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SCAR report

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Contents

Achievements of SCAR to 2006

SCIENTIFIC COMMITTEE ON ANTARCTIC RESEARCH

at the

Scott Polar Research Institute, Cambridge, United Kingdom

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 Standing Scientific Groups and Group of Experts 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, carries reports of SCAR meetings, short summaries of SCAR Standing Scientific Groups, Action Groups and Groups of Experts meetings, notes, reviews, and articles, and material from Antarctic Treaty Consultative Meetings, considered to be of interest to a wide readership.

ACHIEVEMENTS OF SCAR TO 2006

For almost 50 years SCAR has facilitated international collaboration in Antarctic science, adding value to national scientific research in the Antarctic by encouraging the cooperation required to provide pan-Antarctic views beyond the capability of any one country and to establish the role of Antarctica in the global Earth System. SCAR works closely with other global research bodies to ensure that Antarctic science plays its full part in global research programmes. Over the past 15 years SCAR has focused on the detection of global change in Antarctica, studies of the processes linking Antarctica to the global system, the extraction of Antarctica's environmental history from ice cores and sediments, and analyses of the ecosystems on land and in the Southern Ocean and their response to change. The latest scientific programme was outlined at the beginning of the new millennium, and 5 core projects were approved in 2004, addressing the present climate system, climate evolution, biological evolution, lakes beneath the ice, and the effects of the solar wind.

SCAR also provides scientific advice to the Parties to the Antarctic Treaty, to encourage policy-making and good governance based on sound scientific information.

SCAR is an Interdisciplinary Body of the International Council for Science (ICSU).

EXECUTIVE SUMMARY

SCAR's significant achievements in recent years include the following:

1. Determining the functional ecosystem processes of the Southern Ocean ecosystem, including the key role of krill, and documenting the distribution, abundance and long-term trends in Antarctic and Subantarctic seabirds.

2. Understanding the diversity, ecology and population dynamics of the organisms beneath the Antarctic sea ice, and their sensitivity to change.

3. Establishing how Antarctic land, lake and pond life respond to climate change, and identifying the processes determining community response to stress.

4. Discovering a major warming of the Antarctic winter troposphere, 5 km above sea level, that is larger than any other tropospheric warming on Earth.

5. Confirming that, while the Antarctic Peninsula has warmed significantly (3ºC on average and 5ºC in winter on the west coast over the past 50 years), air temperatures in East Antarctica have remained steady or cooled.

6. Determining that the Larsen-B Ice Shelf collapsed because prevailing westerly winds brought more warm air across the Antarctic Peninsula as the planet warmed.

7. Providing the basis for determining the mass balance of the Antarctic Ice Sheet. West Antarctica is losing mass; East Antarctica remains largely stable.

8. Developing a climatology of Antarctic sea-ice for understanding sea-ice formation, validating satellite data, and feeding coupled ocean–ice–atmosphere models.

9. Creating an unprecedented spatio-temporal array of information about the ice sheet as the basis for exploring the variability and recent evolution of Antarctic climate, and using new geological data and numerical modelling to explain the history of the ice sheets and climate since extensive glaciation began 34 million years ago.

10. Generating plans and guiding principles for the exploration and environmental stewardship of unique, pristine, sub-glacial lakes.

11. Providing a wide range of geographic and scientific maps, databases and related products for a wide variety of users, and funnelling the work of the National Antarctic Data Centres into the Antarctic Master Directory.

12. Providing scientific advice on conservation and environmental management issues to the Antarctic Treaty System.

1. INTRODUCTION

This document reviews the achievements of SCAR in improving scientific understanding of Antarctica and its environs, and of the role of Antarctica in the global Earth System, focusing on the past 20 years. It also reviews SCAR's achievements in providing scientific advice to policy makers concerned with different aspects of the Antarctic Treaty. This is a 'living' document that will be updated as new information arrives.

1.1 ANTARCTICA IN THE EARTH SYSTEM

The document begs the question – why do scientific research in Antarctica and its surrounding Southern Ocean? The answer is both simple and profound – to live sustainably on this planet we must understand how it works; we cannot do that without understanding all its parts – including Antarctica.

To appreciate fully how the Earth System works as an integrated whole, and how it has changed through time, we are obliged to study Antarctica, one of the System's most geographically and climatically extreme components. The need grows, the more we realize that the warming that afflicts us all manifests itself sooner and more intensely in the Polar Regions than elsewhere. The fact that nobody lives on Antarctica, apart from a tiny scientific crew, is irrelevant. What happens there affects everyone.

Earth System is a term coined to recognize the interconnectedness of the physical, biological, chemical and geological processes that make up the global environment. The ocean deeps are everywhere connected by the ocean's thermohaline circulation. Deep waters bring climate signals into the Antarctic realm from as far away as the Arctic. Antarctica is **a major driver of ocean circulation**, exporting its own climate signals northward both at the seabed, in the Antarctic Bottom Water that aerates the global ocean deeps, and, at shallower depths, in the Antarctic Intermediate Water that feeds the world's major fisheries with nutrients. Carbon dioxide from the burning of fossil fuels is sucked down into Intermediate and Mode Water in **the world's largest carbon sink** along the northern edge of the Antarctic Circumpolar Current,

thence to fill the upper oceans of the Southern Hemisphere with mildly acid solutions that show increasing potential to dissolve the carbonate shells of planktonic pteropods and coccolithophores and upset ocean ecosystems. Overhead, in the grand scheme of atmospheric circulation, winds bring heat south at high levels from the tropics and feed cold air back towards the equator at sea level. El Niño signals make their way south to Antarctic coasts from the tropical Pacific via giant air-borne Rossby Waves. Antarctica **influences the world's weather system by operating as its refrigerator**. At the same time, like the Arctic, it responds more quickly than other regions to global warming, providing **the world's fastest warming hotspot – the Antarctic Peninsula**. Ice cores and marine sediment cores preserve detailed records of past climate change; the **sediments tell us how Antarctic ice has come and gone over the past 34 million years**, the ice cores tell us about the past 800,000 years. The ice cores have the added virtue of **preserving unique records of the chemistry of the atmosphere**, in the form of gas bubbles.

The Antarctic ecosystem is unique – much more diverse than originally imagined, perhaps because glaciation of the continental shelves forced species down onto the continental slope where they could diversify. Species evolved in extraordinary ways to deal with the cold, some developing antifreeze in their blood. The Antarctic thus offers **unique insights into how ecosystems cope with climate change**. Genes and species flow into and out of Antarctic waters with the tides and currents. Some Antarctic migrants feed around one pole and breed around the other. Locally the ocean is like a "Serengeti", thick with the **world's largest least exploited protein resource – the krill**. Winds, ships and humans contribute to invasions of new species on the land and in the sea.

In the outer reaches of the atmosphere the flow of plasma creates a protective blanket connecting the Arctic and the Antarctic and shielding us from the worst effects of the solar wind. Ozone is another such protective cloak, pierced with polar holes. Astronomers can see through Earth's enveloping atmospheric blanket more clearly here than anywhere else on the planet. But ice is everywhere, poised like a threat to engulf the world's coasts with rising seas if our greenhouse gets too warm. The **West Antarctic Ice Sheet holds the greatest potential for a surprising rise in sea level**; if it disintegrates as rapidly as some think it might it could raise sea level by 5–7metres by 2100

Since its first meeting in February 1958, SCAR has contributed in many ways to developing an understanding of the role of Antarctica and its surrounding ocean in the Earth System. SCAR brings scientists together to address scientific issues from a pan-Antarctic perspective. The emphasis has changed somewhat over the past 25 years, as scientists moved away from a focus on localized regional studies towards developing a more holistic understanding of the operation of the Earth System. At the global level, this shift was marked by the formation, by the International Council for Science (ICSU) and its partners, of the World Climate Research Programme (WCRP) in 1980 and of the International Geosphere-Biosphere Programme (IGBP) in 1986.

As befits an ICSU body, SCAR's developments mirror these global trends in research management. SCAR adapted its programmes to map onto and contribute to those of IGBP and WCRP. In the late 1980s SCAR identified four major interdisciplinary research themes for an Antarctic component of the IGBP (SCAR, 1989):

A. ***Detection of global change in Antarctica;***
B. ***Study of the critical processes linking Antarctica to the global system;***

C. Extraction of palaeoenvironmental information;
D. Assessment of ecological effects.

These themes still underpin most of SCAR's research.

Following an Implementation Plan (SCAR, 1993), SCAR formed the Group of Specialists on Global Change and the Antarctic (GLOCHANT) to address these four themes through six thematic projects and three topic areas:

	Thematic Projects	Addressed by	Status
1	***The Antarctic sea-ice zone: interactions and feedbacks within the global geosphere-biosphere system***	programmes on Ecology of the Antarctic Sea-Ice Zone (EASIZ), and on Antarctic Sea Ice Processes, Ecosystems and Climate (ASPeCt)	EASIZ ended 2004; work continues in EBA; ASPeCT is ongoing
2	***Global palaeoenvironmental records from the Antarctic ice sheet and marine and land sediments***	programmes on ice cores – PICE; on the International Trans-Antarctic Scientific Expedition – ITASE; and on the Late Quaternary Sedimentary Record of the Antarctic Ice Margin Evolution – ANTIME	PICE continues as IPICS; ITASE is ongoing; ANTIME continues as ACE
3	***The mass balance of the Antarctic ice sheet and sea level***	ITASE and the Ice Sheet Mass Balance and Sea Level programme – ISMASS	Both ongoing
4	***Antarctic stratospheric ozone, tropospheric chemistry and the effects of UV radiation on the biosphere***	programmes on Physics and Chemistry of the Atmosphere – PACA; on Antarctic Peninsula Tropospheric-Ionospheric Coupling – APTIC; and on Antarctic Tropospheric Aerosols and the Role in Climate - ATAC	All completed by 2004
5	***The role of the Antarctic in biogeochemical cycles and exchanges: atmosphere and ocean***	EASIZ (see 1 above), and IGBP's Joint Global Ocean Flux Study, JGOFS, with some assistance from SCAR	Now represented by ICED
6	***Environmental monitoring and detection of global change in Antarctica***	EASIZ (1 above) and the Biological Investigations of Terrestrial Antarctic Systems programme, BIOTAS	Now represented by EBA
	Topic Areas		
7	***Improve numerical modelling of the atmosphere, the ocean, sea ice, land ice and ice shelves, and expand the long-term monitoring needed to feed data into such models***	individual SCAR groups as appropriate	ongoing

8	***Improvements in making data available to all, particularly through creation of a comprehensive directory of existing data sets***	the Joint SCAR/COMNAP Committee on Antarctic Data Management (JCADM)	ongoing
9	***More training of young scientists and those from developing countries***	the SCAR Fellowship Programme (from 2002)	ongoing

Many SCAR Members adopted elements of this agenda for global change research. Creation of a GLOCHANT Project Office in Hobart (courtesy of the Australian Antarctic Division), and the appointment of a Project Coordinator in 1995 aided progress in implementation (see the project summary presented to SCAR's Shanghai meeting in 2000 (Goodwin, 1999), and *SCAR Report* nos 11, 13 and 15 (http://www.scar.org/publications/reports/).

