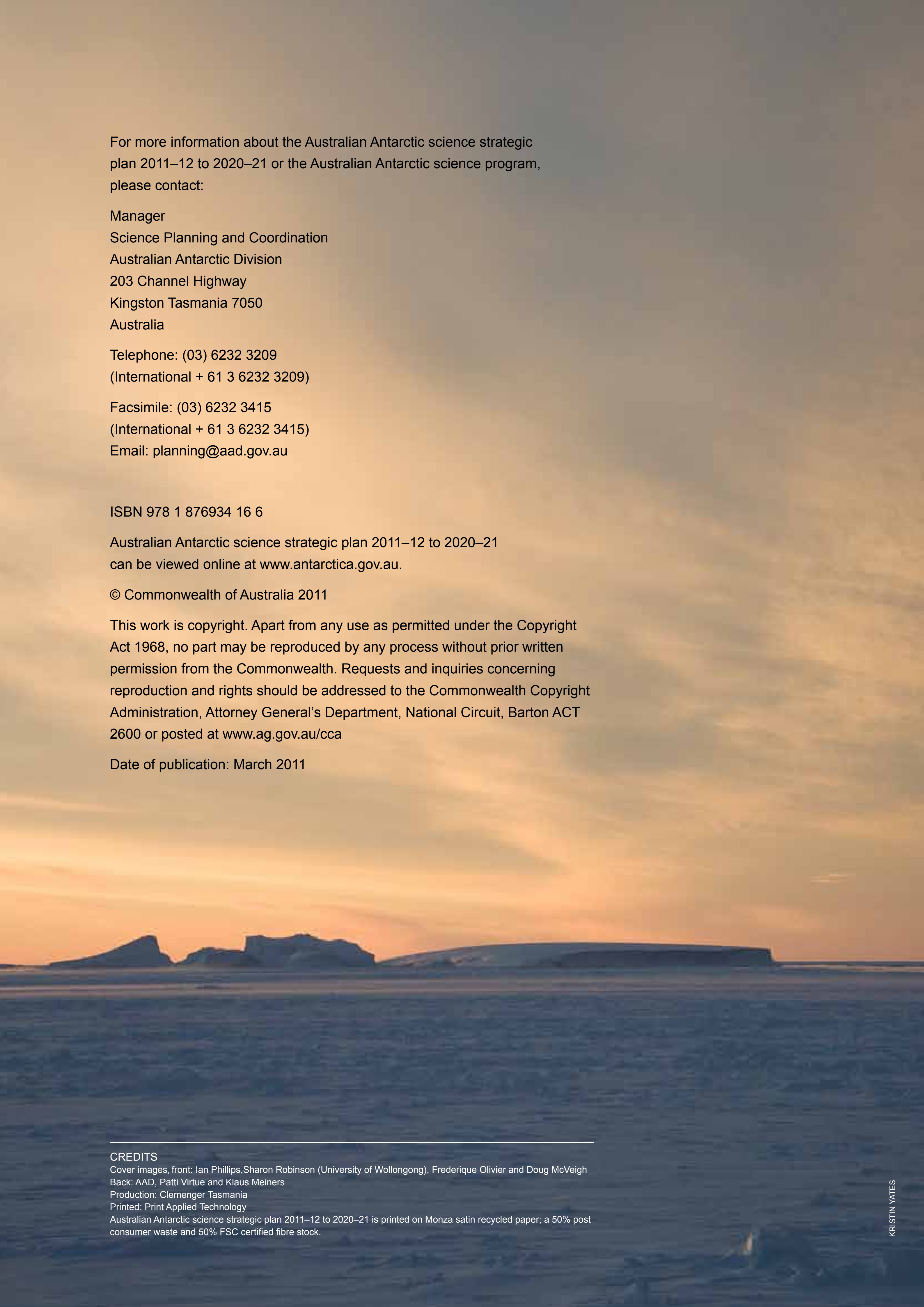
Australian Government
Department of Sustainability, Environment, Water, Population and Communities
Australian Antarctic Division

Australian Antarctic Science Strategic Plan 2011–12 to 2020–21



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KRISTIN YATES

Foreword

Antarctica is an extraordinary place. It is a vast, awe inspiring and unique wilderness. It has captivated explorers from around the globe for centuries, and it is the one place in the world where all countries work together to preserve its values for the common good, under a Treaty that was signed in 1959.

Australia has a unique relationship with the Antarctic. Its isolation, harshness and beauty strike a chord with the Australian people, even though most will never visit. The efforts of our scientists and explorers over the past 100 years, and their stories of triumph and hardship, have been admired universally.

Today our scientific efforts are redoubling as we turn to Antarctica for answers to one of the great challenges of our time – understanding and adapting to changes occurring in our climate, ecosystems and oceans as a result of our high carbon dioxide emitting lifestyles.

The search to understand the drivers and impacts of a changing climate leads inexorably to Antarctica and the Southern Ocean, which we now understand are sentinels of global climate change.

In addition to climate change, projected human population growth over this century, and associated demand for food security, will increase pressure on the underexploited krill resources of the Southern Ocean. Krill – one of the most abundant animals on earth – help sustain the iconic ecosystems of this remote ocean, and will be critical to recovering populations of whales and seals. Balancing ecosystem sustainability and function with the demand for resources is a challenge we must meet. To do so requires excellent science and strong governance.

Australia's Antarctic program is at the forefront of Antarctic and Southern Ocean scientific research and firmly focussed on the national policy priorities of global climate change and environmental management. The Australian Government's long term commitment to continue Australia's international leadership in these vital areas of scientific endeavour is reflected in this new 10 year Science Strategic Plan to guide and direct our Antarctic research into the future.

