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SCAR Group of Specialists on Global Change and the Antarctic
(GLOCHANT)

Published by the

SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH

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GLOCHANT Group of Specialists Report to XXIV SCAR

August 1996

1. An Overview of GLOCHANT and its Linkages with IGBP, WCRP and SCOR

The fourth meeting of the Group of Specialists on Global Change and the Antarctic (GoS/GLOCHANT) was held in Madison, Wisconsin, USA on 10-14 April, 1996. The minutes of the meeting have been circulated within SCAR and are ready for publication in a forthcoming *SCAR Report*. The minutes of the previous GLOCHANT III meeting and the Joint GoSSOE/EASIZ and GLOCHANT Planning Groups 1 and 5 meeting in Tokyo, during April, 1995 have been published in *SCAR Report* 11.

The SCAR Global Change Programme Coordinator, I. Goodwin, presented to the meeting a progress report on the linkages and interactions between SCAR and the other international programmes, particularly, IGBP, WCRP and SCOR. Three research areas have been identified where SCAR has been encouraged to develop contributions to the global programmes. These are:

- Antarctic sea-ice processes, climate variability and ecosystem interactions with the Southern Ocean (WCRP CLIVAR/ACSYS, IGBP JGOFS, and SCOR);
- High resolution Antarctic palaeoenvironmental and palaeoclimatic records from ice cores covering the last 200 years (IGBP PAGES);
- Circum-Antarctic palaeoenvironmental and palaeoclimatic records from sediments covering the last 200,000 years (IGBP PAGES).

In order to discuss these issues and aid in the development of scientific proposals to accommodate these gaps in the global programmes, several invitees were included in the GLOCHANT IV meeting (see GLOCHANT IV Minutes).

This group of scientists identified the following existing and proposed GLOCHANT contributions to IGBP and WCRP:

GLOCHANT Contribution to IGBP PAGES

- The existing programme on Palaeoenvironments from Ice Cores (PICE, co-sponsored and approved by IGBP PAGES), the joint GLOCHANT/PAGES programme, International Trans-Antarctic Scientific Expeditions (ITASE), on 200 years of past Antarctic climate and environmental change, and the proposed GLOCHANT/PAGES workshop on Late Quaternary Antarctic Ice Margin Evolution (ANTIME, preliminary approval from PAGES).

GLOCHANT Contribution to WCRP CLIVAR and ACSYS, and IGBP/SCOR SO-JGOFS

- The proposed programme on Antarctic Sea-Ice Processes, Ecosystems and Climate (ASPECT).

GLOCHANT Contribution to IGBP LOICZ and a proposed Joint SCAR/IASC/ICSI/PAGES/WCRP Working Group on Glaciers, Ice Sheets and Sea-Level (GISSL)

- The existing programme on Antarctic Ice Sheet Mass Balance and Sea-level (ISMASS),

SCAR Contribution to START

- Strong affiliation with START is proposed through the recommended appointment of the GoS/GLOCHANT as the START Regional Research Committee for the Antarctic.

The linkages between the SCAR-GLOCHANT programmes and other international programmes are further illustrated in Appendix 1.

2. Proposal for a GLOCHANT Programme on Antarctic Sea-ice Processes, Ecosystems and Climate (ASPeCt)

At the request of SCAR XXIII (Minutes of XXIII SCAR 5.1.1), ongoing and planned research on sea-ice and biogeochemical cycling in Antarctic waters was examined at the GLOCHANT-III meeting. It was determined that EASIZ, WCRP, SO-JGOFS, and other programmes do not together cover the full scope of required Antarctic sea-ice-zone research, and that there is a special role for the SCAR Global Change Programme in the shelf-to-ice-edge area (pack ice) that is not being adequately covered by other programmes.

Information on the Antarctic sea-ice zone is required for the development and validation of both coupled climate models and biogeochemical models, which currently do not include all important sea-ice processes. Important problems not adequately covered by existing Antarctic research programmes include:

- The broad climatology of sea-ice physical characteristics. Satellite-derived data provide large-scale estimates of ice extent and concentration, but not of the thickness of ice and snow, which are the primary variables affecting many physical and biological, as well as climatic processes.

- Pack-ice ecology, a key component of the polar marine environment.
- Processes such as ice formation, water-mass modification, the maintenance of polynyas, ice-edge and coastal fronts, gas exchange, and air-sea interaction.
- Modelling sea-ice processes (physics and ecology) in coupled atmosphere-ice-upper-ocean models and interlinking local, regional and global scale models.

To address the key identified deficiencies in our understanding and of the sea-ice zone, we propose to establish a programme of multi-disciplinary Antarctic sea ice zone research within the SCAR Global Change Programme. This programme on Antarctic Sea Ice Processes, Ecosystems and Climate is known as ASPECT. A draft science plan for ASPECT is included in Appendix 2. The broad objectives for ASPECT are:

- To establish the distribution of the basic sea-ice properties important to air-sea interaction and biological processes within the Antarctic sea-ice zone (ice and snow-cover thickness distributions; structural, chemical, and thermal properties of the snow and ice; upper-ocean hydrography; floe size and lead distribution) in order to derive forcing and validation fields for models;
- To understand key sea-ice-zone processes for further model development and in order to improve parameterization of these processes in coupled models.

A major thrust of the ASPECT programme is its multidisciplinary focus on the sea-ice zone; combining research on physical sea-ice processes, ocean-atmosphere interaction and sea-ice biology. An inter-disciplinary research approach to the ecology of the sea-ice zone is vitally important in the overall programme. As a SCAR programme, ASPECT is focused towards the role of the unique regional environment of the Antarctic sea-ice zone, but it is essential that it be closely linked to the overall international global change research agenda. Hence interdisciplinary components of ASPECT are designed to contribute to, and extend, international open-ocean programmes, such as JGOFS and GLOBEC. ASPECT will also maintain close scientific links with the SCAR EASIZ programme, a study of the ecology of the Antarctic coastal and continental-shelf zones. Whereas ASPECT will undertake integrated physical and biological work in the marginal ice zone (MIZ) and deep within the pack-ice, the main thrust of the EASIZ work will be near-shore, year-round, and long-term. Work within EASIZ will thus provide important data on temporal variability at a series of sites, to complement the more detailed process studies or data on spatial variability to be obtained within ASPECT.

Many physical elements of ASPECT will contribute to the objectives of the WCRP CLIVAR Programme, a study of Climate Variability and Predictability, which involves investigations of atmosphere, ocean, and land at a variety of time scales. ASPECT plans are particularly relevant to the CLIVAR-DecCen component programme, which is concerned with decadal-to-centennial climate variability and predictability. The ASPECT programme will initiate implementation of parts of the sea-ice-zone research requirements of CLIVAR and will collaborate closely with CLIVAR and other WCRP programmes to ensure the essential global integration of Antarctic regional research. It may be appropriate for some research elements of ASPECT eventually to become a sub-component of CLIVAR, but because of the unique logistic requirements of work in the Antarctic sea-ice zone, ongoing SCAR involvement and sponsorship are essential.

The ASPECT programme will build on existing and proposed research programmes and the shipping activities of national Antarctic operators. The implementation plan includes some components that can be undertaken as part of normal resupply voyages; for example a system of simple but quantified shipboard observations, based on the WMO Classification for ice types, has been shown to provide statistical ice and snow thickness distributions similar to those obtained from more sophisticated techniques. ASPECT will also include a component of data rescue of valuable historical sea-ice-zone information.

The ASPECT programme will achieve its aims by:

- defining a framework of the priority in the Antarctic sea-ice-zone required to address global change and related issues;
- promoting and fostering co-ordinated contributions to this plan from within national research programmes and by building on ongoing projects;
- liaising with other international programmes requiring data and research products from the Antarctic sea-ice zone; and
- convening workshops.

GLOCHANT XXIV-1

We recommend that the ASPECT programme be approved and established as a SCAR Programme, to serve as the major SCAR contribution to global change research, particularly physical processes and climate in the Antarctic pack ice.

3. Proposal for a Joint GLOCHANT/PAGES Workshop Initiative on the Late Quaternary Sedimentary Record of Antarctic Ice-Margin Evolution (ANTIME)

It was the original intention of SCAR-GLOCHANT in 1991 to establish a project on palaeoenvironments from Antarctic ice cores and the sedimentary record. This has been partially achieved through the establishment of a programme on Palaeoenvironments from Ice Cores (PICE). PICE has been approved by the IGBP PAGES SSC and is co-sponsored by GLOCHANT and PAGES. This proposal outlines the need to work towards the establishment of a sister programme to study the record of palaeo-environmental changes contained in the Late Quaternary Antarctic sedimentary record (last 250,000 years), in the marine, coastal, lacustrine, and glacial environments. The full proposal is in Appendix 3. The Antarctic sedimentary record has already yielded high-resolution information on palaeoenvironmental and palaeoclimatic changes, particularly on ice marginal and outlet glacier fluctuations and in lacustrine and marine ecology and biogeochemistry. A coordinated SCAR initiative on circumpolar palaeoenvironmental research, particularly a detailed component on the last 20,000 years including the very-high-resolution Holocene records, would provide a solid basis for the understanding of present and future variability in the Antarctic, when combined with the ice-core records. It is important that the palaeoenvironmental data from ice cores and the sedimentary record be correlated to allow the optimal understanding of past circumpolar changes. It is recommended that the ANTIME initiative focus on two streams: Stream 1 (last 20,000 years) on the last deglaciation and interglacial environmental, climatic, and ice-sheet variability; and Stream 2 (last 250,000 years) on the environmental, climatic, and ice-sheet response to glacial-interglacial cycles. These are slightly different from the PAGES timescales, but are considered to be more appropriate to circumpolar studies.

The proposed ANTIME initiative would first involve the convening of an international workshop for SCAR palaeoenvironmental scientists. It is the intention to obtain joint sponsorship of this workshop from PAGES. The proposed ANTIME initiative has received preliminary approval from the Chairman of the PAGES SSC and the Executive Director. The proposal will be assessed at the PAGES SSC meeting, later this year. The workshop would address the status of knowledge in the following key topics:

- The extent, timing, and regional differences of the Last Glacial Maximum in Antarctica;
- What rapid or episodic events occurred during the Late Quaternary?
- What are the key forcings and feedbacks that influence the retreat and readvance of the Antarctic ice sheet?
- What changes have occurred to the ice shelves and outlet glaciers during the Holocene?
- Technology coordination; and,
- Correlation of Late Quaternary Antarctic environmental history and deep-ocean sedimentary records.

This workshop would take place in Hobart Australia, in July, 1997, in conjunction with the Symposium on Antarctica and Global Change. The workshop would allow a review of existing SCAR national programmes and the status of current knowledge on Late Quaternary environmental change within the Antarctic region. It will also facilitate the identification of priority geographic regions and field and analysis tasks, that would benefit from a multi-national approach. The workshop is seen as a first step in the correlation of circum-Antarctic palaeoenvironmental records from ice cores and the sedimentary record, which is required to understand past circumpolar changes.

GLOCHANT XXIV-2

We recommend that SCAR approve the Late Quaternary Antarctic sedimentary record of Ice Margin Evolution (ANTIME) initiative for a workshop in Hobart, 1997, and encourage its joint sponsorship by IGBP PAGES.

4. The SCAR-PAGES Programme on the International Trans-Antarctic Scientific Expedition (ITASE)

The proposed International Trans-Antarctic Scientific Expedition (ITASE), was endorsed by two of the Working Groups that met at the workshop of the SCAR Steering Committee for the IGBP in Bremerhaven in 1991. Consequently, it was identified as "expected to make a major contribution to two of the core projects in "The Role of the Antarctic in Global Change", those relating to the palaeoenvironmental record and ice-sheet mass balance. It was formally endorsed by the Working Group on Glaciology and approved by the Delegates as Recommendation Glaciology XXII-5, and was subsequently formally endorsed by the GoS/GLOCHANT at their 4th Annual meeting in April, 1996, at Madison, Wisconsin, USA. ITASE has also been formally approved and adopted by the IGBP PAGES core project under their Focus II on Antarctic Palaeoenvironments, it is also a contribution to the IGBP International Global Atmospheric Chemistry (IGAC) core project under their focus on Polar Air Snow Chemistry (PASC), and it links to SCAR-BIOTAS, SO-JGOFS and WCRP-CLIVAR.

The broad aim of ITASE is to establish how the modern atmospheric environment (climate and atmospheric composition) is represented in the upper layers of the Antarctic ice sheet. Primary emphasis is placed on the last ~200 years of the record. This time period was chosen for study because it is relatively simple to recover many ice cores covering this period, and to develop a spatially significant study. Even more importantly, this time period covers the onset of major anthropogenic involvement in the atmosphere and the end of the Little Ice Age. A revised science and implementation plan for ITASE is in preparation. An international ITASE workshop was held in Cambridge, on 2-3 August, 1996, prior to XXIV SCAR; the major outcomes of the workshop are included in Appendix 4. The workshop was co-sponsored by PAGES, GLOCHANT and the US NSF, with substantial financial support from PAGES and US NSF.

Specific ITASE objectives are:

ITASE OBJECTIVE 1

To determine the spatial variability of Antarctic climate (eg. accumulation, air temperature, atmospheric circulation) over the last 200 yrs.

These variations include:

- Extreme events such as volcanic eruptions, dust storms, drought
- Major atmospheric phenomena (eg. ENSO)
- Snow accumulation variations

This extended climatic depiction for the major global atmospheric heat sink will be unrivalled for 10% of the earth's land surface.

ITASE OBJECTIVE 2

To determine the environmental variability in Antarctica over the last 200 yrs.

Environmental proxies could include: sea-ice variation, ocean productivity, anthropogenic impacts, and other, extra-Antarctic continental influences.

Because of the remoteness of the continent, Antarctica is an ideal location to monitor biogeochemical cycles and global scale changes.

In fulfilling these objectives ITASE will:

- Produce continental scale "environmental maps".
- Elucidate transfer functions between components of the atmosphere and snow/ice.
- Verify atmospheric models.
- Interpolate spatial time-series by satellite remote sensing.

Some ITASE traverses have been completed by national programmes, including those of the Chinese, British and the Swedish/Norwegian programmes, since 1992.

It is recognised by the GoS/GLOCHANT and the PAGES SSC that ITASE is a fundamental global change programme, with substantial contributions to the scientific objectives of the GLOCHANT programmes on Ice Sheet Mass Balance and Sea-Level (ISMASS) and Palaeoenvironments from Ice Cores (PICE), and the joint PAGES/CLIVAR initiative.

There have been many field data collected on the physical, chemical and isotopic characteristics of the upper layers of the Antarctic ice sheet, along oversnow traverse routes in the last 30 to 40 years. It has been recognised by representatives of ITASE and GLOCHANT that a data compilation and mapping project is required as a baseline for the detection of global change. The proposed project would collate, synthesise and map the existing ITASE type data (covering the last 200 years), which was collected by expeditions over the last 30 to 40 years. This would allow planned and future fieldwork to be focused on priority geographic areas, where either no data exist, or where more detailed data are required in significant areas. The proposed compilation data set would include: accumulation rate; stable isotopes; chemistry (major anions and cations, MSA), hydrogen peroxide (H_2O_2), organic acids; trace metals; microparticles; cosmogenic isotopes; and borehole temperatures. It is proposed that the project would be undertaken by the SCCP office in Hobart. We request that the project receives some financial support from SCAR.

GLOCHANT XXIV-3

We recommend that SCAR Delegates approve ITASE as a SCAR Programme.

GLOCHANT XXIV-4

We also recommend that SCAR support the proposed project on 'Compilation of the existing ITASE data covering the last 200 years, and collected by expeditions over the last 30 years' as a baseline data set for the detection of global change.

5. Proposal for the Assessment of the Status of Global Change in the Antarctic

It was the view of the participants at GLOCHANT IV, in Madison, Wisconsin, USA, that the importance of the Antarctic to global changes in climate, sea-level and ecosystems must be promoted, is still not fully recognised amongst the wider global scientific community. The participants resolved that an assessment of the status of global change in the Antarctic and the implications for global changes should be researched and communicated to the wider community of global policy makers and scientists. As a first step the participants have prepared the following examples of detected changes in the Antarctic and Southern Ocean (see Appendix 5). The participants in the SCAR Global Change Programme recommend to SCAR that a comprehensive document on the status of global change in the Antarctic should be prepared over the next two years. It is proposed that the document serve as an update to the previous SCAR publication, The Role of Global Change in the Antarctic, which was edited by Professor Gunter Weller in 1992. The document will be coordinated and edited by Goodwin in the Hobart office.

The proposed document would be based on the following structure:

- Seasonal to interannual climate variability;
- Decadal scale changes;
- Changes in ozone, UV, and atmospheric chemistry;
- Detecting changes in ice cover and terrestrial and marine ecosystems; and
- Past changes and future views.

GLOCHANT XXIV-5

We recommend that SCAR Delegates support the research and publication of an update of the 'white book', entitled the 'Status of Global Change and the Antarctic'.

6. Reports on Existing GLOCHANT Programmes

A. Palaeoenvironments from Ice Cores (PICE)

The Programme on Palaeoenvironments from Ice Cores (PICE) met in Boston on 15 - 16 September 1995. The Minutes of that meeting are attached as Appendix 6. One important development for PICE since the last SCAR meeting is that it is now formally sponsored by IGBP PAGES as well as SCAR. As a consequence, the Boston meeting focussed on the bipolar aspect of ice cores by updating information about the major drilling projects in Antarctica and Greenland and discussing a bipolar science plan, the purpose of which would be to establish the interrelationships between the different ice-core-drilling projects. The output of these discussions was the preparation of a document An international strategy for ice-coring in Antarctica and Greenland - Reducing uncertainty in global environmental change, which was presented to

GLOCHANT and PAGES at their respective meetings in April, 1996. A revised version of that document that takes into account the comments stemming from those two meetings is appended (Appendix 7). Another conclusion of the Boston meeting was strong endorsement of ITASE in its efforts to establish a network of surface samples and shallow cores linking existing and planned future deep drilling sites.

Members of the PICE programme met in Cambridge on 5 August, 1996. The members agreed that the phase 1 tasks on the planning and coordination of deep-ice core drilling projects, and the development of a bipolar strategy had been completed. They proposed that phase 2 of the project will involve the development of a data bank of deep-ice core records, which will be coordinated by the Hobart office. The establishment of the data bank will enable the focus of the PICE project to shift to the correlation of these palaeoenvironmental records. It is proposed that the SCAR Global Change Programme Office in Hobart coordinate the establishment of the data bank by correspondence during 1997. A joint SCAR/PAGES-sponsored workshop is proposed to be held in 1998 on the 'Correlation of Antarctic palaeoenvironmental records from deep-ice cores'. This workshop would be held in place of annual meetings for PICE.

B. Ice-Sheet Mass Balance and Sea-Level (ISMASS) Members of the programme on Ice-Sheet Mass Balance and Sea Level (ISMASS) held its third meeting in Chamonix on 17 September 1995. The overall themes of the meeting were first, the coordination of radar sounding of ice thickness along the grounding zones of the entire ice sheet, and second, the evaluation of plans for measurements of surface mass balance and ice velocities.

In regard to the ice-thickness measurements, programme members reported on recent and planned airborne measurements in several different areas: the western margin of the Ronne Ice Shelf (UK, planned for 1995-96), the south-eastern margin of the Ronne Ice Shelf (Germany, 1994-95), the grounding zone of the Brunt Ice Shelf (Germany, 1994-95), the grounding zone of Riiser-Larsen Ice Shelf (Germany, 1985-86), along the Princess Martha Coast of Queen Maud Land (Sweden, proposed for 1997-98), Enderby Land and American Highland, where extensive Russian soundings have been carried out on grids that include crossings of the grounding zones, the east coast of Victoria Land (Italy, planned for 1995-96 and 1997-98), and the eastern edge of the Ross Ice Shelf, where grid surveys by the U. S. (in 1993-96 and planned for 1996-97) extend across the grounding zone. In addition, Australia has carried out measurements on the surface on the 2500-m contour around the entire Lambert Glacier Basin.

An important future prospect for ice-thickness determinations is the accurate measurement of surface height at the edge of the grounding zone, where the ice has just gone afloat and where the ice thickness then can be calculated by Archimedes' principle. Satellite-borne radar altimeters are not effective in this zone, but a laser altimeter, with a much smaller footprint, should be. Consequently, a satellite-borne laser altimeter may obviate the need for airborne radar sounding around much of the Antarctic perimeter.

The principal source of velocities continues to be the analysis by the U. S. Geological Survey of repeated visual satellite imagery. Velocities are now available around most the northern coast of Marie Byrd Land. Glaciologists in other countries, notably Italy, Germany, Australia, and the UK, are also conducting this kind of research. Velocity determinations on the surface in or near the grounding zone have been made or are planned by the UK (Zumberge Coast), Germany (Foundation Ice Stream), Sweden (inland from Wasa Station), Italy (east coast of Victoria Land), and the U. S. (eastern edge of the Ross Ice Shelf). The programme members look forward to the development of Synthetic Aperture Radar (SAR) interferometry into a widely applicable tool for measuring velocities: this will surely happen, but much research on the technique is still needed.

The determination of surface mass balance is a particularly difficult task because it must be extended over the entire surface of the ice sheet, not just around the perimeter. Over the last few years there have been significant advances in the modeling of moisture fluxes across the Antarctic continent, from satellite derived and ground-based meteorological data and a diagnostic circulation model: values for small-scale average accumulation rates with an accuracy of ± 10% are now attainable.

An exciting prospect for the determination of surface mass balance arises from the recent development of a technique to use a high-resolution radar system to provide continuous profiles of the depth to shallow horizons that appear to be annual layers, thus yielding continuous profiles of the accumulation rate. Swedish glaciologists have shown this to work effectively in coastal Queen Maud Land and U. S. researchers are developing the same technique in Greenland.

Another prospect of importance is the potential availability, at least from 1996 to 1998, of the long-range Lockheed P-3 aircraft that has been used for many years by the U. S. Naval Research Laboratory for a worldwide program of airborne magnetics. The P-3 has a range of 5000 km at a low-altitude flight height suitable for measurements and 7000 km at high altitude and thus would be capable of carrying out soundings on most sectors of the Antarctic coastline from a base in McMurdo. The challenge for using the P-3 is to find the financial support required for its operation, which must come from sources outside the United States Navy. The USAP cannot support the activity alone, although it might be able to contribute to an international effort. A more detailed prospectus on the use of the P-3 is attached as Appendix 8.

The members of the programme recognise that a full evaluation of the mass balance of the ice sheet will ultimately involve modelling sheet that incorporates ice dynamics. For such modelling, of course, it is necessary to know the surface elevation, ice thickness, and bed topography of the entire ice sheet, not just of the grounding zones. Consequently, as an aid to the ice sheet modeling projects and mass balance determinations, the ISMASS programme, together with members of the European Ice Sheet Modelling Initiative (EISMINT), proposes a compilation of all the existing surface and bed elevation data to produce a digital data set known as BEDMAP. A specific proposal for BEDMAP is attached as Appendix 9. Furthermore, the members of the programme strongly endorse the proposed laser-altimeter mission of NASA in the United States, which is designed to produce accurate surface elevation over all of the ice sheet north of 86° S.

The full minutes of the programme meeting will be published in a forthcoming SCAR REPORT. Since its meeting in September, the programme has developed a draft Science Plan. It is attached as Appendix 10.

GLOCHANT XXIV-6

We recommend that SCAR recognise the importance of the required radar-sounding surveys of the ice-sheet grounding zones and encourage COMNAP to place a high priority on the logistic support for these surveys.

GLOCHANT XXIV-7

We recommend that the BEDMAP proposal be approved and supported by SCAR, jointly through ISMASS, the Working Group on Glaciology, and the Working Group on Geodesy and Geographic Information, and that SCAR approval be transmitted to EISMINT.

GLOCHANT XXIV-8

We also recommend that SCAR continue to encourage the plans of NASA to launch a laser altimeter (GLAS) on a satellite in a suitable polar orbit (ICESAT)

7. START Regional Research Committee for the Antarctic

A. Response to XXIII-10 (1) Development of a SCAR-sponsored Antarctic Regional Research Network.

At XXIII SCAR it was agreed that a formal interaction with START (System for Analysis, Research and Training of the IGBP, WCRP, and IHDP (the International Human Dimensions of Global Environmental Change Programme)) should be undertaken through the development of a SCAR-sponsored Regional Research Network (RRN) concept (Recommendation XXIII-10 (1)). GoS GLOCHANT member Thorley was tasked with the development of this interaction.

After discussion with the START Secretariat is was agreed that the interaction should be dealt with at 2 levels: (1) at the institutional level between SCAR, START, and its parent programmes (IGBP, WCRP and IHDP) and (2) at the core programme level, between the core projects of IGBP and WCRP and related programmes within SCAR. It was also recognised that there would be benefits in adopting a bi-polar approach to the interaction with START and its parent programmes. Accordingly, a round table meeting was held between members of SCAR, START, WCRP, and IASC in Hanover, New Hampshire, December 6, 1995 to look at these issues. The outcome of this meeting was the agreement that the institutional-level linkage between SCAR and IGBP/WCRP should be developed through the START RRN concept, whilst the inter-programme linkage should be formed through the SCAR Global Change Programme Office.

The institutional-level linkage is being facilitated through the development of a memorandum of understanding (MoU) between SCAR and START. GoS GLOCHANT will take on the role of a START Regional Committee for the Antarctic to promote the principal programmes of IGBP and WCRP in the Antarctic. Whilst it is recognised that SCAR has a wider portfolio of interests than those of START, there is a close congruence of major interests between the two organisations, which indicates the value of joint planning and implementation for the good of global science. The MoU has been prepared in a succession of drafts, and has been reviewed and approved in principle by the SCAR Executive. The MoU was presented to the Deputy Director of START, Dr Hassan Virji, by Dr Ian Goodwin and Prof Olav Orheim at the IGBP Core Project Officers' meeting at Texel, in The Netherlands in February 1996. It has been approved in principle by Dr Hartmut Grassl, the Director of WCRP, and Dr Chris Rapley, Executive Director of IGBP (see Appendix 11 for the MoU). Following any revisions made as a result of discussions at the XXIV SCAR Delegates meeting, it is anticipated that a final version of the MoU will be submitted to the START Scientific Steering Committee meeting, 19-21 September, for their approval.

The programme level linkage, between the core projects of IGBP and WCRP and related programmes within SCAR, is being developed through direct project-to-programme links facilitated by the SCAR Global Change Programme Office; the process benefited greatly from discussions with the Directors of the IGBP Core Projects at the Texel meeting (see accompanying SCAR Global Change Programme annual report).

GLOCHANT XXIV-9

We recommend that SCAR Delegates approve the Memorandum of Understanding between SCAR and START (Appendix 11) for SCAR GLOCHANT to be appointed the START Regional Committee for the Antarctic within the START Regional Research Network, and that approval be forwarded to START.

NB Approval of this recommendation means approval of the concept that START must approve the membership of GoS GLOCHANT. We expect their approval to be routine and automatic, but we cannot guarantee it.

B. Response to XXIII-10 (2) Implementation Plan for an Antarctic Regional Research Center

At XXIII SCAR it was agreed that an implementation plan for an Antarctic Regional Research Centre should be produced jointly by SCAR and START for discussion at XXIV SCAR (Recommendation XXIII-10 (2)).

A central component in the initial proposal for START Regional Research Networks was the Regional Research Centre (RRC), which would act as a focal point for the coordination of research and analysis within the regional network. START has now accepted that the centralised RRC model would not be appropriate for all regions. Much of the functionality required for Antarctic regional research coordination is already present within existing SCAR mechanisms and all that is required is a coordinating node to link these existing mechanisms together. The SCAR Global Change Programme Office in Hobart would provide the natural focus for this coordination function.

GLOCHANT XXIV-10

We recommend that SCAR Delegates task the GoS GLOCHANT (in its role as the START Regional Committee for the Antarctic) to investigate the requirement for Regional Research Centre functions within the Antarctic RRN and to work with the SCAR Global Change Programme Office to develop mechanisms to ensure these requirements are satisfied.

8. Future Role of the GLOCHANT Group of Specialists

Since the establishment of the GLOCHANT Group of Specialists four years ago the role that we see the GoS playing has changed substantially. We now believe that its principal purpose should be to serve as the focus for internal and external coordination for all aspects of SCAR research related to global change. The primary differences from the earlier concept are in the word "all" and in the emphasis on coordination between existing projects and programmes. Between the existing programmes PICE and ISMASS, and the recommended programmes, ITASE, ASPECT and ANTIME, we believe that the important gaps in SCAR global-change-related research have been filled. What is important now is to assure that the SCAR programmes proceed in close coordination with each other and with the relevant programmes of IGBP, WCRP, and SCOR to form the most effective and efficient whole. We must also incorporate a viable mechanism for serving as the START Regional Research Committee for the Antarctic.

To facilitate the substantially altered role that we recommend for GLOCHANT in the future, we propose to SCAR that the membership of GLOCHANT be re-evaluated and replaced with a substantial representation from the global change activities within and without SCAR. We further believe it essential that individuals who agree to be members be required to be motivated and willing to participate actively. One specific suggestion that we have for the makeup of a revised Group of Specialists is as follows:

- An independent chair;
- The Chief Officer of each of the SCAR programmes; BIOTAS, EASIZ, ISMASS, and PICE, and other programmes, such as ITASE, ASPECT and ANTIME when they become approved;
- Scientific representatives from other key international programmes; in particular, SO-JGOFS and SO-GLOBEC (SCOR/IGBP); and ACSYS/CLIVAR DEC-CEN (WCRP);
- Three scientific experts chosen from important global-change research areas not otherwise covered; for example, Arctic research, atmospheric science, numerical modelling, higher-trophic-level biology, data matters, and policy or management fields such as the Antarctic Treaty.