Links with the World Climate Research Programme (WCRP) were cemented in 2004 through a Memorandum of Understanding under which SCAR now co-sponsors with WCRP: (i) the Climate and Cryosphere (CliC) programme devoted to studies of the role of the cryosphere in the climate system; (ii) the joint CLIVAR/CliC/SCAR Southern Ocean Implementation Panel (SOIP), which seeks to observe and understand the role of the Southern Ocean in the climate system; and (iii) the International Programme for Antarctic Buoys (IPAB), which deploys drifting and other buoys for collecting information on oceanography, meteorology and ice drift in the Southern Ocean. These programmes address several of the core themes and projects listed above.

1.2 REFOCUSING SCAR'S RESEARCH PROGRAMME

In the year 2000 SCAR began to review its progress and decided to focus on five key research programmes addressing the four core themes and topics identified above:

Programme	***Theme***	***Project***
Antarctica in the Global Climate System (AGCS)	***A, B***	***1, 2***
Antarctic Climate Evolution (ACE)	***C, A, B***	***2, 3, 5***
Evolution and Biodiversity in the Antarctic (EBA)	***A, B, D***	***1, 4, 5, 6***
Subglacial Antarctic Lake Environments (SALE)	***A, C, D***	***2, 5, 6***
Interhemispheric Conjugacy Effects in Solar-Terrestrial and Aeronomy Research (ICESTAR)	***A, B***	***4***

SCAR's new directions were published in the *SCAR Strategic Plan 2004-2010*. Science Plans for the five new topics were published in 2004 as *SCAR Report* 24, and Implementation Plans in 2005/6 as *SCAR Report* 26. The AGCS programme is linked to the WCRP. The ACE programme is linked to IGBP's Past Global Changes programme (PAGES), and EBA is linked to IGBP's Global Ecosystems Dynamics programme (GLOBEC).

The new programmes will improve descriptions of the natural world, understanding of the processes that operate in the Antarctic, and modelling or forecasting of the changes likely to occur as the climate and the environment alter. Cross linkages are

developing between the five programmes, to bring all disciplines to bear on key issues.

Aside from this focus, SCAR maintains interest in a range of other topics including (in 2007): Birds, Seals, Human Biology and Medicine, Biological Monitoring, Conservation, Effects of Marine Acoustics, Geographic Information, Bathymetry, Geodesy, Geomagnetism, Marine Seismics, Neotectonics, Permafrost, Ice Drilling, Astronomy, Operational Meteorology, Oceanography, and Ice Sheet Mass Balance.

SCAR partners not only WCRP and IGBP, but also other Interdisciplinary Bodies of ICSU, such as the Scientific Committee on Oceanic Research (SCOR) and the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP), as well as a number of the Scientific Unions of ICSU. SCAR represents ICSU in leading development of the Cryosphere Theme of the Partnership with the space agencies and UN agencies for an Integrated Global Observing Strategy (IGOS). SCAR co-sponsors the Integrated Partnership in Ice Core Sciences (IPICS) and the Integrated Climate and Ecosystem Dynamics programme, ICED. SCAR is a partner of the International Permafrost Association (IPA) and of the Council of Managers of National Antarctic Programmes (COMNAP).

1.3 CONTRIBUTING TO THE INTERNATIONAL POLAR YEAR (IPY) 2007-2009

SCAR is making a significant contribution to the 6 research themes of the International Polar Year (IPY)(1 March 2007 – 1 March 2009):

1. **Status**: to determine the present environmental status of the Polar Regions.
2. **Change**: to quantify, and understand, past and present natural environmental and social change in the Polar Regions; and to improve projections of future change.
3. **Global Linkages**: to advance understanding on all scales of the links and interactions between the Polar Regions and the rest of the globe, and of the processes controlling these.
4. **New Frontiers**: to investigate the frontiers of science in the Polar Regions.
5. **Vantage Point**: to use the unique vantage point of the Polar Regions to develop and enhance observations from the interior of the Earth to the Sun and the cosmos beyond.
6. **Human Dimension**: particularly through historical studies and investigations of human biology and medicine in the Polar environment, but also through outreach and education.

Of the 228 IPY-approved proposals, around 47% were relevant to SCAR. 40% of these were Antarctic, and 50% were Bipolar. 75% were in the natural sciences, the rest in education and outreach, with 1 in data and information management. 30% of the science projects are SCAR-led, 5 of them by each of SCAR's 5 major scientific research projects. A further 30% are specifically linked to other SCAR groups, and a SCAR scientist, Taco de Bruin, co-chairs the IPY Subcommittee on Data Policy and Management.

SCAR is well-represented on the Joint ICSU/WMO Committee for the IPY, which steers the IPY process, by individuals including the SCAR President (Chris Rapley), a previous SCAR Vice President (Jeónimo López-Martínez), a member of the Steering Group for EBA (Edith Fanta), the chairman of the SCAR/SCOR Oceanography Group (Eberhard Fahrbach), a former SCAR Delegate (Ian Allison), and the SCAR Executive Director (Colin Summerhayes, *ex officio*).

1.4 PRODUCTS: PUBLICATIONS, DATABASES, AND SCIENTIFIC ADVICE

The results of the activities and deliberations of SCAR's experts and the products of SCAR's workshops and conferences are published either in the refereed scientific literature or as books or reports of various kinds (e.g. see http://www.scar.org/publications/). SCAR's activities also lead to the creation of databases through which scientists from different countries share their data to provide the basis for pan-Antarctic studies and reviews (see data and information on http://www.scar.org/researchgroups/). Several of these databases have wider significance, being used by Antarctic logistics operators and/or by the general public (see http://www.scar.org/information/). SCAR's achievements lie not just in the publications and databases themselves, but also in the influence they have had on thought and action in the wider scientific and policy communities. SCAR's less tangible but no less valuable outputs include the creation of scientific communities with special interests, for instance in topics such as seals, or birds, or astronomy, and the awards of fellowships to young researchers.

Because it is the only independent scientific body with expertise in almost all aspects of the science of Antarctica and the surrounding Southern Ocean, SCAR is recognized as an independent observer to a number of policy-making bodies with responsibilities for the Antarctic region. SCAR provides Information Papers or Working Papers with scientifically based advice and recommendations regarding the conservation or management of the Antarctic environment to (i) the annual Antarctic Treaty Consultative Meeting (ATCM); (ii) the ATCM's Committee for Environmental Protection (CEP); (iii) the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), and (iv) the (Commission for the Agreement for the Conservation of Albatrosses and Petrels (ACAP).

2. WEATHER AND CLIMATE

2.1 WEATHER

SCAR science programmes help to improve weather forecasting.

Key recent advances include:

- **Provision of the *International Antarctic Weather Forecasting Handbook:*** SCAR has worked with the WMO, the British Antarctic Survey, the Australian Bureau of Meteorology and COMNAP to produce the *International Antarctic Weather Forecasting Handbook* (Turner and Pendlebury, 2004). This brings together the experience and expertise of many weather forecasters who have served in the Antarctic. It provides a unique source of information on the techniques of weather forecasting on and around the continent and the details of specific forecasting techniques used at the stations. SCAR continues to work with the meteorological community through its Operational Meteorology Group.
- **Establishing the Antarctic Wind Field:** SCAR has produced what is thought to be the best compilation of surface wind data for the Antarctic created to date. It was produced using a high-resolution atmospheric model covering the continent. The compilation will be of value in studies of blowing snow, sea ice advection and the investigation of katabatic winds (Van Lipzig *et al,* 2004).
- **Assessing the Strengths and Weaknesses of Operational Analyses and Forecasts:** SCAR contributed to the improvement of regional operational weather analyses and forecasts via the Antarctic First Regional Observing

Study of the Troposphere (FROST) project (Turner *et al,* 1996; Turner *et al,* 2004a). FROST determined the strengths and weaknesses of operational analyses and forecasts over the continent and in the surrounding ocean areas, and assessed the value of new forms of satellite data. FROST was based around three one-month Special Observing Periods (SOPs) covering July 1994, 16 October to 15 November 1994 and January 1995. Comprehensive data sets were established of model fields and *in-situ* and satellite observations. High quality manual surface and upper air analyses were prepared to determine the extent to which non-Global Telecommunications System data could improve the interpretation of the synoptic situation. Over the ocean areas during SOP-1, incorporation of the latest data only resulted in a limited improvement in the analyses, indicating that the models are correctly analysing most of the major weather systems. Over the continent, the production of 500 hectoPascal heights from the automatic weather station data greatly helped in the analysis process. The lack of data around West Antarctica was a major handicap in the analysis process. The root mean square errors in the forecasts of the 500 hectoPascal height for the Antarctic were about 20% greater than those for mid-latitude areas. The forecasts from the European Centre for Medium-Range Weather Forecasts were found to be the most accurate of those received.

2.2 CLIMATE

SCAR's **Antarctica in the Global Climate System Programme (AGCS**) aims to understand the behaviour of the climate system of the Antarctic and its relation to the global climate system. The focus is on understanding the behaviour of and interactions between the atmospheric, oceanic and cryospheric elements of the climate system, in order to improve confidence in the outputs of numerical forecasts of climate change for the next 100 years. AGCS will use existing deep and shallow ice cores, satellite data, the output of global and regional coupled atmosphere–ocean climate models, and *in-situ* meteorological and oceanic data to understand how signals of tropical and mid-latitude climate variability reach the Antarctic, and high latitude climate signals are exported northward. Results will be of use to governments in developing national inputs to the Intergovernmental Panel on Climate Change and the UN Framework Convention on Climate Change, and national responses to climate change. AGCS plans can be obtained from the AGCS web page on the SCAR web site. AGCS and its various sub-programmes are co-sponsored by SCAR and the World Climate Research Programme (WCRP). A recent SCAR review of the state of the Antarctic Climate is available as XXX ATCM Information Paper IP 05 from http://www.scar.org/treaty/atcmxxx/. It takes into consideration the results of the 4th report of the Intergovernmental Panel on Climate Change (February 2, 2007), and comments on the inadequacies in that document.