I hope scientists find within these pages inspiration and opportunities to become involved in the Australian Antarctic Science Program. I would like to thank my fellow members of the Antarctic Science Advisory Committee for their contribution to this seminal plan.

Professor Will Steffen

Chair
Antarctic Science Advisory Committee

KRISTIN YATES

Contents

Executive summary

Antarctica and the Southern Ocean are dynamic and critical elements of our earth system:

- Antarctica contains 90% of the ice on earth and 60–70% of its freshwater, which if melted would increase sea level by 60+ metres.
- The seasonal growth of sea ice each year is one of the earth's most significant seasonal cycles, covering an area of 19 million square kilometres at maximum extent. This is 1.5 times the area of the Antarctic continent.
- Antarctic and Southern Ocean water masses dominate the global oceans and in so doing influence the climate of Australia and all of the other continents.
- The Southern Ocean is a major sink for global carbon dioxide emissions (accounting for 30% of the global ocean uptake).
- Regional weather and global climate are heavily influenced by the composition and dynamics of the atmosphere above Antarctica.
- The unique ecosystems and iconic wildlife of the continent and Southern Ocean are sentinels for the rest of the world on the impacts of ocean acidification and global warming.

As we observe how rapidly and profoundly our planet is changing, the need to better understand how Antarctica and the Southern Ocean influence the functioning and resilience of the earth system, and how they will respond to future changes, has become urgent. For Australians, added impetus is provided by the fact that what happens to the frozen continent and the Southern Ocean will have profound impacts on Australia.

Threats to Southern Ocean ecosystems from global change and fisheries exploitation, also drive a need for improved understanding of how best to balance conservation and the global search for food security.

As more tourists, marine harvesters and national program operators and scientists visit Antarctica each year, we face the ongoing challenge of understanding and protecting the unique environmental assets of the frozen continent.

This decadal strategic plan for Australia's Antarctic Science Program is designed to tackle these challenges. It has been developed to build upon the fourth International Polar Year (IPY 2007–09), to which Australia contributed significantly. The IPY highlighted the societal benefit that can be achieved through focused, collaborative and large-scale science. Importantly, the IPY also identified critical gaps in our understanding of Antarctica and the Southern Ocean. This plan focuses and prioritises Australia's Antarctic science to address these critical gaps, and is soundly based on the strong capability provided by Australia's innovation sector and the Australian Antarctic Science Program.

The plan builds on Australia's long and proud history of Antarctic exploration and scientific research: for many years the Australian Antarctic Science Program has been a very important contributor on the global stage. While fundamental research dominated the pioneering years of the program, in more recent times the program has become more strategic and focused on delivering information on important local, regional and international environmental and conservation issues. This trend continues in this strategic plan following Australian Government direction that Australia's Antarctic science should focus on its needs: i.e. meeting the challenges of global change, natural resource sustainability, biodiversity conservation and managing human impacts on the Antarctic continent.

The plan was developed following broad consultation with government science users (policy makers, environmental managers, service providers and defence and national security agencies) and the science community (universities and a number of publicly funded research agencies). It draws from national and international research frameworks and strategic plans, and aims to continue Australia's leading roles in many aspects of Antarctic and Southern Ocean research.

The plan establishes the framework for Australian Antarctic research to which universities, research institutions, the Australian Antarctic Division (AAD), and other national and international government bodies contribute. As well, there will always be logistical and budgetary limits on the amount of science that can be supported by the Australian Government in the Southern Ocean and Antarctica, which will vary from time to time in line with government priorities. Therefore, there will be a need to prioritise within and across themes. Field work in these remote, challenging and dangerous environments is expensive, and requires significant logistical support, and careful planning and coordination. The AAD, in its role of leading the Australian Antarctic program, will continue to drive towards increased efficiency in operations and support of science within the program, and in particular towards greater collaboration with other national programs operating in eastern Antarctica.

This plan will guide the Australian Antarctic Science Program over the next 10 years to focus efforts within four thematic areas:

Theme 1
Climate Processes and Change

Theme 2
Terrestrial and Nearshore Ecosystems: Environmental Change and Conservation

Theme 3
Southern Ocean Ecosystems: Environmental Change and Conservation

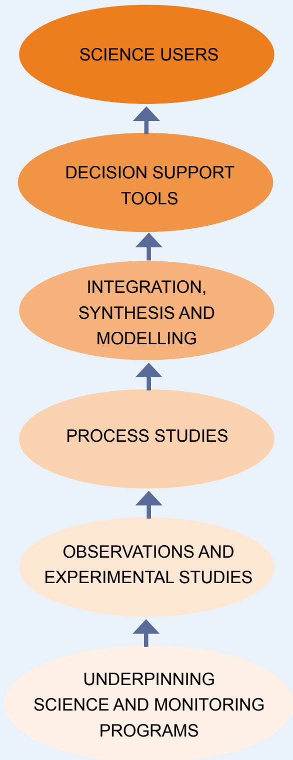
Theme 4
Frontier Science

Themes 1, 2 and 3 address the priority science needs articulated by government policy and resource management agencies. The research in these themes will be designed explicitly to link investment in monitoring, observational and experimental science with the required process studies, synthesis and integrative modelling, and finally to the provision of scientific input to policy makers, conservation and resource managers. There will be increased emphasis placed on delivering project and program outputs and products to the end user community.

The Frontier Science theme provides an opportunity for high quality science projects that address Australia's national science priorities, without the requirement for current policy relevance. The continued support for this more fundamental science is a vital component of the strategic approach across the Australian Antarctic Science Program.

The program will continue to be responsible for a broad suite of ongoing observational activities, including a network of meteorological facilities; ionospheric activity monitoring; geophysical monitoring including seismic, magnetic and GPS networks; and hydrographic and bathymetric mapping. These activities underpin the diverse science portfolio and are of critical importance to Australia's understanding of, and operations in, Antarctica.