However, we also recognise that some balance must be achieved in the national representation, whereas the chairmen of the above science programmes are principally from English-speaking countries. For the SCAR programmes one possibility might be to combine a chair from a non-English-speaking country with a secretary from an English-speaking country. These important matters of representativeness notwithstanding, however, the GoS still believes that the most important criterion for membership selection should be the level of an individual's ability and motivation to contribute. We must keep in mind that the success of the whole SCAR Global Change Programme relies heavily on the active participation of member scientists at times between, as well as at, annual meetings. Furthermore, we must recognise that an important reason for a new membership structure is to establish a suitable committee to fulfil the role required by START to form the START Regional Research Committee for the Antarctic.

GLOCHANT XXIV-11

We recommend that SCAR Delegates re-evaluate the membership of the GoS/GLOCHANT in order to form the START Regional Research Committee for the Antarctic.

NB We suggest that the GLOCHANT programmes and other related SCAR groups be consulted about the proposed changes and that their suggestions for membership of the new GoS be solicited. As some of the task groups and related SCAR groups are jointly sponsored by other international organisations, such as IGBP/PAGES and JGOFS, and as there is a need for continued co-chairmanship from both organisations.

GLOCHANT XXIV-12

We recommend that a copy of this Report to SCAR be sent to the IGBP Secretariat and to the PAGES and JGOFS Core Project Offices, and to the START Secretariat.

9. Terms of Reference

At GLOCHANT III, pursuant to action taken at XXIII SCAR (see Minutes 5.1.5), the GoS developed the following recommended set of revised Terms of Reference to eliminate the implementation aspect of the original Terms of Reference and to increase the emphasis on communication, coordination, and the identification of research needs:

- To provide SCAR Working Groups, Groups of Specialists and national programmes with the best available multidisciplinary advice regarding ongoing Antarctic global change research.
- To provide liaison between SCAR and the other major international programmes on global change, and to promote the applicable Antarctic component within those international programmes.
- To identify research needs in Antarctic process studies, monitoring, and modelling related to global change.
- To plan, promote, and monitor specific projects on problems of global change research in the Antarctic.

These Terms of Reference were approved by the SCAR Executive in Sienna last year, but they may now need revision to accord with a new structure of the GoS, if that evolves from this meeting.

GLOCHANT XXIV-13

We recommend that SCAR delegates formally approve these revised Terms of Reference for the GoS/GLOCHANT, based on those given above but modified as necessary to reflect a re-evaluation of the goals and purposes of the GoS.

10. Statement of GLOCHANT Finances for 1995 and 1996

A. Statement of GLOCHANT Finances for 1995

Item	Allocation $ US	Spend $ US	Balance $ US
GLOCHANT III, Tokyo	25,000	18,085	6,915
PG 1 & 5, Tokyo	12,000	11,690	310
PG 2 / PAGES (PICE)	15,000	6,850	8,150
PG 3 (ISMASS) and other meetings	0	12,320	-12,320
PG 4	9,000	0	9,000
Project Office	11,000	11,000	0
Totals	$ 72,000	$ 59,945	$ 12,055

B. Statement of GLOCHANT Finances for 1996

Item	Allocation $ US	Spend $ US	Balance $ US
GLOCHANT IV, Madison	15,000		
Project Office	8,500		
PGs 2 and 3	15,000		
Total	$38,500		

11. GLOCHANT Budgetary Requirements for 1997 and1998

The following budget is requested for planned GLOCHANT activities in 1997 and 1998 is listed below.

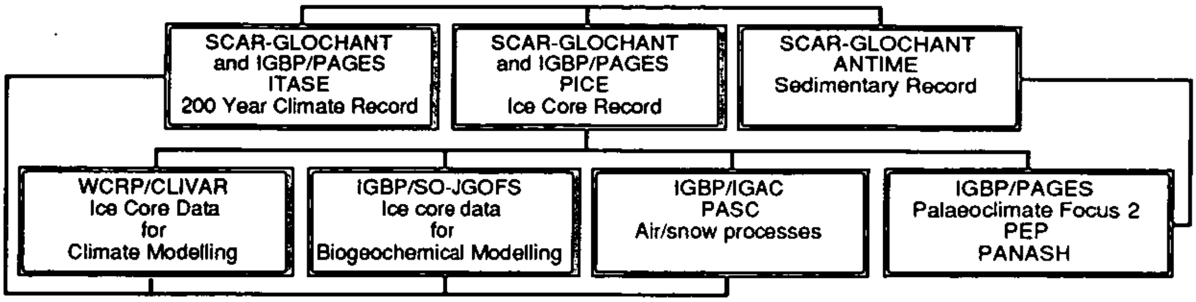
Item	1997	1998
GLOCHANT		
Annual Meeting of 10 people @ $1500	15,000	15,000
ASPECT		
Annual Programme Meeting, 6 people @ $1500	9,000	9,000
Training workshop, 6 add'l people	9,000	
Representation at CLIVAR DEC-CEN, one person	2,000	
Sea Ice Observer's Handbook	3,000	
ISMASS		
Annual Programme Meeting, 6 people @ $1500	9,000	9,000
BEDMAP project	3,000	
PICE		
Joint GLOCHANT/PAGES Workshop on the correlation of the ice core records, (partial support) 6 people @ $1500	9,000	
Ice core data compilation	3,000	
ITASE		
Annual Programme Meeting, 6 people @ $1500 (partial support)	9,000	9,000
Palaeoclimatic data compilation	5,000	5,000
ANTIME		
Joint GLOCHANT/PAGES Workshop, (partial support) 10 people @ $1500	15,000	
Annual Programme Meeting, 6 people @ $1500	9,000	
TOTALS	$78,000	$65,000

List ofAppendices

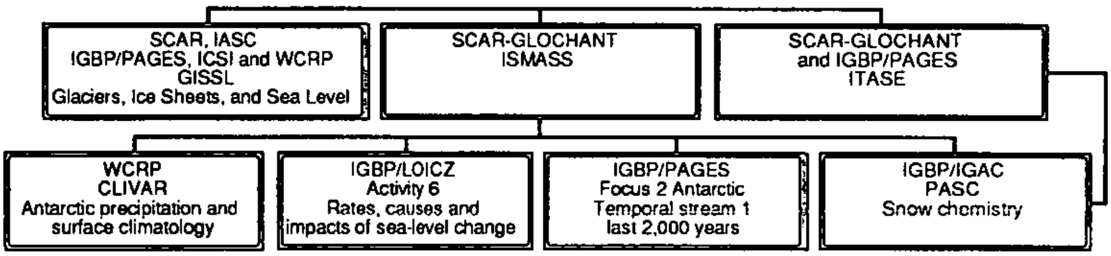
APPENDIX 1

SCAR Global Change Programme linkages

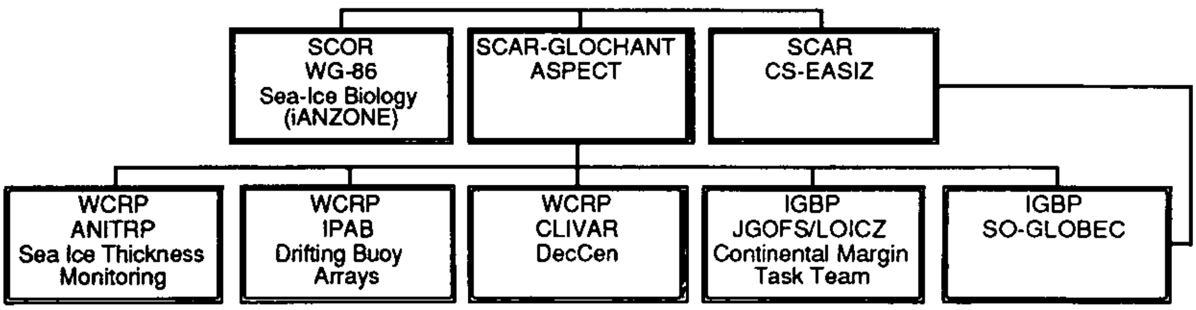
A. PALAEOENVIRONMENTS FROM ICE CORES (PICE)
LATE QUATERNARY ANTARCTIC ICE MARGIN EVOLUTION (ANTIME)
INTERNATIONAL TRANS-ANTARCTIC SCIENTIFIC EXPEDITION (ITASE)



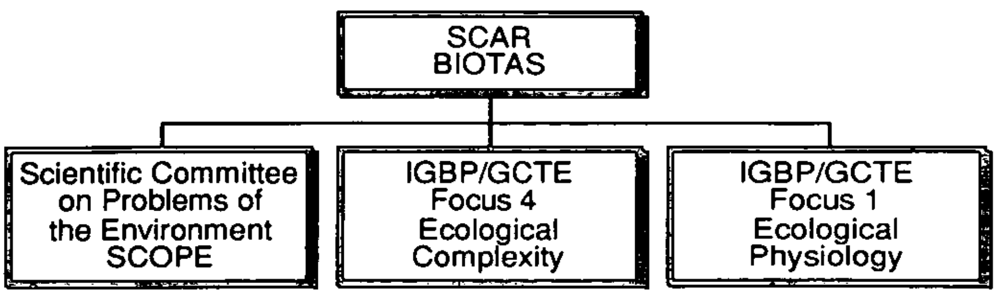
B. ICE SHEET MASS BALANCE AND SEA-LEVEL CONTRIBUTIONS (ISMASS)



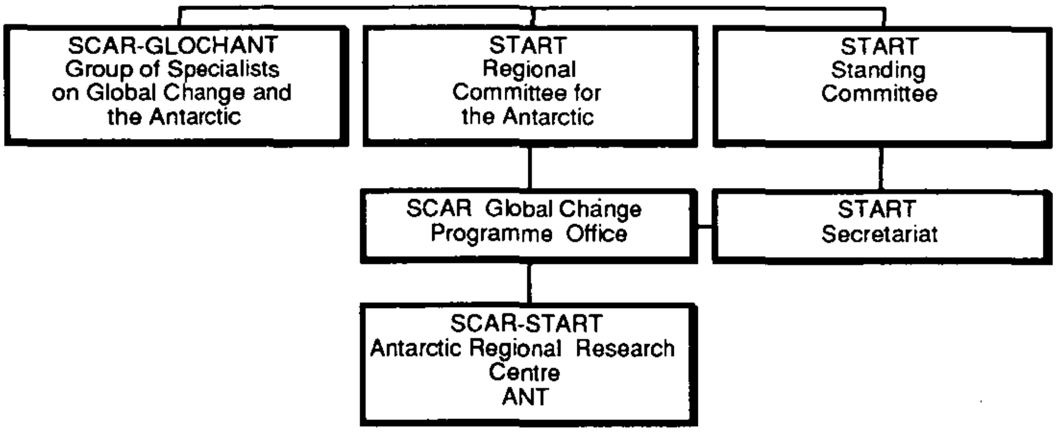
C. ANTARCTIC SEA-ICE PROCESSES, ECOSYSTEMS AND CLIMATE (ASPECT)
COASTAL AND SHELF ECOLOGY OF THE ANTARCTIC SEA-ICE ZONE (CS-EASIZ)



D. BIOLOGICAL INVESTIGATIONS OF TERRESTRIAL ANTARCTIC ECOSYSTEMS (BIOTAS)



E. SCAR AND START LINKAGES



APPENDIX 2

ASPECT

Antarctic Sea-Ice Processes and Climate

PRELIMINARY PLAN

TABLE OF CONTENTS

Executive Summary

Despite the growth of activities in global-change research in the Antarctic, both from SCAR programmes and from other international programmes, such as those of IGBP and WCRP, there remain key deficiencies in our understanding and data from the sea ice zone that are not addressed by current or planned research programmes. Important problems not adequately covered by existing Antarctic research programmes include:

1. The broad climatology of sea ice physical characteristics.
2. Processes such as ice formation, water mass modification, the maintenance of polynyas, ice edge and coastal fronts, gas exchange, and air-sea interaction.
3. Modelling sea-ice processes in coupled atmosphere-ice-upper ocean models. Linking scales (local scale to regional scale to global scale models).

There is a special role for the SCAR Global Change Programme in the shelf to ice-edge area (pack ice) that is not being adequately covered by other programmes. Hence SCAR GLOCHANT proposes to establish a programme of multi-disciplinary Antarctic sea ice zone research called Antarctic Sea Ice Processes and Climate (ASPECT).

The broad objectives for ASPECT are:

1. To establish the distribution of the basic physical properties of sea ice that are important to air-sea interaction and to biological processes within the Antarctic sea-ice zone (ice and snow cover thickness distributions; structural, chemical and thermal properties of the snow and ice; upper ocean hydrography; floe size and lead distribution).
2. To understand the key sea-ice zone processes necessary for improved parameterisation of these processes in coupled models.

The major focus of the ASPECT programme is physical sea ice processes and ocean-atmosphere interaction in the sea-ice zone. Biological processes and ecology within the Antarctic sea ice zone are addressed by the SCAR EASIZ programme, and ASPECT will also be closely linked with that programme to ensure a broad multidisciplinary approach. As a SCAR programme, ASPECT is focused towards the role of the unique regional environment of the Antarctic sea ice zone, but it is essential that this is closely linked to the international global change research agenda. Hence inter-disciplinary components of ASPECT are designed to contribute to, and extend, international open ocean programmes such as JGOFS.

Many physical elements of ASPECT will contribute to the objectives of the WCRP CLIVAR Programme, a study of Climate Variability and Predictability, which involves investigations of atmosphere, ocean and land at a variety of time scales. ASPECT plans are particularly relevant to the CLIVAR-DecCen component-programme, concerned with decadal to centennial climate variability and predictability. The ASPECT programme will initiate implementation of parts of the sea ice zone research requirements of CLIVAR, and will collaborate closely with CLIVAR and other WCRP programmes to ensure the essential global integration of Antarctic regional research. It may be appropriate for some research elements of ASPECT to eventually become a sub-component of CLIVAR, but because of the unique logistic requirements of work in the Antarctic sea ice zone, ongoing SCAR involvement and sponsorship are important.

The ASPECT programme will build on existing and proposed research programmes, and the shipping activities of National Antarctic operators. The plan includes some components that can be undertaken as part of normal resupply voyages; for example a system of simple but quantified shipboard observations that provide statistical ice and snow thickness distributions. ASPECT will also include a component of data-rescue of valuable historical sea ice zone information. The ASPECT programme will achieve its aims by:

- defining a framework of the priority Antarctic sea ice zone research required to address global change and related issues
- promoting and fostering co-ordinated contributions to this plan from within National research programmes and by building on ongoing projects
- liaising with other international programmes requiring data and research products from the Antarctic sea ice zone, and
- organizing workshops to co-ordinate implementation through contributory projects.

1. Introduction

ASPECT (Antarctic Sea Ice Processes and Climate) is proposed as a programme of multi-disciplinary Antarctic sea ice zone research within the SCAR Global Change Programme. ASPECT will specifically address key identified deficiencies in our understanding and data from the sea ice zone. The programme is designed to complement and to contribute to the other international programmes in this region, whilst avoiding unnecessary duplication of effort in either programme management or implementation. It will build on existing and proposed research programmes, and the shipping activities of National Antarctic operators, and will also include a component of data-rescue of valuable historical sea ice zone information.

The ASPECT proposal was developed at a joint meeting of the SCAR groups GLOCHANT, EASIZ and GOSSOE in Tokyo in April 1995. These groups met on the recommendation of delegates at SCAR XXIII to review existing programmes and proposals within the Antarctic sea ice zone, and to consider in particular the overlap between the various programmes. The meeting identified gaps in the present research which warranted the development of a specific new programme of multidisciplinary Antarctic sea ice zone research. The ASPECT plan was developed further at a meeting during GLOCHANT IV in Madison in April 1996, and by correspondence.

While the major thrust of the ASPECT programme is physical sea ice processes and ocean-atmosphere interaction in the sea-ice zone, it will be vital to maintain strong links with programmes of ecological research in the sea ice zone, and in particular with SCAR EASIZ. As a SCAR programme, ASPECT is focused towards the role of the unique regional environment of the Antarctic sea ice zone, but it is essential that this is closely linked to the overall international global change research agenda. Hence inter-disciplinary components of ASPECT are designed to contribute to, and extend, international open ocean programmes such as JGOFS.

Many elements of ASPECT will contribute to the objectives of the WCRP CLIVAR Programme, a study of Climate Variability and Predictability, which involves investigations of atmosphere, ocean and land at a variety of time scales. ASPECT plans are particularly relevant to the CLIVAR-DecCen component-programme, concerned with decadal to centennial climate variability and predictability. The ASPECT programme will initiate implementation of parts of the sea ice zone research requirements of CLIVAR, and will collaborate closely with CLIVAR and other WCRP programmes to ensure the essential global integration of Antarctic regional research. It may be appropriate for some research elements of ASPECT to eventually become a sub-component of CLIVAR, but because of the unique logistic requirements of work in the Antarctic sea ice zone, ongoing SCAR involvement and sponsorship are important.

2. Rationale

The Antarctic sea ice zone remains one of the least known regions of the earth's surface. Apart from satellite derived data on ice extent and concentration, there are few reasonable climatological estimates of ice conditions that can be used for validation of numerical models. What limited information we have, mostly from the Weddell Sea, indicates that the ice characteristics and the dominant processes in the Antarctic are substantially different from those in the central Arctic. The Antarctic sea ice zone acts as a regional boundary between the Antarctic and sub Antarctic, an interface between the upper ocean and the lower atmosphere, and globally, as a region of important interactive physical and biogeochemical processes.

Uncertainties in, and the importance of, the role of sea ice in the climate system are highlighted in a US Global Change Program Report, Forum on Global Change Modeling. On the basis of studies of past climates, which provide evidence for polar amplification of warming it is predicted that under any future global warming scenario, Northern Hemisphere sea ice will probably be reduced, but that projected changes and their timing in the Southern Hemisphere sea ice extent are less certain. Current coupled model studies of an increased carbon dioxide atmosphere are also essentially in conflict in their predicted Southern Hemisphere sea ice response. First simulations with a coupled model even suggested an expansion, but more likely thickening, of the ice cover in particular regions. Other model studies, using different parameterizations of both fluxes and sea ice processes suggest the opposite effect; that instead sea ice extent and thickness will both be drastically reduced in increased atmospheric carbon dioxide scenarios. Through ice-albedo feedback, these latter simulations also suggest that the sea ice retreat itself accounts for a significant fraction (40%) of the global atmospheric warming that will occur under CO_2 doubling, with of course very large increases in the regions more local to the present day ice cover. These projected changes are at present currently impossible to ascertain, because without knowledge of the Antarctic sea ice thickness distribution, it is difficult to provide compelling evidence if and when change occurs. Since the models currently give contradictory results, it suggests that the model parameterizations of sea ice physical processes are different and some, perhaps all, of the models are unrepresentative in some way in their depiction of the sea ice cover. Without present-day knowledge of the ice thickness distribution, models however cannot be verified, so we cannot even ascertain which model physics, if any, are correct

The role of sea ice in the global climate system has been long recognised and included as a study component of major international weather and climate programmes such as the Polar Sub-Programme of the Global Atmospheric Research Programme, and the World Climate Research Programme. However, whereas in the Arctic a number of multi-national co-operative programmes have advanced our understanding of sea ice processes, there have been few similar programmes implemented in the Antarctic, and none covering the whole of the Antarctic sea ice zone. Organisations such as SCOR-CCCO (1981), WMO-CAS (1982), and the JSC for WCRP Working Group on Sea Ice and Climate (1988), have in general left it to SCAR to provide appropriate co-ordination of scientific initiatives in the Antarctic sea ice zone.

Several factors have restricted implementation of such a co-ordinated Antarctic sea ice zone programme before the present. But changed circumstances, now make it timely to initiate such a programme within SCAR. No other organizations have the experience or expertise for Antarctic research that is contained in the national Antarctic programmes of the SCAR countries. Many of the SCAR countries, tied also through the closely associated Council of Managers of National Antarctic Programmes (COMNAP), are already carrying out, and plan to continue, sea ice zone research in both physical and biological sciences within National programmes: substantial new information is now available, particularly from the Weddell Sea, Amundsen and Bellingshausen Seas, and the Indian Ocean sector. A number of sophisticated, ice-capable research vessels are now working in the Antarctic, and at the same time the increased number of nations working in the Antarctic has seen a growth in all types of shipping activity. And new remote sensing capabilities, particularly active radar systems, have greatly enhanced sea ice observation from space.

A number of other international programmes, for example CLIVAR, JGOFS, and SCAR-EASIZ, have planned activities of direct relevance, but even together do not cover the full scope of the required Antarctic sea ice zone research. The inter-relationship between ASPECT and other relevant international programmes is discussed further below. Important problems that are not being adequately covered by existing Antarctic research programmes include:

1. Broad climatology of sea ice physical characteristics. Satellite derived data provide large scale estimates of ice extent and concentration, but not of the thickness of ice and snow, which are the primary variables affecting many physical and biological processes, as well as climate processes.
2. Processes such as ice formation, water mass modification, the maintenance of polynyas, ice edge and coastal fronts, gas exchange, and air-sea interaction.
3. Modelling sea-ice processes in coupled atmosphere-ice-upper ocean models. Linking scales (local scale to regional scale to global scale models).

There is a special role for the SCAR Global Change Programme in the shelf to ice-edge area (pack ice) that is not being adequately covered by other programmes, and for providing information on the sea ice system for development of coupled models: current models do not include all of the relevant sea ice processes and many important parameters are not available. The role of sea ice (including albedo feedback, ice thickness, flux correction and ice dynamics) has not been well addressed and sea ice should be incorporated into both climate and ecological models. SO-JGOFS would welcome development of models that include sea ice.

3. Overall Objectives of ASPECT

ASPECT is a multi-disciplinary programme of research within the Antarctic sea ice zone. Its overall aim is to understand and model the role of Antarctic sea ice in the coupled atmosphere-ice-ocean system. This requires an understanding of key processes, and the determination of physical, chemical, and biological properties of the sea ice zone. These are addressed by objectives which are:

1. To establish the distribution of the basic physical properties of sea ice that are important to air-sea interaction and to biological processes within the Antarctic sea-ice zone (ice and snow cover thickness distributions; structural, chemical and thermal properties of the snow and ice: upper ocean hydrography; floe size and lead distribution). These data are required to derive forcing and validation fields for climate models and to determine factors controlling the biology and ecology of the sea ice-associated biota.
2. To understand the key sea-ice zone processes necessary for improved parameterization of these processes in coupled models.

4. ASPECT Key Scientific Questions

Key scientific questions which must be answered to meet the objectives are:

i. What are the broad-scale time-varying distributions of the ice and snow-cover thickness, ice composition and other physical characteristics in the Antarctic sea ice zone?

There are currently no systematic, spatially distributed data sets available of the seasonal and regional variability of the ice and snow thickness distribution for the Antarctic sea ice zone. Such data, together with those on ice extent, and concentration, would provide a sensitive and essential test of the performance of numerical atmosphere-ocean models. Similarly, climatic compilations of the main features of ice drift and, in more sophisticated models, the percentage total ice formed by different processes (basal freezing, frazil formation, snow flooding) provide good validation of models. Remote sensing validation and algorithm development are also necessary to use existing and future satellite derived data in a quantitative monitoring mode for sea ice model verification and input fields.

Similar physical data are required to support research into the biology and ecology of the sea-ice-associated biota, and to scale-up from local studies of ecosystems and the biogeochemical system to the whole Antarctic. In particular, the ASPECT and EASIZ programmes together need to quantify the variance spectra of major components of the ice-associated biota and the characteristics of the physical environments with which these are associated.

ii. What are the dominant processes of ice formation, modification, decay and transport which influence and determine ice-thickness, composition and distribution?

Air-ice-ocean interaction effects in the Antarctic are manifested in changes in ice thickness, structure and composition. Flooding of the snow cover followed by refreezing leads to a higher than usual surface salinity, while melting at the base from high ocean heat flux can lower the salinity of the ice from that seen in a bottom freezing condition. A key early finding about the composition of Antarctic sea ice, and its fundamental difference with Arctic sea ice, is the high percentage of frazil ice structure (typically 40 to 60% of the ice structure) that is observed in much of the seasonal ice cover around Antarctica. The dominant growth regime relating to frazil ice structure is the early interaction of the open ocean wave field with the growing ice cover. This turbulent growth regime causes the frazil ice crystals to form dynamically into pancake ice floes. Ice growth can take place quickly up to some tens of centimetres of ice thickness, but at these thicknesses the ice strongly attenuates the incident wave field, essentially shutting down the driving for further ice growth by the pancake ice growth mechanism. Further modification of these initial ice covers can then proceed thermodynamically either by slow growth beneath the ice cover if the heat flux to the atmosphere is high enough, or by bottom melting in areas of relatively high ocean heat flux.

In areas interior to the pack ice edge, other processes of ice modification that are observed in Antarctica, are ice growth in leads created by ice divergence. Divergence of up to 10% per day has been observed under extreme conditions. Consequently, new open water is frequently exposed within the pack, and much of the total ice mass forms by rapid freezing in these areas. As well as thermodynamic growth, leading primarily to congelation or columnar ice structure, the deformational processes of rafting and ridge-building are also important in the development and distribution of sea ice. Episodic periods of divergence and ice formation in new open water, followed by convergence and thickening by deformation, are related to the passage of synoptic weather systems.

The physical structure and the physical-chemical composition of ice cores also reveal metamorphic changes relating to thermal forcing; the creation of snow ice from surface flooding by sea water; and also formation of superimposed ice from snow melt and refreezing. In areas near ice shelves, significant amounts of bottom accretion of what is called platelet ice, can also occur from the advection of super-cooled water to the surface. Wind and ocean current driving can also contribute to changes by transporting ice from source to sink regions. This ice dynamical effect can produce effects in contradiction to that inferred from a perception of the air temperature fields. In the western Weddell Sea for example, the thickest ice is found in the north, a result of ice deformation and advection effects rather than in the south where the coldest air temperatures are found.

iii. What is the role of coastal polynyas in determining total ice production, heat salt and biogeochemical fluxes, and water mass modification?

Coastal polynyas are a common feature of the perimeter of the Antarctic continent. As opposed to the generally larger deep-water polynyas, such as the Weddell Polynya, the polynyas on the continental shelf are believed to be primarily "latent heat" polynyas: that is, heat loss from the ocean surface is balanced by the latent heat of new ice formation and the polynya is maintained by wind or tidal current removal of the new ice.

The polynyas are regions of intense heat loss from the ocean to the atmosphere, and of rapid and copious ice growth: they may be significant as "ice factories" for the total sea ice zone. Brine rejected during ice growth is concentrated in the polynya areas and can cause localised water mass modification as well as significantly increasing the salinity of Antarctic continental shelf water. In the south west Weddell Sea High Salinity Shelf Water (HSSW) formed through this process is the parent water mass for the production of Ice Shelf Water (ISW) under the Filchner-Ronne Ice Shelf. ISW leaving the continental shelf leads subsequently to the formation of Weddell Sea Bottom Water (WSBW). Adelie bottom water, which occurs on the shelf and shelf slope in the region from 130°E to 150°E, has a recent origin (<5 years) and appears to be intricately linked to processes in the coastal polynyas of the region. There appear to be significant regional differences in the activity of coastal polynyas.

Ice production in polynyas bordering ice shelves may be enhanced both by an off-shelf wind-field or by an oscillating tidal current. The outgoing tide opens a lead (polynya) where ice production may be very intense, whereas the incoming tide concentrates the newly-formed ice along the ice front. The accumulated production in such latent heat polynyas has been estimated to be as much as 20-30 metres of sea-ice per year.

The ice free polynyas play an important role for Antarctic marine biological systems, and in the control of biogeochemical fluxes. Polynyas have potential importance in biogeochemical cycling in terms of air-sea gas fluxes and vertical convection as a carbon transport mechanism.

Our knowledge of the local wind-fields in the ice-shelf polynya areas is very poor, and the variation in the tidal currents along the edge of the floating ice-shelves is also virtually unknown. Measurements of wind and tidal currents should therefore accompany any measurement programme of ice formation in polynyas.

iv. What are the processes that control the ice-water interactions at the ice-edge, and their seasonal changes?

Ice edges, or the zones where the ice cover interacts with the open ocean, have high seasonal and regional variability around Antarctica. Ice edges essentially can be divided into three phases: a growth phase of ice advance, a decay phase where the ice edge retreats; and an intermediate or "equilibrium phase" with small advance and retreat oscillations.

The ice edge growth phase during the fall-winter period, usually proceeds, when open ocean waves are present, by the growth of frazil ice transitioning primarily into pancake ice fields. If shorelines are present or unusually calm conditions exist without ocean waves, the ice edge may advance instead as thin flat sheets of nilas ice. In some regions, the onset of winter conditions allows ice that is advected in from other regions to stay frozen rather than melt, so the ice edge advances by the advection of floes that have been maintained through the summer period. The seasonal cycle of warming air temperature or warm water advection leads to the ice edge retreat. Wave action at the ice edge leads to breaking up of the larger floes. Combined with solar heating of the water in the increased perimeter area of the broken floes, melting is accelerated and the combined mechanical and thermal deterioration of the ice edge proceeds. In some regions, such as the northern Weddell Sea, this decay phase can be considerably delayed or stopped if the ice transport from the south is high enough to keep the ocean water chilled and also shielded from solar heating until the summer season is over. The equilibrium phase occurs when the ice edge is brought to a northern boundary usually corresponding to an ocean frontal structure where warm water exists on the northern side of the front so that the ice transported there is melted as it crosses the front. Variations in the ice advection rate or alternate period of cold air and warm air advection can then cause the oscillations of the ice edge, slightly advancing or retreating after the mean equilibrium position is reached.