A key tool:

- **Reference Antarctic Data for Environmental Research: the READER Project:** Determining the extent of environment change across the Antarctic in recent decades requires the creation of data sets of key environmental variables. The conventional surface and upper air meteorological data have been brought together within the READER (Reference Antarctic Data for Environmental Research) project. The READER data set includes monthly and annual mean near-surface climate data (temperature, surface and mean sea-level pressure (MSLP) and wind speed) derived from historical observations. A high level of quality control makes this the most accurate

series of monthly mean data (http://www.antarctica.ac.uk/met/programs-hosted.html) (Turner *et al,* 2004b)

Key recent advances include discoveries of:

- **Warming of the west Antarctic Peninsula:** Analyses of the READER data set permit assessments of climatic change over the Antarctic since the IGY in 1957/58 (Turner *et al,* 2004c), and show that the atmosphere over the western Antarctic Peninsula has warmed more near the surface than anywhere else on Earth (3ºC on average and 5ºC in winter over the past 50 years), while the rest of the continent has shown little change.
- **Warming of the ocean west of the Antarctic Peninsula:** The warming on the Antarctic Peninsula (above) appears linked to a decrease in sea ice in the adjacent Bellingshausen Sea, where the summertime surface and near-surface ocean has warmed by more than 1ºC – faster than most other parts of the world ocean. The sea has also become more saline in summer by more than 0.25 parts per thousand. These ocean changes are both positive feedbacks, acting to promote further decrease in ice production and further atmospheric warming. As the ocean warms only near the surface, the cause is likely to be meteorological, rather than oceanic as some people have suggested. These ocean changes will affect the marine ecosystem, which is highly sensitive to changes in ocean temperature. Further warming may lead to losses in species and populations (Meredith and King, 2005).
- **Warming of the Winter Troposphere:** Analysis of the balloon-launched radiosonde data for the Antarctic reveal a major warming of the Antarctic winter troposphere that is larger than any previously identified regional tropospheric warming on Earth, especially 5 km above sea level where temperatures increased at 0.5 – 0.7°C per decade over the last 30 years (Turner *et al,* 2006)
- **Variability in the Link between Antarctica and El Niño:** There is a long-range link between the El Niño-Southern Oscillation (ENSO) and the climate of the Pacific coast of Antarctica. The link was stronger in the 1990s, than in the 1980s. The weak link in the 1980s spring season was caused by interference between the Pacific South American pattern associated with ENSO, and the Southern Hemisphere Annular Mode (SAM), the primary mode of variability of the Southern Hemisphere atmosphere outside the tropics (Turner, 2004).
- **No Significant Trend in Snowfall:** Using the Polar MM5 climate model it can be shown that - averaged over the continent - the annual trends in snow accumulation are small and not statistically different from zero, suggesting that recent Antarctic snowfall changes do not mitigate current sea level rise (Monaghan *et al,* 2006)
- **The Cause of Ice Shelf Collapse:** Since the mid-1960s the east coast of the northern Antarctic Peninsula has warmed rapidly in summer, with near-surface temperatures increasing by more than 2°C leading to the collapse of the two northern sections of the Larsen Ice Shelf. The warming is attributed to westerly winds becoming strong enough in summer to carry warm maritime air from the west over the barrier presented by the Antarctic Peninsula. Strengthening of the westerly winds results from a shift of the dominant meteorological pattern – the Southern Hemisphere Annular Mode (SAM) – into its positive phase, in which surface pressures drop over the Antarctic and rise in mid-latitudes. Model experiments show that the shift in the SAM to its positive phases in recent decades was larger than anything occurring in long simulations of the present climate. For that reason the shift is thought to be predominantly a response to anthropogenic forcing and provides the first

evidence that increasing levels of greenhouse gases contributed, at least in part, to the observed rapid warming on the Antarctic Peninsula (Marshall, *et al,* 2006).

- **Warming of the Southern Ocean:** Advanced numerical models can now reproduce the warming observed at mid-ocean water depths in the Southern Ocean, which is more rapid than elsewhere in the world ocean. Analyses show that the Southern Ocean would by now be even warmer than it is but for the masking effects of volcanic and other aerosols (Fyfe, 2006).
- **Central Antarctica is Likely to Warm Significantly in the Next 100 Years:** Analyses of the models of Antarctic climate produced for the Intergovernmental Panel on Climate Change (IPCC 2007) show that some models are better than others at reproducing observed climate data. Weighting the models according to their skill, and producing an average of the weighted ensemble, gives some confidence in the forecast that over the next 80–100 years we are likely to see the marginal sea-ice zone warm during the winter by up to 0.6ºC/decade, and central Antarctica warm by 0.4ºC/decade in all seasons. Sea-ice is projected to decrease by 25%, and precipitation to increase by 3 mm/decade on average, mostly on the margins. Westerly winds will strengthen over the ocean, mostly in autumn, but coastal easterlies will weaken (Bracegirdle and Turner, in preparation).

Other key advances include:

- **Recommendations for the Collection and Synthesis of Antarctic Ice Sheet Mass Balance Data:** Determining the growth or shrinkage of the great ice sheets is a longstanding unsolved scientific problem concerning the Earth's Polar Regions. SCAR's Ice Sheet Mass Balance and Sea-Level (ISMASS) group recently provided its key recommendations on the way forward (see ISMASS Committee, 2004; James *et al,* 2004; Jacka, 2004; and Hamilton, 2005). Resolving the problem holds the answer to the question of how much sea level may rise, and how fast, in response to global warming. New approaches were needed because the arrival of new techniques (Satellite Synthetic Aperture Radar (SAR) interferometry, Lidar and airborne coherent Ground Penetrating Radar (GPR), and remote-sensing campaigns) showed that the 'static' picture of a slowly changing Antarctic ice sheet was wanting; the new picture is dynamic. New observations have shown unexpected changes in ice stream velocities including acceleration on the one hand and complete shutdown on the other. Melting at the base of floating ice shelves may account for up to one third of their loss of mass. Extensive, rapid thinning is occurring in several sections of the West Antarctic Ice Sheet interior and in the Amundsen Sea sector including Pine Island and Thwaites glaciers. 87% of the glaciers in the Antarctic Peninsula are retreating. The Whillans Ice Stream on the Siple Coast has slowed and the region is thickening, largely in response to the shutdown of Ice Stream C. The collapse of the Antarctic Peninsula ice shelves (e.g. Larsen Ice Shelf in 2002) has led to more rapid discharge from previously dammed glaciers and ice streams. While the mass balance of West Antarctica is slightly negative (ice sheet loss), that of East Antarctica appears neutral. The ISMASS recommendations form the basis for a new research agenda on a dynamic ice sheet.
- **Development of a Sea-Ice Database:** Until very recently the Antarctic sea ice zone was one of the least known regions of the Earth's surface, despite its importance as an interface between the ocean and the atmosphere, and as a region of significant interaction between physical, biogeochemical, and biological processes. In 1996 SCAR formed the Antarctic Sea Ice Processes and Climate (ASPeCt) group to improve understanding of the Antarctic sea

ice zone, and in particular to improve the supply of data critical for numerical models of the ocean–ice–atmosphere system by establishing the basic physical properties of sea ice, such as the thickness and properties of the ice and its snow cover; the size and distribution of floes and leads, and the characteristics of the associated ocean and atmosphere. ASPeCt recovered and standardized historical and ongoing collections of sea-ice data from ships to develop a base-line climatology of Antarctic sea ice and snow thickness and properties. An ice observation protocol that involved making hourly observations from vessels moving through pack ice was adopted. A PC-based software package and user manual were developed for use by the sea ice community, and a CD-ROM for guiding sea ice observers in the observation protocols and use of the software (available online at http://www.aspect.aq). This methodology was used to translate previous ice observation logs and to include most voyages in the sea-ice zone following the establishment of ASPeCt. The sea-ice thickness climatology now has 20,000 individual observations of sea-ice thickness and characteristics that are in a single, quality controlled, standardized, digital format, obtained from over 80 voyages. The methodology has been extended to analyse helicopter videotapes for sea-ice conditions. As a result, ASPeCt now aims to provide space-derived ice thickness fields (with defined error estimates) for the entire Antarctic sea-ice zone for all seasons. The sea-ice database will be used to validate satellite altimeter data, both radar and laser, on sea-ice freeboard, and to establish quantitative confidence limits on derived thickness fields from existing and planned space altimeter missions. ASPeCt's observations also improved understanding of the processes and rates of sea-ice formation and its relation to polynyas.

- **Developing a Climate and Environmental History for the Past 200 Years:** To put modern climate in perspective, and as the basis for predictions of future climate change, it is essential to obtain an accurate historical view of climatic and environmental change. The International Trans Antarctic Scientific Expedition (ITASE) programme was established in 1990 to collect and interpret a continent-wide array of environmental parameters, assembled particularly through shallow drilling along continent-wide over-snow traverses, to help to understand what controls climate variability over Antarctica and the Southern Ocean. As of 2004, ITASE had completed >20,000 km of snow radar, recovered more than 240 firn/ice cores (total depth 7000 m), remotely penetrated to ~4000 m into the ice sheet, and sampled the atmosphere to heights of >20 km. ITASE data allow previously unavailable reconstructions of past regional to continental scale variability in atmospheric circulation and temperature, which can be used to demonstrate the evolution of Antarctic climate, to test meteorological reanalysis products. Chemical analyses of snow samples also enable researchers to determine the sources and paths of aerosols. ITASE also assists in evaluating mass balance on the ice sheet. For instance, ITASE data on the distribution of snow precipitation over the continent show that the interaction of surface wind and subtle variations of surface slope cause significant variations in the spatial distribution of snow at short and long spatial scales. This means that the traditionally used single cores, stakes, and snow-pits do not accurately represent the geographical and environmental characteristics of snow accumulation. For details see Mayewski and Goodwin (1997), Mayewski *et al* (2005), and the project web site (http://www.ume.maine.edu/itase/).

3. ECOLOGY AND BIODIVERSITY

3.1 THE SOUTHERN OCEAN ECOSYSTEM

The Southern Ocean, which for SCAR's purposes includes everything south of the Subantarctic Front, and includes the world's largest surface current – the Antarctic Circumpolar Current – is home to a unique ecosystem in which higher predators like fish, seals, whales, and penguins feed on giant swarms of krill – tiny shrimp-like pelagic crustaceans or euphausiids. The Southern Ocean is also unique in being the world's largest high nutrient – low chlorophyll region, where primary productivity is low despite the supply of nutrients to the surface by vertical mixing. Lack of micronutrients, like iron, constitutes a limiting factor in phytoplankton growth. Nevertheless, the Southern Ocean is an important sink for carbon dioxide during the phytoplankton blooms that occur in the marginal ice zone as the ice melts in spring and summer. In the winter the Southern Ocean is a net source for carbon dioxide released from waters upwelling near the coast. The possibility needs to be considered that increasing dissolution of carbon dioxide may acidify the Southern Ocean and interfere with the operation of its ecosystem.