The program will undergo a mid-term review to evaluate progress towards theme goals and assess needs for development of new thematic areas. The Australian Academy of Science National Committee for Antarctic Research will support the Antarctic Science Advisory Committee in recommending future priorities within the program.



Theme and stream portfolio flowchart

In designing theme and stream project portfolios, leaders will need to determine the relative importance of and required investment in different components of the science 'supply chain' from observations through to development of decision support tools.

In streams where established observing or monitoring systems already provide significant data, it is expected that more emphasis will be placed on targeted process studies, synthesis, modelling and development of decision support tools.

However, where streams lack this mature observational foundation, there is likely to be more investment in designing and expanding observational and experimental activities, perhaps supported by development of conceptual or qualitative models of how the system works.

Regardless of the stream design, each project will need to clearly articulate how it will contribute to the theme and stream goals, and in so doing meet user needs.

The Australian Antarctic Science Program will continue to welcome and support involvement by Australian and international scientists willing to contribute to advancing Australia's interests in the Antarctic. High priority will be placed on collaboration across the Australian and international research communities.

The program is founded on scientific excellence but in evaluating projects, greater emphasis will be placed on the relevance of the research to policy makers and end users, and to broader outreach of research results to the public and other stakeholders. A partnership approach between researchers and decision makers is essential to the success of the program and theme leaders will play an important role in ensuring alignment of the research to the needs of decision makers.

The research themes in brief

Theme 1

Climate Processes and Change

Theme goal: To improve understanding of the role of Antarctica and the Southern Ocean in the global climate system, with special focus on addressing critical gaps in knowledge identified by the Intergovernmental Panel on Climate Change.

The research will be divided into four streams:

1.1 The Antarctic ice sheet

1.2 Oceans and marine ice in the Southern Hemisphere

1.3 Atmospheric processes and change

1.4 Antarctic palaeoclimate.

Key expected outcomes for this theme are:

- enhanced detection and attribution of climate change in the Antarctic system across the oceans, cryosphere and atmosphere
- enhanced performance of coupled earth system models through improved representation of the dynamics of Southern Ocean and Antarctic processes providing more robust analysis of climate change to guide domestic and international responses
- enhanced capability to adapt to the impacts of climate change through improved understanding of the nature and extent of change in ocean carbon sinks, sea level rise, regional climate variability, and Southern Ocean biophysical systems.

Theme 2

Terrestrial and Nearshore Ecosystems: Environmental Change and Conservation

Theme goal: To investigate the effects of environmental change, caused by local and global processes, on key Antarctic and subantarctic terrestrial and coastal[1] ecosystems and provide the scientific basis to guide enhanced environmental protection for these ecosystems.

The research will be divided into three streams:

2.1 Trends and sensitivity to change

2.2 Vulnerability and spatial protection

2.3 Human impacts: prevention, mitigation and remediation.

Key expected outcomes for this theme are:

- identification of key ecosystem sensitivities and vulnerabilities to environmental stressors
- identification of signals of ecosystem change caused by human pressures, both from local activities and from global processes
- scientific foundation for a system of spatial management and area protection that takes into account the particular characteristics of Antarctica
- scientific and technical foundation for practical measures to prevent, mitigate or remediate detrimental change caused by human activity.

1. Coastal in the context of this plan is the marine area extending from the coast to a depth of 200 metres.

Theme 3

Southern Ocean Ecosystems: Environmental Change and Conservation

Theme goal: To conduct the scientific research necessary for understanding the impact of global change on Southern Ocean ecosystems, the effective conservation of Antarctic and Southern Ocean wildlife and the sustainable, ecosystem-based management of Southern Ocean fisheries.

The research will be divided into four streams:

3.1 Marine ecosystem change

3.2 Wildlife conservation

3.3 Southern Ocean fisheries

3.4 Protecting marine biodiversity.

Key expected outcomes for this theme are:

- significantly improved understanding of the impacts of ocean acidification on selected biota and ecosystems of the Southern Ocean, including assessment of their resilience to predicted change scenarios
- identification of sensitive marine indicator species or systems for tracking and understanding the impacts of environmental change
- assessment of the risks of global change impacts on Southern Ocean ecosystems and species of high conservation or fisheries value, including evaluation of the probability of different food web structures arising under predicted changes in the ocean and sea ice systems
- better knowledge about the status and trends of important Antarctic wildlife populations (whales, seals and seabirds), leading to improved conservation planning and management measures
- improved scientific information for fisheries managers (including improved mitigation strategies to reduce bycatch) and integration of fisheries data into ecosystem models to assist in management decisions
- the design of a comprehensive, adequate and representative network of spatial management areas, including marine protected areas in the Southern Ocean (and within the Commission for the Conservation of Antarctic Marine Living Resources Area), particularly focusing on the marine biodiversity in the waters off East Antarctica.

FREDERIQUE OLIVIER

Theme 4

Frontier Science

The Frontier Science theme has been developed to encourage and support research that falls outside of the priorities within the other thematic areas, but within Australia's national science priorities. The theme will be guided by the Chief Scientist of the program, who will be assisted by leaders in the fields.

Key initiatives within the plan

- Annual Antarctic and Southern Ocean Symposium starting in 2011–12
- Theme/stream workshops to design coordinated and integrated research plans and share information on progress within each stream
- Two-stage application process – expression of interest followed by full application
- Emphasis on the importance of outreach and educational programs
- Post-doctoral fellowships
- Top-up scholarships for post-graduate students

Context

Australia has a long and close association with the Antarctic going back to the 1800s. Amongst our earliest associations were an 1899 expedition to Cape Adare, on which Tasmanian born physicist Louis Bernacchi travelled; support of Scott's 1901–04 and Shackleton's 1907–09 expeditions; and the Australasian Antarctic Expedition led by Sir Douglas Mawson in 1911–14. The Australian Antarctic Division (AAD) was formed in 1948 to administer and coordinate Australian National Antarctic Research Expeditions, which later became the Australian Antarctic program.