The regional variability in the ice edge can be characterised by the period of time that the ice edge exists in these various phases, for example the Weddell Sea undergoes a short advance period, a prolonged equilibrium phase, and a rapid decay phase due to the high transport. In other regions, the ice edge regime is primarily thermodynamically or air temperature controlled, so that the equilibrium phase is very short at the maximum ice edge extent, and the ice advance and retreat are both relatively lengthy and nearly equal in time. The result of these differences in regime can effect the amount, and the position and timing of fresh water flux at the ice edge, and thus impact strongly on the biological regime, and lead to seasonal and regional variations in ice edge blooms around Antarctica.

The seasonal ice zone makes a major contribution to the biological pump of CO2 in the polar region. Every year its northern border moves within a large band of latitude and the ice edge represents a key component of the Southern Ocean dynamics both with regards to the transfer of energy between the atmosphere and the ocean and to the biogeochemical fluxes. Often, but not always, the spring time retreating ice edge is a locus of elevated phytoplankton biomass. There may be a causal link to the sea ice retreat, via increased light availability, surface water stratification, "seeding" by sea-ice algae, or inputs of trace nutrients such as iron from accumulated aerosols. Alternatively, the correlation may largely reflect separate responses to seasonal increases in solar radiation and open water temperatures. Further coherence may occur because, at least in the late stages of melting, the algae can reduce the sea-ice albedo and thus its rate of melting. It has been assumed that the seasonally retreating melting ice can create density structure that increases the stability of the water column in its immediate wake. This environment determines favourable conditions for phytoplankton ice-edge bloom development. Nonetheless field observations conducted in the eastern Weddell Sea and in the Indian sector lead to the conclusion that this conceptual model is not valuable for MIZs submitted to intense transfer of energy from the atmosphere. Availability of realistic description of the ice field and structure will greatly improve coupled physical-biogeochemical models for the ice-edge ecosystem, of major interest for EASIZ and SO-JGOFS.

It is important to understand these links for several reasons. In assessing interannual variations in biological activity, a model able to incorporate changes in physical forcing is desirable, so that trophic structure, predator/prey, and population variations may be better understood. In the context of global climate change, photosynthesis represents the start of the biological transport path which removes atmospheric carbon dioxide to the deep sea and sediments. The ecosystem structure influences what proportion of this fixed carbon reaches the deep sea or is recycled within the upper ocean and returned to the atmosphere.

ASPECT needs to determine:

1. What are the physical factors controlling the dynamics of the density structure in the MIZ, and how do these impact on the behaviour and timing of MIZ blooms.

2. Whether changes in the geochemistry of sea ice affect the isotope fractionation of sea ice biota and consequently the isotope ratios of particulate matter in sea-ice and the water column.

3. Whether sea-ice acts as an accumulator for trace metals, and if so do the elevated concentrations of elements such as Fe or Mn explain qualitative or quantitative changes in the primary production in the surface waters of the MIZ.

5. ASPECT Links with the SCAR -EASIZ Programme

The SCAR EASIZ (Ecology of the Antarctic Sea-Ice Zone) programme originated as a successor to the SCAR BIOMASS programme. The aim of this programme is to improve understanding of the structure and dynamics of the Antarctic coastal and shelf marine ecosystem. The Antarctic continental shelf is distinctive in being depressed by the weight of continental ice, the proximity or direct contact with shelf ice, the very low riverine input, and the extensive glacial input in the form of bottom water, surface melt and glacial debris. The Antarctic sea-ice zone is also a highly seasonal environment, with large and important differences in biology between summer and winter.

The biota associated with sea ice includes all those organisms whose distribution is determined by the physical structure of sea-ice cover, and includes organisms ranging in size from microbiota inhabiting the ice fabric to large vertebrates using the ice surface as a resting place or feeding site. Compared with the open ocean, the means of estimating the abundance and distribution of these organisms involves a disparate range of techniques. This implies that building up a picture of the interrelationships within this community is a task closer to the approaches of benthic or terrestrial rather than pelagic ecology. At present, there are major gaps in our understanding of the variability of distribution of organisms, which make a large-scale understanding of the system more or less impossible

Sea ice is a heterogeneous environment. It offers different habitats to a range of organisms, and the physical characteristics of the ice affect the ecology and physiology of those organisms. At small scales, the internal structure of sea ice determines the distribution of microbiota, whilst crystal fabric and ice salinity regulate growth rate through influence on nutrient availability and light climate, including ultra-violet. At larger scales, irregularities in ice topography provide structural diversity for zooplankton, affecting interactions with their predators and prey. At the largest scales, irregularities in ice topography provide structural diversity for zooplankton, affecting interactions with their predators and prey. At the largest scales, the ice-edge zone represents a complex environment where the ecological processes are controlled by the interaction between the biota, the ice and ocean.

An ability adequately to scale up from the relatively local measurements of biological processes in the ice-associated ecosystem to regional estimates of quantities such as carbon cycling or biogenic gas fluxes is a requirement of Southern Ocean global change programmes. To achieve this, we need to be able to use large-scale description of environmental variability to model biogeochemical properties at regional scales. Such an approach would complement studies in the pelagic system, which involve an understanding of the effects of spatial and temporal heterogeneity on ecosystem interactions relevant to ocean biogeochemical cycling.

The EASIZ programme, initiated in the 1995/96 austral summer season, is an integrated study concerned with both benthic and pelagic indicator species (their population structure and dynamics) as influenced by sea ice. Because shallow-water communities are more sensitive to global change, particular attention will be paid to their biology and to understanding seasonal, inter-annual and long-term changes. EASIZ also places special emphasis on the community level. Although ship-borne studies will form an important part of the EASIZ programme, a central role will be played by the network of coastal marine stations around Antarctica. These stations are of great importance in supporting long-term studies, and in allowing work throughout the austral winter.

Key scientific areas for joint attention by ASPECT and EASIZ are:

1. How does the physical structure of the ice influence the taxonomic composition of the associated biota, and its production?
2. To what extent are the scales of variability in sea-ice physical structure reflected in those in the associated biota?
3. To what extent are biological measurements made in areas close to open water (marginal ice- zone or polynyas) representative of the bulk of the sea-ice zone?

The work undertaken within ASPECT will thus complement, rather than overlap, the EASIZ programme. Whereas ASPECT will be undertaking integrated physical and biological work from ships during dedicated cruises at the marginal ice zone (MIZ), or deep within the pack-ice, the main thrust of EASIZ work will be near shore, year-round, and long-term. Work within EASIZ will thus provide important data on temporal variability at a series of sites, to complement the more detailed process studies or data on spatial variability to be obtained within ASPECT. In addition the physical studies proposed under ASPECT will contribute significantly to the overall aims of EASIZ. Close scientific links will be maintained between the two programmes, and the combined results will contribute substantially to our understanding of the Antarctic sea-ice zone.

6. Links with other International Programmes

ASPECT will complement and contribute to the other international programmes concerned with global change, and with an interest in the Antarctic sea ice zone. Presently active components of other programmes relevant to ASPECT include:

WCRP

The World Climate Research Programme (WCRP) emphasises the physical climate system, while the companion IGBP focuses on biological and chemical processes involved in global change. The Antarctic climate research issues of interest to the WCRP could in principle be construed broadly to include the roles in the global climate of Antarctic sea ice, ocean circulation, ice sheets, and atmosphere, and of course the interactions among these components. The time scales of interest span a great range because of the very long intrinsic time scales of the ice sheets (centuries), although, say, ocean-ice sheet interactions might be much more rapid. Other parts of the system likely have important seasonal to decadal variability, as well as trends.

IPAB and AnITRP

The WCRP has established two programmes which use automatic observing systems to increase meteorological and sea ice related data from the Antarctic region: the International Programme for Antarctic Buoys (IPAB), and the Antarctic Ice Thickness Research Programme (AnITRP). The objective of IPAB is to establish and maintain a network of drifting buoys in the Antarctic sea ice zone in order to support research in the region related to global climate processes, to meet real-time operational meteorological data requirements, and to establish a base for ongoing monitoring. AnITRP aims to principally obtain ice thickness data using upward looking sonar instruments. These instruments, moored to the ocean bottom, record the keel depth of sea ice drifting over their location from sonar ranging measurements made every few minutes. Both programmes are essentially routine observing ones, providing data for initialisation and validation of climate models and for monitoring. The major contributions to both come from national programmes of SCAR members. Data from ASPECT will contribute to, and build on these programmes.

ACSYS

WCRP has also developed the Arctic Climate System Study (ACSYS) for the Northern Hemisphere, but there are no equivalent process studies in the Antarctic sea ice zone. However modelling of Antarctic sea ice, and to some extent of ice-ocean interaction, is presently within the purview of the Sea Ice/Ocean Modelling Panel of ACSYS. A particular emphasis of the ACSYS SIOM Panel has been model development suitable for incorporation into interactive global numerical circulation studies.

CLIVAR

CLIVAR, a study of Climate Variability and Predictability, is a major new initiative of WCRP (since March 1993) which builds on TOGA and WOCE, and aims to determine the extent to which climate can be predicted, and the extent of human influence on climate. CLIVAR involves investigations of atmosphere, ocean and land at a variety of time scales, and is organised into three component programmes: the most relevant of these to Antarctic sea ice zone studies is CLIVAR-DecCen, concerned with decadal to centennial climate variability and predictability. The CLIVAR Science Plan includes consideration of the variability of the ocean's ice cover, and of ocean processes involving sea ice. The ASPECT programme will initiate implementation of some of the sea ice zone research requirements of CLIVAR, and must collaborate closely with CLIVAR and other WCRP programmes to ensure the essential global integration of Antarctic regional research. It may be appropriate for some research elements of ASPECT to eventually become a sub-component of CLIVAR (a 15-year research programme).

WCRP has indicated that discussion of the need for internationally co-ordinated Antarctic climate research should be included in the appropriate workshops being planned under ACSYS and CLIVAR within the next two years, but is unlikely to establish a new Antarctic study group itself in advance of these workshops.

IGBP

JGOFS

JGOFS is the IGBP core project concerned with the role of the oceans in the global carbon cycle. It has two major goals, set out in its science plan (SCOR 1990). The first goal is to 'determine and understand on a global scale the processes controlling the time-varying fluxes of carbon and associated biogenic elements in the ocean, and to evaluate the related exchanges with the atmosphere, sea floor and continental boundaries'. The second is to 'develop a capability to predict on a global scale the response of oceanic biogeochemical processes to anthropogenic perturbations, in particular those related to climate change'.

The major field components of JGOFS consist of a series of regional studies. The location of these has been determined to study specific phenomena (see JGOFS Implementation Plan - SCOR 1992). The largest regional study in both areal extent and the amount of scientific effort already devoted to it is in the Southern Ocean. This was selected because it is the largest and potentially most significant of the so-called HNLC (high nutrient-low chlorophyll) regions of the world ocean, where annual phytoplankton production is insufficient to utilise fully the dissolved macronutrient pool.

The Southern Ocean regional study (SO-JGOFS) compiled its own science and implementation plan (SCOR 1993). In this it set its own objectives, based on those of the JGOFS science plan but tailored specifically to the circumstances of the Southern Ocean. Two of these relate directly to the areas of interest of the SCAR ASPECT proposal. The first is the question 'What is the effect of sea ice on carbon fluxes in, and to, the Southern Ocean?', and the second is 'What are the major features of spatial and temporal variability in the physical and chemical environment, and in key biotic systems?'.

SO-JGOFS recently evaluated its progress at a symposium examining the first four years of fieldwork. At its meeting following the symposium, the planning group examined progress with respect to specific objectives. It recommended that links with SCAR's global change programme be strengthened, and in particular noted the potential for the ASPECT proposal to promote sea ice research which would be complementary to JGOFS studies. JGOFS interests in the Antarctic sea-ice system include the relative importance of sea ice biota in carbon cycling, the factors governing the location of marginal ice zone phytoplankton blooms, and the physical effects of sea ice in modulating air-sea fluxes of radiatively active gases and solar radiation.

There are some areas where data of fundamental importance to our understanding of the Southern Ocean as a biogeochemical system cannot be obtained within the scope of normal JGOFS process cruises. These relate mainly to the features of variability of the sea ice and its associated biota. SO-JGOFS needs to be able to scale-up small- and meso-scale processes studies to regional estimates. Following the 1995 symposium, three key areas were identified:

- The need to model the complex interactions between sea ice and surface hydrographic features;
- The need to establish an operational protocol for using satellite data to map the marginal ice zone as a biogeochemical province;
- The need to understand the role of ice biota in carbon cycling.

GLOBEC

GLOBEC (Global Ocean Ecosystems Dynamics Research) is an IGBP programme concerned with off-shelf (water column) processes, invertebrate and vertebrate indicator species, as well as the physics that influences the population dynamics of animals and predator/prey interactions. The main aim is to understand the linkages between physics and biology on different scales. A Southern Ocean component, SO-GLOBEC will concentrate in three areas: the Antarctic Peninsula, the eastern Weddell Sea and the Indian Ocean sector. Two groups of species will be studied: zooplankton (copepods and krill) and top predators (seals and penguins). There are no direct overlaps between ASPECT and SO-GLOBEC.

SCAR

APIS

APIS (Antarctic Pack Ice Seals), an initiative of the SCAR Working Group on Biology, is concerned with a census and the population dynamics of marine mammals, primarily crabeater seals, within the sea ice zone. Techniques for the reliable and precise counting of marine mammals are being developed by APIS, and protocols for counting seabirds already exist. Although there are few scientific overlaps with ASPECT there are some possibilities for shared logistic support. ASPECT cruises may provide ships-of-opportunity for some work on seabirds and marine mammals. Regular contact will be maintained between the ASPECT and APIS programmes to ensure that all opportunities for logistical co-operation are taken; and ASPECT data on ice characteristics will be made available to the APIS programme.

SCOR

WG86

The SCOR Working Group 86 on Sea Ice Ecology was established to review the emerging field of sea ice ecology, to determine the existing connections between the within-ice ecology and the physics and chemistry of the sea ice environment, and to co-ordinate, through review publications and conference organization the at-large and emerging research community on this topic, including both Arctic and Antarctic researchers. Participation in ASPECT development, and close interaction with SCOR (along with SO-JGOFS) on ASPECT issues has been a special topic of WG86, and the full endorsement of the development of ASPECT has been given by WG 86. Since the development of a research programme is outside the mandate of SCOR working groups, the ASPECT sea ice ecological component can be regarded as the natural extension of WG86's activities into that realm, and therefore has received its full encouragement and support. Future activities of WG86 that will closely co-ordinate the ASPECT development include the establishment of a series of Gordon Research Conferences on Polar Marine Science, to be held annually beginning in 1997. The first two of these Sea Ice Ecology and Sea Ice Ecology in Globally Changing Environments are of direct relevance to ASPECT ecological studies and will provide important forums for discussion of science results in a timely manner as they develop.

IAnZone

AnZone (Antarctic Zone) has been an affiliation of working-level scientists concerned with the physical marine sciences (primarily physical oceanography, with contributions from sea ice physics, and boundary layer atmospheric sciences) in that region of the Southern Ocean poleward of the Antarctic Circumpolar Current (the Antarctic Zone). Three major experiments in the Southern Ocean have been completed or are underway under AnZone auspices, the Ice Station Weddell (ISW) drift in 1992, the Antarctic Zone Flux Experiment (ANZFLUX) conducted in the eastern Weddell Sea in 1994 and upcoming oceanographic work (1997-99) in the confluence of the Weddell and Scotia Seas near the Antarctic Peninsula on deep ocean ventilation (DOVETAIL).

Significant sea ice work relating to the design of ASPECT has been conducted on these previous AnZone experiments. These efforts provide some historical climatology on the ice thickness distribution for the Weddell Sea region and significant process experiments on the dynamics and thermodynamics of pack ice in the first and second year ice of the eastern and western Weddell Sea. These efforts, when further synthesized and integrated, form a firm foundation for ASPECT studies, and also represent a significant fraction of the ASPECT effort to date. Unlike some regions for example, the climatology of the ice thickness distribution in the Weddell Sea can build on this base, and ASPECT transects are designed to fill gaps there rather than the full seasonal and regional set that are necessary for some other regions.

A broader international group of IAnZone (International Antarctic Zone) has recently been affiliated as a standing committee of SCOR. The goal of IAnZone is to advance knowledge of climate processes within the Antarctic zone through development and co-ordination of observational and modelling programmes, and it will have a primary role in overviewing many of the physical aspects of the oceanography in the Antarctic. It will also conduct process experiments primarily relating to water mass formation processes and the longer-term climatic variability of the ocean, contributing to the CLIVAR program at the decadal to century time scales.

IAnZone and ASPECT have intersecting interests in terms of the role of sea ice in the oceanic and climate systems, and close co-ordination has been established. Joint interaction with CLIVAR between IAnZone and ASPECT has been initiated to ensure the unified Antarctic contribution to the physical side of climate studies will be both adequately considered and presented in that forum. From the operational side, close co-ordination will also be undertaken to, for example, conduct joint cruises to those regions that satisfy the aims of both projects. Co-ordination on the science (e.g. the role of coastal polynyas in water mass modification as well as sea ice formation and air-sea interaction), on the optimal use of limited numbers and schedules of suitable icebreakers, as well as the presentation of the unified air-ice-ocean science to the climate community will be satisfied by this co-operative approach. The approach to ensure this co-ordination has been the direct participation of both ASPECT scientists and IAnZone scientists in each other's meetings and the formulation of science programmes.

GCOS and GOOS

GCOS (Global Climate Observing System) and the climate module of GOOS (Global Ocean Observing System) are proposed operational observing systems sponsored by a consortium of WMO, IOC, UNEP, and ICSU. These programmes are in the planning stage only as yet, but they will address all aspects of the physical climate system, including consideration of sea ice. In their operational form they will not include process studies, nor the same detailed spatial and temporal resolution as many of the present climate-related research programmes, but their implementation will rely on the results from the research programmes, and they will continue some of the research observational programmes as ongoing operational observations.

7. Implementation Strategy

The ASPECT programme aims to achieve its goals by co-operation within the SCAR community. Some components of this co-operation may involve multi-national process studies, but much will be achieved within individual National Programmes provided that there is a framework of co-ordination, and that common observational protocols are established. Where possible the programme will build on existing and proposed research programmes, and the shipping activities of National Antarctic operators. The implementation plan will include some components that can be undertaken as part of normal resupply voyages; for example a system of simple but quantified shipboard observations that provide statistical ice and snow thickness distributions. ASPECT will also include a component of data-rescue of valuable historical sea ice zone information.

The role of an ASPECT Scientific Steering Group will be to:

- define a framework of the priority Antarctic sea ice zone research required to address global change and related issues;
- promote and foster co-ordinated contributions to this plan from within National research programs and by building on ongoing projects;
- liaise with other international programmes requiring data and research products from the Antarctic sea ice zone; and
- convene workshops to co-ordinate implementation through contributory projects.

Elements of the ASPECT programme addressing each key scientific questions should include the following:

*i. **The broad-scale time-varying characteristics of the ice***

Transects involving direct ice sampling by coring is the principal method for determining the dominant variations in growth, metamorphism and decay in various regions. Seasonal sampling is also necessary to determine the evolution of the ice cover. Preliminary work has suggested that in some regions these compositional changes can also vary interannually, and that repeated visits to some regions at the same season but different years can also establish how these changes are related to variability in forcing from the ocean and atmosphere.

Broad scale surveys are required to define a climatology of the time-varying state of the ice thickness distribution and snow cover; structural, chemical and thermal properties of the snow and ice; floe, lead and ridge distribution and upper ocean. A minimum requirement is for autumn, winter, spring and summer measurements along transects perpendicular to the Antarctic coast and spaced at intervals of about 15-30° of longitude. Ice-capable vessels used by an increasing number of national Antarctic programmes are capable of undertaking these surveys in all seasons.

It is not proposed that the surveys be undertaken in any one year, but that a composite climatological picture of the Antarctic sea ice zone be built up over a number of years. The surveys can be achieved by standardised ship-based observations along a series of systematic transects, building on ongoing national efforts (including re-supply voyages) and co-operating with other programmes with survey requirements such as EASIZ and APIS.

Observations during the transects will include both underway measurements and on-site sampling. Underway measurements might include:

- Ship-based area-wide estimates of ice conditions (Appendix C);
- estimates of the ice and snow cover thicknesses of individual floes overturned by the passage of the ship (Appendix C);
- continuous meteorological and near surface oceanographic measurements including, where possible radiation (incoming short wave, PAR, surface albedo) and turbulent fluxes;
- in addition instrumentation developments should make a number of direct underway ice measurements possible, such as ice thickness and ridge height estimation with boom mounted altimeters and inductive electro-magnetic devices.

On-site sampling, proposed at least every half-degree of latitude along the transects, of

- ice and snow core characteristics (temperature, salinity, structure, etc.);
- profiles along floes of ice thickness, snow thickness, ice-snow interface temperature, etc.;
- hydrographic measurements to at least the depth of the mixed layer.

Sampling required for components of the EASIZ programme should be undertaken at the same time, viz:

- sea-ice biology and nutrients (JGOFS and EASIZ protocols);
- water column biology (using JGOFS and EASIZ protocols).

A fundamental requirement of EASIZ is to devise means of measuring spatial (and temporal) variability of the biological community at the same scales as variability in the physical environment of the sea ice. Studies at some of these scales are well-established, but there is a dearth of information (from the sub-millimetre scale within the ice to the hundreds of kilometres of regional variation), on spatial variability which would allow the linking of different ecosystem components into a coherent structure.

A minimum requirement is to define a sea ice climatology for each of autumn, winter, spring and summer seasons along transects perpendicular to the Antarctic coast and spaced at intervals of about 15-30° of longitude of the time-varying state of the main variables. These include:

- ice extent and concentration;
- ice and snow thickness distribution;
- ice drift and deformation;
- ice formation type; and
- floe size and ridging distribution.

ii. The dominant processes of ice formation and modification determining ice-thickness, composition and distribution

iii. The role of coastal polynyas

*iv. **The processes at the ice-edge***

Specific process studies will be necessary to tackle these problems. In some cases these may be relatively simple and short and might be undertaken as components of the transect programme. In other cases specific multi-disciplinary, and possibly multi-ship, studies will be required.

For example, a small number of selected coastal polynyas should be studied at different seasons in multi-disciplinary studies including elements of meteorology, oceanography, glaciology, marine biology, and remote sensing. A pilot polynya project in one of the Wilkes Land coastal polynyas (ACoPS) has been suggested as a bi-lateral US/Australian effort for late winter 1998. This is being planned as a two-ship operation, with the vessels operating in the polynya for over-lapping periods, thus providing a short period when both are available for components requiring measurements at multiple sites, and also extending the total experimental period from late winter with high ice production (investigation of polynya maintenance, water mass modification, etc.) through to the spring plankton bloom. This pilot study could serve as a precursor to wider circumpolar studies of Antarctic polynyas and sea ice characteristics. Because of the link between coastal polynyas and marine biology, a polynya programme would be complementary to EASIZ.

New research tools that could be used in process studies include Automatic Underwater Vehicles (AUVs) that could be launched under the ice to measure ice thickness; passive and active microwave satellites, synthetic aperture radar (SAR), and the Sea Viewing Wide-Field-of-View Sensor satellite (SeaWIFS).

Ice edge interactions can be addressed by process studies such as a programme of transects perpendicular to the ice edge extending ~100km into the open ocean and penetrating a similar distance into the sea ice. These transects would be repeated several times over the period of ice retreat and during the development of the spring "bloom" to document ice decay, albedo changes, and possible seeding by sea-ice algae.

Within the pack, the ice thickness, radiation budget, melting rate, presence of sea-ice algae, trace element abundances and their transfer to the underlying ocean are all important, and should be measured to support the joint objectives of ASPECT and EASIZ. Coring and sampling of the bottom of the ice, and underway measurements of water column nutrients, fluorescence, pCO_2, etc. are also required.

In the open ocean, water column stratification, trace and major nutrient availability, light availability, phytoplankton abundance and productivity, and particle export from the euphotic zone are among the desirable measurements. While most of the activity is likely to be within the top 200 metres, deeper casts to ~1000m are important to look at source strengths for vertical mixing of warmer waters, trace metals and nutrients; to provide baseline values for fluorescence, dissolved organic carbon, suspended particles; and to examine the nature and rate of mesopelagic remineralization via particle C/N/P ratios and dissolved oxygen measurements. Free drifting sediment traps are desirable. It is important to extend the study well out into the open ocean, as increased spring activity can also occur there, so that the ice edge effect can be placed in the context of its surroundings.

8. Other Considerations

Historical data

Historical data, in the form of ice charts and analogue or narrative reports on ice conditions, exist in the archives of a number of National Programmes. For example the Russian programme has archived data (in hard copy form) of ice observations made from the scientific ships during Antarctic cruises since 1956. ASPECT is investigating the feasibility of analysing and translating such data into a quantitative data base to further contribute to a climatology of the Antarctic Sea Ice Zone. This would permit extension of the most recent (since about 1988) quantitative ship-based ice observations back in time and over a wider region. It may be possible to generate ice thickness distribution information for the period October-November over about 70% of the sea ice zone. This is a sizeable first step in the ASPECT goal to obtain a sea ice climatology, without the necessity of new cruises.

Remote sensing

Remotely sensed data will continue to be a principal tool of sea ice zone research. However there remain uncertainties in the interpretation of even such basic data as that from the SSM/I passive microwave sensors. ASPECT transects offer the opportunity to obtain systematic ground-truth data to improve current passive microwave algorithms, and for the interpretation of the new generation of active radar sounders.

The new generation of radar satellites, such as ERS series and RADARSAT, provide a capability of high resolution imaging regardless of cloud or light conditions. Presently however, no processing capability exists which can perform routine processing of Antarctic radar data to provide geophysical sea ice products. The development of an Antarctic Radarsat Geophysical Processing System would support ASPECT objectives.

Modelling

An important function of ASPECT is to provide modellers with both forcing data (data to initialise the model) and validation data (independent data to verify the model) from a region where there are presently few such data. The physical climate modelling of Antarctic sea ice, and to some extent of ice-ocean interaction, is presently within the purview of the Sea Ice/Ocean Modelling Panel of ACSYS. A particular emphasis of the ACSYS SIOM Panel has been model development suitable for incorporation into interactive global numerical circulation studies, an activity clearly of interest to CLIVAR. ACSYS will continue its involvement in Antarctic sea ice issues, and ASPECT will work though ACSYS and CLIVAR to ensure the essential global integration of Antarctic regional data. ASPECT will also provide the process information necessary to improve sea ice parameterization schemes in coupled climate models.

Both SO-JGOFS and SO-GLOBEC include modelling components. One aim of SO-JGOFS is to model the carbon cycle, and this includes modelling of the impact of sea ice on the development of phytoplankton. JGOFS is especially concerned with developing regional and large-scale models, and would welcome development of models that include sea ice.

Data

ASPECT, in consort with the SCAR Global Change Office, will establish and maintain a sea ice climatology data set based on contributed shipboard observations (in standard format). Other data management policy issues (e.g. centralised or distributed systems) will require further consideration as part of the implementation plan. It will be important to identify any needs for data exchange with other international programmes and problems with restricted access to data.

9. Management

ASPECT will be managed by a Scientific Steering Group (SSG), composed of scientists working in relevant fields. It is essential that a representative of the EASIZ SSG is one of the members of the ASPECT Group, and vice versa. The SSG will be responsible for developing an ASPECT implementation plan, continually refining and updating the ASPECT science plan, and promoting and co-ordinating ASPECT activities. Much of the work of the SSG will be done by e-mail, but it will be necessary for the SSG to meet once a year. The SSG will maintain close links with, and representation where appropriate on, other relevant international programmes. Workshops with broad international representation should be held when necessary to plan multi-national projects, and to review results and progress.

Close contact should be maintained with the Council of Managers of National Antarctic Programmes (COMNAP) to co-ordinate logistic support requirements.

One member of the ASPECT SSG should be a member of GLOCHANT itself. The SCAR Global Change Office should be responsible for the day-to-day operation of ASPECT and for tasks such as Newsletter production, meeting organisation, and possibly data base management.

Appendix A

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Appendix B — Proposed 1997-98 milestones for ASPECT

- Completion of the ASPECT Science Plan.
- Appointment of an SSG and development of an implementation plan.
- Development of observational protocols and an observer's handbook.
- Establish an inventory of potential contributors and forthcoming cruises.
- Preliminary planning workshop for the US/Australia bilateral coastal polynya study.
- Compilation of existing data to define "best-estimate" of October-November ice and snow thickness distribution.
- Establish the ASPECT ice-climatology data base at the SCAR Global Change Office. Contributions to the climatology received from both scientific cruises, and cruises of opportunity.
- Hold a planning/training workshop for the ASPECT transect project.
- Integration of identified national programmes into ASPECT goals (e.g. March 1998, UK, sea ice formation at ice shelf edge; September 1998, US/Australia, coastal polynya study).

Appendix C — Shipboard ice observation protocols

Using simple, but quantified observations from vessels traversing the sea ice zone, it is possible to derive information on the ice and snow thickness distributions, and their regional and seasonal variability. Underway ship-board observations are able to provide useful information, particularly of the relatively undeformed ice between ridges, because much of the pack area in the Antarctic is composed of floes 0.7 m or less in thickness. Such observations obviously do not compare with instrumentally derived records for precision, but data can be collected over large areas and, provided the data base is large enough, have been show to provide statistically meaningful thickness distributions. The observations are far less reliable in ridged or heavily deformed ice, and proper account must be made for the bias that arises from the vessel's route, particularly for non ice-breaking ships.

The method used for several years by a number of nations, and forming the basis of the ASPECT ice thickness climatology, makes use of three different types of observations. Each type of observation has different strengths and weaknesses, but they can be combined to provide a best-estimate distribution.

A In the first observation, estimates are made of the ice and snow cover thicknesses of individual floes tipped up by the passage of the ship. These measurements are made once per hour on 25 randomly selected floes. A 40 cm diameter buoy, hung on a rope over the side of the ship and approximately 1 m above the ice, provides a scale for the thickness estimates. The data are edited to exclude any observation within 6 nautical miles of the previous observation, to avoid biasing caused by slow progress in heavy ice conditions.