As a climax to many years of marine biological work, the Southern Ocean ecosystem was investigated in detail by the Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS) Programme (1977 to 1991), in a consortium led by SCAR and including the Scientific Committee on Oceanic Research (SCOR), the International Association of Biological Oceanography (IABO), and the Food and Agriculture Organisation (FAO) of the United Nations. BIOMASS aimed to improve understanding of the Antarctic marine ecosystem to enable effective management of the living resources of the Southern Ocean (El-Sayed, 1994). It was, and remains, the only marine biological experiment of its kind and scale ever mounted around Antarctica or elsewhere. Ships from 12 countries made a grand total of 31 cruises in austral seasons of the 1980–81 (First International BIOMASS Experiment - FIBEX) and 1983–84 and 1984–85 (Second International BIOMASS Experiment - SIBEX) (see BIOMASS reference list). As with all SCAR programmes, the BIOMASS fieldwork and analysis were funded through national programmes. SCAR provided coordination in planning operations and integrating results for a modest investment of some US$50,000 per year. Key BIOMASS references include El Sayed (1977, 1981, 1985); Kils (1981); Wilson (1983); Efremenko (1985); Kock *et al* (1985); El Sayed and Tomo (1987); Evans *et al* (1987); Miller and Hampton (1989); and Kellerman (1989).

BIOMASS also paved the way for Southern Ocean work by later global ocean research projects such as the Southern Ocean components of the Joint Global Ocean Flux Study (SO-JGOFS) and IGBP's Global Ocean Ecosystem Dynamics (GLOBEC) programme (SO-GLOBEC), which were jointly run by IGBP and SCOR. SCAR is now a co-sponsor of Southern Ocean GLOBEC, which brings together scientists from several national organizations and from the International Whaling Commission (IWC) to study the year-round lifecycle of Antarctic zooplankton, particularly krill, as well as predators of krill, such as marine mammals and seabirds. SO-GLOBEC is notable for its conduct of observations and research in every season, including the Antarctic winter. It is now concerned with the development and testing of ecosystem models that can explain the data and be used as the basis for forecasting trends and patterns in the krill. For details see SO GLOBEC at http://www.globec.org/.

SO-GLOBEC will end in 2007 but, efforts to understand the operation of the Southern Ocean ecosystem will continue through the Southern Ocean component of

a newly emerging IGBP programme, IMBER (Integrated Marine Biogeochemistry and Ecosystem Research). That component, co-sponsored by SCAR, is named ICED (Integrating Climate and Ecosystem Dynamics (in the Southern Ocean), and is seen as the successor to JGOFS and GLOBEC in the region. For details see http://www.antarctica.ac.uk/Resources/BSD/ICED/.

Key advances from BIOMASS include:

- **Establishing the role of krill in the Southern Ocean ecosystem:** BIOMASS produced a mine of information about the pelagic ecosystem, and especially the distributions of fish and krill. Establishing the key role of krill was a breakthrough in understanding the operation of the Southern Ocean ecosystem.
- **Laying the Groundwork of the Creation of CCAMLR:** The findings of BIOMASS led directly to the creation of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), and its adoption of an ecosystem-based approach to fisheries management. BIOMASS data started the CCAMLR database.

3.2 ECOLOGY OF THE SEA-ICE ZONE

The vast plains of sea ice that surround Antarctica in the southern summer and double the size of Antarctica in the southern winter play a key role in the Southern Ocean ecosystem, sheltering larvae and providing the nutrients to stimulate productivity in the marginal ice zone as the ice melts each year. In 1990, SCAR's Group of Specialists on Southern Ocean Ecology developed the EASIZ (Ecology of the Antarctic Sea Ice Zone) programme to investigate the role of sea-ice in the Antarctic coastal marine ecosystem. The aim was to improve understanding of the structure and dynamics of the Antarctic coastal and shelf marine ecosystem, the most complex and productive in Antarctica, and likely the most sensitive to climate change, paying particular attention to what makes the biology of this ice-dominated system so distinctive, and to understand seasonal, interannual, and long-term changes. The aim was achieved through an integrated study of the way in which the water column and benthos are linked by bentho-pelagic coupling over the Antarctic continental shelf. Because water column processes were already well-covered by other programmes (JGOFS, GLOBEC), EASIZ focused mostly on the benthos. Between 1994 and 2004, over 150 scientists from more than 17 countries were involved with extensive EASIZ projects on ships (most in the Weddell and Ross seas, and around the Antarctic Peninsula) and on the shore (mostly around the Antarctic Peninsula) (Arntz and Clarke, 2002; Clarke *et al,* 2006).

EASIZ overturned some previous paradigms – e.g. that the Antarctic was species poor – and replaced them with a revised picture linking assemblage structure and population dynamics to the glacial marine setting. The legacy is a wide-ranging reassessment of the diversity, history and ecology of Antarctic benthos, and of the coupling of the system to water column processes, plus a fundamental revision of our view of physiological adaptation to temperature in polar marine organisms. We now know that the system is not species poor; it is not relatively undisturbed; it is complex, not simple; and it does not shut down in winter.

Key advances from EASIZ include:

- **Benthic communities are highly diverse** - as diverse as those in most temperature locations and significantly more so than those in the Arctic. The low inorganic sedimentation rate and a strong seasonal flux of phytodetritus

encourage sessile suspension feeders; unusually dominant and complex suspension feeding communities were found on some hard substrates in locations unaffected by deposition of glacial material. The flux creates a benthic 'food bank' providing a cushion against the vagaries of seasonal supply from the surface.

- **There is no single Antarctic biogeographic province:** Gastropods and molluscs fall into three major subregions: East Antarctica; the Scotia Sea and Antarctic Peninsula; and the Subantarctic Islands. Most Antarctic molluscs are known from few locations; few have a truly circumpolar distribution. Communities dominated by sponges are most prolific in regions free from iceberg disturbance of the seabed.
- **Growth and recovery rates are slow:** New isotope-based methods and traditional field methods show that many groups of organisms grow slowly because of the cold; this is an advantage in an environment that is dark for many months and where food supply is sporadic. However, it makes them vulnerable to rapid change or human impact. EASIZ established the broad features of the dynamics of settlement and recruitment to Antarctic benthic assemblages. While the diversity of larval types in the plankton is high, their abundance is low. Recruitment to hard substrates is slower than anywhere else so far studied. These findings help to explain why recovery from disturbance is slow.
- **Establishing the major features of the evolutionary history:** links were identified between important evolutionary events and particular tectonic and palaeoclimatic events, for instance (i) the timing of the diversification of many groups was matched to the inception of the Antarctic Circumpolar Current (and hence the Polar Front), and (ii) cycles in the diversification and extinction dynamics of continental shelf benthos were related to glacial–interglacial cycles.
- **Use of underwater imagery to quantify ecological data:** EASIZ developed techniques for collecting high quality underwater images that could be used to describe benthic assemblages quantitatively, to identify unknown and unexpected associations between organisms, and to revolutionize our understanding of the frequency of iceberg scouring and the time-scale of ecological recovery from scouring events.
- **Fundamental contributions to Antarctic taxonomy:** EASIZ taxonomists made important contributions to our understanding of the pycnogonida, amphipod and isopod crustaceans, and the major groups of cnidarians, providing one of the best diversity inventories for any marine region of the world, and establishing a centre for the further development of this work – the Marine Biodiversity Information Network (MarBIN). Some organisms are present at very low diversity (decapod crustaceans); others are unusually diverse (pycnogonids). Of the global populations of species, the percentages in Antarctic waters are as follows: 17.5% of Pycnogonids; 12.2% of polychaetes; 9.4% of ascidians, 8.3% of amphipods, and 8.1% of bryozoans, although the Southern Ocean is only 8% of the global ocean, and the Antarctic coast is only 2% of the global coastline.
- **Tests of general ecological theories:** Studies of macrobenthic diversity in relation to disturbance, on both large scales (iceberg scour) and small scales (depth gradients in brash-ice impact) confirmed the predictions of the Intermediate Disturbance Hypothesis, in that the highest diversities were found in areas with a patchwork of areas at different stages of recovery from intermittent ice-scour. Studies of bryozoan population dynamics in the Antarctic rocky intertidal zone provided an unusually clear example of the trade-off between pioneering life history and competitive ability: early colonisers of newly available habitat tend to be fast growers with early

reproduction, but they lose out to superior competitors that arrive later. This pattern, expected from ecological theory, has rarely been demonstrated in the sea. Comparative studies of bryozoan interaction matrices from polar, temperate and tropical latitudes revealed a strong latitudinal cline in the intensity of competitive interactions - polar communities tended to be very hierarchical, whereas those in the tropics were characterised by networks of intermediate or indeterminate outcomes. Theory had predicted the strong latitudinal cline, but tests had proved hard to undertake. The result from EASIZ was doubly valuable in that the pattern it revealed was the opposite of that expected.

3.3 BIRDS AND SEALS

SCAR's Group of Experts on Birds uses national data to examine pan-Antarctic populations, providing primary reference material and databases on seabirds from the region (for details and key publications see http://www.birds.scar.org/). In the early 1980s, the group initiated the ongoing International Survey of Antarctic Seabirds (ISAS), which aims to document the distribution, abundance and where possible, long-term trends in Antarctic and Subantarctic seabird breeding populations. Inventories have been completed for 8 species of penguins (Emperor, King, Adélie, Chinstrap, Gentoo, Macaroni, Royal and Rockhopper) and 4 species of petrels (Giant Petrel, Antarctic Petrel, Cape Petrel, and Snow Petrel). A further 8 inventories are in progress (Southern Fulmar, Kelp Gull, Antarctic Tern, skuas (2 species), Wilson's Storm Petrel, Antarctic Prion, shags). The data form the basis for SCAR's advice to the Scientific Committee of CCAMLR on the status and trends of Antarctic and Subantarctic seabirds, and to the Committee for Environmental Protection (CEP) of the Antarctic Treaty Consultative Meeting (ATCM). In recognition of the Group's expertise, SCAR has attended meetings of ACAP (Agreement for the Conservation of Albatrosses and Petrels) as an Observer, providing advice and data on the distribution, abundance, population trends and regional conservation status of Southern Giant Petrels. In addition, SCAR is a member of two ACAP Working Groups (Status and Trends, and Breeding Site Inventory). Bird data may help to identify possible Marine Protected Areas, because seabirds can be used as proxies for related biological activity (i.e. prey species).

Key advances from the Birds Group include:

- **The development of inventories:** These provide key baseline data for researchers, managers and the tourism industry. They help SCAR and BirdLife International to select candidates for Important Bird Areas (IBAs). They also help to identify potentially critically endangered species. In due course they will form part of an updated "*Atlas of Antarctic Birds*".
- **Seabird data at sea:** The Group coordinated Southern Ocean seabird-at-sea surveys for BIOMASSS, providing baseline data on the distribution and abundance of seabirds at sea, and preliminary understanding of the relationship between seabirds and the environment The surveys, which continue, are used to assess overlap between at-sea ranges of seabirds and high seas fisheries, to identify the species potentially at risk from fishing. The at-sea surveys are also used to validate satellite-tracking studies of large species (albatrosses and giant petrels), and to monitor the interaction between fisheries and the smaller petrels that cannot be monitored from space.