The Antarctic Treaty (incorporating the area south of 60°S) has provided the basis for managing the Antarctic since it came into force in 1961. The Treaty has put aside the potential for differences over questions of sovereignty and provides for cooperative research.

Australia took a leading role in the formulation of the Treaty and was one of the 12 original signatories. Australia takes its responsibilities as a Treaty nation very seriously; for example, it led the development of the Protocol on Environmental Protection (the Protocol) to the Antarctic Treaty [1998] ATS 6, which includes a ban on mining in Antarctica. Australia recognises increasingly the immediate importance of Antarctica as a priority location for conducting globally significant scientific research, particularly as it relates to climate change science. Strong emphasis has been placed by Australia on Antarctic environmental protection, particularly through the adoption and implementation of measures under the Protocol. Australia also seeks to pursue economic opportunities arising from Antarctic-related activities (other than exploitation of Antarctica's mineral resources).

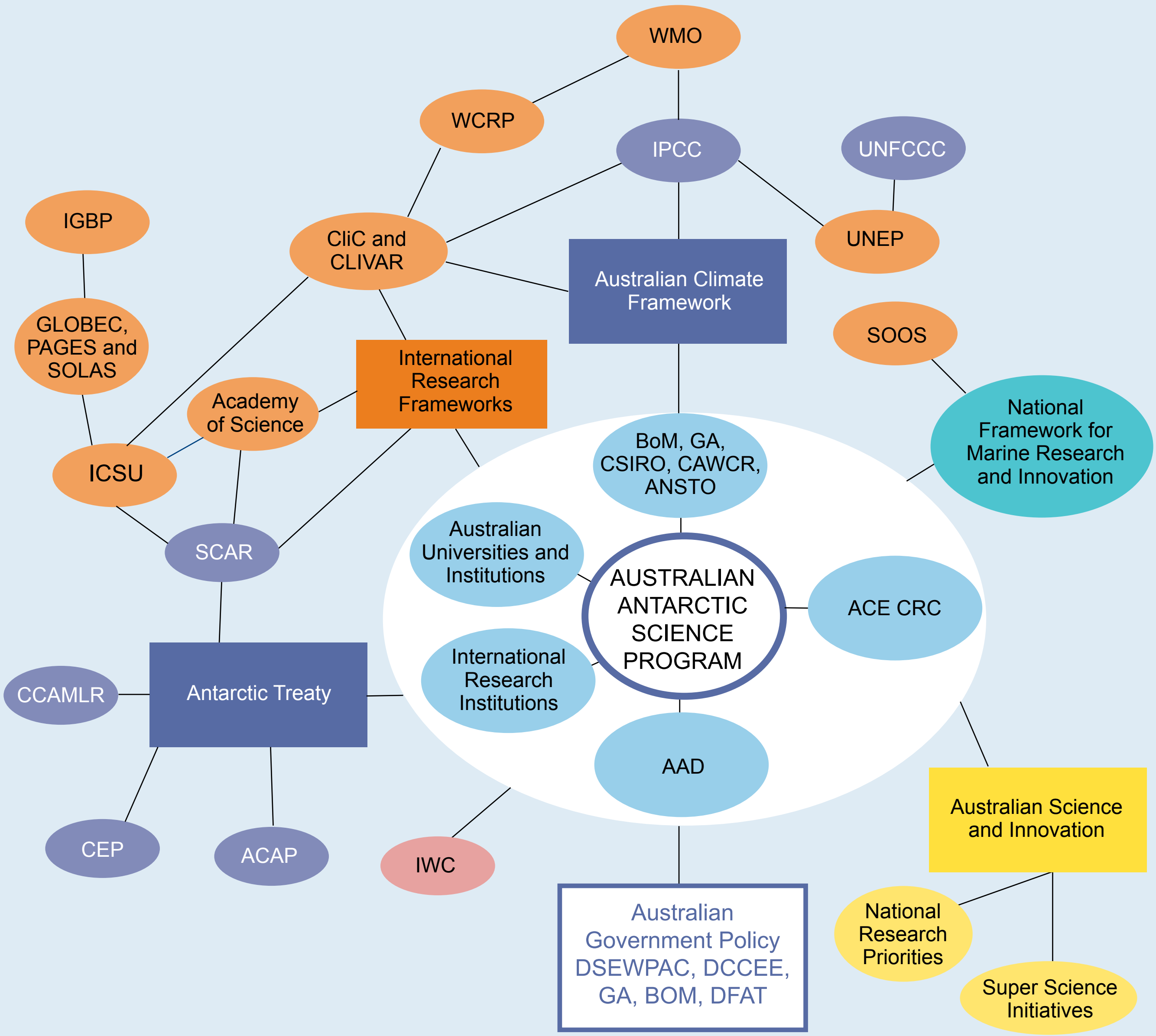
In 2009 the Australian Government reaffirmed the importance of Antarctica to national interests and agreed on the following key policy priorities for Australia's future engagement in the Antarctic:

- Maintaining and increasing Australia's physical presence in the Australian Antarctic Territory (AAT), including through scientific research, facilities and transport capabilities and the ability to conduct activities in all parts of the AAT, the Heard Island and McDonald Islands (HIMI) external territory and their adjacent waters.
- Maintaining Australia's diplomatic presence and increasing Australia's influence in Antarctica through actively engaging internationally in matters affecting Antarctic governance arrangements, including under the Antarctic Treaty and other international instruments.
- Continually improving the environmental management of Australia's activities and encouraging other states active in Antarctica and the Southern Ocean to do likewise, including through a revitalised Australian inspection program.
- Delivering scientific outputs that meet the defined policy needs of government.
- Pursuing collaborative science and logistics relationships with states active in eastern Antarctica focusing on Australia's key bilateral partners.
- Pursuing possible economic opportunities arising from Antarctic-related activities, including from:
  - well managed Antarctic tourism
  - sustainable, well regulated Southern Ocean fisheries
  - Australia's Antarctic gateway cities (Hobart, Perth and Sydney).