Individual ship-based estimates from overturned floes are accurate to about 0.1 m in thickness, but depend on floes turning sufficiently for their keels become clearly visible. However, the sample may be biased because a high percentage of ridged floes (which represent the thickest ice in the pack) tend to break into their component parts when hit by the ship and are not measured; and in low concentration pack near the ice edge, floes tend to be pushed aside rather than turning over, making such observations impossible.

B For the second observation, an observer, usually on the bridge of the vessel, visually estimates the thickness, concentration, and snow cover of the three dominant ice thickness categories (based on the WMO classification) in the vicinity (~0.5 nautical mile) of the vessel. Thickness estimates are supported by the observations on over-turned floes, as above. The data are entered on log sheets using a code for different classifications

Ice concentration: The fractional ice concentration in each of the 3 dominant ice categories.

Ice type: For each category: based on the WMO classifications, but also including three different new ice types and brash.

Ice and snow thickness: For most thin ice categories ice thickness is a redundant check of ice type estimates.

Floe size: Classified into approximately logarithmic spaced bins.

Topography: Generally only the thickness of level ice is estimated. But the extent (area and sail height) of ridging is also estimated to derive an approximation of total ice mass using a simple model which assumes that the overall pack is in hydrostatic balance, and that ridge sails have a triangular section. The inadequacies of this model are acknowledged, but there is clearly a need for such a correction if realistic average ice thicknesses over large areas of the pack are to be determined from the ship-based observations. The topography code also includes a descriptor for the state of consolidation and weathering of ridges.

Snow Type: A descriptor, used primarily for estimating area-averaged surface albedo.

Open Water: A descriptor. Again the data are edited to exclude any observation within 6 nautical miles of the previous one.

Individually these visual estimates provide the least accurate ice and snow thickness, but they do provide a reasonable estimate of the areal coverage of different ice thickness categories and of their topography. They give a good estimate of the thin ice end of the distribution (since the thickness of new snow-free ice is distinguishable by its albedo) and of the open water fraction within the pack. They also provide (albeit very crudely) an estimate of ridged ice.

C From some vessels direct thickness measurement can be made *in situ* by drilling, preferably along transects across floes. Such observations are necessarily limited in number, and do not represent very thin or unconsolidated ice which is dangerous to access; nor do they represent very thick, heavily ridged floes which the ship is unable to penetrate (e.g. multi-year ice or very heavy first year ice), and which would be extremely time consuming to sample.

Observational bias is a concern when making sea ice observations from a ship because of the inherent tendency to avoid heavy ice and follow easily navigable routes. On cruises entirely dedicated to sea ice research, the ship's course can be chosen to minimise this bias, but some areas of extreme ridging or multi-year ice may remain unsampled. In practice however the three different methods have been shown to give surprisingly similar thickness distributions over a range of thicknesses from about 0.3 m to 1.2 m, with method B providing a reasonable information on the thinner ice.

These methods, and the results derived from them, are detailed further in *Allison and Worby* [1994], *Worby and Jeffries* [in press] and *Worby et al.*, [in press]. The ASPECT SSG will produce and distribute an observational manual, logging sheets, and software for checking and analysing the data.

Appendix D Geochemical and trace metal studies of sea ice in ASPECT.

(Contributed by G. Dieckmann)

1. Introduction

ASPECT provides an opportunity also to address some of questions asked about the polar oceans, by palaeo-oceanographers, biological oceanographers and modellers. As far as the sea ice zone is concerned, these problems are not covered by other programmes. They will fit well into a multidisciplinary sea ice project, represent a rather novel approach to sea ice research, and could be integrated into ASPECT standard analyses of sea ice cores.

2. Geochemistry of Sea Ice

Question:

Do changes (physical, biological, chemical) in the geochemistry of sea ice affect the isotope fractionation of sea ice biota and consequently the isotope ratios of sequestered particulate matter. i.e. are they likely to be reflected in sediment cores?

Rationale:

Biological removal of CO_2 from sea ice (interstitial brine) may have important implications for the $^{13}C/^{12}C$ isotopic composition of particulate matter derived from sea ice. Photosynthesis limited by CO_2 diffusion results in reduced enzymatic ^{13}C discrimination, elevating the ^{13}C of the organic fraction ($^{13}C_{org}$). Uptake of HCO_3, supplementing CO_2 diffusion into cells would similarly increase $^{13}C_{org}$. It is plausible that CO_2 (aq) depletion during periods of high primary productivity enhances ice algal $^{13}C_{org}$ to values significantly above those measured in surface water phytoplankton. The $^{13}C_{org}$ in sedimentary records has been proposed as a proxy for past sea surface CO_2 (aq) concentrations and there is evidence that sea ice-derived organic carbon contributes significantly to sedimentary C_{org}. Consequently, the alteration of the sedimentary $^{13}C_{org}$ via input of ^{13}C-enriched organic carbon from sea ice should be considered when reconstructing past sea surface CO_2 (aq) concentrations from $^{13}C_{org}$ data in seasonally ice-covered regions of the Polar Oceans.

Neogloboquadrina pachyderma (Ehrenberg, 1861) is the only true subantarctic pelagic foraminifera. It has been found in new ice, congelation ice and the underlying water column of the Weddell Sea. *N. pachyderma* is incorporated into the ice in large numbers at the time of its formation. An investigation in the Weddell Sea revealed the average number of foraminifera per litre of ice to be 87 with numbers ranging between 0 and 1075. Sea ice there contained 70 times more foraminifera per unit volume than the underlying water column and on an aerial basis the sea ice cover has approximately the same number as 60 m of underlying water column. The foraminifera are usually incorporated into the ice when it is being formed dynamically and are thus subsequently associated mainly with granular ice. Many foraminifera are able to survive and grow in the ice where algal biomass in winter is high compared to the water column, perhaps indicating an overwintering strategy. These observations may have implications for palaeo-oceanographers. *N. pachyderma* abundance and chemistry have long been used as tools for monitoring polar surface-ocean changes, and for correlating these changes to fluctuations in atmospheric and thermohaline circulation. In polar regions *N. pachyderma* comprises more than 90% of the marine surface sediment assemblage. Thus this species provides an important ecological and geochemical proxy of past polar ocean temperature, salinity and nutrient conditions.

Gradients in the rate of evaporation and precipitation with latitude result in an approximately linear salinity-$\partial^{18}O$ relationship (cf. multiple stage distillation). In higher latitudes, linear salinity- ^{18}O relationship is governed primarily by a two component mixing process of glacial meltwaters from the high latitudes with mean ocean water. Therefore, ^{18}O compositions of sea surface waters can be estimated from salinity. In high latitude surface waters, however, sea-ice formation and meltwater input can locally result in an increase in salinity without an observable change of the water isotopic composition and thus decouple the S- ^{18}O relationship. Consequently, for areas influenced by sea-ice formation or meltwater, independent salinity- ^{18}O relationships must be generated because modern calibration studies show discrepancies between isotopically derived and ecologically derived sea surface temperature estimates.

Objective:

To determine the impact of geochemical changes within sea ice on the isotope relationships of the sea ice biota. Consequences for the sedimentary record past and present?

3. Trace Metals (Fe, Mn) in Sea Ice

The hypothesis that Antarctic phytoplankton suffers from iron deficiency, thus preventing blooming and the exhaustion of the high concentrations of macronutrients, has not been entirely resolved. The role of sea ice, in particular is little understood. Evidence of high iron concentrations in sea ice indicates that iron may accumulate there and become available upon melting thus possibly contributing to the favourable conditions which lead to the often described localized ice edge blooms. The verification of the role of sea ice, other than its effect of stabilizing the surface water layer, is thus an important goal.

Objective:

To investigate whether sea acts as an accumulator of trace metals and weather elevated concentrations in melting sea ice (e.g. Fe) account for localized enhanced primary productivity in surface waters?

Appendix E

List of Acronyms and abbreviations.

ACDP	Acoustic Doppler current profiler
ACSYS	Arctic Climate System Study (WCRP)
ACSYS-SIOM	ACSYS– Sea Ice/Ocean Modelling Panel
AnITRP	Antarctic Ice Thickness Research Project (WCRP)
ANZFLUX	Antarctic Zone Flux experiment
APIS	Antarctic Pack-Ice Seals programme (SCAR)
ASPECT	Antarctic Sea-Ice Processes, Ecosystems and Climate (SCAR-GLOCHANT)
AUV	Automatic Underwater Vehicle
BIOMASS	Biological Investigations of Marine Antarctic Systems and Stocks (SCAR)
BIOTAS	Biological Investigations of Terrestrial Antarctic Systems
CCCO	SCOR Committee on Climate Change and the Oceans
CLIVAR	Climate Variability and Prediction Research (WCRP)
COMNAP	Council of Managers of National Antarctic Programmes
EASIZ	Ecology of the Antarctic Sea-Ice Zone (SCAR-GoSSOE)
CTD	Conductivity Temperature Depth (probe)
DecCen	Decadal to Centennial climate variability and predictability (CLIVAR)
ECMWF	European Centre for Medium Range Weather Forecasts
ERS	Earth Resources Satellite, European Space Agency
GCOS	Global Climate Observing System
GLOBEC	Global Ocean Ecosystems Dynamics Research (IGBP)
GOOS	Global Ocean Observing System
GoSSOE	Group of Specialists on Southern Ocean Ecology (SCAR)
HNLC	High nutrient-low chlorophyll
HSSW	High Salinity Shelf Water
IAnZone	International Coordination of Oceanographic Research within the Antarctic Zone
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Programme
IOC	International Oceanographic Commission
IPAB	International Programme for Antarctic Buoys (WCRP)
IPCC	Intergovernmental Panel on Climate Change
ISW	Ice Shelf Water
JGOFS	Joint Global Ocean Flux Study (SCOR and IGBP)
JSC	Joint Scientific Committee for WCRP
MIZ	Marginal Ice Zone
ROV	Remote Observational Vehicle
SCAR	Scientific Committee on Antarctic Research
SSG	Scientific Steering Group
SSM/I	Special Sensor Microwave Imager, DMSP Satellite Program
SCOR	Scientific Committee on Oceanic Research
SO-JGOFS	Southern Ocean - JGOFS
TOGA	Tropical Ocean and Global Atmosphere Experiment (WCRP)
UNEP	United Nations Environment Programme
UV	Ultraviolet Radiation
WCRP	World Climate Research Programme
WG	Working Group
WMO	World Meteorological Organization
WMO-CAS	WMO–Commission on Atmospheric Sciences
WOCE	World Ocean Circulation Experiment (WCRP)
WSBW	Weddell Sea Bottom Water

APPENDIX 3

SCAR Proposal
August 1996

A SCAR-GLOCHANT proposal for a workshop initiative on the Late Quaternary Sedimentary Record of the Antarctic Ice Margin Evolution (ANTIME)

Executive Summary

It was the original intention of SCAR-GLOCHANT in 1991 to establish a project on Palaeoenvironments from Antarctic ice cores and the sedimentary record. This has partially been achieved through the establishment of a programme on Palaeoenvironments for Ice Cores (PICE). PICE has been approved by the IGBP PAGES SSC and is co-sponsored by GLOCHANT and PAGES. This proposal outlines the need to work towards the establishment of a sister programme to study the record of palaeo-environmental changes contained in the Late Quaternary Antarctic sedimentary record (last 250,000 years), in the marine, coastal, lacustrine, and glacial environments. The Antarctic sedimentary record has already yielded high-resolution information on palaeoenvironmental and palaeoclimatic changes, particularly on ice marginal and outlet glacier fluctuations and in lacustrine and marine ecology and biogeochemistry. A coordinated SCAR initiative on circumpolar palaeoenvironmental research, particularly a detailed component on the last 20,000 years, including the very high-resolution Holocene records, would provide a solid basis for the understanding of present and future variability in the Antarctic, when combined with the ice-core records. It is important that the palaeoenvironmental data from ice cores and the sedimentary record be correlated to allow the optimum understanding of past circumpolar changes. It is recommended that the ANTIME initiative focuses on two streams: Stream 1 (last 20,000 years) on the last deglaciation and interglacial environmental, climatic, and ice-sheet variability; and Stream 2 (last 250,000) on the environmental, climatic, and ice-sheet response to glacial-interglacial cycles. These are slightly different from the PAGES timescales, but are considered to be more appropriate to circumpolar studies.

The proposed ANTIME initiative would first involve the convening of an international workshop for SCAR palaeoenvironmental scientists. It is the intention to obtain joint sponsorship of this workshop with PAGES. The workshop would address the status of knowledge in the following key topics:

- The extent, timing, and regional differences of the Last Glacial Maximum in Antarctica;
- What rapid or episodic events occurred during the Late Quaternary?
- What are the key forcings and feedbacks that influence the retreat and readvance of the Antarctic ice sheet?
- What changes have occurred to the ice shelves and outlet glaciers during the Holocene?
- Technology coordination; and,
- Correlation of Late Quaternary Antarctic environmental history and deep ocean sedimentary records

This workshop is proposed to take place in Hobart, in July, 1997, in conjunction with the Symposium on Antarctica and Global Change. The workshop would allow a review of existing SCAR national programmes and the status of current knowledge on the Late Quaternary environmental change within the Antarctic region. It will also facilitate the identification of priority geographic regions and field and analysis tasks, which would benefit from a multi-national approach. The workshop is seen as a first step in the correlation of circum-Antarctic palaeoenvironmental records from ice cores and the sedimentary record, which is required to understand past circumpolar changes.

Introduction

The physical and dynamical processes controlling the nature of the Antarctic ice sheet and the surrounding oceans have been found to be highly variable, both geographically and temporally, on interannual to interdecadal timescales. Because of this large background variability and because instrumental records span such a short time span, it is difficult to predict the responses of the ice sheet to future forcings, such as global warming. Attempts to determine this variability on century to millennial time scales by medium depth ice-core drilling and analysis have been only partially successful. Ice cores have provided detailed historical information on climatic variability, with respect to changes in temperature, relative humidity, moisture source, and atmospheric circulation. They cover periods from the last few hundred years to the last 10,000 years, at Law Dome and Taylor Dome, East Antarctica, and Dyer Plateau, Antarctic Peninsula, and over the past ~250,000 years at Vostok and Dome C, in the East Antarctic interior. The new Law Dome summit core may provide a detailed climatic record over the Holocene and perhaps the Late Pleistocene transition, whilst the proposed Siple Dome and Byrd Basin cores may also provide a detailed Holocene climatic and late glacial history of the West Antarctic ice sheet. In addition, the present and proposed deep drilling activities at Dome C and Dronning Maud Land (EPICA) and Dome Fuji (Japan), will result in new ice-core records covering multiple glacial-interglacial cycles. However, the ice-coring projects to date have experienced significant difficulties in absolute dating and in providing temporal data on changes in ice-sheet elevation and fluctuations in ice dynamics during the Holocene and Late Pleistocene. This information is vital if we are to understand the response of the ice sheet to climatic variability as well as other forcing mechanisms (ie. rising sea-level and deformation of the bed on which the ice sheet rests).

This difficulty might be overcome by utilising the geological record. The Antarctic sedimentary record in the marine, coastal, lacustrine, and glacial environments has already yielded high-resolution information on palaeoenvironmental and palaeoclimatic changes, particularly on ice marginal and outlet glacier fluctuations and in lacustrine and marine ecology and biogeochemistry. We believe that a coordinated SCAR initiative on circumpolar palaeoenvironmental research, focussed on the Late Quaternary (last 250,000 years) Antarctic sedimentary record, particularly a detailed component on the last 20,000 years, including the very high-resolution Holocene records, would provide a solid basis for the understanding of present and future variability in the Antarctic, when combined with the ice-core records.

Proposed ANTIME Initiative

SCAR-GLOCHANT has developed a joint initiative with IGBP-PAGES on coordinating Antarctic ice-core drilling and the analysis of ice-core records, known as 'Palaeoenvironments from Ice Cores' (PICE). The PICE science plan is entitled, "An international strategy for ice-core drilling in Antarctica -- Reducing uncertainty in global environmental change". PICE will investigate ice-sheet palaeoenvironments on two time scales, Stream 1 (the last 2,000 years), and Stream 2 (the last 250,000 years). It was the original intention of SCAR-GLOCHANT in 1991 to also develop a sister project on Palaeoenvironments from the Antarctic sedimentary record. However, this has not been initiated to date, and this proposal outlines the need and context for such a project and probable linkages or joint sponsorship from other organisations such as the IGBP-PAGES.

At present, Quaternary research is conducted around the Antarctic ice margin by scientists from a number of nations. Quaternary sequences have been cored on the continental shelf by marine geological programmes and have been partially recorded by seismic surveys conducted by the SCAR-ANTOSTRAT programme, although the later surveys were low resolution and did not resolve the younger Quaternary strata. However, most of the Late Quaternary and Holocene research has been focused on the inner continental shelf, in the coastal zone in fjords and beach sequences, and in the vicinity of the terrestrial ice margin and adjacent lakes. As with the GLOCHANT-PAGES programme on ice coring, there is a strong need to coordinate the international research on the variability and evolution of the Antarctic ice margin to maximise the international resources and target the Antarctic areas of most mutual interest. A coordinated effort would allow international resources to be available for specific regional projects and allow for efficient exchange and correlation of findings between the sedimentary and ice-core science communities. Such an exchange of data and correlation of findings could be a major focus for a GLOCHANT/PAGES initiative. It is also important to recognise that a multi-disciplinary approach including geology, glaciology, chemistry, and biology is required to develop fully a comprehensive palaeoenvironmental history.

We propose that GLOCHANT and the Working Groups on Geology and Solid Earth Geophysics jointly develop a SCAR initiative to coordinate research on the Late Quaternary Antarctic sedimentary record, which we refer to at this stage as ANTIME (Antarctic Ice Margin Evolution). We envisage that ANTIME together with the ice-core project will form the SCAR contribution to PAGES and that it will complement the PAGES/SCOR IMAGES transects in the circum-Antarctic regions. We are investigating a joint sponsorship of the initiative with the International Union for Quaternary Research (INQUA) and whether some aspects may contribute to the International Geological Correlation Project (IGCP). There is the potential for a strong linkage between ANTIME and the SCAR EASIZ programme with respect to the post-glacial evolution of the continental shelf, coastal zone, and the coupled ecosystem development.

A priority for ANTIME is the drilling and retrieval of a long continuous core that spans at least the last 250,000 years. Such a core would provide the data source necessary to correlate and reconcile the ice sheet and environmental history with that determined from the continental shelf and deep ocean. A second priority for ANTIME is to plan for the retrieval of a number of cores that span the Holocene from geographically widespread locations in the vicinity of outlet glaciers and ice shelves around Antarctica. These are required to resolve high-resolution palaeoenvironmental and palaeoclimatic records, which are comparable to the younger ice-core records. On the basis of these priorities it is recommended that the ANTIME project focus on two streams: Stream 1 (last 20,000 years) on the last deglaciation and interglacial environmental, climatic, and ice-sheet variability; and Stream 2 (last 250,000) on the environmental, climatic, and ice-sheet response to glacial-interglacial cycles. These are slightly different from the PAGES timescales but are considered to be more appropriate to circumpolar studies.

It is proposed to commence this initiative by organising a SCAR sponsored International Workshop, at Hobart in 1997, in conjunction with the Symposium on Antarctic and Global Change, to: discuss the state-of-the-art palaeoenvironmental data on the Late Quaternary in Antarctica; plan future multi-national field programmes; and plan for the coordination of technology and stratigraphic correlations. It is intended that representatives from all the marine and glacial geological programmes in SCAR countries should be invited to the proposed workshop, together with representatives from PAGES. The key themes for the workshop are outlined below.

Key Themes for the ANTIME Initiative

1. The Extent, Timing and Regional Differences of the Last Glacial Maximum in Antarctica

Our present state of knowledge on the timing of the Last Glacial Maximum (LGM) in Antarctica is scant and contradictory. Investigations of the marine sedimentary record on the continental shelf in East Antarctica and in the Weddell and Ross Seas suggest that the ice sheet may have been grounded near the continental shelf break sometime during the last glacial cycle. The East Antarctic onshore geologic record of isostatic and relative sea-level changes and glacial fluctuations indicates that a much smaller ice-sheet expansion occurred at the time of the Northern Hemisphere (LGM) around 18,000 to 20,000 yr B.P. (Colhoun *et al.*, 1992). In fact, the maximum post-glacial emergence is an order of magnitude less than in the Arctic since the LGM. The marine evidence from the western Ross Embayment suggests that at 18,000 yr B.P. the grounded Ross Ice Sheet possibly extended only onto the middle shelf near Coulman Island (Licht, 1996). More cores are required in the central and eastern Ross Sea to confirm this. A fundamental question remains: were the Antarctic ice sheets at their maxima during the Northern Hemisphere LGM or at some earlier time in the last glacial cycle? Were the glacial maxima of the East Antarctic and West Antarctic Ice Sheets in phase or were they regionally offset? These are important gaps in our knowledge and understanding of the Antarctic response to climatic and sea-level forcings. This is also a crucial question for the resolution of global sea-level fluctuations and the calibration of ice-sheet models such as that of (Huybrechts, 1992) that are used to predict the future response of the ice sheets to global warming. There are two opposing views on the sea-level contribution of Antarctica during the LGM: (Colhoun *et al.*, 1992) presented the minimum estimate of between 2.5 and 5m, which was biased towards the East Antarctic raised beach evidence, whereas Tushingham and Peltier (1991) and Nakada and Lambeck (1988) apply a much larger sea-level contribution of 25m and 35 m, respectively, in their global relative sea-level modelling experiments.

To rectify these gaps and address these divergent views, it is necessary to broaden the geographic coverage; this, in turn, requires international participation in onshore and marine programmes. A SCAR initiative would provide the opportunity for international cooperation in marine geological and geophysical surveys: on the East Antarctic shelf basins, including, the Mertz-Ninnis Trough, the Totten Trough, Prydz Bay, Lutzow-Holm Bay, and the Rennick Trough; in the Ross Sea; in West Antarctica at Pine Island Bay and along the west coast of Graham Land; and on the South Orkney Plateau. An international effort focusing on high-resolution seismic surveys using a sparker and 3.5 kHz equipment is required, together with the drilling of long sediment cores and more detailed work on the recognition of glaciomarine, iceberg turbate, and subglacial diamicton facies transitions. The ANTOSTRAT project has led to the collection and establishment of a detailed seismic library on the continental shelf stratigraphy. However, the Late Quaternary is not well represented because it is a shallow sequence and is often located in the bubble pulse of the ANTOSTRAT seismic surveys, which were optimised for the earlier Cenozoic record.

It will be necessary to focus onshore studies of Late Quaternary glacial geology, palaeobiology, and geochemistry in the priority regions adjacent to high-resolution seismic surveys and marine coring sites, to enable correlations to be made and to gain a better understanding of the nature and mechanisms of palaeo-environmental change. Regional analysis of the onshore and offshore sedimentary records, together with data on postglacial relative sea-level change and isostatic rebound, will enable the nature and extent of the coastal ice-sheet expansion to be established. It is necessary to correlate the palaeo-geography and timing of the coastal ice-sheet expansion during the last glacial cycle with the marine geological evidence, to understand the response of the Antarctic drainage basins to climatic and sea-level change.

2. What Rapid or Episodic Events Occurred during the Late Quaternary?

The emerging bipolar data sets are suggesting that rapid change and episodic events have characterised the Late Quaternary environment, rather than slow transformations from interglacial to glacial climates. These events have been associated with a rapid response of the polar ice sheets to abrupt climatic changes over much shorter intervals than the orbitally modulated 20 kyr to 100 kyr Milankovitch insolation cycles and include:

- Dansgaard-Oeschger glacial interstadial (warm) events with a duration of 200 to 2,500 yr;
- Rapid sea-level changes;
- Abrupt temperature changes such as during the Younger Dryas event, now believed to have been global;
- Pulses of (ice-rafted) glacimarine sedimentation, known as Heinrich events, in the North Altantic Ocean;
- Ice surges and fast flow events in the northern Hemisphere and in the Antarctic Peninsula region.

However, we do not know how many, if any, of these episodic and rapid events occurred in mainland Antarctica, nor do we know whether they are triggered by global forcings. If the latter is the case, then rapid or episodic changes, such as those associated with the peak warming of the Last Interglacial (LIG), during oxygen isotope Stage 5e (119,000 to 132,000 yr B.P.), may be typical of the type of change we can expect from future global change. Consequently, it is important that we gain a complete understanding of the nature of these past changes. Investigation and recognition of rapid changes and episodic events in the Antarctic stratigraphic record may make it possible to determine their forcings and to discriminate between events on different time scales. The US West

Antarctic Ice Sheet (WAIS) history and dynamics project on climatic, sea-level, and glaciological interactions includes a significant effort to resolve some of the regional issues in West Antarctica, including the Ross Sea. However, a coordinated effort in West and East Antarctica is required to address both the regional and bipolar climatic and sea-level histories. This is a large undertaking and would significantly benefit from a coordinated multinational effort amongst SCAR countries.

3. What are the Key Forcings and Feedbacks that Influence the Retreat and Re-advance of the Antarctic Ice Sheet?

The major physical change in the Antarctic environment is the fluctuation in geographic extent of the Antarctic ice-sheet margin between glacial and interglacial periods. However, oscillations in the position of the margin, particularly in West Antarctica and along the deep marine embayments in East Antarctica, also likely occurred within the interglacial periods (such as the suggested outlet glacier advance during the Mid-Holocene) and their forcings and response are equally important to resolve.

We know little of the forcing mechanisms that control the retreat, readvance, and stability of the Antarctic ice sheets. It is imperative that we understand these mechanisms if we are going to be able to predict the response of the ice sheet to future global warming. These mechanisms include: eustatic sea-level changes, warm deepwater incursions on the shelf, isostatic loading and unloading in equilibrium or disequilibrium with the ice-sheet status, glacial bed conditions and deformation, ocean circulation, and climatic changes. Only scant evidence for the timing of the post-glacial retreat, from the emergence of coastal bedrock and Holocene raised marine shorelines, has been collected at present. However, these data suggest that the isostatic response around Antarctica differed widely between regions and that the drainage basins may have responded to different forcings.

We need to develop an understanding of the regional evidence, style, rates, extent, and timing of post-glacial retreat. It is important to approach this problem by focusing on:

- Stratigraphic correlation of glacial marine retreat deposits around Antarctica; and
- Correlation of all emerged marine shoreline data around Antarctica and planning for additional fieldwork in unsurveyed regions.

Advance and retreat of the ice sheet and ice shelf have undoubtedly had a significant influence on Antarctic bottom water production. Various workers have attempted to examine the history of Antarctic bottom water by examining the deep sea record, but the results have been mixed. Ledbetter and Ciesielski (1986) argued that Antarctic bottom water production is greatest during glacial maxima, whereas Pudsey (1992) concluded that Antarctic bottom water production decreases during glacial maxima. Ultimately, the linkage between Antarctic bottom water production and glacial conditions on the continent awaits a better understanding of ice-sheet/ice-shelf expansion and contractions during the last few glacial cycles. In this way, ANTIME has a potential contribution to the history of Antarctic bottom water production and a linkage with deep- sea geological investigations undertaken by the IMAGES programme in the Southern Ocean and South Atlantic Ocean.

4. What Changes in the Ice Shelves and Outlet Glaciers have Occurred during the Holocene?

Present data suggest that the ice shelves and outlet glaciers have fluctuated during the Holocene and that these fluctuations have been in response to climatic and oceanic circulation changes. However, little is known of the Holocene climatic record in Antarctica. Evidence from deep ice cores indicates that a climatic optimum occurred during the early Holocene at 11,000 to 9,000 yr B.P., which is significantly earlier than the Mid-Holocene optimum generally recorded at mid- to low-latitude sites. Did the polar regions lead the climatic amelioration during the Holocene? Howard and Prell (1992) presented palaeooceanographic evidence from the southern Indian Ocean that points to a similar climatic optimum in the early parts of interglacial stages 11, 9, 7, and 5.

How have the Antarctic ice sheet, outlet glaciers, and ice shelves responded to small climatic fluctuations during the Holocene. Do our modern observations of ice behaviour reflect these past, rather than modern, climatic fluctuations? The marine sedimentary record is proving to be an important source of data on Holocene climatic change. This has largely been due to the significant advancement in the high-resolution dating of Holocene deposits using AMS ^{14}C techniques and to the identification of inner shelf and fiord locations with high sedimentation rates, which have made it possible to define decadal to century scale variability, such as the 200-yr cycles interpreted in the Antarctic Peninsula sediments (Domack, 1993; Leventer, In press).

Detailed onshore geological studies have demonstrated that the ice margin and outlet glaciers have fluctuated on the timescales of 10 to 1,000 years during the Holocene in response to changes in mass balance. Similarly, direct observations of the modern ice grounding zones using submersible remotely operated vehicles (ROVs) are allowing a picture to develop on the physical, sedimentological and oceanographic processes controlling the location of the ice margin. (Powell pers. comm., 1996) has reported that the sedimentology, sea floor morphology, and epibenthic communities in the McMurdo Sound area all indicate that the major part of the East Antarctic Mackay Glacier grounding line has retreated this century. This retreat has occurred despite rapid sedimentation of glacially transported debris at the grounding line. Antarctic bottom water production displays strong regional differences, especially between the Weddell and Ross sea regions. Observations show that most of the bottom water production takes place in the Weddell Sea, in part due to the interaction between the floating ice shelf and the underlying sea water (Foldvik and Gammelsrod, 1988). The reason for this unexpected difference between the Ross and Weddell Sea regions may be attributed to the different directions of the surface wind field in these regions. The off-shelf wind field in the Ross Sea leads to a compensating flow of warm water onto the continental shelf that may increase the melting near the grounding line, reduce the density of the resulting ice-shelf water and hence reduce the production of bottom water. The sedimentary record can provide boundary conditions on the history of Antarctic ice-shelf bottom water production, the history of shelf break mixing, and the occurrence of coastal and offshore polynyas.