SCAR's group on seals monitors the abundance of seals throughout the region (for details see http://www.seals.scar.org/). In the years between 1964 and 1972, when

the Convention for the Conservation of Antarctic Seals was concluded in London, SCAR was engaged in developing practical conservation measures and the Consultative Parties were considering the form of an appropriate international instrument. The resulting Convention covers all species of seals in Antarctic waters. Although there has been no attempt to exploit Antarctic seals commercially since 1964, the SCAR Group of Specialists on Antarctic Seals (currently the Expert Group on Seals) has continued to monitor the take of seals for scientific purposes. Under the Convention, SCAR has a defined role to continue to provide information on seal research and to provide advice on various aspects of seal biology. For general information see Laws (1993).

Key advances from the Seals Group include:

- **Provision of data on Antarctic and Subantarctic Fur Seals:** These data showed that the populations of these specially protected species were large and expanding. These data were used to convince the Antarctic Treaty Parties meeting in Edinburgh in June 2006 to de-list these animals from specially protected status (see XXIX ATCM Working Paper 39 on the SCAR web site at http://www.scar.org/treaty/atcmxxix/), on the basis that in terms of the IUCN criteria there was no longer any significant risk of extinction of the species in the Treaty region. Regardless of the delisting, within the Treaty area these species will continue to have the protection offered by the Protocol.
- **Provision of data on the Ross Seal:** SCAR finds that although the species is relatively abundant and not vulnerable, there is insufficient evidence for any trend in population that might favour a change in its specially protected status at this time (see XXX ATCM Working Paper 27 on the SCAR web site at http://www.scar.org/treaty/atcmxxx/).

3.4 TERRESTRIAL LIFE

If we understand the patterns of biodiversity and what drives them, then we have the basis for an effective tool for managing and conserving the environment. SCAR has been studying how land, lake and pond life respond to the dramatic climate changes affecting in particular the Antarctic Peninsula and the Subantarctic islands, where surface temperatures have warmed by up to 3ºC in 50 years. This research, carried out through SCAR's RiSCC programme (Regional Sensitivity to Climate Change in Antarctic Terrestrial and Limnetic Ecosystems) has helped to improve understanding of the interactions between climate change and indigenous and introduced species, and the way ecosystems function. These studies will help to predict the effects of climate change on biodiversity. RiSCC looked at the changes in species diversity and performance with latitude along the Antarctic Environmental Gradient (AEG), which covers about 30 degrees of latitude from Marion Island at 47ºS to central Victoria Land at 77ºS, and includes a range of climatic zones from cool temperate islands to the frigid and arid continent. RiSCC researchers have published a number of books (see reference list) and150+ publications in the peer-reviewed scientific literature. RiSCC researchers are still carrying out research on the mechanism behind colonization patterns of recently de-glaciated areas. These studies comprise ecophysiological research; research on dispersal units and patterns; and molecular genetic research on the variability of colonizing populations.
Like other SCAR projects, RiSCC brought the community together by generating international expeditions, by creating scientific networks, and by stimulating the formation of groups with particular regional foci (e.g. on the Subantarctic; on the Antarctic Peninsula; on the Ross Sea, and so on). The simultaneous research

carried out on Heard Island, Kerguelen and Marion Island had not proved possible before RiSCC.

RiSSC incorporated SCAR'S former BIOTAS programme on Biological Investigations of Terrestrial Antarctic Systems, and is now part of SCAR's new EBA programme.

Key advances include:

- **Developing the Biodiversity Database:** scientists from many countries have fed 80,000 biodiversity records into the SCAR biodiversity database, housed in the Australian Antarctic Division Data Centre. These form the basis for defining biodiversity regions, and provide key information for environmental management and conservation.
- **Recognizing Patterns of Biodiversity:** RiSCC scientists are now analysing the patterns of Antarctic biodiversity datasets as the basis for a biodiversity atlas of Antarctica. The data will be accessible within a publicly accessible Geographical Information System. It was a surprise to find that there is a striking biogeographical 'divide' between the biota of the Antarctic Peninsula and that of the rest of the continent – confirming the suggestion that the biota are not 'recent'. Within these two areas are local centres of endemism and diversity, suggesting that future research will reveal biogeographical domains within the continent. RiSCC scientists discovered that diversity was much higher than was anticipated in the Transantarctic Mountains. They also discovered 'living fossils', species that evolved from the ancient faunas of Gondwana, which have survived for millions of years. More work is needed to find out how they resist environmental change. The results will help us to understand better the evolutionary processes.
- **Raising Awareness of Invasive "Alien" Species:** Studies of non-indigenous species have raised awareness of the problem of invasive species, and brought the issue to the forefront for the CEP, for example through the "Aliens of Antarctic" paper in the February 2005 issue of Biological Reviews, and through XXVIII ATCM Working Paper 37 (http://www.scar.org/treaty/atcmxxix/). Human impacts can be and have been important in introducing alien species, at least 200 alien plants and animals having already been introduced into the Subantarctic, some with drastic effects on local species and ecosystems. More work is needed on the risks of introduction of alien species to Antarctica.

3.5 EVOLUTIONARY BIOLOGY AND BIODIVERSITY

Evolution is the major unifying principle of biology pervading all levels of organization from molecules to ecosystems, and the Antarctic is a natural laboratory for evolutionary research. In due course, SCAR biologists' work on Antarctic evolutionary biology became focused through the Subcommittee on Evolutionary Biology of Antarctic Organisms (EVOLANTA). EVOLANTA's Science Plan for a SCAR Programme on Evolution in the Antarctic was finalized appropriately at a meeting held in 2000 at Down House in Kent, UK, where Darwin wrote *"The Origin of Species"*. SCAR approved the Science Plan and associated Implementation Plan in Tokyo in July 2000.

EVOLANTA aimed to improve fundamental understanding of the evolutionary history and biology of the Antarctic biota and to place it in the context of climatic and tectonic change. It linked existing work, stimulated new research on evolution in response to climate change, complemented other Antarctic programmes, and stimulated the application of molecular biological techniques to problems in Antarctic biology.

EVOLANTA brought people together in 2 workshops (in Curitiba in Brazil, and in Pontignano in Italy), the results of which were published as Special Issues of *Antarctic Science* (volume 12 (3) of September 2000; and volume 16 (1) of March 2004).

At the SCAR meeting in Bremerhaven in October 2004 EVOLANTA was absorbed into the new Evolution and Biodiversity in the Antarctic (EBA) programme, which also encapsulates the follow-on to the RiSCC programme (see earlier). EBA's goals are to examine the evolution history of Antarctic organisms, the evolutionary adaptation of organisms to the Antarctic environment, the patterns of gene flow and consequences for population dynamics, the diversity of organisms, ecosystems and habitats in the Antarctic, and the impact of past, current and predicted future environments.

EBA incorporates the SCAR Marine Biodiversity Information Network (MarBIN), and the RiSCC terrestrial biodiversity database. MarBIN is the Antarctic node of the global Ocean Biogeographical Information System (OBIS), and links to the Global Biodiversity Information Facility (GBIF). It helps to establish the census of Antarctic marine biodiversity, to examine patterns of biodiversity and to identify gaps.

Key advances include:

- **The Census of Antarctic Marine Life (CAML):** CAML is a five-year international project to investigate the distribution and abundance of Antarctica's marine biodiversity (see http://www.caml.aq). The CAML Office is hosted by the Australian Antarctic Division and funded by the Sloan Foundation. CAML aims to study how biodiversity is affected by environmental change, and how change will alter the nature of the ecosystem services provided to the planet by the Southern Ocean. All groups of organisms will be included, from microbes to whales. In addition to traditional taxonomy, the use of powerful new tools for genetic sequencing will determine the extent to which the Antarctic marine fauna and flora is responding to change. CAML is collaborating with oceanographers and geophysicists, recognizing the integrated nature of marine ecosystems. Research will be conducted in the pelagic, sea-ice, and benthic realms in as many locations around Antarctica as the provision of research vessels will allow. To date, CAML has the prospect of coordinating research on over a dozen ships from a similar number of nations, with the potential to be the largest project yet undertaken in Antarctic marine biodiversity. The fieldwork began in December 2006 and will continue through 2007-08 as a contribution to the International Polar Year (IPY). Initial results show rapid re-colonization of the seabed beneath the former Larsen A ice shelf in the Weddell Sea.

4. SPACE AND ASTRONOMY

4.1 ASTRONOMY

Until recently SCAR had two astronomy groups: the Antarctic Astronomy and Astrophysics Expert Group (AAA), and the Plateau Astronomy Site Testing in Antarctica Action Group (PASTA). Members of these groups tend to meet in the margins of international astronomy meetings, such as the "Wide Field Survey Telescope at Dome C/A conference" in Beijing, China, in June 2005. This was the first conference on Antarctic astronomy to be held in China, and included a report from the Chinese traverse team on their successful expedition to Dome A. Another

astronomical highlight of 2005 was the first winter-long operation of the French-Italian "Concordia" Station at Dome C. Both Dome C and Dome A show promise of offering exceptionally good conditions to astronomers. The AAA group is in the process of defining a major SCAR Scientific Research Programme on astronomy and astrophysics.

Key advances include:

Ideal Location for Astronomy: The PASTA group has shown that the Antarctic plateau is the best place on Earth for surface-based astronomy.

4.2 GEOSPACE

The Antarctic continent offers a unique vantage point for examining the near-Earth space environment – known as Geospace – which extends upwards from the top of the troposphere through the stratosphere, mesosphere, thermosphere, and ionosphere, and into the magnetosphere. SCAR's bipolar programme on Inter-hemispheric Conjugacy Effects in Solar-Terrestrial and Aeronomy Research (ICESTAR) will create an integrated, quantitative description of the upper atmosphere over Antarctica, and its coupling to the global atmosphere and global Geospace. ICESTAR's upper atmosphere scientific research at both poles will require internationally coordinated deployment and operation of instruments located at manned bases, or remotely deployed and serviced from such bases, along with exchange and integration of data from multiple sources.

A coordinated effort, via ICESTAR, is needed at this time to process the increasing volume of experimental data, and to handle effectively the addition of the many new data sets expected to come on-line in the near future. These include new magnetometer chains, new polar orbiting satellites (which allow a simultaneous view of the southern and northern polar regions), new ionospheric radars, new mesospheric/thermospheric wind measurements, and new digisonde data. Use of these tools and assimilation of data from as many sources as possible will enable examination of the system as a whole. Creation of the ICESTAR data portal and use of the Antarctic Data Master Directory will enable these developments to grow.

ICESTAR is coordinating its bipolar activities with the Polar Research working group of the International Association of Geomagnetism and Aeronomy (IAGA). ICESTAR'S output will help governments to manage advanced communications and electronic systems, including satellites. A web site has been established at http://www.siena.edu/physics/ICESTAR/.