These policy priorities set the context for the Australian Antarctic program going forward – including its important science activities – and have guided the Antarctic Science Advisory Committee's development of this strategic plan.

Connections between the Australian Antarctic Science Program and Australian and international research programs and policy

(acronyms in Appendix 1)



Introduction


ANDREW JACKSON

In the 100 years since the geologists Professor (Sir) Edgeworth David and Sir Douglas Mawson first reached the South magnetic Pole, Australia's Antarctic science has earned a reputation for excellence in discovery, innovation and delivery on national and international goals. Science is commonly described as the 'currency' of the Antarctic Treaty system and has been the cornerstone of an enduring culture of cooperation in Antarctica. As such, the Australian Antarctic Science Program (hereafter referred to as the program) has been central to demonstration of Australia's commitment to its claim to 5.9 million square kilometres (42%) of Antarctica and the status of Australia among the 48 Antarctic Treaty Parties.

The AAD is part of the Commonwealth Department of Sustainability, Environment, Water, Population and Communities. The division leads and facilitates the program and directs approximately 70% of its annual budget to support scientific activities and support staff. These funds support research grants, students and fellowships; transport and field logistics; marine science voyages; and the maintenance of four stations: three in eastern Antarctica and one on subantarctic Macquarie Island in the Southern Ocean.

The program is diverse in scope, covering physical and life sciences in the atmospheric, terrestrial and marine domains, as well as human biology and medical research. It ranks behind only the larger US and UK programs in the publication of peer reviewed technical literature[2], and has also been very influential through the publication of high quality science in the Scientific Committee Proceedings of the International Whaling Commission (IWC), the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), and has made significant contributions to the Intergovernmental Panel on Climate Change (IPCC) reports.

Underpinning the diverse science portfolio, and of critical importance to Australia's understanding of, and operations in, Antarctica, the program is also responsible for a broad suite of ongoing observational activities – including a network of meteorological facilities; ionospheric activity monitoring; geophysical monitoring including seismic, magnetic and GPS networks; and hydrographic and bathymetric mapping.

The program is highly collaborative, involving researchers from universities and government research agencies throughout Australia and the world (Figures 1 and 2). For example, in 2008–09, 119 projects, led by scientists from 31 institutions, were undertaken by the program. The projects involved collaboration with a further 242 institutions from 28 countries. Australian scientists also work closely with collaborators in the science programs of other countries, and to support this, the AAD has formal Memoranda of Understanding covering science and operational cooperation with a number of Antarctic Treaty nations.

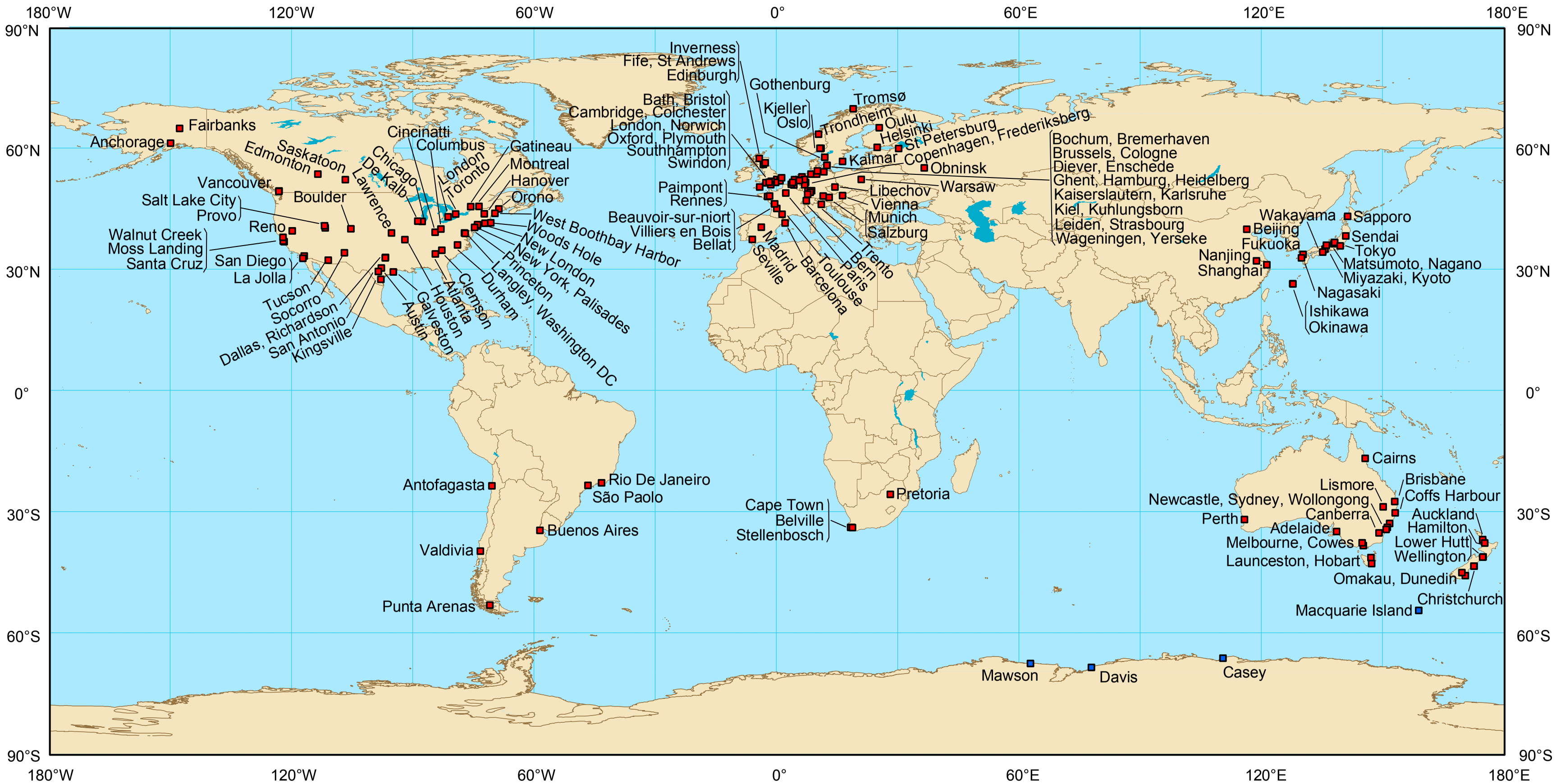
Since 1999, Antarctic science directions and investment have been guided by a strategic plan, developed by ASAC, and signed off by the responsible Australian Government Minister. In line with the 2009 policy priorities for Australia's future engagement in the Antarctic (see context section) the program is required to ensure that its scientific outputs meet defined policy needs of government.