It is difficult to draw continent-wide conclusions from regional ice-shelf and outlet-glacier fluctuations, particularly in regard to the climatic and oceanographic forcings, especially because the East and West Antarctic ice sheets may have responded independently. Consequently, a coordinated international effort is required to ensure a focused and representative regional coverage. Suitable sites include:

- Prydz Bay and the Vestfold Hills
- Vincennes Bay and Law Dome
- Palmer Deep and Livingston Island, Antarctic Peninsula
- Western Ross Sea and the Transantarctic Mountains

5. Technology Coordination

Our knowledge of past glacial and climatic events would be enhanced if technological aspects could be coordinated amongst SCAR nations. The following aspects could be addressed in the proposed SCAR international workshop:

- Continent-wide chronological comparisons of glacial and climatic events have been difficult due to the uncertainty in the radiocarbon ^{14}C reservoir corrections and their changes with time throughout the Late Pleistocene and Holocene. It is important to develop a strategy to determine calibrated reservoir corrections for the terrestrial and marine Antarctic environments with respect to the palaeoceanographic circulation;
- Improvements in seismic stratigraphy and stratigraphic interpretations could be made through a technology comparison of international high-resolution sub-bottom imaging techniques;
- Similarly, an international approach to the standardisation of sedimentological description in Antarctic terrestrial, lacustrine, and marine environments would permit the continent-wide comparison and correlation of geological events;
- Planning the cooperative use of submersible Remote Observational Vehicles (ROV) and the further development of this technology would significantly increase our knowledge of the morphology and sedimentation at modern grounding zones and beneath ice shelves;
- Ship platforms and the capability to drill long sediment cores are highly specialised. The planning of international cruises and the sharing of technology amongst SCAR nations would significantly increase the potential for solving many of the key scientific questions.

6. Correlation of Late Quaternary Antarctic Environmental History and Deep-ocean Sedimentary Records

A key need for the understanding of the relationships between Antarctic glacial history and the record of past global change is for nearshore sedimentary records to be tied to continuous, well-dated, offshore sections. The advantage of this type of integrated approach is that it would maximise the benefits and cover for the shortcomings of both types of sequences. The offshore drilling and coring targets currently under consideration by ODP and IMAGES provide continuous Neogene records to which a battery of proven chronostratigraphic tools can be applied, including magneto- and biostratigraphy and orbital tuning of high-resolution isotopic, lithostratigraphic, and physical properties measurements of whole cores and discrete samples. In the late Quaternary, these types of paleoceanographic records provide important stratigraphic tiepoints between marine and ice-core chronologies. However, the types of far-field measurements available from pelagic sediment sections only provide indirect indicators of the behaviour of the Antarctic ice sheets. For example, oxygen isotopic variations interpreted as records of global ice volume do not resolve the locations and variability of particular ice masses. Antarctic margin sequences, for their parts, are often devoid of the biogenic carbonate needed for stable isotopic measurements and have not provided easily interpretable palaeomagnetic records (notable exceptions include the Antarctic margin records of Grobe and Mackensen (1992). Similarly, despite several DSDP/ODP legs to Antarctic margin targets, much work remains to be done to tie high-latitude siliceous biostratigraphies into low-latitude, largely calcareous-based biostratigraphic schemes. A particularly glaring need is for nearshore-offshore transects in the Pacific Sector of the Antarctic. Most of the paleoceanographic community's understanding of the Southern Ocean comes from the Atlantic (eg. Charles and Fairbanks, 1992) and Indian (eg. Howard and Prell, 1992) Sectors and they assume that these histories characterise the overall Southern Ocean response to a (presumed) essentially Northern Hemisphere forcing (orbital forcing and North Atlantic Deep Water variability). The Southern Ocean may show considerable regional variability, especially if the near-field effects of ice-sheet dynamics play an important role in Southern Ocean circulation (a Southern Hemisphere counterpoint to the Heinrich events of the North Atlantic). In this case the East and West Antarctic ice sheets may behave quite differently and independently and drive sector-scale variability in the flux of meltwater and ice-rafted debris.

It is proposed that a direct linkage between the SCAR ANTIME initiative and the IMAGES and ODP programmes will optimise the possibilities for the correlation of the Antarctic and deep Southern Ocean sedimentary records. This will form a major SCAR contribution to the IGBP PAGES programme.

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List of Acronyms

ANTIME	Antarctic Ice Margin Evolution (SCAR)
ANTOSTRAT	Antarctic Offshore Stratigraphy (SCAR)
DSDP	Deep Sea Drilling Program
EPICA	European Programme for Ice Coring in Antarctica
GLOCHANT	Group of Specialists on Global Change and the Antarctic (SCAR)
IGCP	International Geological Correlation Project (IUGS/UNESCO)
IMAGES	International Marine Global Change Study (SCOR/PAGES)
INQUA	International Union for Quaternary Research (ICSU)
ODP	Ocean Drilling Program
PAGES	Past Global Changes (IGBP)
PICE	Palaeoenvironments from Ice Cores (SCAR-GLOCHANT)
WAIS	West Antarctic Ice Sheet

APPENDIX 4

Summary Report from the GLOCHANT/PAGES Workshop on the ITASE Programme, Cambridge, U.K.

2-3 August, 1996

1. An Overview of ITASE - 200 Years of Past Antarctic Climate and Environmental Change

The proposed International Trans-Antarctic Scientific Expedition (ITASE), was endorsed by two of the Working Groups that met at the workshop of the SCAR Steering Committee for the IGBP in Bremerhaven in 1991. Consequently, it was identified as "expected to make a major contribution to two of the core projects in "The Role of the Antarctic in Global Change", those relating to the palaeoenvironmental record and ice-sheet mass balance. It was formally endorsed by the Working Group on Glaciology and approved by the Delegates as Recommendation Glaciology XXII-5, and was subsequently formally endorsed by the GoS/GLOCHANT at their 4th Annual meeting in April, 1996, at Madison, Wisconsin, USA. ITASE has also been formally approved and adopted by the IGBP PAGES core project under their Focus II on Antarctic Palaeoenvironments, it is also a contribution to the IGBP International Global Atmospheric Chemistry (IGAC) core project under their focus on Polar Air Snow Chemistry (PASC), and it links to SCAR-BIOTAS, SO-JGOFS and WCRP-CLIVAR. Some ITASE traverses have been completed by national programmes, including those of the Chinese, British and the Swedish/Norwegian programmes, since 1992.

The broad aim of ITASE is to establish how the modern atmospheric environment (climate and atmospheric composition) is represented in the upper layers of the Antarctic ice sheet. Primary emphasis is placed on the last ~200 years of the record. This time period was chosen for study because it is relatively simple to recover many ice cores covering this period, and to develop a spatially significant study. Even more importantly, this time period covers the onset of major anthropogenic involvement in the atmosphere, and the end of the Little Ice Age. A revised science and implementation plan for ITASE is in preparation. An international ITASE workshop was held in Cambridge, on the 2-3 August, 1996, prior to XXIV SCAR. The workshop was co-sponsored by PAGES, GLOCHANT and the US NSF, with substantial financial support from PAGES and US NSF. This report summarises the major resolutions, recommendations and field planning which were determined at the workshop.

2. ITASE Objectives

Specific ITASE objectives are:

- **To determine the spatial variability of Antarctic climate (eg accumulation, air temperature, atmospheric circulation) over the last 200 yrs.**

These variations include;

- Extreme events such as volcanic eruptions, dust storms, drought
- Major atmospheric phenomena (eg. ENSO) snow accumulation variations

This extended climatic depiction for the major global atmospheric heat sink will be unrivalled for 10% of the earth's land surface.

- **To determine the environmental variability in Antarctica over the last 200 yrs.**

Environmental proxies could include: sea ice variation, ocean productivity, anthropogenic impacts, and other, extra-Antarctic continental influences.

Because of the remoteness of the continent, Antarctica is an ideal location to monitor biogeochemical cycles and global scale changes.

In fulfilling these objectives ITASE will:

- Produce continental scale "environmental maps".
- Elucidate transfer functions between components of the atmosphere and snow/ice.
- Verify atmospheric models.
  Interpolate spatial time-series by satellite remote sensing.

3. Proposed Ice Core Measurements

It was agreed that a standardised suite of measurements would be collected from surface snow samples and shallow ice cores on oversnow traverses. These ice core measurements are as follows:

Table 1 - Primary ITASE ice core properties

Accumulation rate	TS*
Gamma-ray and beta detection	TS*
Laser-light scattering	TS*
Electrical conductivity (ECM)	TS*
Dielectric	TS*
Physical properties (size, shape, arrangement of grains, c-axis fabrics, depth-density analyses, melt layers, visible strata)	TS*
Stable isotopes (δD, $\delta^{18}O$ and deuterium excess)	TS*
Major chemistry (Ca, Mg, Na, NH_4, K, Cl, SO_4, NO_3)	TS*
Microparticles	TS*
Other chemistry (F, I, Br, MSA, H_2O_2, HCHO)	TS*
Cosmogenic isotopes (^{10}Be, ^{36}Cl, ^{26}Al)	S*
Temperature	TS

Table 2 - Secondary ITASE ice core properties

Radionuclides *
Tephra *
Trace metals (Se, Pb, Hg, V, Mn)
Trace elements (Cs, Rb, Ba, Sr)
Isotopes (Nd, Sr, Pb)
Gases (CO_2, CH_4, N_2O, CFCs, CO, methyl-halides)
Biological particles (pollen, diatoms)
Biogenic compounds (DMSO, $DMSO_2$)
Organic acids

S = surface
TS = time-series
* = dating control

4. ITASE Research Activities

Participants at the workshop determined that ITASE comprise four research phases, as follows:

PHASE 1	remote sensing, meteorology, geophysics
PHASE 2	ground-based sampling (eg., ice cores, snowpits, ground truth, high resolution radar)
PHASE 3	associated studies (eg., surface glaciology, AWS, aerosol monitoring)
PHASE 4	modelling and interpretation

5. An Overview of Proposed ITASE Fieldwork

The field planning of ITASE has been designed to build upon existing national programmes and their plans for oversnow traverses for the period 1996 to 2002. The majority of proposed traverse routes are already planned to establish and resupply the deep drilling programmes. In this manner ITASE plans to build upon traverses of 'opportunity' for the collection of shallow ice cores at intervals of 100 km along these routes.

6. Summary of the ITASE Cambridge Workshop Agreement

The following resolutions were agreed to by the national representatives and the SCAR Global Change Programme Coordinator.

1. ITASE to be coordinated from the GLOCHANT office in Hobart
2. ITASE Programme members comprises national representatives and the SCAR Global Change Programme Coordinator
3. Hobart office to coordinate the selection of ITASE Programme chair (rotating position)
4. Hobart office (with the help of members of the programme) to:
   - prepare a list of ITASE researchers
   - identify cores of opportunity
   - prepare annual logistics updates
   - thematic maps of exiting data (pre 1990) on accumulation rate, $\delta^{18}O$, temperature and chemistry
   - ITASE post 1990 data updates
   - coordinate an ITASE workshop in late 1997 or early 1998
5. Hobart office to organise (with the help of programme members) and to develop a document on 'Guidelines for the standardisation of Ice Core sampling, analysis and storage methods'
6. ITASE co-sponsored by SCAR-GLOCHANT and PAGES, and forms a major contribution to the joint PAGES/CLIVAR initiative

APPENDIX 5 An overview of Global Change in the Antarctic

Introduction

It was the view of the participants at GLOCHANT IV in Madison, USA, that the importance of the Antarctic as a powerhouse for global changes in climate, sea-level, and ecosystems must be promoted, since it was recognised by the group that this message has been somewhat diluted in recent years amongst the wider global scientific community. As a first step towards addressing this deficiency, the participants at GLOCHANT IV have prepared a sampling of the detected changes in the Antarctic and Southern Ocean. It is recommended by the group that a comprehensive document on the status of global change in the Antarctic should be prepared over the next 2 years, for a wide readership, including the wider community of global policy makers and scientists. It is proposed that the document serve as an update to the previous SCAR publication, *The Role of Antarctica in Global Change*, which was edited by Professor Gunter Weller in 1992. The document would include sections on:

- Decadal-scale changes;
- Seasonal to interannual climate variability;
- Changes in ozone, UV, and atmospheric chemistry;
- Detecting changes in ice cover and terrestrial and marine ecosystems; and
- Past changes and future views.

Decadal Scale Changes in the Southern Ocean

The most conspicuous changes observed in the Southern Ocean on a decadal time scale are associated with the Weddell Polynya, which was observed by satellites during the 1974–79 winter seasons (Gordon, 1978, Martinson *et al.*, 1981). The Weddell Polynya appeared as a huge ice-free area in an otherwise ice-covered region located in the

Central Weddell Gyre near Maud Rise. The intense surface cooling and subsequent deep convection within the polynya cooled the central gyre by nearly 1 °C down to 2700 meters. The Weddell Polynya event stands out as a major perturbation in the ocean and presumably in the climate system as well.

A substantial contribution to the production of Antarctic Bottom Water is due to processes in the Southern Weddell Sea, notably to the cooling and transformation of sea water under the floating Filchner and Ronne Ice Shelves (Foldvik and Gammelsrod, 1988). The available records of temperature and current do not show year-to-year changes of the especially cold Ice Shelf Water produced there. However, an analysis of the Weddell and Ross regions suggests that the markedly different contributions to the ice-shelf-related bottom-water production in these regions may be coupled to differences in the regional wind fields. If this assumption is correct we may expect large variation in bottom-water production and in hydrography on time scales coupled to the variability of the wind field. Recent global ocean modelling has revealed pronounced short-period oscillations, specifically in the Southern Ocean. See Mork and Skagseth (1996) for a discussion of a distinct 45-year period.

Decadal Scale Changes of the Antarctic Ice Sheet

There is abundant evidence that the glaciological characteristics of the Antarctic ice sheet can change significantly, even dramatically, on the time scale of a few decades. Perhaps the most startling evidence has come from the study of the ice streams of the West Antarctic drainage system that flow into the Ross Ice Shelf. There, field evidence (distribution and depths of buried crevasses) reveals that sudden reorganizations of the ice streams have occurred in the last thousand years. Ice stream C abruptly stagnated (Retzlaff and Bentley, 1993), one of the boundaries of neighbouring ice stream B underwent a sudden lateral jump of ten kilometers or so (Bentley *et al.*, 1994), and a portion of ice stream A became quiescent (S. Shabtaie, pers. comm., 1995). In addition, portions of the system are grossly out of balance today -- ice streams B and C are hyperactive (strongly negative mass balance) and stagnant (strongly positive mass balance), respectively (Shabtaie and Bentley, 1987), and Crary Ice Rise (an island of grounded ice in the Ross Ice Shelf near the mouth of ice stream B) is migrating upstream and changing the regional velocity field (MacAyeal, *et al.*, 1987; Bindschadler, 1993). All these imbalances are large enough to cause changes that are readily observable in a decade.

Observations of the Ross Ice Shelf itself also can reveal abrupt changes because tracers of past flow preserved in the shelf can be compared with the present-day flow of the ice (Neal, 1979, Bentley, 1979, Jezek, 1984). One striking deformation of the flow tracers has indeed been found. A few hundred years ago there was a large pulse of ice from the vicinity of ice streams A and B; the flow after that pulse reverted to what it was beforehand (Casassa *et al.*, 1991), apparently as suddenly as it started.

Major changes have occurred in other ice shelves also, particularly along the Antarctic Peninsula. Vaughan and Doake (1996) investigated the relationship between ice shelf retreat in the Antarctic Peninsula and the observed mean trend in atmospheric warming. They found that of the nine ice shelves studied, the five northerly ones have retreated dramatically in the last 50 years, while those farther south showed no clear trend. Comparison with air-temperature data shows that the pattern and magnitude of ice-shelf retreat is consistent with the existence of an abrupt thermal limit on ice-shelf viability, the isotherm associated with this limit having been driven south by the atmospheric warming. This isotherm is the O °C mean monthly January temperature, given by proxy in the climate record as the -5 °C mean annual temperature. The warming observed around the Antarctic Peninsula corresponded to a southward migration of the -5 °C isotherm of 200 km on the west side of the Peninsula but only about 50 km on the east side, due to the influence of the perennial pack ice of the Weddell Sea on the eastern side. Three ice shelves on the west side and two on the east side have disintegrated where the limiting isotherm has intersected them. Ice shelves therefore appear to be sensitive indicators of climate change as indicated by the air temperature and sea-ice studies in the region.

Large interdecadal changes have been reported in the mass input (snow accumulation) rates in several places, particularly in East Antarctica. Morgan *et al.* (1991), from ice core studies in Wilkes Land, showed variability on time scales up to a century, including significant changes since 1950; the present rate is an estimated 20% above the long-term mean, after reaching a minimum around 1960. Mosley-Thompson *et al.* (1995) found a similar 30% increase since 1960 at the South Pole and so did Pourchet *et al.* (1983), on Dome C and Mosley-Thompson *et al.* (1987) in central East Antarctica. Peel (1992) reported a comparable increase from core studies at two sites on the Antarctic Peninsula.

Seasonal to Annual Climate Variability in Antarctica

Recent studies of the variability of surface air temperature and sea-ice climatologies in the western Antarctic Peninsula Region (Smith *et al.*, 1996) have established:

1. a significant warming, strongest in mid-winter (5.5 °C) but also in fall and summer temperatures (4.1 °C and +1.5 °C, respectively) over the 1941-1991 record;
2. a significant anti-correlation between surface-air temperatures and sea-ice extent; and
3. long-term persistence in surface-air temperature and sea-ice anomalies, where two to four low-temperature/high-ice years are followed by one to three high-temperature/low-ice years, a pattern coherent with the Southern Oscillation Index (SOI), indicating that there may be an ENSO teleconnection between the western Antarctic Peninsula region and lower latitudes.

The west coast of the Antarctic Peninsula has been identified as a region of extreme climatic variability and change (King, 1994). The climate record from Faraday station exhibits a high level of interannual variability superimposed on a gradual warming of about 2.5 °C from the late 1940s to the present. The shorter record from Rothera station, 300 km farther south, exhibits similar characteristics. Although the record high temperatures of 1989 (Morrison, 1990) have yet to be equalled, there is no indication that the warming trend has significantly abated. The interannual temperature variations observed in this region are poorly correlated with observations from continental Antarctica and the Peninsula warming trend is much larger than those seen elsewhere in the Antarctic. Precipitation on the west coast of the Peninsula shows a high degree of interannual variability superimposed on a secular increase (Turner *et al.*, in press). Interannual variations in precipitation are, however, poorly correlated with those in temperature and are believed to reflect year-to-year variations in the frequency of synoptic-scale cyclones reaching the region. The association between the longterm trends in temperature and precipitation has yet to be investigated.

Interannual temperature variations on the west coast of the Peninsula are well correlated with fluctuations in sea-ice extent immediately to the west (Weatherly *et al.*, 1991; King, 1994). Because there is a strong feedback between ice extent and temperature, it is not yet clear which one of these processes is driving the other. Significant relationships have been observed between variations in atmospheric circulation and the development of sea-ice anomalies in the Bellingshausen and Amundsen Seas (Harangozo, in press). There is no overall trend in sea-ice extent in this region, but the sea-ice record is short (1973-present) and exhibits large interannual variations. Thus, while atmosphere-ice-ocean coupling is clearly important in driving interannual variability, its role in the longer-term changes is not yet clear.

Murphy *et al.* (1995) have developed a data series on fast-ice duration in the South Orkney Islands from 1904 to present. In the latter part of the record, from the 1960s to the 1990s, there is the onset of interannual cyclicity in the fast-ice duration with a period of 7 to 8 years. This local pattern reflects the general condition for sea-ice distribution, as satellite data have revealed good agreement between the arrival of pack ice around the South Orkney Islands and the onset of fast ice at Signy Island. A principal component analysis also indicated a connection to the El Niño Southern Oscillation (ENSO), with fast-ice duration lagging the ENSO signal by one or two years. Murphy *et al.* (1995) demonstrate further that recent South Orkneys data are good proxies for the northward ice extent in the Weddell Sea. For much of this recent period, the South Orkneys data show a distinct periodicity at about eight years. Examination of sea-ice maps for the whole of Antarctica show that there is no change in overall area covered in winter, but that there is a pattern of ice-extent maxima and minima around the continent that appears to rotate at about 40° longitude per year, entirely consistent with the observed periodicity.

This precession of maximum sea-ice anomalies around Antarctica has become known as the Antarctic Circumpolar Wave (White and Peterson, 1996). White and Peterson (1996) have identified interannual variations in surface atmospheric pressure, sea-ice extent, sea-surface temperature and wind stress in the Southern Ocean. They claim these anomalies propagate eastward with the circumpolar flow, with a period of 4 to 5 years and taking 8 to 10 years to encircle the pole. Comparison with results of Smith *et al.* (1996) for the area to the west of the South Orkney Islands suggests a clockwise circumpolar precession in the position of ice-extent anomalies, in phase with the ENSO signal in the western Antarctic Peninsula and lagging by 1 to 2 years in the region to the east at Signy Island. A second outcome of the study was a clear indication of decline in fast ice over the 1930's to 1950s, with the new, decreased endurance coinciding with the period when the ENSO signal in the variability also became evident.

Changes in Marine Ecosystems

The mechanism and properties of the ENSO in the Equatorial Pacific are well-documented, and teleconnections to other parts of the ocean, especially to the Equatorial Atlantic and to the Indian Ocean, have been demonstrated. Although similar variability has been found in the Southern Ocean, this has so far received less attention, even though it has the potential to provide a direct link between the Southern Hemisphere oceans. Interannual variability in the Southern Ocean manifests itself in changes, both in the large-scale physical environment (see above), and in biological dynamics.

South Georgia is located on the northern part of the Scotia Ridge, situated in the path of the Antarctic Circumpolar Current (ACC) after it passes through the Drake Passage. Research has demonstrated that the environmental variability in the pelagic system around South Georgia is correlated strongly with the South Orkneys sea-ice-duration time series. The summer temperature, salinity, and nutrient concentrations in seawater close to South Georgia all co-vary with the sea-ice duration in the South Orkney Islands during the preceding winter. This demonstrates a coherence between oceanographic properties in localities approximately 550 km apart. There are similar correlations between the South Orkneys sea-ice-duration series and the atmospheric pressure gradient between South Georgia and the South Orkneys, indicating again that the atmospheric forcing and oceanographic conditions act in concert.

Krill biomass around South Georgia shows major fluctuations from year to year. Initial assessment of this phenomenon by Priddle and co-workers at BAS, suggested that this resulted from large-scale variability in the physical system influencing the transport of krill to the South Georgia region, rather than local changes in population size. Breeding success for krill-dependent predators shows dramatic interannual variability, which reflects the occurrence of seasons with low krill availability. Other ecological and behavioural variables can also be linked to food supply. The Antarctic fur-seal, which is abundant at Bird Island, is dependent on krill as the dominant element of the diet of females feeding pups. Fur seals show increased foraging time in years of low krill abundance, because feeding trips have to be longer to collect sufficient food. The lower food supply and longer intervals between feeding results in low pup mass at weaning. In some extreme low-krill years, such as in 1994, there has been extensive mortality of fur seal pups. The growth rates of adults, estimated from annual layers in teeth, also shows marked interannual variability. Such changes show correlation with ENSO, and this pattern has emerged from various other studies of demographic variables in a range of Antarctic seal species from widely spaced locations.

Many data link observations of interannual variability, ranging from physical oceanography through microbial nutrient cycling and zooplankton abundance, to effects at higher trophic levels. There are demonstrable differences in the timing and magnitude of phytoplankton production around South Georgia that appear to be linked to water temperature. In cooler years, phytoplankton biomass in the South Georgia region tends to be low; it reaches its peak value relatively late in the season. In contrast, warm years result in high biomass blooms early in the season. Similar variability is apparent at higher trophic levels in the pelagic system. Data on all levels of the ecosystem have been collected during the course of a wide range of research cruises and fisheries surveys, but, though these provide a large body of information on the biological effects of large-scale variability, they cannot address effectively the underlying mechanisms.

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This overview was prepared by S F Ackley, C R Bentley, A C Clarke, A Foldvik, I D Goodwin, J C King and J H Priddle.

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APPENDIX 6

SCAR Group of Specialists on Global Change and the Antarctic (GLOCHANT)

Report of the 1995 bipolar meeting of the GLOCHANT/ IGBP-PAGES Task Group 2 on Palaeoenvironments from Ice Cores (PICE)

Members of the PICE Group present: Dr. D Raynaud (Chairman, France), Dr D A Peel (Secretary, UK), Dr J White (USA), Mr. V Morgan (Australia), Dr. V Lipenkov (Russia), Dr. J. Jouzel (France), Dr. H Shoji (Japan, proxy for Professor. O Watanabe).

Apologies: Professor O. Watanabe (Japan).

Other participants: Professor P. Mayewski (USA), Professor B Stauffer (Switzerland), Dr H Zimmerman (PAGES), Professor C Hammer (Denmark), Professor S Johnsen (Denmark), Dr H Miller (Germany).

The meeting was held at the Airport Hilton Hotel, **Boston, Massachusetts, USA, 15-16 September 1995,** immediately prior to the joint GISP2-GRIP workshop held at Wolfeboro, New Hampshire, U.S.A. The Chairman of the task group, Dr D Raynaud, presided, together with Dr D A Peel who was nominated as Secretary of the group.

1. Introduction

1.1 H Zimmerman briefly outlined the relationship between IGBP-PAGES (Past Global Changes) & SCAR-GLOCHANT. PAGES is designed to focus on the past global changes over the last 250 kyr. It has joined with the SCAR-GLOCHANT to formulate a coherent bipolar approach to the future strategies for polar ice-core drilling. We require a bipolar science plan which establishes the relationship between national ice-core drilling projects, and a framework for continental scale analyses of palaeoenvironmental changes.

1.2 D Raynaud briefly reviewed the history of the group. Following the Col de Porte meeting of the GLOCHANT Planning Group on Palaeo-environmental records (24-25 February, 1994), a draft Antarctic ice-coring strategy document had been prepared. A new document was now needed to make a much stronger case, and should especially emphasize bipolar aspects. An update of factual information is needed.

2. Update of Major Antarctic Drilling Projects

2.1 VOSTOK (V. Lipenkov)

Deep ice coring was initiated at Vostok Station in 1970; the latest borehole, Hole 5G was started in 1990 with a thermal drilling system and is now continuing with an electromechanical drill. Since 1989, drilling has been carried out as a joint Russian-French-American project. The aim of the project is to obtain high resolution climatic records covering approximately the past 500 kyr. These data are needed to validate the predictive climatic models, as well as to establish the interrelationships between climate change in Antarctica and climate changes over the Southern Ocean (registered in marine cores) and in the Northern hemisphere. The project also aims to elucidate the external forcing mechanisms and internal dynamics of the Earth's environmental systems.

Drilling reached a depth of 3100 m in Sept. 1995, where the estimated age of the ice is 320 kyr BP. Drilling was then stopped over winter owing to a shortage of the densifier for the hole liquid. Drilling continued during the 1995/96 field season, and was intended to continue through the 1996 winter. In the event, it was decided to close the station for the 1996 winter, when the drilling had reached 3349.68 m depth in Jan. 1996. According to guidelines recommended by the SCAR and Lake Vostok Workshop (Cambridge, May 1995), drilling should be stopped at a point ~25 m above the surface of the subglacial lake beneath Vostok (at ~3650 m depth). To confirm the existence of the lake as well as to determine the thickness of the ice, water layer and lake sediments in the vicinity of the station, a seismic survey was undertaken during the 1995/96 field season in an area about 2 km² around the borehole. Plans have been made to reopen the station for the 1996/97 summer season. It was pointed out that modelling has not yet taken account of the lake, and dating is becoming more problematic.

The group congratulated all who had made this project such an outstanding success.

2.2 Dome Fuji (H Shoji, O Watanabe)

A new deep drilling programme commenced in 1994 at Dome Fuji, the highest point of the eastern Queen Maud Land ice sheet. At the centre of ice sheet flow, the deposited layers suffer minimal horizontal deformation by ice motion, and it is expected that an ice core from this site will clarify the climatic and environmental changes over the past 150,000 to 200,000 years.

Preparations for a deep ice coring operation at Dome Fuji started in 1991 and were completed with a successful camp construction by the JARE-35 party in 1995. The mean annual temperature at the site is -58°C, with a minimum of -78.1°C. The JARE-36 party started deep ice core drilling by extending the JARE-34 pilot hole from a depth of 112.6 m. Drilling has been continued by JARE-37, and by end of March 1996 had reached 840 m depth. The core quality is reported to be excellent and drilling is proceeding. A portion of the recovered core will be brought back to Japan by the JARE-36 party at the end of the field season. It is planned to reach 2500 m depth in 1997.

Once drilling is completed the focus will shift to mass balance studies in the Shirase drainage basin (1997-2001). The JARE 38 and 40 parties plan to drill several 100 m depth ice cores around the Dome Fuji site and along a flowline from Dome Fuji to Shirase Glacier, near the coast, and along an ice divide between the Shirase and Lambert drainage basins. These will be used to identify changes in surface mass balance during the past 200 years. These will investigations will contribute to the GLOCHANT-ITASE project. The shallow drillings will be coordinated with radio echo sounding and satellite remote sensing observations. There are also plans to perform atmospheric chemistry work after deep drilling is completed.

2.3 US Antarctic Drilling Programmes (J White, P Mayewski)

WAISCORES (West Antarctic Ice Sheet Program, ice cores)

WAISCORES, the ice coring part of WAIS (West Antarctic Ice Sheet Program), will address several fundamental questions concerning the nature and causes of climate change, the past variability of climate, and the stability of the West Antarctic ice sheet.