Key advances include:

Release of prototype virtual observatories and data portals:

- for optical data (browser for quicklook data): see http://gaia-vxo.org.
- for magnetometer data (Virtual Global Magnetic Observatory; VGMO.NET): see http://mist.engin.umich.edu/mist/vgmo/vgmo.html; and
- for the multi-instrument data sets at South Pole Station: see http://siena.isti.com/.

Recent highlights include papers showing that:

- solar energetic particles (protons) cause chemical reactions in the middle atmosphere above about 40 km, producing NO_2 that is associated with ozone destruction inside the polar vortex.

- atmospheric tides perturb the equatorial ionosphere plasma density, creating anomalies in the plasma field near the equator; plasma drifts upwards into low density gaps created by the westward movement of positive ions.
- where the solar wind magnetic field has a strong east-west component, asymmetries observed in the onset locations of auroral substorms in both polar regions are 5-10 times larger than empirical models anticipate. This asymmetry must be kept in mind when conducting research on bi-polar geospace phenomena.

5. EARTH SCIENCES

5.1 ANTARCTIC CLIMATE EVOLUTION

Understanding the evolution of Antarctica and its role in the Earth System requires understanding the evolution of the Antarctic ice sheet. This can be achieved by studies of the stratigraphy and chemistry of the ice, of the geology beneath the ice, and of the stratigraphy of the sediments deposited on the seabed around Antarctica, as well as by developing and applying well-designed numerical models tested against hard data.

Formed in 1996, the Late Quaternary Sedimentary Record of the Antarctic Ice Margin Evolution programme (ANTIME) used the onshore and offshore sedimentary record to establish Antarctica's climate, environmental and ice sheet history over the last glacial cycle (from today back to 130,000 years ago) and, at a higher level of detail, over the last 10,000 years. ANTIME was part of SCAR's global change programme (GLOCHANT), and held its first workshop in July 1997, in Hobart (Goodwin and Pudsey, 1998; Webb and Cooper, 1998). The second workshop was held in September 1998 in Tokyo (Goodwin *et al,* 1999). At the XXVI SCAR meeting in Tokyo (2000), ANTIME was subsumed into SCAR's new Antarctic Climate Evolution (ACE) programme. ACE also incorporates the former SCAR Antarctic Off-shore Stratigraphy programme ANTOSTRAT, which focused on offshore seismic stratigraphy, augmented by drilling, and which ended in 2001. ANTIME and ANTOSTRAT had helped to synthesize the state of knowledge at that time, and to highlight the importance of geological records in the assessment of Antarctic's climate history.

ACE promotes the exchange of data and ideas between research groups focusing on the evolution of Antarctica's climate system and ice sheet, by organizing meetings and symposia, promoting the development and funding of international research collaborations, and publishing the results of collaborative efforts (see http://www.ace.scar.org).

ACE is coordinating the integration of enhanced geological data and improved Antarctic palaeoclimate models for a series of time periods from the onset of glaciation around the Eocene-Oligocene boundary 34 Ma ago, to the last glacial maximum (LGM) 20,000 years ago, in order to establish the origin of the present configuration of the ice sheet. ACE results will be of use to governments in developing national inputs to the Intergovernmental Panel on Climate Change and the UN Framework Convention on Climate Change, and national responses to climate change.

Given the head start provided by ANTIME and ANTOSTRAT, ACE researchers have already made some significant advances in our understanding of Antarctic history. For instance, ACE has contributed to advances in pan-Antarctic science by

publishing three Special Issues of international journals, each of which establishes the state of the art in the subject, and makes key recommendations for future work, thereby influencing the direction of the science (Florindo *et al,* 2003; Florindo *et al,* 2005; Barrett *et al,* 2006).

Key advances include:

- **Improved understanding of the origins of the ice sheet:** DeConto and Pollard (2003) showed that the onset of the Antarctic Ice Sheet at 34 million years was an inevitable consequence of the decreasing CO_2 content (hence cooling) of the atmosphere, and not simply the result of the opening of the Drake Passage. The implication is that the opening of Southern Ocean gateways could only have triggered glaciation if the climate system was already near a glaciation threshold.
- **Antarctic temperatures declined throughout the mid-Tertiary:** Drilling off the Antarctic margin at Cape Roberts, Victoria Land, shows contrary to expectation, that coastal temperatures declined progressively through Oligocene and early Miocene time (Barrett, 2003, 2006). This finding is leading to a re-evaluation of global palaeotemperature curves for the period. The drilling confirms that between 33 and 17 million years ago the Antarctic ice sheet fluctuated in response to variations in insolation forced by changes in the Earth's orbital parameters.

- **The Miocene history of the Lambert Glacier can be determined from offshore drilling:** Drilling by the Ocean Drilling Programme into a trough mouth fan on the continental slope in Prydz Bay, shows that glacial debris flows built up on the fan during advances of the Lambert Glacier to the shelf break, apparently because the glacier had carved a deep trough within which fast flowing sediments could become transported onto the fan (see Taylor *et al,* 2004). This enables us to establish the Miocene history of the Lambert Glacier, the largest fast-flowing outlet glacier in the world, which drains approximately 12% of the East Antarctic ice sheet.

- **The ice retreat from the shelf edge to the coast was extremely rapid at the end of the Last Glacial Maximum:** The retreat of the ice from the shelf edge to the coast at the end of the Last Glacial Maximum, beginning at around 11,500 calendar years ago, probably took no more than 800 years, in response to a large-scale, rapid warming event. Understanding how rapid such changes can be helps to assess what change may be in store for humankind with further rapid warming.

ACE also stimulates technological developments:

- **Geological drilling:** ACE promotes geological drilling in Antarctica, through the ANDRILL programme (http://www.andrill.org), which samples the rock record of climate change. Many of the ACE team are also members of the ANDRILL community.
- **Radio-Echo Sounding:** ACE promotes the acquisition of radio-echo sounding data in Antarctica so as to establish subglacial topography, a critical yet currently incomplete boundary condition for numerical models.
- **Numerical Models:** ACE encourages the development of new models of the ice–ocean–climate–lithosphere system in Antarctica. For example, DeConto and Pollard have recently built a model that predicts sediment transport beneath the ice sheet. When included in time-dependent runs of ice sheet development the model reveals how sediments are eroded and deposited.

Such output can be compared against the geological record to help understand ice sheet histories.

5.2 SUBGLACIAL ANTARCTIC LAKE ENVIRONMENTS (SALE)

SALE promotes, facilitates, and champions cooperation and collaboration in the exploration and study of sub-glacial lakes and streams in Antarctica. It aims to understand the formation and evolution of sub-glacial lakes and streams; to determine the origins, evolution and maintenance of life in these environments; and to determine the limnology and palaeoclimate history recorded there. SALE encourages adherence to appropriate standards of environmental protection in sampling sub-glacial environments (http://salepo.tamu.edu/). SALE has held a number of scientific workshops in association with large scientific meetings, notably of the European Geophysical Union and the American Geophysical Union (http://salepo.tamu.edu/).

Key advances include:

- **The inventory of subglacial lake features:** Over 145 subglacial lakes have been found, showing that these environments are common.
- **Lakes appear to be linked by a sub-ice hydrological system:** This suggests an important role for these features in controlling ice movement and flow. The sub-ice hydrological system is sufficiently highly pressured to force water up into the lower few tens of metres of drill holes, where it abruptly freezes.
- **Palaeo-outbursts of subglacial waters have created novel landforms:** These landforms may record instances of abrupt past climate change.
- **The Lake Environments are Dynamic:** Biogeochemical studies of Lake Vostok accretion ice demonstrated that the lake environment has varied over time frames of thousands of years suggesting these systems are dynamic and not stagnant.
- **Dissolved Gas Concentrations may be High:** The age of Lake Vostok suggests that water has been cycled over 30 times yielding total dissolved gas concentrations high enough to have important implications for drilling into the lake. The high oxygen concentration (50 times more than air-equilibrated water) may pose a severe biological stress.

5.3 GEODESY

Geodetic information underpins all studies of the solid Earth. SCAR's Expert Group on Geodetic Infrastructure of Antarctica (GIANT) provides a common geodetic reference system (see http://www.geoscience.scar.org/geodesy/giant.htm), which contributes to studies of physical processes, and helps to monitor horizontal and vertical motions. Much of the work is carried out in conjunction with the International Association for Geodesy's (IAG) Sub-Commission on Antarctica. GIANT researchers manage permanent geoscientific observatories, from which repeat Global Positioning System (GPS) measurements are made, and make the data widely available. The Group also conducts continent-wide and regional campaigns to collect information on crustal movement. The Group collaborates with the IAG Antarctic Gravity project. It promoted an Antarctic airborne gravity project; coordinated with others on new satellite gravity data missions such as GRACE and GOCE; and developed gravity ties between stations, airfields and absolute gravity sites. The Group has also monitored the impact of atmosphere variability on Antarctic GPS observations, and especially the impact on Global Navigational Satellite System (GNSS) Observations in Antarctica in relation to geophysical research. The Group provides essential

ground truth data for satellite missions. It also carries out research on the generation of high accuracy Digital Elevation Models (DEMs) over limited areas, and on using high accuracy DEMs in the monitoring of aircraft landing sites, and studies ice shelf dynamics as a means of investigating the behaviour and effect of tides.

5.4 MAGNETISM

SCAR'S Antarctic Digital Magnetic Anomaly Project ADMAP was created in 1995 under the auspices of SCAR and IAGA (International Association of Geomagnetism and Aeronomy) to compile national near-surface and satellite magnetic anomaly data into a digital map and database for the Antarctic continent and surrounding oceans. The ADMAP magnetic compilation is part of the World Magnetic Anomaly Map. The unified dataset is a powerful tool for determining the structure, processes and tectonic evolution of the continent, together with providing information valuable in the reconstruction of the Gondwana and Rodinia supercontinents. ADMAP also coordinates protocols for data distribution; serves as a reference for future survey planning; and archives and maintains the magnetic anomaly database of Antarctica. Details about ADMAP are available from http://www.geology.ohio-state.edu/geophys/admap.

Recent achievements include:

- Release of the ADMAP grids to the public in November 2003, including: (i) the 5-km grid of airborne and ship-borne survey data showing data gaps; (ii) the 5-km grid of airborne and ship-borne survey data with the gaps filled using a crustal magnetization model (Golynsky et al., 2001).
- A 10-km grid of airborne and ship-borne survey data with the coverage gaps filled using a crustal magnetization model that satisfies both the near-surface and 650-km altitude magnetic observations from the Ørsted satellite mission.
- Development of a DVD of the compilation of data up to1999 for release to the World Data Centres.
- Update of the near-surface anomaly predictions from Magsat in the ADMAP database with the significantly more accurate observations from the Ørsted and CHAMP satellite missions.
- Development of improved modelling of the Antarctic core field, and its secular variations, and external fields for better definition of crustal anomalies in magnetic survey data.
- Compilation of rock magnetic and other physical properties into a database to support geological applications of the ADMAP data.
- Development and promotion of regional and continental scale interpretation efforts of ADMAP data to provide new insight into global tectonic and geologic processes in the Antarctic context.
- Support for the World Magnetic Anomaly Map initiative of the International Association of Geomagnetism and Aeronomy (IAGA).