Thus, this 10 year plan seeks to encourage, guide and focus Antarctic and Southern Ocean[3] research so that it can deliver the maximum benefits to Australia and to the international community as we seek to meet the global challenges of climate change, ocean acidification, population growth and its demands for food and energy security, and the increasing human footprint on the Antarctic continent.

2. Dastidar, P.G., Ramachandran, S. (2008) Intellectual Structure of Antarctic Science: A 25-Years Analysis, *Scientometrics*, 77 (3), 389–414.

3. For the purposes of this plan, the Southern Ocean is defined as the areas covered by the Antarctic Treaty and the CCAMLR Convention. Where there are drivers within projects to extend the research further north (e.g. species migratory ranges, dynamics of ocean currents and processes etc), these will be considered on a case-by-case basis.

Figure 1: Map of locations of participating institutions within the program in 2009-10



Produced by the Australian Antarctic Data Centre, September 2010
http://data.aad.gov.au/aadc/mapcat/
Map Catalogue No: 13860
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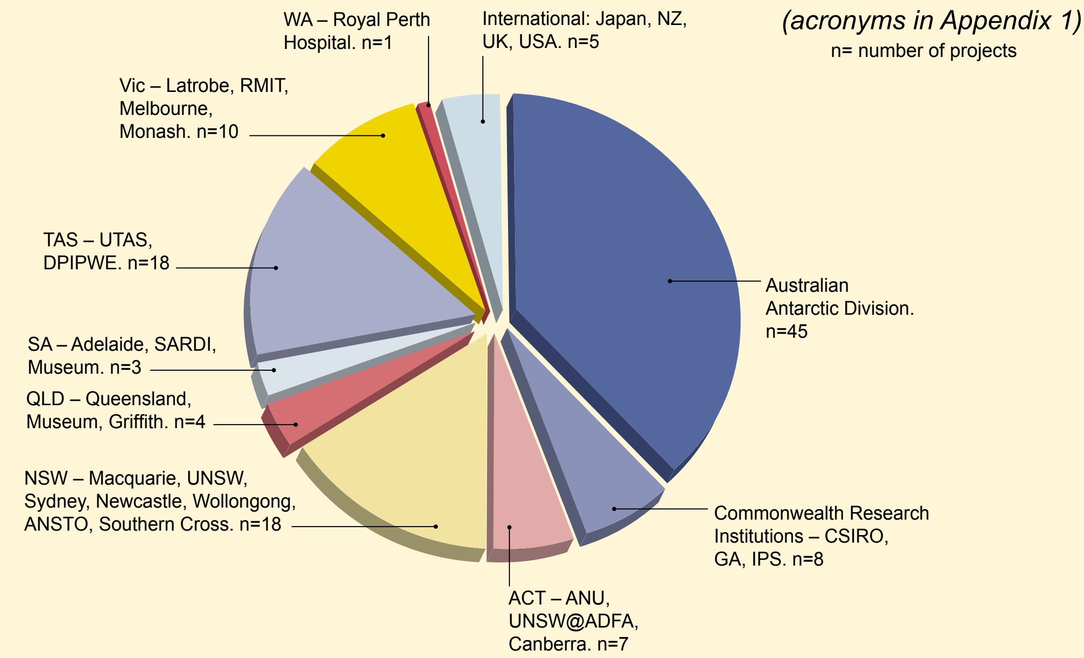
Figure 2: Australian Antarctic science program chief investigator institutions in 2009–10



Background to the Australian Antarctic science strategic plan 2011–12 to 2020–21

The imperative for science to support policy and regulatory frameworks – at local, regional and global scales – has never been greater. The physical and chemical impacts of global warming and change on Antarctica and the Southern Ocean (e.g. ice sheet decay and its impact on sea level rise, ocean carbon uptake and its impacts on acidification and biological systems including coral reefs and critical ocean ecosystems) are becoming increasingly evident and of concern. Uncertainties around the nature, extent and rate of change in polar systems were highlighted in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) in 2007, and the resulting changes within coastal and ocean ecosystems were identified in a scoping meeting for the Fifth Assessment Report. These uncertainties drive Australian and international efforts to better understand the critical polar components of the earth system. Natural resources and ecosystems of the Southern Ocean face the threats of human extraction and climate change while the unique and precious ecosystems of the Antarctic continent face pressures and risks from an increased human footprint (new stations, tourism and even science).