The goals of WAIS are:

- to improve our understanding of how instabilities in the West Antarctic ice sheet may cause a rise in sea level and;
- to improve our understanding of the causes and characteristics of climate change.

The WAISCORES project proposes that two deep ice cores be drilled in West Antarctica. The first ice-core will be drilled at Siple Dome to a depth of 1000 m. This is a coastal dome in a location at the base of the main ice streams currently draining the southern part of the West Antarctic ice sheet, to the Siple Coast. This location is believed to be sensitive to potential changes in the extent of the West Antarctic ice sheet. It is expected to yield a precisely datable stratigraphic record, and enable a detailed interhemispheric comparison of prominent Holocene climatic features. Several research programmes have been funded to recover and analyse core from the Siple Dome site. Camp construction and shallow-drilling will commence in 1996-97. Reconnaissance surface studies, including stable isotopes, chemistry and accumulation rate, were conducted around Siple Dome in 1994-95 and around the Byrd region in 1995-96. As a strategy, there will be minimal field personnel - most scientists will go to national core lab at Denver to analyse the core. Drilling is due to start in 1997/98 and surface work in 1996/97. The scientific proposals have been reviewed scientifically but the schedule for drilling has still to be decided. Some surface studies have been done at Siple Dome. Radio echo sounding shows absolutely horizontal layering and well defined visible stratigraphic layering. The expected age of the core is 40-70 kyr with 7-11 cm ice/yr accumulation. The site shows good promise for a high resolution Holocene record, and evidence for several glacial age rapid climate change events. The second ice-core drilling site will be located in the centre of the West Antarctic ice sheet along the ice divide, near Byrd station. It is planned to drill one 2000 m deep core at this site. Accumulation rates of snow at this location are comparable to those in central Greenland, and hence it is believed to be a good location for replicating the high resolution Greenland palaeoenvironmental records in

Antarctica. The ultimate age at this site is currently unknown, but is expected to be at least 100,000 years. It is hoped that the Siple Dome drilling may start in 1997. Currently, drilling on the Inland core is scheduled to begin in 1999.

In East Antarctica, an ~550 m core has been drilled to bedrock at Taylor Dome, near McMurdo Sound. The length of the record is ~140 kyr with +/- 350 yr error at the time of the Younger Dryas. Comparisons with the Vostok and GISP2 cores have been conducted and have revealed notable bipolar similarities.

2.4 *EPICA (J Jouzel)*

EPICA is a long-term (ca seven years) European deep ice-core drilling project in Antarctica, to derive high resolution records of climate and atmospheric composition through several glacial-interglacial cycles. To achieve EPICA's goals it is planned to drill at two sites, in order to achieve the required resolution of the climate and gas records on different timescales, and an adequate continent-wide perspective.

The first four-years phase (1996-2000) will focus on a deep (3500 m) drilling at Dome C, East Antarctica with the aim to characterise the major climate shifts during the past several glacial-interglacial cycles. A core from this location, which is ideally placed to secure an undisturbed long record, will allow examination of the relative phasing of climate and climate-forcing parameters associated with these major climate-change events. The core location is also optimal to put the Antarctic record into a global context and to produce a record for comparison with the ocean, continental and Greenland ice-core records. The project has been accepted by the European Union (EU) and funding approved for the first three years at the level of 90% of the original request.

During the second phase of the project, starting around 2000, a core will be obtained from Dronning Maud Land, an area of Antarctica most strongly influenced by the Atlantic ocean, and a region of somewhat greater annual snowfall rate and thinner ice cover, that will enable records of higher time resolution during the Holocene and last glaciation. This phase of the project is designed to focus specifically on the rapid climate oscillations, the Dansgaard/Oeschger events, that have been detected across Greenland especially during the later stages of the last glaciation.

Dronning Maud Land is also one of the least explored sectors of Antarctica, hence a large-scale framework of basic geophysical and geochemical survey will be undertaken during the first phase of the project, to gather the essential information that will be needed to locate an optimal deep drilling site, and to characterise the pattern of climate change across the region during the past centuries, and its representation in the ice-core record.

The direct costs for Phase 1 of EPICA, which will start in 1996, will be shared by ten national partners (Belgium, Denmark, France, Germany, Great Britain, Italy, Netherlands, Norway, Sweden and Switzerland) and by funding from the Framework 4 Programme of the EU. There may be opportunities for involvement of other countries, eg Russia and Australia, but extra money would be needed

2.5 *Australian Deep Drilling Programmes* (V Morgan)

Analysis of the 1200 m core from Law Dome Summit South (DSS) is continuing. The very high snow accumulation at DSS allows precision dating by layer-counting for a large part of the Holocene, however, the rapid thinning required to balance the accumulation leads to a layer thickness of only about 9 mm in the transition from the Last Glacial Maximum (LGM). There is 6 m of clear, isotopically warm ice at the bottom of the core above the silty basal ice. In 1995/96 an unsuccessful attempt was made to obtain silty ice from the bottom of the DSS borehole, due to slight borehole closure at depth. The borehde was successfully relogged to obtain vertical strain rates.

The record is ideal to extend the instrumental climate record for East Antarctica and to characterise in detail the climate during periods of important climatic fluctuations of large scale significance that have been documented in other parts of the world, such as the so-called European Little Ice Age and the Mediaeval warm period.

Field work to be carried out during the 1995/96 season covers:

- re-logging of the borehole for ice flow determination - temperature logging.
- surface strain grid re-measurement.
- shallow coring at DSS to extend the record up to the present, and to the west to investigate the accumulation gradient across the dome.
- radio echo investigations of the thickness of the basal ice and the internal layers.
- drilling for silty ice at the bottom of DSS with a rock cutting adaptor fitted to the drill motor section.

Plans are being developed for future deep drilling on the ice sheet inland of Law Dome. At a site some 600 km inland, ice thickness exceeds 4000 m, and a core to near bedrock could be expected to produce a record going back more than 400,000 years, before bedrock effects make the timescale unreliable. The area lies on the flank of the ice sheet, and the deep ice could come from near either the Dome C or Vostok depending on the exact location. Site surveys would be made around 1998, and drilling could start about 2002. The project does not have national support at this stage.

3. Update of Major Greenland Drilling Projects

3.1 *GISP2 (P Mayewski) and GRIP (B Stauffer)*

The GISP2 and GRIP deep ice core drilling projects in central Greenland collected parallel ice cores, each extending more than 3 k m deep and 110,000 years past. Findings have been detailed in roughly 200 refereed publications so far. A recent joint workshop (Wolfeboro, New Hampshire, Sept. 1995) hosted by the US GISP2 project was designed to exchange data and ideas, finalize arrangements for a special joint issue of JGR Oceans and Atmospheres (due out in 1996), and to plan future analyses and ice-coring projects.

The earth has experienced large, rapid, regional-to-global climate oscillations throughout most of the last 110,000 years, of a scale that agricultural and industrial humans have not faced. A few of these stadial/interstadial oscillations, such as the Younger Dryas (YD) event, had been known for decades or longer from pollen and other records. Many more were found in the first Greenland deep ice cores, but most of the oscillations occurred in ice from close to the bed where ice flow may have disturbed the climatic record. These events are recorded far enough above the bed in the new cores that ice flow is unlikely to have altered the climatic record. Indeed, the new cores show an almost perfect match back to 110,000 years ago.

These millenial-scale events, which frequently begin or end rapidly, represent quite large climate deviations: probably many degrees C in temperature, twofold changes in snow accumulation; order-of-magnitude changes in windblown dust and sea-salt loading, roughly 100 ppbv in methane concentration, etc., with cold, dry, dusty, and low-methane conditions correlated.

The events also are regional to global: they are observed in local climatic indicators such as snow accumulation rate and the isotopic composition of snow linked to temperature; in regional climatic indicators such as windblown sea salt and continental dust, and in regional-to-global indicators such as atmospheric concentrations of methane, nitrate and ammonium. Some events are readily identified in the ocean-sediment record in regions critical to global ocean circulation. Furthermore, new correlation techniques involving the gaseous composition of the atmosphere demonstrate that the major events also are recorded in the isotopic temperature record of the Vostok core from central East Antarctica.

The latest investigations, based on an analysis of borehole temperatures, suggest that ice-age temperatures in central Greenland were roughly 20°C colder than today. This verifies the commonly held belief that climate changes are amplified in polar regions. Independent estimates based on the stable isotope analysis of the ice indicate that the calibration of the isotope thermometer may be non-linear in Greenland over glacial to interglacial timescales, with a considerably smaller $\delta^{18}O/T$ gradient in glacial times compared with the gradient calculated for the modern period.

Initial interpretation of the GRIP ice-core data indicated that the large, rapid climate oscillations that dominate the record of the last 110,000 years also persisted through the previous warm period, The Eemian interglacial. Careful physical examination of the cores shows that significant structural disturbances from ice flow occur at or slightly above the depth where the climate records from the two cores diverge. Details of the gas records and of the chemistry indicates that some Eemian ice is probably present but that the stratigraphic sequence is probably disturbed. Ultimately, just as these cores were needed to validate the rapid oscillations observed in older cores, a new core or cores from sites where the Eemian ice is further from the bedrock, and thus less sensitive to flow disturbance, will provide the best answer.

GISP2 has produced ~150 peer-reviewed papers to date covering a wide range of topics such as: site survey; analytical and statistical techniques; physical processes of snow and ice; ice core drilling design and operation; transfer functions (eg., snow/atmosphere); unique events (eg., volcanism, biomass burning, anthropogenic emissions); palaeoenvironmental reconstructions; and bipolar, Arctic and GISP2/GRIP comparisons.

The work on GRIP has left several major important questions:

The 'lead parameter' $\delta^{18}O$

Recent studies have indicated that the $\delta^{18}O/T$ ratio may be strongly affected by changes in the moisture source. Now two new papers analysing the GRIP & GISP2 borehole T profiles indicate much smaller ratios in glacial times, with the implication that glacial-interglacial changes were much larger than previously deduced from isotopic profiles.

CH_4 record

Must be a global record. The Younger Dryas (YD) signal in CH_4 has to be a global and Vostok & Summit profiles overall agree well over YD, but there are quantitative differences in the early Holocene.

CO_2 record

There are problems in Greenland - with significant differences between the Greenland and Antarctic records during 1000-1600AD, diverging with depth.

The Eemian

The GISP2 and GRIP records of the Eemian interglacial period disagree, most probably due to disturbances in the stratigraphy at one or both sites. Such disturbances, some 300 m above the bedrock, were unexpected. The series of rapid climate shifts in the last glacial, which were first detected within 50 m of bedrock in the Camp Century and Dye 3 records, were fully verified only halfway through the ice sheet in both Summit records. Understanding the causes of the disturbances in the deepest parts of the Summit records must be a priority.

3.2 North GRIP (C Hammer)

Although both Summit cores in Greenland show an almost perfect correspondence in palaeoclimate system parameters, they differ markedly in the bottom 300 m. Thus it remains an open question, whether the last interglacial was characterized by rapid climate fluctuations as was determined from the GRIP core. Because of the far reaching consequences for our understanding of the climate system this question must be resolved. A further deep ice core is therefore necessary, preferably in a location where ice of Eemian age is further away from bedrock and less disturbed by bedrock undulations than is the case for the Summit cores. Denmark has secured national funding to drill a new deep core at such a site in North Greenland. The area has a lower precipitation than Summit, consequently Eemian ice may be 300 m above bedrock. Presite survey work, including German radio echo sounding of the North GRIP area has been carried out and drilling is planned to start in 1996. This core will, provide further evidence on Eemian climate, yield much information on spatial variability of past climate conditions in Greenland and extend the presently available Greenland climate record further back in time.

The primary aim of the drilling will be to obtain Eemian ice. It will be a low budget operation, cutting down on the science in the field. Some scientists from other nations will be invited, although they will have to obtain funding. Planning is mapped over five years, but funding is for three years in the first instance. The EPICA drill test (to 300 m) will be carried out near the site next season. Drilling of the North GRIP core is planned for 1997-98.

4. ITASE *(P Mayewski)*

The broad aim of ITASE is to establish how the modern atmospheric environment (climate and atmospheric composition) is represented in the upper layers of the Antarctic ice sheet. Primary emphasis will be placed on the last ~200 years of the record through the recovery of closely spaced (~100 km) ice cores. This time period was chosen for study because it is relatively simple to recover many ice cores covering this period and to develop a spatially significant study. Further, this time period encompasses the onset of major anthropogenic influence on the atmosphere and the end of the Little Ice Age, two notable complexities in climate change records. Specific objectives include:

- Developing a high resolution spatial array of the major environmental parameters measured in ice cores to assess recent change (the last 200 years) and provide a baseline for future environmental change.
- Developing a proxy equivalent (e.g., temperature, accumulation, humidity, atmospheric composition, circulation path) for the incomplete Antarctic instrumental record to assess climate change.
- Investigating changes in accumulation rate as an aid to sea level prediction, ice sheet modelling and as a measure of climate change.

Scientific guidelines for ITASE have been established by the ITASE Steering Committee. Traverse routes have been proposed in order to sample the broad range of geographic, glaciological and meteorological conditions that characterise the Antarctic ice sheet. These traverse routes are the product of several international planning meetings attended by the international representatives of ITASE.

A joint IGBP-PAGES and SCAR-GLOCHANT ITASE Workshop is scheduled for the 2-3 August, prior to the XXIV SCAR meeting to update ITASE activities and develop a Science and Implementation plan. A national US ITASE meeting is to be held in late May 1996.

5. GLOCHANT Bipolar Document: Discussion

There was a general discussion on updating and developing the GLOCHANT document on an international strategy for ice-core drilling.

The document should make a much stronger case for the need for multiple deep drillings in Antarctica—especially why there was a need for 3+ holes in East Antarctica and 2+ holes in West Antarctica. It should demonstrate how work in Antarctica is related to work in the north and generally emphasize the justifications for a bipolar approach. Modelling efforts in relation to site selection and core interpretation should be included, and the contribution of ice-core work to understanding the stability of the west Antarctic ice sheet highlighted.

A structure for the new document was agreed and contributions for the component sections were drafted. Progress reports for the individual projects were submitted and partly updated in April, 1996.

6. GLOCHANT Bipolar Document: Preparation

First drafts for the document were criticized and a revised structure for the document agreed. The following authorships for producing the final document were agreed:

Actions

First draft:	D A Peel and D Raynaud
Conclusions:	D A Peel and D Raynaud
Figure on ice-core parameters revealing facets of environmental change:	B Stauffer and P Mayewski
Comparative Figure of profiles of stable isotopes in different media: GRIP/GISP2/Vostok/Marine:	J Jouzel
Maps of Greenland and Antarctica showing all deep drilling sites	

Future meetings

It was agreed that a meeting should continue to be held each year.

The composition of the group could be adapted to reflect the area of expertise needed.

The setting up of a workshop (GLOCHANT-PAGES) for ITASE could be a suitable focus for 1996.

D A Peel
18 March 1996

APPENDIX 7

INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH AND INTERNATIONAL GEOSPHERE–BIOSPHERE PROGRAMME

A SCAR/GLOCHANT and IGBP/PAGES initiative July 1996

An international Strategy for Ice -coring in Antarctica and Greenland Reducing uncertainty in global environmental change

Executive Summary

Paleoclimate data covering a variety of timescales and representing different parts of the global climate system are needed to improve our understanding of the mechanisms driving climate change. Ice cores yield archives both of climate and associated chemical changes in the atmosphere. The GLOCHANT/PAGES Task Group on Palaeoenvironments for Ice Cores (PICE) has drawn together proposals for a series of national and multinational projects over the next decade involving deep ice-core drilling in different parts of East and West Antarctica and in Greenland.

Taken together, the various proposals aim to ensure that representative climate records are achieved for the principal climatic zones of the polar ice sheets, and that these records will give maximum resolution during the two time-streams identified as priority targets by PAGES. These encompass high-resolution reconstructions of the Holocene and long-range reconstruction of climate and related changes in atmospheric chemistry through the more extreme climate changes occurring over glacial cycles. This co-ordinated effort (GLOCHANT/PAGES) should lead to major advances that will reduce the uncertainty in predicting future global environmental change.

Introduction

Palaeoclimatic data on a variety of time-scales are needed to give perspective to ongoing changes and to improve our understanding of the mechanisms driving climatic changes. The palaeoenvironmental records derived from the analysis of polar ice cores are unique in several ways. Polar ice-core records are the only archives which, along with highly resolved evidence of past climate change, including air temperature and snowfall rate, also preserve information on the atmospheric concentration of the principal greenhouse gases, on the concentration of atmospheric aerosols, and on a wide range of major and minor chemical constituents in the atmosphere.

Ice-core research has already made substantial contributions to our understanding of the mechanisms driving global climatic changes. For instance, ice cores from both Antarctica and Greenland provide strong evidence that the atmospheric concentration of greenhouse gases has closely paralleled pre-anthropogenic global climatic changes throughout the last glacial to interglacial cycle. These studies have provided the only firm data to demonstrate the increase of the greenhouse gases since the pre-industrial period. Also, several discoveries were totally unexpected, and had not been predicted by any models. Thus ice cores from Greenland have revealed the existence of a series of major, abrupt climatic shifts both during and at the end of the last glaciation. Major shifts are found to have occurred during time intervals of a fraction of a human life.

Comparison with results from deep-sea sediments suggests that the ice-sheet-surface-changes were connected with a re-ordering of the deep-ocean circulation, and therefore may have global implications. Based on the methane record from both Greenland and Antarctic ice, and on growing evidence from deep-sea and terrestrial climate records, it can be concluded that these climate fluctuations not only affected the North Atlantic and adjacent regions, but also mid-lower latitude regions.

Some evidence from the ice cores recently drilled at Summit in Greenland suggests the new possibility that fast climate oscillations occurred during the last interglacial, the Eemian epoch. However, the records of the two cores in their lower parts deviate considerably from each other and probably are affected by stratigraphic disturbances. This is supported by the comparison of the gas records obtained in these two cores with undisturbed, high-resolution Antarctic ice records. A new drilling in another sector of the Greenland ice sheet, where the Eemian ice may be located further above bedrock, should provide further evidence for resolving the issue of abrupt climatic variations during interglacial periods.

The findings raise several key questions that will not be answered by existing ice cores:

- Climate variability: Are the rapid climatic changes of the last climatic cycle global events, or have they been restricted to a region of the Northern Hemisphere? Are rapid climatic changes also observed in previous climatic cycles? What factors can contribute to the speed of the climate changes observed in Greenland? Is the apparent stability of the Holocene climate in Greenland an exception for the past 500,000 years?
- Forcing factors, feedbacks and mechanisms: What are the causes of natural variations in greenhouse gas concentration observed during the last and earlier glacial-interglacial cycles and how far was global climate driven by these changes? How has atmospheric chemistry changed in response to climate? Is there evidence of any feedback via, for example, interference with the oxidation capacity of the atmosphere, that regulates the levels of certain greenhouse gases such as methane? How important are the marine biogenic aerosols of the southern ocean in climate forcing?
- Coupling between the Northern & Southern Hemispheres: What is the phasing of climate between the Northern and Southern Hemispheres in the various stages of the last glacial cycle? Are global climate changes triggered in the Northern Hemisphere or is the opposite sequence possible? How are global climate changes coupled between the two hemispheres? What is the link between ice-core and marine sediment records from other latitudes?
- Ice-sheet stability and control on global sea level: What were the long-term linkages between climate, snowfall rates, and ice sheet history, and how are these related to global sea level?

The answers to these questions are important for the prediction of future climate, influenced by anthropogenic effects. New ice cores from optimal locations both in Antarctica and Greenland are needed to complement the existing records. For instance, additional Antarctic records will enable us to investigate the rapid climate events in a global context. Considering the complex structure of the atmosphere over Antarctica and the interactions with the surrounding ocean, ice cores from several locations will be needed to answer these important open questions. These archives will also provide unique evidence on climate forcings (such as: greenhouse gases, atmospheric oxidation capacity, atmospheric turbidity, biogenic feedbacks, and solar variability), on climate variability, on climate mechanisms, on the long term climate/ice sheet interactions, and on the role of Antarctica in sea-level change.

The Bipolar Approach

The polar regions play a major role in the climate system of the Earth. Indeed the existence of large ice masses is a key component of the Earth's radiation balance, and changing the extent of the ice sheets affects the albedo of the polar regions, which in turn affects both atmospheric and oceanic circulations. Furthermore, equilibrium global circulation models predict that global climatic changes are enhanced in the high latitude regions. For these reasons polar ice-core records are key tools for investigating the global-versus-local nature of climatic changes and the mechanisms driving the North-South climatic connection under different climatic conditions and over different time scales.

The comparison between the ice-core records and other proxy data clearly indicate larger glacial-interglacial temperature changes in Greenland and Antarctica than at lower latitudes. The major long-term climatic trends over the last 110,000 years for both ice sheets are the same and it appears now that the major, abrupt climatic Dansgaard/Oeschger events affected both polar regions, although the Antarctic signal is much weaker. A close investigation is needed to understand the precise phase relationship between the Antarctic and Greenland temperature changes and the mechanisms, such as greenhouse gases and deep water circulation that link the high-latitude regions. New ice-core sites should be selected on the basis of criteria including time resolution and origin of air masses.

It is also clear that the bipolar approach provides unique information on the different atmospheric circulation regimes characterizing the two polar areas, through measurements of dust and various chemical species (eg. major anions, cations, MSA) in the Greenland and Antarctic ice. Furthermore, the ice contains global indicators, including records of changes in the composition of well-mixed atmospheric gases (CH_4, CO_2) that will be extensively used in the future to correlate the different bipolar records. This approach appears already as one of the most powerful tools to investigate the phase relationship between the various palaeo-indicators of different climatic forcings, for example, greenhouse gases, ice extent and volume, and aerosols.

Past and Present Drilling

Greenland

Evidence from a recent combined study of the GRIP and GISP2 ice cores from Summit, in the central part of Greenland, now strongly suggests that the deepest parts of both cores, extending before 110,000 years ago, have been disturbed by ice flow. Whilst it is believed that ice from marine isotope stage 5e, the Eemian period, can be identified in both cores, the prospects for establishing an unambiguous and detailed stratigraphic record of Eemian climate from these cores is remote. Nevertheless, there appears to be some corroborative evidence for structure in this interglacial climate in several marine sediment sequences from the eastern North Atlantic region and the Nordic sea. If climate instability in this previous warm period is real, then this would have major significance for investigating present climate. Renewed efforts are now needed to obtain an independent high resolution record of the Eemian climate in Greenland, suitable for comparison with the Antarctic records. Plans for a new deep drilling project in North Greenland (North GRIP), mainly funded by Denmark, have now been approved. A German geophysical survey to locate the optimal drilling site is currently underway in an area of lower accumulation rate (15cm ice/yr), where it is anticipated that the Eemian ice will lie significantly further above the bed than at Summit. It should offer the best opportunity for achieving an undistorted Eemian record and a resolution of the uncertainties at Summit. The prospect of extending the ice-core records through two glacial cycles should also be pursued in order to match the available Antarctic records.

Antarctica

The Vostok core, already at 3350m depth in January 1996, the deepest ice core and the longest continuous ice-core record so far achieved, has led to many major advances in ice-core research. Although there are still 350m to be drilled, the record extends through at least three complete glacial cycles. As the depth increases, corrections for ice-flow also increase, and the record may become more difficult to interpret unambiguously. Furthermore, drilling must be terminated about 25m above a subglacial lake. A priority is to achieve additional new records spanning up to several glacial cycles at dome sites in both West and East Antarctica, where flow corrections to the records from great depth in the ice are minimised. Such sites are not located near existing manned stations, which were selected for logistic reasons, and will require much more demanding logistics to establish. These longer records are needed to create a cryospheric complement to the marine sediment records of the Pleistocene glaciations, and to examine the ice-core evidence of climate and associated changes in atmospheric composition both through the various stages of the last glacial cycle and through a series of major glacial-interglacial climatic oscillations.

Strategy for Future Drilling

The Antarctic ice sheet spans an area larger than the United States and comparable to Europe. It covers a correspondingly wide range of both climatological and glaciological regimes. No single site can be presumed to deliver a climate record that is representative of the whole continent, nor can it yield a record of optimal resolution of both climate parameters and gas mixing ratios across the whole time range of interest. Alternative sites possess a variety of physical attributes that determine the resolution and long-term stability of the records attainable, and they experience different sensitivities to climate/circulation changes in adjacent ocean and continental areas. Significant differences have been observed already in, for example, the characteristics of the deglaciation sequence recorded in different Antarctic cores, which may have important implications for coupling the Antarctic and Greenland records. Plans are being formulated for a series of national and multinational drillings during the next decade in different parts of East and West Antarctica covering time-scales ranging from centuries up to several hundreds of thousands of years.

The major dome sites in East Antarctica have been targeted to achieve the longest possible records, benefiting from a combination of very low annual snow accumulation rate and minimal long-term ice flow disturbance. Such sites will also provide the best opportunity to correlate the ice core records with the marine sediment records and other terrestrial records, contributing to a much more coherent global picture. Planned drilling in West Antarctica and in Dronning Maud Land is more closely focussed on the last glacial cycle and is designed to achieve records of comparable resolution to the Greenland records. These records will be especially valuable for documenting the amplitude and phasing of Antarctic climate shifts through the sequence of Dansgaard/Oeschger events and the deglacial and early Holocene sequences. These sites are likely to be most sensitive to changes in the extent of the West Antarctic ice sheet and are likely to provide the strongest evidence on questions relating to the stability of the West Antarctic ice sheet and its relationship to climate. Further deep drilling is also planned in North Greenland in an effort to discover whether an undistorted stratigraphic record of the last interglacial can be found in another part of the Greenland ice sheet, to allow proper comparison with the Antarctic records.

Late glacial and Holocene

A priority is to obtain high-resolution records from Antarctica that can complement the new records from central Greenland. The records should allow thorough investigation of the Southern Hemisphere climate at the time of the rapid and highly non-linear climate events in Greenland. By selecting sites with suitably high accumulation rate, it should be possible to date the records stratigraphically and hence enable investigation of the relative timing and linkages of events in the Northern and Southern Hemispheres. Existing records from Vostok, Dome C, and Byrd show significant differences in the detail of the deglacial sequence and in the mid-Holocene, which may be related in part to the low temporal resolution of the Vostok record, but could also reflect local changes in the surface elevation of the ice sheet or of climate in the vicinity of Byrd. The existing Antarctic ice-core records show much weaker late-glacial rapid climate events, including the Younger Dryas, than are observed in Greenland. Is this behaviour more generally a reflection of a fundamentally less variable Southern Hemisphere climate, or is there a tendency for buffering of climate trends in the interior of the Antarctic continent where cores have been drilled so far? Several new high-resolution cores from coastal localities are needed to address this problem. Large areas of the bed of the West Antarctic ice sheet lie below sea level. This situation may be inherently unstable, with a potential maximum effect on world sea level of up to 5-6m, should there be a major surge. Studies on cores from West Antarctica in particular will contribute to our understanding of how instabilities in the West Antarctic ice sheet may cause a rise in sea level and will add to our knowledge of how the West Antarctic ice sheet has reacted to major climate fluctuations in the past (see page 6).

Cores from sites near the coast of Antarctica provide information that is complementary to that from cores from the inland ice sheet. Coastal sites tend to have higher accumulation and thinner ice, so that the record is shorter, but of higher resolution. An important feature of the higher accumulation is that it results in the preservation of seasonal cycles and hence allows the ice to be precisely dated and the variation of the layer thickness (and therefore of snow accumulation) with time to be continuously determined. The glaciological information is valuable for determining the accuracy of ice-flow models that are used for dating cores in which annual counting is not possible. Coastal sites are also more sensitive to effects such as changes in ice-sheet size and sea-ice boundaries and therefore can serve as control or sources of correction data for inland sites.

Law Dome:

Deep drilling (ca 1200m) has been completed at Law Dome, a coastal site with a high annual snowfall rate that is generating a very high resolution record of climate change during the past several thousand years. The record is ideally suited for extending the instrumental climate record for East Antarctica and characterizing in detail, with an excellent chronology, the climate during periods of important climatic fluctuations of large-scale significance that have been documented in other parts of the world, such as the Little Ice Age and the Mediaeval warm period. Law Dome is particularly well suited to studies of anthropogenic input to the atmosphere. Because air is trapped only at the close-off depth in the firn, the age of the trapped air is different from that of the ice. The difference ranges from about 2000 years for the lowest accumulation inland site to 40 years or less at Law Dome, where data from the last few decades overlap direct atmospheric measurements and thus confirm the accuracy of the ice-core data.

Future deep drilling is being considered some 600km inland of Law Dome, on the flank of East Antarctica. The site will have a great ice thickness combined with a moderate snow accumulation rate and should allow extension of the Law Dome record at reasonably high resolution back at least 300 kyr. The core will add to the geographical coverage of data from other cores, and will contribute to understanding the past changes in the configuration of the East Antarctic ice sheet.

Siple Dome:

The US WAISCORES programme will address several fundamental questions which revolve around the nature and causes of climate change, the past variability of climate, and the stability of the West Antarctic ice sheet.

The goals of WAIS are:

1. to improve our understanding of how instabilities in the West Antarctic ice sheet may cause a rise in sea level, and
2. to improve our understanding of the causes and characteristics of climate change.

