reflection seismic data in Antarctic waters.

## GENERAL CONCLUSIONS

We investigated a large sub-marine slide – the Gebra Slide – on the continental margin of Trinity Peninsula, Central Bransfield Basin, Antarctic Peninsula. The slide scar is clearly expressed in the bathymetry, over an area of 230 $km^2$. The associated debris-flow deposit extends over a total surface of about 280 $km^2$. The total volume of sediment involved in the mass movement is about 20 $km^3$. The Gebra slide took place in two phases. Indirect dating, using seismic-stratigraphic criteria, suggests that both phases occurred at the transition between the last glacial period that affected the area and the present-day interglacial (between 13500 and 6500 yrs. B.P.). Large slope failures like this may be an important factor controlling slope-to-basin sediment transport in periods other than glacial maxima.

Integration of swath-bathymetry data and high-resolution seismic reflection profiles on the scale of the whole Trinity Peninsula margin has also allowed us to portray with unprecedented detail the sub-glacial sedimentary system of the Last Glacial Maximum in this part of the Antarctic Peninsula. The studied sedimentary system over extends 250 km, from about 1000 m above sea level to about 2000 m water depth. We propose a model for sub-glacial sedimentary systems during glacial periods that consists of (1) an upper ice-catchment or erosional zone on the innermost continental shelf, extending onshore; (2) a transitional erosional-depositional zone on the inner shelf with drumlins on the sea floor; (3) a depositional outer-shelf zone with mega-scale glacial lineations or "bundle structures"; and (4) a debris apron on the continental slope and base of slope formed under floating ice shelves but with debris delivery linked to grounding lines along the shelf break. The data clearly outline the dramatic shift of ice cover and depositional conditions off the northern Antarctic Peninsula between the LGM and the present day.

We also developed a new multi-functional deep-tow reflection seismic acquisition system for collecting good-quality high-resolution seismic data in Antarctic waters. The system is characterised by a modular design, including a surface seismic source, an umbilical cable, a winch with slip-ring units, a MC or SC streamer sub- or deep-tow streamer, a streamer-depth monitor and a deep-water digital acquisition system. The system can be operated in various different configurations: e.g. the sub-tow profiling mode, the full deep-tow profiling mode, the “Jumbo” profiling mode using two receivers, and the “touch-and-go mode including stationary meassurements on the sea floor. The system has been successfully deployed in the Antarctic and in the northeastern Pacific.

The system remains under continuous development and new applications are currently being implemented and tested.