Together with the Australian Government's Antarctic policy priorities and goals, there are a number of broader government policy objectives, priorities and international agreements that relate to and are reliant upon scientific observations from Antarctica and the Southern Ocean. Australian Government policy makers provided their priorities for science and information as input to the plan. National Frameworks for Climate Change Science, Marine Research and Innovation, and Space Science and Astronomy also provide guidance on Antarctic and Southern Ocean priorities.

The drive for policy relevance and impact within the program will not diminish the emphasis on scientific excellence. Peer review of all science proposals and thorough reviews of project impacts will continue to be the cornerstones of program governance and prioritisation of science.

This is the first time a decadal strategy for the program has been developed – previously the planning had been in five-year cycles. Recognising the potential for change in policy drivers and science opportunities over the decade, ASAC, in collaboration with the Australian Academy of Science National Committee on Antarctic Science, will encourage active discussion of new Antarctic science themes over the next few years and formally consider the need for these as part of the mid-term review of the program in 2015.

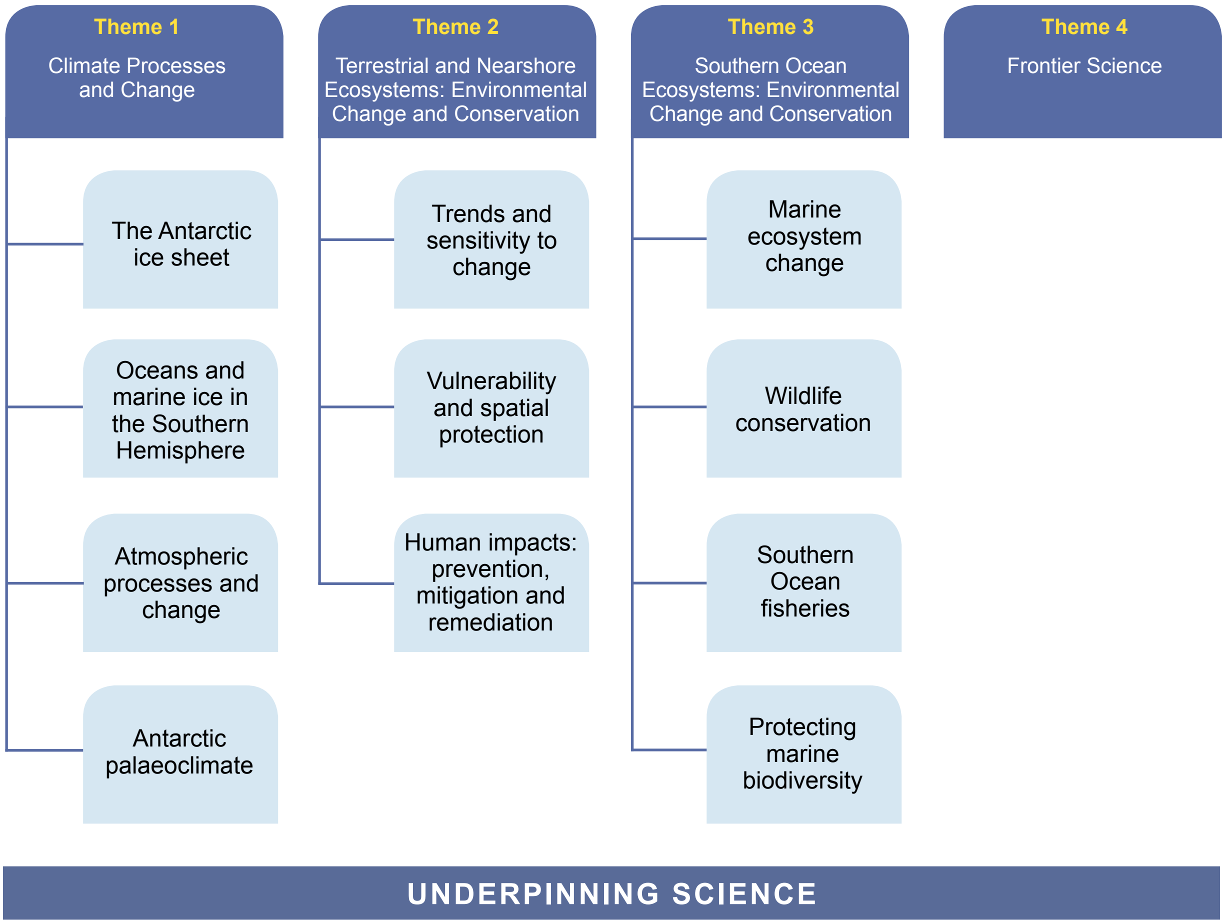
Research focus

The plan centres around four science themes:

1. Climate Processes and Change
2. Terrestrial and Nearshore Ecosystems: Environmental Change and Conservation
3. Southern Ocean Ecosystems: Environmental Change and Conservation
4. Frontier Science

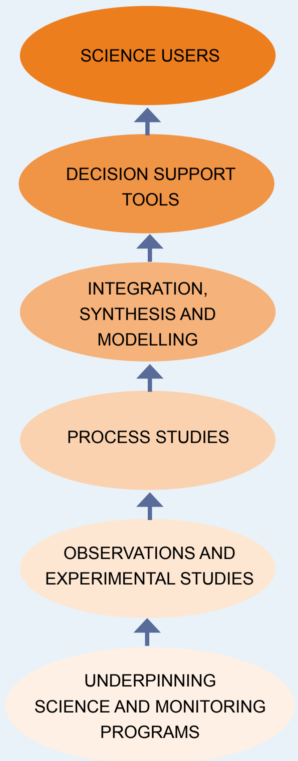
The first three themes are interrelated and connect directly to key government policy drivers. Theme 1 will provide the fundamental climate process and change information that addresses global and regional climate questions, and inform the ecosystem-based themes 2 and 3. Each of these three policy-related themes has a goal and expected outcomes. All research undertaken within each theme will need to demonstrate clearly how it will contribute to achieving the theme goal and outcomes. To assist in coordinating the research effort within themes, each one has been subdivided into streams of research effort (Figure 3). Each stream has defined goals and research questions which link to the theme goal.