5.5 NEOTECTONICS

The Antarctic Neotectonics (ANTEC) Group promotes and coordinates research relevant to Antarctic neotectonics; identifies 'target sites' where there is a need for deployment of geodetic and seismic stations and arrays, and airborne, marine and field campaigns; encourages and coordinates the installation of instruments at permanent sites and in regional networks (GPS, gravity, seismic) for focused studies in target areas; and promotes and coordinates sharing of instrumentation, logistics, and data.

Recent achievements include:

- The Airborne Mapping Task Group encouraged development of coordinated international airborne campaigns over promising targets for neotectonic research.
- A web-based resource of information on technological components required for autonomous remote observatories has been started as the Technological Information Resources project, jointly with GIANT (see above).
- A start has been made on compiling data for the integration of datasets to study neotectonics of selected regions.
- And an Antarctic Seismology Web Resource (AnSWeR) has been developed. http://wwwrses.anu.edu.au/seismology/answer/. Information about ANTEC is available from the website: http://www.antec.scar.org/.

5.6 ACOUSTICS

The Action Group on Acoustics in the Marine Environment considers the effects on marine mammals of noise created by marine scientific activities such as echo-sounding and airgun surveys. This Group provides input to the discussions of the Committee for Environmental Protection at Antarctic Treaty Consultative Meetings (ATCMs) and provides scientific background information for national regulators responsible for issuing permits for marine surveys. The Group's reports are available from the SCAR website at http://www.scar.org/researchgroups/geoscience/acoustics/.

Key advances:

- SCAR's acoustics reports provide a risk analysis approach to determining the possible effects on cetaceans of marine scientific activities.
- The report of the third workshop (January 2006) concluded that ship noise levels in the Antarctic Peninsula need consideration in future because of the increase in tourist vessel traffic.
- That report recommended that Parties to the Antarctic Treaty collect data on ambient noise in the Antarctic, to establish the natural acoustic baseline.

6. DATA AND INFORMATION SERVICES

SCAR provides a service to its Members and to the wider scientific community by managing systems for the collection and exchange of scientific and geographic data and information.

6.1 GEOGRAPHIC INFORMATION SERVICES

Geographic location is a fundamental requirement for integrating and communicating Antarctic scientific information. The Standing Committee on Antarctic Geographic Information (SC-AGI)(formerly an Expert Group) provides fundamental geographic information products and policies in support of Antarctic science programmes, operations managers and the wider public. It integrates and coordinates Antarctic mapping and GIS programmes; promotes an open standards approach to support free and unrestricted data access; and promotes capacity building to build strengths in Antarctic geographic data management. Its work helps to provide geographic limits to Antarctic Specially Protected Areas (ASPAs) and Antarctic Specially Managed Areas (ASMAs), or locations of Historic Sites and Monuments, and geospatial web services that might be needed for scientific, logistic, or tourism-related applications.

SC-AGI's activities will lead to creation of an Antarctic Spatial Data Infrastructure (AntSDI), details of which can be accessed at https://gcrc.carleton.ca/confluence/display/ANTSDI/SCAR+SC-AGI.

On-line Information products and services include:

- **Place Names:** The SCAR **Composite Gazetteer of Antarctica** is an authoritative reference database of all Antarctic place-names approved by recognized bodies. At the end of 2006 the database included 35,551 records from 22 countries and from the GEBCO (IHO) gazetteer. The names of more than 17,700 Antarctic topographic features are available on line at http://www3.pnra.it/SCAR_GAZE. Work continues to add new data and to correct errors in positional information.
- **Map Catalogue:** The SCAR **Map Catalogue** (housed by the Australian Antarctic Division) is a public-access on-line catalogue of all known Antarctic maps published by Members (http://aadc-maps.aad.gov.au/aadc/mapcat/). It allows searches for published maps by using spatial coverage, keywords, place-names, etc., and SCAR Members can update their information online. A companion Feature Catalogue provides a detailed description of the nature and the structure of Geographic Information Systems and map information.
- **Topographic Database:** The **Antarctic Digital Database (ADD)**, first released on CD ROM in 1993, is the primary source of continent-wide topographic data for Antarctica. A Web Map Server and a Web Feature Server have been created, allowing direct access to the ADD from both web sites and computer software: www.add.scar.org/ add_main.html. The database has been created from SCAR Members' data. It is widely used by COMNAP, tourist operators and the science community. This site also provides access to maps of Specially Protected Areas, Historic Sites and Monuments, and the Seal Reserves of the Convention on the Conservation of Antarctic Seals.
- **The SCAR King George Island Geographical Information System (KGIS):** This project provides an integrated geographic database of King George Island, and contains integrated and consistent topographic data. The database contains new topographic and hydrographical data for the more important ice-free areas. An interactive map viewer, a Web Map Service and a Web Feature Service have been established, allowing direct access to the KGIS database from both web-sites and computer software. (http://www.kgis.scar.org/).
- **The Cybercartographic Atlas of Antarctica:** With its 'open' framework this Atlas (which is being developed with assistance from the Social Science and Humanities Research Council of Canada) has the potential for wide use by scientists, educators, the public, governments, Treaty Parties and COMNAP. Baseline modules include topics such as: Exploration, Politics, Environmental Protection, Sea Ice, Glacial Morphology, Biodiversity, Ecology, and Territorial Claims: http://www.carleton.ca/gcrc/caap/.

6.2 SCIENTIFIC INFORMATION SERVICES

A number of scientific databases and services have been created by interested groups of scientists, for the benefit of the wider community.

On-line Information products and services include:

- **READER:** the **REference Antarctic Data for Environmental Research** database comprises digitized surface meteorological data. Monthly mean

data are provided on-line. Updates are being made as new data (e.g. Russian upper air data) are made available and digitized: http://www.antarctica.ac.uk/met/READER/.

- **The Antarctic Biodiversity Database:** The Australian Antarctic Data Centre has established an Antarctic-wide database of biodiversity data (http://www.aad.gov.au/). It includes the RiSCC terrestrial/freshwater database. A Marine Biodiversity Information Network (MarBIN) is housed in Belgium. Both databases are linked to the Global Biodiversity Information Facility (GBIF), and MarBIN is also linked to the Ocean Biogeographical Information System (OBIS), through which it makes a contribution to the Census of Antarctic Marine Life (CAML).
- **Antarctic Bedrock Mapping (BEDMAP):** The BEDMAP database comprises data collected on surveys undertaken over the past 50 years, and describing the thickness of the Antarctic ice sheet. Digital topographic models for the Antarctic continent and surrounding ocean have been derived from these data, and grids are available representing: (i) ice-sheet thickness over the ice sheet and shelves; (ii) water-column thickness beneath the floating ice shelves; (iii) bed elevation beneath the grounded ice sheet; and (iv) bathymetry to 60°S including the areas beneath the ice shelves (see http://www.antarctica.ac.uk/bedmap/).
- **Seismic Data Library System (SDLS):** Offshore seismic profiles of multi-channel seismic-reflection data have been collected to form a central resource in the Seismic Data Library System (SDLS), housed at the US Geological Survey (http://walrus.wr.usgs.gov/sdls/). The SDLS makes Compact Disc copies of seismic data over 4 years old available for joint projects, distributes them to regional libraries, and is working towards making data available via the Internet. Seismic data and seismological results relating to the Antarctic are also available through an online database (http://rses.anu.edu.au/seismology/answer/) maintained at the Australian National University:
- **Master index for Antarctic positional control:** SCAR Geoscience Standing Science Group maintains this index, which can be accessed via (http://www.geoscience.scar.org/geodesy/giant.htm#controldb).
- **Geodectic Control Database:** SCAR collects and makes available through the SCAR Geodetic Control Database geodetic and surveying information from across the continent: http://www.geoscience.scar.org/geodesy/giant.htm#controldb. The on-line databases show geodetic control points and permanent geodetic markers useful for a host of applications including satellite calibration, aerial mapping, satellite imaging and navigation. The high precision positional data come from 7 countries, and date back as far as 30 years:
- **Geophysical and geodetic observatories:** Information on permanent observatories is listed in web-accessible form at (http://www.geoscience.scar.org/geodesy/perm_ob/sites.htm).
- **Tide gauge data**: Tide gauge data on sea level measured around Antarctic are managed by the Global Sea-level Observing System (GLOSS), and archived by the Permanent Service for Mean Sea-level (PSMSL) (http://www.pol.ac.uk/psmsl/).

6.3 DATA AND INFORMATION MANAGEMENT

SCAR aims to facilitate free and unrestricted access to Antarctic scientific data and information in accordance with article III-1c of the Antarctic Treaty. This is the task of the Joint SCAR-COMNAP Committee on Antarctic Data Management (JCADM). JCADM's members are the managers of National Antarctic Data Centres (NADCs).

JCADM continues to recruit new members from SCAR nations, and now includes 30 countries. JCADM collects metadata on Antarctic datasets and makes them available through the Antarctic Master Directory (AMD), which is hosted by the Global Change Master Directory (GCMD). The total number of dataset descriptions (DIFs) input by JCADM's members to the AMD increased by 30% from 2966 (June 2004) to 3848 (July 2006). The number of nations contributing rose in the same period from 16 to 23. Each NADC can provide its own DIF entries to the AMD, and provide a national view of the metadata in the AMD. JCADM provides capacity building to improve the data management capacity of existing NADCs. Access is shown by the number of downloads of DIFs, which increased from 100/month in July 2003 to 500/month in July 2006.

JCADM is linked closely to SCAR scientific programmes and databases, as well as to international data programmes such as the Global Biodiversity Information Facility (GBIF), the Ocean Biogeographic Information System (OBIS), the International Oceanographic Data and Information Exchange Committee (IODE), and the Climate and Cryosphere Project (CliC).

7. PROVISION OF SCIENTIFIC ADVICE TO INTERGOVERNMENTAL BODIES ON CONSERVATION AND OTHER ISSUES

7.1 SCAR'S ROLE AS AN OBSERVER TO INTERGOVERNMENTAL BODIES

SCAR is an Observer, and the primary source of independent scientific advice, to the annual Antarctic Treaty Consultative Meeting (ATCM), which includes meetings of the Committee for Environmental Protection (CEP) of the Antarctic Treaty System. SCAR presents a lecture to the ATCM and provides Working Papers and Information Papers for consideration. Recent highlights include approval for the de-listing of Fur Seals (2006), and adoption of a Resolution on sustained observations of the Antarctic environment and climate (2007).