The WAISCORES project plans to drill two deep ice cores in West Antarctica. The first to be drilled is a core from Siple Dome. This is a coastal dome in a location at the base of the main ice streams currently draining the southern part of the West Antarctic ice sheet. This location is believed to be sensitive to potential changes in the extent of the West Antarctic ice sheet. The Siple Dome Project is an integrated effort that involves a roughly 1000m core, several 150m cores, numerous snowpits and hand-augered cores and an atmosphere/ice interaction programme. It is anticipated that drilling will begin in 1997, with camp set-up in 1996. Currently, drilling on the inland core is scheduled to begin in 1999. Dome Siple is located between ice streams C and D and has 320m of topographic closure. This is high enough not to be easily overridden by inland ice during times of a larger West Antarctic ice sheet. Airborne ice-penetrating radar shows clear internal reflectors. The maximum ice thickness is 1031m near the summit of the dome, and the geometry of the internal reflectors indicates that the flow divide has not shifted over the time corresponding to half of the ice sheet thickness, or about 10,000 years. A 160m core was recovered in 1994-95 from this site. Field observations of visual stratigraphy revealed a detectable annual signal to the bottom of this core (1,563 years BP). Based on the radar and accumulation data, the age of the ice at 90% depth is expected to be 80,000 to 200,000 years.

Berkner Island:

Berkner Island was targeted by a joint German /British project for intermediate-depth drilling in 1994-95, and 180 and 150m cores have been recovered from the two twin summits, Thyssenhohe and Reinwarthohe, respectively. The ice-core record at these coastal sites is likely to be sensitive to changes in the ice coverage and atmospheric circulation over the Weddell Sea, which are in turn related to larger-scale circulation changes over the Atlantic. The Weddell Sea region has been identified as an area of particular interest in detecting past changes in the circulation of the Atlantic Ocean and in ocean-atmosphere interactions in the marginal ice zone, which may be indicative of larger-scale changes in atmospheric circulation. It is certainly of interest in relation to climate changes affecting West Antarctica, the region of Antarctica believed to be most sensitive to the effects of climate change.

Provisional stratigraphic dating indicates that the longer record extends for more than 1000 years, and hence will be very suitable for studying climate changes corresponding to the Little Ice Age and the Mediaeval Warm period. The site has moderate snow accumulation rate, experiences no summer melting, and has a very well preserved seasonal stratigraphy in several parameters, hence it is expected to yield a very accurately dated record. The record will also help to establish a linkage between records from the Antarctic Peninsula and future ice-core records from Dronning Maud Land. No firm plans have been set to drill to bedrock at this site (~1000m) although it is likely that this site would allow the retrieval of a well-dated Holocene record, and possibly through the last glacial termination. This record would contain valuable long-term information on the conditions and ice coverage in the Weddell Sea, as well as potential evidence on whether Berkner Island was over-ridden by grounded ice in the region of the Filchner-Ronne ice shelves during the LGM.

The last and earlier glacial-interglacial cycles

Deep drilling in central Antarctica aims to contribute to the understanding of the mechanisms driving long-term climate change and their coupling with the biogeochemical cycles. The longest records from central East Antarctica will span several glacial-interglacial cycles, possibly to 500,000 years ago or more, and will be especially suitable for examining the climate forcing and feedback mechanisms driving the principal climatic cycles throughout the most recent geological period. Evidence on the associated responses of the ice sheet which have implications for the prediction of future global sea-level will also be obtained. Dome sites in central areas of the East and West Antarctic ice sheets will provide records requiring minimal corrections for ice flow, even for multiple-glacial-cycle records. These records will be highly suitable for correlation with the oceanic, continental, and Greenland ice records, and hence for establishing the synchroneity of climatic events in both hemispheres, as well as providing evidence for the linking mechanisms involved.

Vostok:

Drilling at Vostok Station is continuing as a joint Russian-French-American Project. Drilling at this site of extremely low accumulation rate is planned to continue until the end of 1996, when the drill should reach the proximity of the subglacial lake at a depth of 3700m, ice of age older than 400 kyr. At this depth the corrections of the climate data for horizontal flow become progressively more important, because the site does not lie on an ice divide, so accurate dating becomes problematic. Nevertheless, it has been possible to match the stable isotope profile with the SPECMAP timescale back to marine isotope stage 7.5 (down to 2750m depth). Analysis will continue to provide high-resolution climatic records on past temperature, pressure, and circulation changes with parallel evidence on the principal greenhouse gases, CO2 and CH4, on the isotopic composition of atmospheric oxygen, a global indicator, and on the changing composition of the atmospheric aerosol.

Once deep drilling is completed surface traverses are envisaged which will enable more precise corrections for horizontal flow and a more reliable interpretation of the Vostok record.

Dome Fuji:

Deep drilling at Dome Fuji in East Dronning Maud Land, one of the principal spreading centres of the East Antarctic ice sheet, was started by the Japanese Antarctic Research Expedition in 1995. The site is ideally placed to achieve one of the longest, glaciologically most stable, and continuous climate records possible on the Antarctic continent, up to 500 kyr long. The site has a very low annual snowfall rate (3.2cm water/yr) and around 3km ice thickness. Investigations are planned to centre around two major projects:

i. The reconstruction of long-term palaeo-climate and environmental change, and comparison with behaviour in Greenland as the site lies South of the Indian/Atlantic Ocean.
ii. Investigation of the ice-dynamical behaviour in this sector of the ice sheet, including an assessment of the mass balance and its changes in the past in response to climate change. These studies will be supported by a series of traverses to be undertaken once deep drilling is completed.

Dome Concorde:

A new long-term European deep ice-core drilling project (EPICA) that aims to obtain high resolution records of climate and atmospheric composition through several glacial-interglacial cycles has just been launched. The project is centred around ultimate deep drilling at two complementary sites in East Antarctica to achieve an optimum temporal resolution on different timescales and a satisfactory continent-wide perspective.

During the first four-year phase (1996-2000), deep drilling (to 3500m) is planned at Dome Concorde, a site optimally placed to secure an undisturbed multiple-glacial-cycle record in East Antarctica that will complement with better resolution, and could extend, the Vostok record. Both sites lie in a region of Antarctica influenced by the Indian and Pacific Oceans, in contrast to Dome Fuji, where there is likely to be a stronger Atlantic influence and possibly greater influence of subsiding air from the upper atmosphere. The record will focus on the major climate shifts that have characterised the past several glacial cycles. With an annual snowfall rate around twice that at Vostok, the record will have an enhanced resolution during the last and previous interglacials, and allow a detailed examination of the relative phasing of climate and global forcing parameters in comparison with the Greenland records. The Dome Concorde site should offer excellent resolution through the Eemian interglacial, which lies only halfway through the ice sheet, well clear of any conceivable ice-flow disturbances caused by bedrock irregularities. The new core will be very suitable for a detailed examination of the existence and character of rapid climate events during both glacial and interglacial stages. The site is located south of the Indian/Pacific Oceans.

Dronning Maud Land:

During the second phase of the project, starting around AD2000, a core is planned in Dronning Maud Land, an area of Antarctica most strongly influenced by the Atlantic Ocean. This area possesses somewhat greater snow accumulation rate and thinner ice cover than other sites in the East Antarctic interior, so it should yield records of correspondingly higher time resolution during the Holocene and the last glaciation. This phase of the project will focus more specifically on the rapid climate oscillations during the last glacial age that have been detected across Greenland. It should be ideally placed to detect signals of changes in the deep circulation of the Atlantic Ocean, which are believed to have been implicated in the rapid climate events. Because Dronning Maud Land is also one of the least explored parts of Antarctica, an extensive geophysical and shallow-coring survey will take place before the deep drilling to locate an optimal site for deep drilling and to produce a better understanding of the ice dynamics in this sector of Antarctica, which will be needed to interpret and date the future ice core.

Central West Antarctica:

The US WAISCORES project has a proposal to drill a second core located on the ice divide in the centre of the West Antarctic ice sheet. Accumulation rates of snow at this location are comparable to those in central Greenland, and hence it is believed to be a good location for replicating in Antarctica the high resolution of the Greenland palaeoenvironmental records. The ultimate age at this site is currently unknown, but is expected to be at least 100,000 years. The site is likely to yield one of the longest, most detailed palaeo-climate records possible from the West Antarctic ice sheet. The data will be valuable for investigating the long-term stability of the ice sheet and its relationship to climate. Dating accuracy is expected to be excellent, so a thorough interhemispheric comparison of the prominent climatic features of both the Holocene and the glacial period should be possible.

Whether instability of the Antarctic ice sheet can affect sea-level rise is one of the great problems of glaciology. For example, the work by Peltier (1994) indicates that the Antarctic ice contributed 22m to sea-level rise late in the post-LGM deglaciation. In addition, the Byrd $\delta^{18}O$ record implies that there may have been a local fall of roughly 100m in the level of the ice sheet during the mid-Holocene. If the stable isotope anomaly was caused by an elevation drop, the stability of the West Antarctic ice sheet during the Holocene is called into question. Both the coastal and inland cores proposed in WAISCORES will directly address this problem.

Spatial Perspectives: ITASE

Modern instrumental weather records reveal important differences in inter-decadal trends in different parts of Antarctica. Significant differences are also apparent in comparisons between the existing deep ice-core records, for example in the magnitude of shifts observed at Vostok and Byrd at the end of the Younger Dryas event. In order to achieve a stronger basis for interpreting the deep ice cores and to assess their large-scale significance, a joint international effort ITASE (International Trans-Antarctic Scientific Expedition) is planned to recover a network of shallow cores across the continent. The network will link existing and planned future drilling sites together with existing weather stations, which are sited mainly in coastal regions. The broad aim is to establish how the modern atmospheric environment (climate and atmospheric composition) has been recorded in the upper layers of the ice sheet during the past 200 years. The main objectives are to provide a framework to set the ice core records in a regional context, and to achieve a better understanding of the processes that control the isotopic and chemical composition of snowfall across Antarctica. The data will also provide a firm reference for monitoring future changes of climate and atmospheric composition over the continent, including the role of anthropogenic activity. Determination of the snow accumulation rate and trends during the past 200 years will significantly improve estimates of the mass balance of the ice sheet and trends in response to recent climate change, of direct relevance to the prediction of future global sea level.

Linkages to Other Programmes

The co-ordinated GLOCHANT/PAGES effort (PICE) is linked to several other programmes. The main interactions are:

1. PICE conforms with the objectives of the SCAR Regional Research Programme on the Role of the Antarctic in Global Change.
2. The objectives of PICE form a major component of the Past Global Changes (PAGES) Core project and will require strong interactions with the activities planned under IGAC/PASC (Polar Air-Snow Chemistry) to ensure that the interpretation of ice-core data is well-supported by more process-oriented investigations.
3. Data from the planned drilling activities will contribute directly to the global palaeoclimatic linkages that will be developed within the PAGES/PEP (Pole-Equator-Pole) transects and within PAGES/PANASH (Palaeoclimates of the Northern and Southern Hemispheres).
4. PICE will promote close links with SCOR/JGOFS (Joint Global Ocean Flux Study) and with the WMO/WCRP so that the ice-core data can feed into modelling aspects of the linkages among the biogeochemical cycles and physical climate.
5. PICE will provide linkages to programmes focused on Late Quaternary palaeoenvironments from the sedimentary record, such as the proposed SCAR/GLOCHANT initiative on the Late Quaternary Antarctic ice margin evolution (ANTIME).
6. PICE will also link to the atmosphere modelling community, an interaction that needs to be encouraged to ensure that the selection of drill sites is optimised to suit the environmental problems targeted, and that the palaeodata will provide the boundary conditions and control needed to improve GCM's.

Conclusions

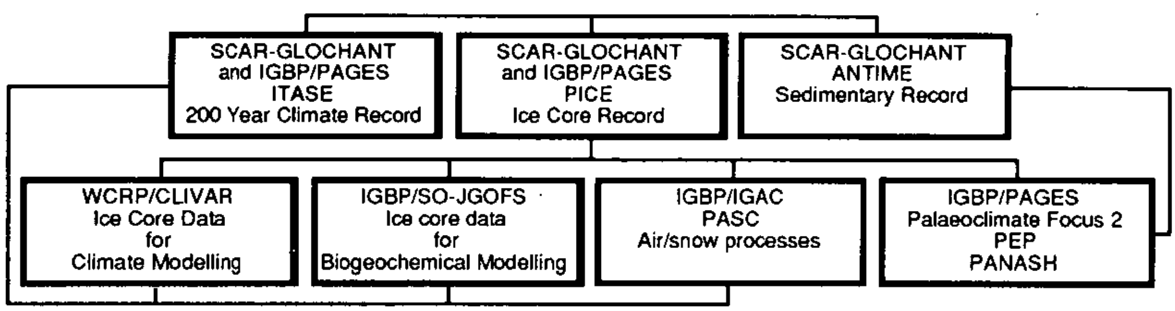
Projects have been presented for a series of national and multinational deep drillings during the next decade in different parts of East and West Antarctica and in Greenland. Taken together, the various proposals aim to ensure that representative climate records are achieved for the principal climatic zones of the polar ice sheets, and that records are obtained that give maximum resolution during time frames that overlap the two time streams identified as priority targets by PAGES. These time streams encompass, respectively, high-resolution reconstructions of the Holocene, and long-range reconstructions of climate through the more radical climate changes occurring over glacial cycles.

The coordinated PAGES/GLOCHANT effort should produce major reductions in the uncertainties surrounding a global environmental change. It will contribute in understanding:

- the climate variability at different time scales,
- the respective role of various radiative forcings,
- the interaction between biogeochemical cycles and climate,
- the North/South climate connection,
- the influence of the polar regions on the climate,
- the climate /ice-sheet control on global sea level.

April 1996

PICE linkages:



APPENDIX 8

Proposal for joint support of a Long-range Radar-sounding Aircraft
To: SCAR National Committees and Managers of National Antarctic Programmes
From: The SCAR/GLOCHANT Task Group on Antarctic Mass Balance and Sea Level (ISMASS)

Background

At XXII SCAR, in the summer of 1992, the SCAR Delegates established the Group of Specialists on Global Change and the Antarctic (GoS/GLOCHANT) to aid SCAR in developing its global change program. At its first meeting GoS/GLOCHANT established several Planning Groups in specific areas of global-change research. One of them, the Planning Group on Antarctic Mass Balance and Sea Level, became what is now known as the Task Group on Ice Sheet Mass Balance, or ISMASS. At its first meeting, in September, 1993, this Group decided that it would set as its first objective the promotion of a better determination of the present-day mass balance of the grounded portion of the Antarctic ice sheet. There were many reasons for this: only changes in the grounded portion of the ice sheet have any effect on sea level; the contribution of the Antarctic ice sheet is the largest uncertainty in the analysis of present-day sea-level rise; evaluating the present-day mass balance would avoid the thorny complexities of glacial dynamics; the subject was not receiving much attention in the national programs of SCAR countries because it was not one that could be addressed effectively by individual nations looking only at portions of the ice sheet; and, consequently, it was a project that was well suited to cooperative, coordinated effort among all SCAR programs that have the capability to contribute to it.

There are two basic approaches to determining present-day mass balance -- the integrated approach and the component approach. The integrated approach involves the determination of the change in volume of the ice sheet by measuring its change in surface height using radar and laser altimeters mounted in satellites. The component approach involves the separate determination of the ice-mass fluxes onto the ice sheet and outward from the ice sheet across the grounding line into the ocean. Calculation of the input means calculation of the integrated surface mass balance across the ice sheet, pwhereas calculation of the output in turn has two parts, both of which must be carried out around the entire perimeter of the ice sheet: measurement of the column-mean glacial velocity across the grounding line and measurement of the ice thickness along the grounding line.

Because of the long time that must elapse before changes in ice-sheet volume have been measured directly and because remaining uncertainties in the integrated approach will make an independent approach important, the Task Group has decided to proceed with the promotion of the component approach. This work will be done by a combination of analysis of satellite images and field work that will require a coordinated SCAR effort.

Here we are specifically concerned with one particular element of that effort -- the measurement of ice thickness around the entire Antarctic perimeter. There are no proven means of measuring ice thickness from satellite observations, although there is a possibility to be pursued -- if surface heights can be measured accurately at or just seaward of the grounding line and if the height of the geoid can be determined sufficiently accurately, then the ice thickness can be calculated from Archimedes principle. Nevertheless, the principal means of measuring ice thickness remains airborne radar sounding. Extensive airborne radar sounding has already been conducted in Antarctica, but virtually all of has been either in an aereal-survey mode or along glacial flow lines.

It is on changing that situation that the Task Group will concentrate its activity. Sounding around the entire Antarctic perimeter can only be accomplished by an extensive effort by as many as possible of the SCAR countries that have now the capability for the airborne work or are developing that capability for the future. At its last meeting in Chamonix in September, 1995, the Task Group began planning this effort -- representatives of the capable countries presented their past and current radar-sounding work, very little of which has been carried out along grounding lines, and discussed where there national programs might be able to carry out soundings in the future. Discussions were begun on specific sections of the Antarctic perimeter that could be accessed by particular countries. At the conclusion of the meeting the Task Group decided further to:

1. encourage national programs to conduct soundings along grounding lines;
2. coordinate the sounding programs with the aim of producing continuity of measurements around the continent while avoiding unnecessary duplication; and
3. search for ways to complete the coverage, i.e. find the that are not accessible by national programs acting on their own. This means looking for internationally cooperative modes of logistic support and seeking new capabilities, particularly aircraft with longer ranges than the typical helicopter or small fixed-wing airplane currently used for radar sounding.

Potential Availability of a Long-Range Aircraft

Right now there is a particularly attractive possibility for obtaining the use of a long-range aircraft -- the potential availability of the P-3 reconnaissance aircraft formerly used in Project Magnet of the United States Naval Oceanographic Office. The P-3 is a four-engine, turbo-prop plane derived from the Lockheed Electra. It was designed for long-range, long-endurance, maritime patrols at low altitude. A standard P-3 is capable of 10-11 hour flights at speeds ranging from 325-750 km/hr, while still maintaining a two-hour fuel reserve. Range varies from 4500-6000 km depending on altitude (100-10,000 m). In research configuration, the P-3 has a scientific payload of more than 4000 kg and can carry up to 8 scientists in addition to the flight crew.

The Project Magnet P-3 has been specially modified to minimize the effect of the plane on magnetics measurements. A sixth fuel tank was also installed to increase the endurance by up to 2 hours more than that of a standard P-3. The Project Magnet P-3 is flown under international treaty to improve the geomagnetic reference model and is probably the only turbo-prop aircraft in the world with sufficient range to fly from Australia or New Zealand to Antarctica and return without landing. Most of the Antarctic continent (as well as a large proportion of the marginal seas surrounding the continent) would be within the operational range of this aircraft if it were based on the sea ice in McMurdo Sound. The Project Magnet aircraft was recently transferred to the Naval Research Laboratory (NRL) to be operated along with NRL's other four research-configured P-3's. Because the primary geomagnetic mission of the aircraft will be eliminated in 1996, the Project Magnet aircraft is available for other research tasks. THIS WINDOW OF OPPORTUNITY TO OBTAIN ACCESS TO AN UNPARALLELED GEOPHYSICAL PLATFORM IS LIMITED. If alternate mission requirements for the aircraft are not identified, it will be eliminated from the U. S. Navy (USN) inventory and scrapped. It is unlikely that an aircraft with equivalent capabilities will ever be built again and the loss of this scientific asset would be tragic for the research community.

The Project Magnet P-3 is not at present equipped with an ice-penetration radar. NRL personnel have been in touch with two different organizations to investigate the addition of a radar system. One is the British Antarctic Survey (BAS), who recently finished the initial field deployment of a 150-MHz radar and have indicated a willingness to collaborate with the NRL group. Discussions with P-3 engineers indicate that the antennas could be installed in a 5-meter-wide area between the wheels of the main landing gear that has sufficient clearance and the necessary wing pylons and hard points for mounting. A little more than 2.5 km penetration was achieved during the first field deployment of this radar on a Twin-Otter. BAS plans to upgrade this to 4 km by increasing amplifier power and converting to a chirped transmission. The other group is at the University of Kansas; they have built a 150-MHz chirped-radar system of modern design and have successfully flown it on a NASA P-3 over Greenland, with excellent ice-thickness-sounding results.

Given sufficient penetration, the 150-MHz frequency has significant advantages for P-3 operations compared to longer wavelengths. There should be no need for migration of the return echoes. Hyperbolic diffractions were not observed in the field test of the BAS radar. Also, the antennas are smaller and are mounted closer to the wings (1/4 wave separation = 0.5 m) than for a lower-frequency system. Since the P-3 typically operates at indicated airspeeds of 450 km/hr, the reduced size of the antenna system considerably reduces the complexity and cost of developing an antenna system as well as reducing the drag on the aircraft.

Other sensor systems can be easily added to the P-3, including gravimetry and magnetics systems, a scanning laser altimeter, a hyper-spectral imager, a passive radiometer, and atmospheric sampling equipment. We envision several types of Antarctic studies which could make use of the P-3's capabilities.

Here is an excellent opportunity to obtain a unique facility for airborne geophysical work in Antarctica. The specific interest for the ISMASS Task Group is in the radar sounding capability, but there would be great potential value as well in the airborne gravity and magnetics surveying of which the P-3 is capable. With the P-3 most of the coastline of the continent would be accessible for ice-thickness sounding.

Equipment and Capabilities

With the exception of a scanning laser system, which might be provided by NASA, and the ice-penetrating radar systems discussed above, NRL can provide all of the equipment and computer systems necessary for data acquisition and reduction. This would include interferometric GPS positioning systems, nadir-pointing laser and 10-GHz radar altimeters, and data acquisition systems for surface profiling. Gravimetric and magnetic subsystems could also be provided if desired.

NRL has a great deal of experience in kinematic GPS and aerogeophysics. Besides NRL, only research groups at NASA have demonstrated operational capabilities for long-baseline (thousand km and greater) kinematic GPS with accuracies in the 1-m range. GPS and airborne geophysical operational techniques and data reduction software developed by NRL for use in Greenland make it possible to obtain high-quality survey data on a routine basis with very little data loss.

Cost Sharing

The basic P-3 flight-hour charge for 1996 is estimated to be $2700/hour. There is some possibility (but by no means any assurance) of cost sharing, with NRL providing up to 80% of the flight-hour costs under its basic research program. In this event, deployment costs would be limited to the residual portion of the flight-hour expenses, the per-diem costs for the air crew during transfer of the aircraft to and from Antarctica, salary costs for the NRL civilian technical support staff during the field deployment, and support for the radar group. Salaries for the USN aircrew will be paid by NRL. NRL might also be able to reimburse the U. S. Antarctic Program for the fuel costs of flights in Antarctica.

Besides contributing to the aircraft costs, NRL will provide the salary of the principal investigator. All field equipment necessary for the operation, except the radar sounder, is presently owned by NRL and will be provided at no cost to the users. It is difficult to imagine a more efficient or cost-effective method of obtaining radar soundings over inaccessible portions of the Antarctic perimeter than to take advantage of the U. S. Navy's considerable investment in aircraft, equipment, software development, and expertise. Proposal to SCAR Countries

The ISMASS Task Group is seeking financial and logistical support from SCAR countries to make it possible for the Project Magnet P-3 to carry out radar soundings in Antarctica. It is our concept that the P-3 could be used both to supplement the coverage for national programs that have radar-sounding aircraft of limited range and to provide coverage for national programs without sounding aircraft of their own. Suitable cooperative arrangements for the analysis and publication of data collected would be worked out.

At this time we are asking for expressions of interest from national programs in pursuing the possibilities further. If a joint, cooperative effort can be mounted it could go a long way toward facilitating our ultimate goal of ice-thickness sounding around the entire Antarctic perimeter.

APPENDIX 9

BEDMAP
Antarctic Bedrock Mapping Project

Antarctic research has developed vigorously in recent years. Antarctica is now truly a "continent for science", the scene of first-rate research in all departments of environmental science and the focus of cooperation between scientists from nations across the world. And yet there are some areas in which our knowledge is failing to keep pace. One such, is the shape of the continent beneath the ice. Indeed, it could be argued that we have better maps of the surface of the moons of Jupiter than we do of the surface beneath theAntarctic Ice Sheet! An improved map of the continent beneath the ice sheet would be of immense value to many areas of research.

Numerical modelling of the ice sheet covering Antarctica is the goal of many researchers and our politicians and taxpayers are expecting these modellers to provide concrete answers to difficult questions about the future ice sheet and sea level. The models are getting better but somehow mapping has been left behind. And whilefield workers are collecting vast amounts of data modellers find them too difficult to handle and so are basing their models on old and substandard base data. BEDMAP could fill the gap and present them with a variety of easily used maps and girded data, reducing a major limitation on the models, the lack of a realistic map of bedrock on which to base them! The time is now right for a new initiative to update and improve the 1983 SPRI bedrock map and that this can best be achieved when sponsored by bodies such as SCAR-GLOCHANT (Scientific Committee on Antarctic Research - GLObal Change in ANTarctica) and EISMINT (European Ice Sheet Modelling Initiative - an ESF funded project)

Over the next few years we would like to see the drawing together of data collected by researchers all over the world into a single database and map-product. This would create new map of the continental surface beneath the ice and so be the basis for much glaciology and geoscience in Antarctica for the next 10 or 20 years.

This is clearly an ambitious project, but one with strong and achievable science goals. There exists a huge data archive of ice thickness in Antarctica, but this is being slowly lost in the archives of Institutes around the world. BEDMAP is one attempt to save it.

Science Background

The Antarctic Ice Sheet is a complex system to model. It is clear that its overall development can be strongly controlled by local basal conditions. For example, around 90% of ice discharge from the continent passes through the ice streams and yet, it seems that these ice streams can be "switched on" or "switched off" in only a few hundred years by subtle changes in sub-ice drainage patterns.

Similarly, the evolution of ice shelves is strongly dependent on the distribution of sea-bed shoals that might act as nucleation sites for ice rises. What is clear is that to mimic reality ice-sheet models should use the highest resolution bed rock data available. Sadly, many of the models presently running are based on bedrock maps derived from datasets which contained data-holes covering hundreds of thousands of sq. km. It is likely that entire mountains and basins were overlooked in these maps.

These maps are no longer adequate for the purposes of modelling and are no longer the best we can do! Since the publication of the last

Antarctic bedrock compilation in the SPRI Geophysical Folio Series (Drewry and Jordan, 1983) considerable advances have been achieved:

- new ice thickness data has been collected by many nations covering much of the sectors not visited before 1983.
- satellite altimetry has almost entirely removed the need to rely on inaccurate barometric altimetry
- mapping has been refined and digitised the areas that can be classified as ice free
- coastal bathymetry has been much improved and is available digitally
- GIS systems currently available allow incorporation all this data into a single determination of bedrock elevation

We propose that all these data be brought together initially as a database and that this is then compiled into a bedrock map. Both database and compilation would provide invaluable tools for the participants and then the greater community. At this stage the project might be considered as completed or the momentum might drive the project over a longer timescale and a permanent home for the database might be sought. In any case we would aim to produce a variety of products for use within many disciplines.

RESPAC - an ice thickness database

One database of airborne radar sounding measurements is RESPAC. This is held and maintained at BAS and includes all the digitised data from the SPRI/NSF/TUD campaigns of the 1970/80s together with 300 000 km of flights collected by BAS since the 1960s. Subsets of the RESPAC data has been made available to researchers on request for the last 5 years.

The project demonstrates that well managed and freely available bedrock data can be of considerable value many years after its collectors have left the field and moved on.

Data available for bedrock compilation

Ice sheet thickness
Airborne radar sounding
Oversnow radar sounding
Oversnow seismic sounding
Rock outcrop data

Ice sheet surface elevation
ERS-1 altimetry (were available)
Airborne and oversnow altimetry (elsewhere)
Map/survey data for the mountainous regions

Sub-ice shelf sea-bed
Oversnow seismic data

Bathymetry over continental shelf
Previous compilations of bathymetry (eg GEBCO)

Bedrock beneath Filchner-Ronne-Schelfeis – a collaborative mapping venture

A recent collaboration between around 10 institutes under the auspices of the Filchner-Ronne Ice Shelf Project has produced a new series of geophysical maps of Flichner-Ronne Ice Shelf and its hinterland. These have included a new compilation of airborne radar sounding, groundbased seismic surveys and bathymetry, giving a much improved view of the bed beneath ice sheet in this area (Vaughan et al., 1994). This has already been of proven value to oceanographers, geophysicists and glaciologists, with digital versions being supplied to around 10 groups.

The success of this project demonstrates both the feasibility of combining bedrock data collected by a variety of techniques and the enthusiasm of researchers to contribute data to a properly run international project.

Strategy

To gain access to all relevant data BEDMAP must be an international project with which all the dataholders would want to be associated.

Initially researchers who hold relevant data would be invited to get involved, together with some invited experts to deal with other aspects of the project (bathymetry, surface elevation).

Overall the project would have to be guided by a steering group, but to be a truly valuable exercise, BEDMAP should aim to include as much data as possible. The project will stand or fall depending on the breadth of participants that it attracts and to encourage cooperation preferential access to the final products will be given to the participating workers. Although small-scale surveys in support of local studies are of little value in terms of large scale mapping taken as a whole they can all contribute to the larger picture.

To foster a sense of cooperation it is important that BEDMAP has a well defined and inclusive publication policy that encourages scientific use of the products, but gives significant reward to the participants.

Funding

In an ideal world, adequate international funding would be available to support BEDMAP, but this is not the case and it likely that the project will have to proceed by the enthusiasm of the participating researchers. That is not to say that individual workers should not use participation in BEDMAP as the basis for funding proposals, simply that for BEDMAP to be of lasting value will require well defined and driven by significant scientific goals.

Since BEDMAP proposes to collect no new data the only requirement for funding would be towards the direct costs of collaboration, data manipulation, publication and dissemination. If initial expression of support is adequate, funding to cover these costs will be sought from a suitable source.