SCAR is also an Observer to the Scientific Committee of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), and participates in CCAMLR's annual meetings. SCAR's Census of Antarctic Marine Life (CAML) programme provides perhaps the strongest current link to CCAMLR's interests, especially during the IPY. SCAR's Marine Bioversity database (MarBIN) should also prove useful to CCAMLR, as should links to SCAR's EBA programme (Evolution and Biodiversity in the Antarctic).

As an Observer, SCAR also provides advice and data to meetings of the Advisory Committee on Albatrosses and Petrels (ACAP), on the distribution, abundance, population trends and regional conservation status of seabirds. In addition, SCAR is a member of two ACAP Working Groups (Status and Trends, and Breeding Site Inventory), and provides ACAP with information on the potential contribution of at-sea seabird data to the selection of high seas Marine Protected Areas (MPAs)(seabirds can be used as proxies for the distribution of their prey).

In developing its advice, SCAR has been assisted by various of its subgroups, notably of the Group of Specialists on Environmental Affairs and Conservation (GOSEAC), which was replaced in 2004 by the Standing Committee on the Antarctic Treaty System (SC-ATS). Key reports include Holdgate and Tinker (1979); Zumberge (1979); Bonner (1980); Benninghoff and Bonner (1985); Bonner and Lewis-Smith (1985); Rutford (1986); Bleasel (1989); Lewis-Smith *et al* (1994);Dingwall (1995); Dingwall and Walton (1996); and Kennicutt (1996). See also the GOSEAC reports on http://www.scar.org/publications/reports/.

7.2 USE OF SCAR'S ADVICE BY INTERGOVERNMENTAL BODIES

SCAR's interest in conservation produced scientific advice that led in 1964 to the adoption by the Antarctic Treaty of the Agreed Measures for the Conservation of Flora and Fauna. Subsequently, in 1991, these formed the core of a more comprehensive environmental agreement - the Protocol of Environmental Protection to the Antarctic Treaty – which also swept up many other aspects of environmental management on which SCAR had provided advice.

SCAR developed the original concepts of Sites of Special Scientific Interest and Specially Protected Areas for Antarctica, as well as an exemplar framework for management plans for Antarctic Specially Protected Areas (ASPAs) based on Moe Island. In addition SCAR provided a Management Plan Handbook and a Visit Report Form, as well as the scientific advice to modify and edit plans for these sites when submitted by governments, prior to their adoption.

SCAR has been instrumental in recommending the procedures adopted for cleaning up the Antarctic environment: (i) SCAR designed the Checklist for Environmental Inspections under the Antarctic Treaty; (ii) together with COMNAP, SCAR developed the Environmental Impact Assessment (EIA) Guidelines and good practice; and (iii) also along with COMNAP, SCAR developed the Environmental Monitoring Handbooks. Subsequently SCAR organized the workshop with IUCN that put environmental education onto the ATCM agenda.

SCAR provided key advice that led to the Treaty Parties adopting the IUCN criteria for listing and delisting species, and on the basis of that provided the advice that led to the delisting of Fur Seals.

The work done by SCAR on the BIOMASS programme (see 2.1 above) formed the foundation for the creation of the Scientific Committee of CCAMLR. The SCAR BIOMASS database was adopted by CCAMLR as the basis for its initial work programme. SCAR has also provided CCAMLR with published data on higher predators.

SCAR was deeply involved in initiating and developing the Convention for the Conservation of Antarctic Seals.
SCAR also provided several published reports (Holdgate and Tinker, 1979; Zumberge, 1979; Rutford, 1986; see references) containing advice for the negotiation of the Convention on the Regulation of Antarctic Mineral Resource Activities (CRAMRA), a convention that was eventually abandoned and replaced by the Protocol on Environmental Protection to the Antarctic Treaty.

SCAR also developed Codes of Conduct for (a) Fieldwork, and (b) the Use of Animals for Scientific Purposes in Antarctica – advice that is being revised at time of writing (mid-2007).

8. EDUCATION AND TRAINING

In 2002 SCAR won the Prince of Asturias Award for International Cooperation, 2002, which enabled SCAR to begin a Fellowship Programme that supports some 3-5 doctoral or post-doctoral students for short periods of research in laboratories other than their own, as a means of building up the international network of young researchers in Antarctic science. SCAR is in the process of establishing a wider ranging education and training programme.

9. OUTREACH AND COMMUNICATION

As a means of bringing the Antarctic science community together SCAR has created the SCAR Open Science Conferences, which take place over 3–4 days in July every 2 years. These conferences are the highlight of SCAR's Science Week, during which its scientific study groups meet to plan future activities. SCAR has a Communications Strategy to guide its outreach and communications activities. Key features of the strategy are the continued development of the web site (http://www.scar.org), and the issuing of a quarterly Newsletter and Bulletin.

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12. LIST OF ACRONYMS AND ABBREVIATIONS

AAA	Antarctic and Astronomy and Astrophysics
ACE	Antarctic Climate Evolution
ADD	Antarctic Digital Database
ADMAP	Antarctic Digital Magnetic Anomaly project
AEG	Antarctic Environmental Gradient
AGCS	Antarctica in the Global Climate System
AMD	Antarctic Master Directory
ANDRILL	Antarctic Geological Drilling Project
AnSWeR	Antarctic Seismology Web Resource
ANTEC	Antarctic Neotectonics
ANTIME	Late Quaternary Sedimentary Record of the Antarctic Ice Margin Evolution
ANTOSTRAT	Antarctic Off-shore Stratigraphy Programme
AntSDI	Antarctic Spatial Data Infrastructure
APTIC	Antarctic Peninsula Tropospheric-Ionospheric Coupling
ASPeCT	Antarctic Sea-Ice Processes and Climate
ASMA	Antarctic Specially Managed Area
ASPA	Antarctic Specially Protected Area
ATAC	Antarctic Tropospheric Aerosols and their Role in Climate
ATCM	Antarctic Treaty Consultative Meeting
BEDMAP	Antarctic Bedrock Mapping
BIOMASS	Biological Investigations of Marine Antarctic Systems and Stocks
BIOTAS	Biological Investigations of Terrestrial Antarctic Systems

CAML	Census of Antarctic Marine Life
CCAMLR	Convention on the Conservation of Antarctic Marine Living Resources
CD-ROM	Compact Disc – Read Only Memory
CEP	Committee for Environmental Protection
CliC	Climate and Cryosphere Programme
CLIVAR	Climate Variability Programme
COMNAP	Council of Managers of National Antarctic Programmes
CRAMRA	Convention on the Regulation of Antarctic Mineral Resource Activities
DEM	Digital Elevation Models
DIF	dataset description
DVD	Digital Versatile Disc
EASIZ	Ecology of the Antarctic Sea-Ice Zone
EBA	Evolution and Biodiversity in the Antarctic
EIA	Environmental Impact Assessment
ENSO	El Niño-Southern Oscillation
EVOLANTA	Evolutionary Biology of Antarctic Organisms
FAO	Food and Agriculture Organization of the United Nations
FIBEX	First International BIOMASS Experiment
FROST	First Regional Observing Study of the Troposphere
GBIF	Global Biodiversity Information Facility
GCMD	Global Change Master Directory
GEBCO	General Bathymetric Chart of the Ocean
GIANT	Geodetic Infrastructure for Antarctica
GLOBEC	Global Ocean Ecosystems Dynamics project
GLOCHANT	Global Change and the Antarctic
GLOSS	Global Sea-Level Observing System
GNSS	Global Navigational Satellite System
GOCE	Gravity and Climate Experiment
GOSEAC	Group of Specialists on Environmental Affairs and Conservation
GPR	Ground Penetrating Radar
GPS	Global Positioning System
GRACE	Gravity Recovery And Climate Experiment [???]
IABO	International Association of Biological Oceanography
IAG	International Association for Geodesy
IAGA	International Association of Geomagnetism and Aeronomy
IBA	Important Bird Area
ICED	Integrated Circumpolar study of Biogeochemistry and Ecosystem Dynamics
ICED	Integrating Climate and Ecosystem
ICESTAR	Inter-hemispheric Conjugacy Effects in Solar-Terrestrial and Aeronomy Research
ICSU	International Council for Science
IGBP	International Geosphere-Biosphere Programme
IGOS	Integrated Global Observing Strategy
IGY	International Geophysical Year 1957–58
IHO	International Hydrographic Organization
IMBER	Integrated Marine Biogeochemistry and Ecosystem Research

IODE	International Ocean Data and Information Exchange Programme
IPA	International Permafrost Association
IPAB	International Programme for Antarctic Buoys
IPCC	Intergovernmental Panel on Climate Change
IPICS	Integrated Partnership in Ice Core Sciences
IPY	International Polar Year 2007–09
ISAS	International Survey of Antarctic Seabirds
ISMASS	ice sheet mass balance and sea-level
ITASE	International Trans-Antarctic Scientific Expedition
IUCN	International Union for the Conservation of Nature (World Conservation Union)
IWC	International Whaling Commission
JCADM	Joint SCAR/COMNAP Committee on Antarctic Data Management
JGOFS	Joint Global Ocean Flux Study
KGIS	King George Island Geographical Information System
MarBIN	Marine Biodiversity Information Network
MPA	Marine Protected Area
MSLP	mean sea-level pressure
NADC	National Antarctic Data Centre
OBIS	Ocean Biogeographical Information System
PACA	Working Group on Physics and Chemistry of the Atmosphere
PAGES	Past Global Change programme
PASTA	Plateau Astronomy Site Testing in Antarctica
PC	Personal; Computer
PICE	Palaeoenvironments from Ice Cores
PSMSL	Permanent Service for Mean Sea-Level
READER	Reference Antarctic Data for Environmental Research
RiSCC	Regional Sensitivity to Climate Change in Antarctic Terrestrial and Limnetic Ecosystems
SALE	Subglacial Antarctic Lake Exploration
SAM	Southern Hemisphere Annular Mode
SAR	Synethetic Aperture Radar
SC-AGI	Standing Committee on Antarctic Geographic Information
SCAR	Scientific Committee on Antarctic Research
SC-ATS	Standing Committee on the Antarctic Treaty System
SCOR	Scientific Committee on Oceanic Research
SCOSTEP	Scientific Committee on Solar-Terrestrial Physics
SDLS	Seismic Data Library System
SIBEX	Second International BIOMASS Experiment
SO-GLOBEC	Southern Ocean – Global Ocean Ecosystem Dynamics
SOIP	Southern Ocean Implementation Panel
SO-JGOFS	Southern Ocean – Joint Global Ocean Flux Study
SOP	Special Observing Periods
SPA	Specially Protected Area
SSSI	Site of Special Scientific Interest
UK	United Kingdom
UN	United Nations
UV	Ultra-Violet
VGMO	Virtual Global Magnetic Observatory

WCRP	World Climate Research Programme
WMO	World Meteorological Organisation