Final product

There are a variety of possible forms for the final products:

- Hardcopy map to be published by BEDMAP consortium and/or SCAR
- Gridded dataset at various resolutions for modelling
- Open access flightline database
- Publication in quality journal or cornerstone paper by BEDMAP consortium
- CD-ROM

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+ Representatives from the SCAR working group on glaciology
+ Representative modellers (eg Huybrechts)
+ Cartographers (eg Sievers)
+ Satellite altimeter specialists (eg Zwally, Bamber, Remy)

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APPENDIX 10

SCAR/GLOCHANT Task Group on Antarctic Ice Sheet Mass Balance and its contribution to Sea Level (*ISMASS*)

Science Plan July 1996

Introduction

Global sea-level has been rising over the last 100-200 years, with an estimated rise of 1.5-2mm/yr. This is a central issue in global change research since a large proportion of the world's population dwell in the coastal zone, particularly on low-lying coasts. The major processes presumably responsible for this sea-level rise are:

- thermal expansion of the oceans;
- increased melting of the temperate glaciers and ice caps; and,
- imbalance in the Greenland and Antarctic ice sheets, where ice discharge and ablation may be exceeding the surface snow accumulation rate.

In 1992, SCAR Delegates at XXII SCAR in Bariloche, Argentina established the Group of Specialists on Global Change and the Antarctic (GoS/GLOCHANT) to develop and coordinate international, multi-disciplinary research projects on the role of the Antarctic in global change. These were based on a regional research plan that SCAR developed (SCAR, 1993). Upon SCAR Executive approval these projects are then recommended to SCAR member nations for implementation within their national programmes. A Task Group on the Antarctic Ice Sheet Mass Balance and Sea-Level (ISMASS) was established by GLOCHANT in 1993 to address the requirements for a coordinated international approach to resolving the role of the Antarctic ice sheet in sea-level change. This document describes the science plan for the ISMASS project.

The Antarctic ice sheet contains sufficient ice to raise world-wide sea level by more than 60 m if melted completely. The amount of snow deposited annually on the grounded ice is equivalent to 5 mm of global sea level. Thus, the Antarctic ice sheet might be a major source of water for the present-day 2 mm/yr rise in sea level, but the uncertainty is large.

Despite all available measurements of snow accumulation, ice velocities, surface and basal melting, and iceberg discharge, it is still not known for certain whether the ice sheets are growing or shrinking, although best estimates suggest a slow growth. The uncertainty in the estimate of the total mass balance is at least 20%, equivalent to a global sea-level change of about 1 mm/yr. Furthermore, the discovery from recent field studies of the West Antarctic ice sheet that rates of discharge from some of the major ice streams have changed markedly in recent decades and centuries has heightened concern about the stability of that marine-based portion of the ice sheet.

The volume and geographic extent of the Antarctic ice sheet have undergone major changes over geological time. The ice sheet was significantly larger during the Last Glacial Maximum, some 20,000 years ago, and retreated to near its present geographic extent about 6,000 years ago. Several mechanisms in the ice sheet-lithosphere system, notably glacio-isostatic adjustments and the effect of temperature on the viscosity of the ice in the deeper layers, have long response times. It is likely that the ice sheet is still reacting dynamically to the glacial-interglacial transition between 20,000 and 10,000 years ago, and the subsequent increase in the snow accumulation rate. Consequently, it is not clear whether the present Antarctic contribution to sea-level (whatever it may be) is the result of changes in accumulation rates over the last century, or due to the long-term dynamical response.

Future enhanced greenhouse warming will affect the mass balance of the ice sheets. Warming of the oceans could increase basal melting of the floating ice shelves, which could result in faster flow of the grounded continental ice into the ocean, contributing to sea-level rise. On the other hand, atmospheric warming and reduction in sea-ice cover could give rise to increased precipitation over the continent, thereby contributing to sea-level lowering.

Realistic predictions of the response of Antarctica to enhanced greenhouse warming and the resulting sea-level contribution will not be possible until the present mass balance is determined and a better understanding of the atmosphere-ice-ocean processes and ice dynamics is developed.

It is useful to make a distinction between:

1. the static effects, directly related to changes in accumulation and ablation and operating instantaneously on sea level, and
2. the dynamic effect, in which the ice flow responds to internal changes and/or, in a delayed fashion, to external forcing. Dynamic responses lag forcings by at least 100 years.

The Key Scientific Objectives

The long-term Objectives of the GLOCHANT programme on Antarctic ice-sheet mass balance and sea level (ISMASS) are:

1. To determine the present distribution of surface elevation change on the ice sheet.
2. To determine the values of the mass balance components, calculate the net mass balance of the ice sheet, and determine how that net balance is distributed between the grounded and floating portions of the ice sheet, and hence determine the sea-level contribution.
3. To determine how the ice sheet changed during the last 20,000 years and what changes are continuing.
4. To identify and evaluate the important processes that affect moisture flux across the continental periphery and determine the patterns of deposition on the ice sheet.
5. To identify and evaluate the physical controls on the motion and areal extent of ice streams and outlet glaciers.
6. To quantify the interaction between the ocean and the ice shelves and how this interaction varies in space and time, and to determine the implications of this interaction for the discharge of grounded ice.
7. To develop the capability for predicting from various climate scenarios the change in grounded ice volume that would occur over the next decades to several centuries (SCAR, 1993).

ISMASS Methodology

At the first meeting, in September, 1993, the Task Group decided that it would set as its first task a better determination of the present-day mass balance of the grounded portion of the Antarctic ice sheet. There were many reasons for this:

- only changes in the grounded portion of the ice sheet have direct effect on sea level;
- the contribution of the Antarctic ice sheet is the largest uncertainty in the analysis of present-day sea-level rise;
- the task involves only static effects (Objectives 1, 2, & 4)
- the subject was not receiving much attention in the national programs of SCAR countries because it was not one that could be addressed effectively by individual nations looking only at portions of the ice sheet; and,
- it was a project that was well suited to cooperative, coordinated effort among all SCAR programs that have the capability to contribute to it.

There are two basic approaches to determining present-day mass balance — the integrated approach and the component approach. The integrated approach involves the determination of the change in volume of the ice sheet by measuring its change in surface elevation using radar and laser altimeters mounted in satellites. The component approach involves the separate determination of the mass input onto the ice sheet and the mass flux discharged from the ice sheet across the grounding line (the boundary between grounded and floating ice) into the ocean. The mass input can be calculated by the integration of surface mass balance across the ice sheet, whereas calculation of the mass flux in turn has two parts: measurement of the column-mean glacial velocity across the grounding line and measurement of the ice thickness along the grounding line. Both of these measurements must be carried out around the entire perimeter of the ice sheet.

Integrated approach to mass balance determination

The basic principle of the integrated approach is relatively simple — measure the height of the ice sheet repeatedly over a period of years to determine its changes through time. The only tool now available for continent-wide use is the satellite-borne radar altimeter. The altimeter-bearing satellites of the 1970s and 1980s had orbits that carried them at best only to a latitude of 72°, so they covered only a small fraction of the entire ice sheet. The situation is much improved now, with the ESA satellites ERS-1 and ERS-2 in orbits that reach to 82° latitude, although that still leaves a substantial portion of the ice sheet uncovered.

There is another serious problem with the radar altimeter besides the orbital limitation. Over ice sheet surfaces with a slope greater than two degrees, and rough or extensively crevassed surfaces, the radar altimeter tends to lose its signal and produces poor or no measurements. This results in a loss of data particularly in the marginal portions of the ice sheet, where the surface elevation changes and ice flow are likely to be the greatest. This problem could be alleviated by the use of a laser altimeter, because of the small footprint size of that instrument. The US space agency, NASA, has plans to launch a satellite bearing a laser altimeter into an orbit that will reach to 86°S latitude, tentatively in the year 2002. The laser altimeter should yield surface elevations over the entire ice sheet north of 86 degrees with a regional-mean accuracy of 10 cm or better.

Satellite altimeters presumably will produce good determinations of the changing surface height of the ice sheet, but that does not in itself yield changes in ice-sheet mass. Corrections will have to be made for tectonic and isostatic changes in the height of the glacial bed and for changes in the mean density of the firn layers. These are non-trivial tasks: an aid to the latter may come from measurements associated with studies of the surface mass balance (discussed below). Even after the change in mass has been calculated, there still remains the difficulty of separating secular changes from the changes associated with the interannual variability of snowfall.

These problems are serious ones, and virtually assure that it will be well over 10 years before satellite measurements can yield a quantitatively significant figure for the Antarctic contribution to sea-level change. The work with the radar and laser altimeters is done by individual investigators supported by the space agencies in several countries; consequently, the Task Group believes that there is no particular role for SCAR to play in this regard, other than to encourage the space agencies to continue the work.

Component approach to mass balance determination

The Task group believes that the component approach should be the main focus of the coordinated SCAR research, because of the long time that must elapse before changes in volume can be determined by the integrated approach and because uncertainties in the integrated approach make it important to have an independent means of evaluating the mass balance. This work will be done by a combination of analysis of satellite images and field work that will require a coordinated SCAR effort.

Mass input

There are two principal approaches to measuring the mass input to the ice sheets: measuring "moisture flux divergence," i.e. the difference between total amounts of water vapour passing inward and outward across the ice-sheet margins, and measuring the amount of snow that accumulates on, and ice that ablates from, the surface. Snow accumulation rates can be measured in at least two different ways. The classical way, still the most reliable, is by direct measurement from observations on the surface, principally by finding the depth to well-dated H-bomb-fallout horizons and increasingly by annually resolved ice-core and snow-pit studies. A newer method of great potential value, but one that has not yet been fully developed and tested, is to calculate the accumulation rate from the microwave emissivity of the surface. The grain size and shape in the uppermost ten meters of snow depends upon the accumulation rate (but also on other parameters), and the characteristics of the grains, in turn, affect the emissivity. Unfortunately, these effects are not fully understood; the best to hope for at present is an effective means of interpolating between points where the accumulation rate has been measured on the surface. For this, as well as for validation of the moisture-flux technique, a good distribution of surface measurements is essential.

Mass output

The output flux can be considered to be the product of two quantities whose values must be known around the entire perimeter of the grounded ice sheet bounded by the grounding line — the mean columnar velocity across the grounding line and the ice thickness along the grounding line. Velocities at the surface of the ice sheet can be measured by satellite techniques; if measured at or just seaward of the grounding line those velocities will be essentially constant with depth in the ice. Velocities can be determined by relocating identifiable surface features on repeated high-resolution visual and SAR imagery (although it has yet to be shown that SAR images have the resolution needed for this technique). SAR interferometry has extremely high resolution and may therefore be most useful on slow-moving ice; however, the technique is still young and under development and there are problems relating to wide-spread application to the ice sheets that remain to be solved. Several SCAR countries have programs to measure velocities using satellite techniques — the Task Group is coordinating these efforts to provide the best possible coverage of the entire continent. It is also encouraging the development of the still nascent interferometric technique.

There is no proven means of measuring ice thickness from satellite observations, but there is a possibility to be pursued — if surface heights can be measured accurately at or just seaward of the grounding line and if the height of the geoid can be determined sufficiently accurately, then the ice thickness can be calculated from Archimedes principle. Nevertheless, the principal means of measuring ice thickness remains airborne radar sounding. Extensive airborne radar sounding has already been conducted in Antarctica, but virtually all of has been either in an areal-survey mode or along glacial flow lines. There have been as yet no flights carried out specifically to measure ice thickness along a grounding line.

Specific plan

Airborne radar sounding around the entire Antarctic perimeter grounding zone can only be accomplished by an extensive effort by as many as possible of the SCAR countries that now have the capability for the airborne work or are developing that capability for the future. The principal planned activity of the Task Group is to coordinate radar sounding around the grounded perimeter of the Antarctic ice sheet. At its last meeting in Chamonix in September, 1995, the Task Group began this specific planning — representatives of the capable countries presented their past and current radar-sounding work, very little of which has been carried out along grounding lines, and discussed where their national programs might be able to carry out soundings in the future. Discussions were begun on specific sections of the Antarctic perimeter that could be accessed by particular countries. The Task Group will undertake to:

- encourage national programs to conduct soundings along grounding lines;
- coordinate the sounding programs with the aim of producing continuity of measurements around the continent while avoiding unnecessary duplication;
- search for ways to complete the coverage, i.e. find the capability to conduct the soundings along portions of the perimeter that are not accessible by national programs acting on their own. This means looking for internationally cooperative modes of logistic support and seeking new capabilities, particularly aircraft with longer ranges than the typical helicopter or small fixed-wing airplane currently used for radar sounding.

Secondarily, the Task Group plans to encourage and promote national and international work toward the other aspects of the component approach. In particular, it will:

- coordinate the measurements of velocities by analysis of sequential satellite imagery around the continental periphery, again to produce continuity and limit duplication;
- encourage more scientists to develop the expertise needed to use the SAR interferometric technique and apply it to the measurement of glacial velocities in Antarctica;

- assist in the development of the ITASE program (see section below);
- encourage the further theoretical development and application of passive microwave radiometry of determining surface mass balance; and
- promote theoretical and applied advances in calculating the snow accumulation rate on the Antarctic interior using moisture-flux-divergence techniques.

The Task Group plans to meet annually and conduct its business by correspondence between meetings. It will be aided actively by the SCAR Global Change Programme Office; the Programme Coordinator is a contributing member of the Task Group.

Development of the International Trans-Antarctic Scientific Expedition (ITASE)

ITASE is an essential component of ISMASS that addresses Objectives 2 and 4. It is a joint initiative between GLOCHANT and the IGBP-PAGES (Past Global Changes) core project, and was accepted by SCAR in 1991. It is a multi-national programme whose aim is to develop a high resolution (sampling interval: ~50–100 km) interpretation and 3-D map documenting principally the last 100–200 years of climate, atmosphere and surface conditions over the Antarctic ice sheet. It also aims to develop a program of medium-depth ice-core drilling across Antarctica which will provide paleoclimatological information covering the last few thousand years. The ITASE project will be conducted on oversnow traverses into the interior of the ice sheets. The multi-parameter investigation will include:

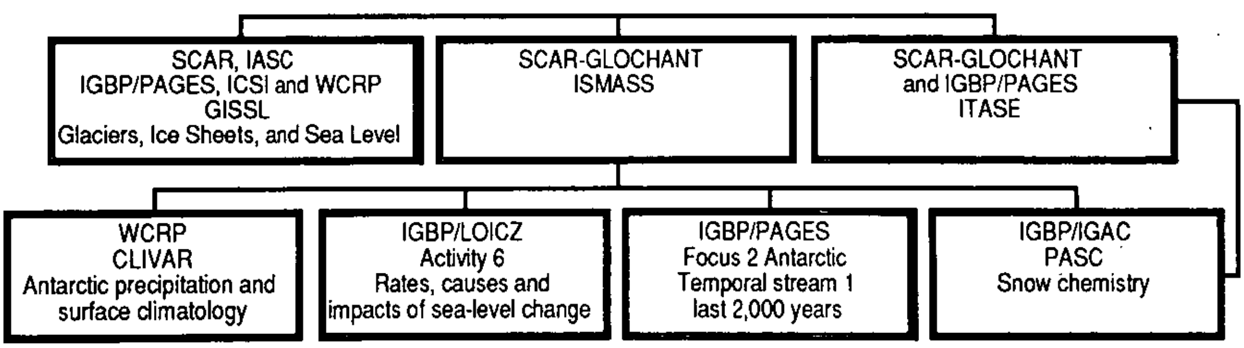
- major snow chemistry, (major anions and cations, MSA, organic acids, trace metals, H_2O_2);
- stable isotopes, δD, $\delta^{18}O$, excess D, beta activity, tritium, ^{10}Be;
- Microparticles (continental dust, volcanic ash), biological particles (microbes and spores);
- snow accumulation rate;
- high resolution radio-echo sounding;
- snow temperature profiling, and;
- ground truthing of remote sensing data; and
- a platform for the deployment of field instrumentation, such as automatic weather stations.

The ITASE project will provide an important baseline for assessing recent and future environmental change in Antarctica. It will also provide an interface between existing and proposed international intermediate and deep ice-core-drilling activities and related transfer- function experiments.

Linkages to Other International Programmes

ISMASS has strong linkages to the IGBP core project on Land-Ocean Interactions in the Coastal Zone (LOICZ), particularly to its Framework Activity 6 — Determination of the rates, cause and impacts of sea-level change. It also has linkages with the World Climate Research Programme (WCRP) through its CLIVAR project on climate variability. ISMASS potentially will contribute research on precipitation and snow accumulation variability over Antarctica to CLIVAR. Through the ITASE project, ISMASS has linkages to the IGBP core project on Past Global Changes (PAGES) and to the International Global Atmospheric Chemistry Project (IGAC). These linkages are shown graphically below.

ISMASS linkages:



List of Acronyms and Abbreviations

CLIVAR	Climate Variability and Prediction Research (WCRP)
GLOCHANT	Group of Specialists on Global Change and the Antarctic
IGAC	International Global Atmospheric Chemistry Programme (IGBP)
IGBP	International Geosphere-Biosphere Programme
ISMASS	Ice Sheet Mass Balance and its Contribution to Sea Level
ITASE	International Trans-Antarctic Scientific Expedition
LOICZ	Land-Ocean Interactions in the Coastal Zone
PAGES	Past Global Changes Programme (IGBP)
SCAR	Scientific Committee on Antarctic Research
WCRP	World Climate Research Programme

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APPENDIX 11

Memorandum of Understanding between SCAR and START, for SCAR-GLOCHANT to become the START Regional Committee for the Antarctic, within the START Regional Research Network.

Preamble

The polar regions are known to have a key role to play in the investigation of a range of global environmental problems. The existing international committees responsible for coordinating scientific research in the Antarctic (Scientific Committee for Antarctic Research - SCAR) and the Arctic (International Arctic Science Committee - IASC) share common objectives in promoting scientific research on global change in the polar regions. They both recognise that to realise the full research potential of the polar regions, the existing and proposed regional research programmes will need to be linked firmly to established international programme frameworks.

Objectives

Existing global framework programmes that share the objectives addressed by the SCAR and IASC regional programmes are the International Geosphere-Biosphere Programme (IGBP) and the World Climate Research Programme (WCRP), and, for the Arctic only, the Human Dimensions of Global Change Programme (HDP). To ensure truly global research coverage it is essential to provide a formal relationship between the existing and proposed research programmes for the polar regions and the programmes of IGBP, WCRP and HDP.

Any such agreement must provide not only for planning and implementation of programmes but also for data issues (including access, quality, and management) and training. Such an agreement must also incorporate clear mechanisms for adequate cross-representation and information transfer between appropriate committees of SCAR and these global programmes.

Agreement

A formal international link between SCAR and the global programmes can be most appropriately developed through the System for Analysis, Research and Training of IGBP, WCRP, and HDP (START). In this context it is agreed that SCAR will become an affiliated regional organisation to START with the responsibility for implementing START objectives, where appropriate, in Antarctic research programmes.

The development of the relationships between existing and proposed Antarctic programmes as well as the provision of advice to START on the Antarctic aspects of global change will be the responsibility of the SCAR Group of Specialists on Global Change and the Antarctic (SCAR-GLOCHANT), who will become the de facto START Regional Committee for the Antarctic. The membership of this regional committee will be jointly endorsed by SCAR and START.

There will be representation of SCAR-GLOCHANT at appropriate START meetings, including those of Regional Directors, and liaison with the START Secretariat will be undertaken through SCAR's Global Change Programme Coordinator.

The location and implementation of any Regional Research Centres and Regional Research Sites will be the subject of joint discussions between SCAR and START.

It is recognised by SCAR that START normally expects regional committees to promote the principal programmes of IGBP, WCRP and HDP in that region. It is recognised by START that SCAR has a wider portfolio of interests than those of START. However, there is a close congruence of major interests between the two parties which indicates the value of joint planning and implementation for the good of global science. SCAR has identified those Antarctic programmes that are directly relevant to existing IGBP and WCRP objectives and, through START, will seek formal acceptance of these programmes by the appropriate committees.

Major research themes that are currently identified as of joint interest include:

- the effects of enhanced UV on ecosystems
- the effects of present climate change on mass balance of ice sheets and thus on sea level
- the characterisation of past global changes
- the changing chemistry of the atmosphere
- the flux of carbon in pelagic and coastal marine ecosystems

The relationship between SCAR, IGBP, and WCRP for these general themes are outlined as Annex 1.

This Memorandum of Understanding will be subject to review every five years, although details of the agreement may be revised sooner by mutual agreement. Either party may revoke the agreement by giving six months written notice.

Acronyms

ACSYS	Arctic Climate System Study
ANTOSTRAT	Antarctic Offshore Stratigraphy
ASPECT	Antarctic Sea-ice Processes, Ecosystems and Climate
BIOTAS	Biological Investigation of Terrestrial Antarctic Systems
CLIVAR	Climate Variability and Predictability
CS–EASIZ	Coastal and Shelf – Ecology of the Antarctic Sea Ice Zone
GCTE	Global Change and Terrestrial Ecosystems
GLOCHANT	Group of Specialists on Global Change and the Antarctic
ISMASS	Ice Sheet Mass balance
LOICZ	Land Ocean Interactions in the Coastal Zone
PAGES	Past Global Changes
PICE	Palaeoenvironments from Ice cores
SO–JGOFS	Southern Ocean – Joint Global Ocean Flux Study

Annex 1

The relationships between SCAR, IGBP and WCRP Core Projects

SCAR	IGBP	WCRP
ANTOSTRAT	PAGES	
ASPECT	LOICZ, SO–JGOFS	ACSYS, CLIVAR
BIOTAS	GCTE	
CS–EASIZ	LOICZ, SO–JGOFS	
ISMASS	LOICZ, PAGES	CLIVAR
PICE	PAGES	
SCAR–GLOCHANT	IGBP	WCRP

APPENDIX 12

List of acronyms and abbreviations

ACoPS	Antarctic Coastal Polynya Study
ACSYS	Arctic Climate System Study
ADOX	Atlantic Deep Ocean Exchange
AnITMP	Antarctic Ice Thickness Monitoring Project
AnZone	International Coordination of Oceanographic Research within the Antarctic Zone
APIS	Antarctic Pack-Ice Seals programme
ASPECT	Antarctic Sea-Ice Processes, Ecosystems and Climate (GLOCHANT)
ATOC	Acoustic Thermometry of Ocean Climate
AUV	Automatic Underwater Vehicle
AWI	Alfred Wegener Institute for Polar and Marine Research(Germany)
BAS	British Antarctic Survey
BIOMASS	Biological Investigations of Marine Antarctic Systems and Stocks
BIOTAS	Biological Investigations of Terrestrial Antarctic Systems
CCAMLR	Convention for the Conservation of Antarctic Marine Living Resources (Antarctic Treaty System)
CCCO	Committee on Climate Changes and the Ocean (SCOR)
CEMP	CCAMLR Ecosystem Monitoring Programme
CG	Coordinating Group (GLOCHANT)
CG-1	Coordinating Group 1 on Data Management (GLOCHANT)
CG-2	Coordinating Group 2 on Numerical Modelling (GLOCHANT)
CLIVAR	Climate Variability and Prediction Research (WCRP)
CNRS	National Centre for Scientific Research (France)
COMNAP	Council of Managers of National Antarctic Programmes
CS-EASIZ	Coastal and Shelf – Ecology of the Antarctic Sea-Ice Zone (GoSSOE)
DecCen	Decadal to Centennial climate variability and predictability
DIC	Dissolved inorganic carbon
DIS	Data and Information System
DOC	Dissolved organic carbon
ENSO	El Niño - Southern Oscillation
EPICA	European Ice Coring in Antarctica
FRISP	Filchner-Ronne Ice Shelf Programme
FROST	First Regional Observing Study of the Troposphere
GAIM	Global Analysis, Interpretation and Modelling (IGBP)
GAW	Global Atmosphere Watch
GCOS	Global Climate Observing System
GCTE	Global Change and Terrestrial Ecosystems (IGBP)
GEWEX	Global Energy and Water Cycle Experiment
GLOBEC	Global Ocean Ecosystems Dynamics Research
GLOCHANT	Group of Specialists on Global Change and the Antarctic (SCAR)
GLODAR	Global Data Archive Rescue
GOOS	Global Ocean Observing System
GoS	Group of Specialists (SCAR)
GoSSOE	Group of Specialists on Southern Ocean Ecology (SCAR)
GRIP	Greenland Research Ice Core Project
GSBRN	Global Surface Baseline Radiation Network (GEWEX)
GTS	Global Telecommunication System
IAG	International Association for Geodesy
IAMAP	International Association for Meteorology and Atmospheric Physics
IAPSO	International Association for the Physical Sciences of the Ocean
IASC	International Arctic Science Committee
ICAIR	International Centre for Antarctic Information and Research (New Zealand)
ICAP	International Circum-polar Arctic Ice Drilling Project
ICSU	International Council of Scientific Unions
IGAC	International Global Atmospheric Chemistry Programme (IGBP)
IGBP	International Geosphere-Biosphere Programme
IGBP-DIS	IGBP - Data and Information System
IGS	International Glaciological Society
IHDP	International Human Dimensions of Global Environmental Change Programme
IOC	International Oceanographic Commission
IPAB	International Programme for Antarctic Buoys
IPCC	Intergovernmental Panel on Climate Change
ISCCP	International Satellite Cloud Climatology Project (GEWEX)
ISMASS	Ice Sheet Mass Balance
ITASE	International Trans-Antarctic Scientific Expedition
IUGG	International Union of Geodesy and Geophysics

JEISSO	Joint Expeditions in the Indian Ocean Sector of the Southern Ocean
JGOFS	Joint Global Ocean Flux Study (SCOR and IGBP)
JSC	Joint Scientific Committee for WCRP
LOICZ	Land-Ocean Interactions in the Coastal Zone (IGBP)
LTER	Long term ecological research (US)
MAST	Marine Scientific Technology
MIZ	Marginal Ice Zone
NATO	North Atlantic Treaty Organization
NIPR	National Institute of Polar Research (Japan)
NOAA	National Oceanic and Atmospheric Administration (USA)
PACA	Working Group on Physics and Chemistry of the Atmosphere (SCAR)
PAGES	Past Global Environmental Changes Programme (IGBP)
PASC	Polar Air and Snow Chemistry Programme
PASE	Polar Air-Snow Experiment
PIC	Particulate inorganic carbon
POC	Particulate organic carbon
PG	Planning Group (GLOCHANT)
PG-1	Planning Group 1 on Sea Ice (GLOCHANT)
PG-2	Planning Group 2 on Global Palaeoenvironmental Records from the Antarctic Ice Sheet and Marine and Land Sediments (GLOCHANT)
PG-3	Planning Group 3 on Antarctic Mass Balance and Sea Level (GLOCHANT)
PG-4	Planning Group 4 on Trace Gases, Aerosol Particles, and UV Radiation in the Antarctic Atmosphere (GLOCHANT)
PG-5	Planning Group 5 on Biogeochemical Cycles (GLOCHANT)
ROV	Remote Observational Vehicle
RRC	Regional Research Centre (START)
RRN	Regional Research Network (START)
SAGE	Stratospheric Aerosol and Gas Experiment
SAR	Synthetic Aperture Radar
SCALOP	Standing Committee on Antarctic Logistics and Operations
SCAR	Scientific Committee on Antarctic Research
SCOPE	Scientific Committee on Problems of the Environment (ICSU)
SCOR	Scientific Committee on Oceanic Research
SeaWIFS	Sea Viewing Wide Field-of-View Sensor
SIEFS	Sea Ice Ecology and Flux Study
SIOM	Sea Ice/Ocean Modelling Panel
SO-GLOBEC	Southern Ocean - GLOBEC
SO-JGOFS	Southern Ocean - JGOFS
SPARC	Stratospheric Processes and their Role in Climate (WCRP)
START	System for Analysis, Research and Training (IGBP)
TOGA	Tropical Ocean and Global Atmosphere Experiment
ULS	Upward-Looking Sonar
UNEP	United Nations Environment Programme
UV	Ultraviolet Radiation
WG	Working Group
WAIS	West Antarctic Ice Sheet Initiative
WOCE	World Ocean Circulation Experiment (WCRP)
WCRP	World Climate Research Programme
WMO	World Meteorological Organization
WMO–CAS	World Meteorological Organization Commission on Atmospheric Sciences
WWW	World Wide Web

SCAR Report

SCAR Report is an irregular series of publications, started in 1986 to complement *SCAR Bulletin*. Its purpose is to provide SCAR National Committees and other directly involved in the work of SCAR with the full texts of reports of SCAR Working Group and Group of Specialists meetings, that had become too extensive to be published in the *Bulletin*, and with more comprehensive material from Antarctic Treaty meetings.

SCAR Bulletin

SCAR Bulletin, a quarterly publication of the Scientific Committee on Antarctic Research, is published on behalf of SCAR by Polar Publications, at the Scott Polar Research Institute, Cambridge. It carries reports of SCAR meetings, short summaries of SCAR Working Group and Group of Specialists meetings, notes, reviews, and articles, and material from Antarctic Treaty Consultative Meetings, considered to be of interest to a wide readership. Selections are reprinted as part of *Polar Record*, the journal of SPRI, and a Spanish translation is published by Instituto Antártico Argentino, Buenos Aires, Argentina.

Polar Record

Polar Record appears in January, April, July, and October each year. The Editor welcomes articles, notes and reviews of contemporary or historic interest covering the natural sciences, social sciences and humanities in polar and sub-polar regions. Recent topics have included archaeology, biogeography, botany, ecology, geography, geology, glaciology, international law, medicine, human physiology, politics, pollution chemistry, psychology, and zoology.

Articles usually appear within a year of receipt, short notes within six months. For details contact the Editor of *Polar Record*, Scott Polar Research Institute, Lensfield Road, Cambridge CB2 1ER, United Kingdom.
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The journal may also be used to advertise new books, forthcoming events of polar interest, etc.

Polar Record is obtainable through the publishers, Cambridge University Press, Edinburgh Building, Shaftesbury Avenue, Cambridge CB2 2RU, and from booksellers. Annual subscription rates for 1998 are: for individuals £50.00 ($86.00), for institutions £80.00 ($138.00); single copies cost £22.00 ($38.00).

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