Figure 3: Outline of themes and streams



There will be greater emphasis on, and support for, larger integrated science projects within these themes, an initiative aimed at promoting collaboration and at more efficient planning and operational support for science in Antarctica. Each stream will develop a plan encompassing five- and ten-year outputs, and a clear strategy for their delivery into the relevant government departments and the international science framework where applicable.

The Frontier Science theme has been developed to encourage and support research that falls outside of priorities of the three policy related themes, but within Australia's national science priorities. A limited number of Frontier Science projects will be supported each year. These will not require justification against policy drivers, but rather be judged on their science excellence and fit to the program's objective of using Antarctica's special attributes for the benefit of science and humanity.



Theme and stream portfolio flowchart

In designing theme and stream project portfolios, leaders will need to determine the relative importance of and required investment in different components of the science 'supply chain' from observations through to development of decision support tools.

In streams where established observing or monitoring systems already provide significant data, it is expected that more emphasis will be placed on targeted process studies, synthesis, modelling and development of decision support tools.

However, where streams lack this mature observational foundation, there is likely to be more investment in designing and expanding observational and experimental activities, perhaps supported by development of conceptual or qualitative models of how the system works.

Regardless of the stream design, each project will need to clearly articulate how it will contribute to the theme and stream goals, and in so doing meet user needs.

We will continue to balance investment across tactical, strategic and fundamental research[4] within each theme; support critical long-term monitoring of the Antarctic environment and ecosystems; champion and facilitate the participation of Australians in high priority international collaborations; and welcome the involvement of overseas scientists in the program.

An important component of the program, and an integral part of this plan, are the essential monitoring activities carried out at our stations and throughout the AAT. Although not explicitly components of the research program, these monitoring activities underpin research in many of the thematic areas outlined previously. In particular, essential monitoring activities conducted by the Bureau of Meteorology, Ionospheric Prediction Service Radio and Space Services, Australian Radiation Protection and Nuclear Safety Agency, and Geoscience Australia will be continued over the life of the plan.

4. For the purposes of this plan, 'tactical' research encompasses short-term projects designed to answer specific questions from policy makers, environmental managers and operational users of science data – these projects deliver results generally within 1–2 years; 'strategic' research encompasses projects that provide a finding/data of direct relevance to achieving a strategic goal identified within the plan (i.e. there is a demonstrated link between the output of the project and the outcomes we are looking for) – these projects deliver their results in the medium term, generally within 3–5 years; and 'fundamental' research encompasses projects that contribute to high-level goals within Antarctic or national science priorities, but are not expected to provide outputs of direct relevance to the expected outcomes within the life of the plan – these projects may vary in term, with those seeking terms longer than five years requiring discrete milestones and performance review criteria.

ROLE OF THE OBSERVATORIES IN ANTARCTICA

Some observatories have operated continuously for more than 50 years and they continue to make an important contribution in monitoring of the Antarctic and global physical environments.

Seismic monitoring

Australian seismological stations at Macquarie Island and Casey form part of the global seismograph network that monitors earthquakes not only in Antarctica but anywhere in the world. The information they provide supports tsunami warning systems, including the Australian Tsunami Warning Centre, and studies of continental plate motions. The stations are operated jointly by Geoscience Australia and the United States Geological Survey.

Nuclear monitoring

Stations in Antarctica, notably the seismological station at Mawson, contribute to the global monitoring of nuclear tests. These stations are listed as part of the International Monitoring System of the Comprehensive Nuclear-Test-Ban Treaty which Australia has signed and ratified. Australia's obligations under the treaty include the establishment, operation, maintenance and upgrade of these Antarctic stations, and the provision of uninterrupted data. Construction of an infrasound array at Davis is expected to begin in the 2012–13 summer.

Geomagnetic monitoring

Australia's three geomagnetic observatories in Antarctica – at Macquarie Island (established in 1952), Mawson (1955) and Casey (1999) – monitor the earth's continuously changing magnetic field and form part of wider Australian and international observatory networks. The data and information provided by geomagnetic observatories are required by international treaties to support maritime and aviation navigation and by airborne geophysical surveys to study the nature of the Antarctic continent below the ice cover. Other applications include magnetic direction-finding, magnetic detection, and the mitigation of geomagnetic hazards. These data also contribute to research into the nature of geomagnetic phenomena (particularly in auroral zones), earth structures and processes, and solar-terrestrial physics. Geomagnetic data from Australian observatories in Antarctica are provided to the Ionospheric Prediction Service for space weather forecasting and research. Antarctic geomagnetic data contribute to global research in this field, such as the international program Project INTERMAGNET, to develop global models of the planetary magnetic field.

Geodesy

Geodesy provides the fundamental reference frame that allows accurate location on the earth's surface (by GPS). The Australian geodetic program, including its field work and computations carried out in Antarctica, contributes to the development of the International Terrestrial Reference Frame, within which all positioning activities in Antarctica are undertaken. The geodetic program therefore supports, directly or indirectly, navigation of aircraft and ships, and the monitoring of the atmosphere, oceans and coastal zones. The geodetic infrastructure in Antarctica is also used as a reference and calibration for Australian and international research programs that use geodetic and satellite-derived gravity data to study ice mass balance in Antarctica, such as Project POLENET, undertaken in the International Polar Year.

Meteorology

Weather observations are undertaken by the Bureau of Meteorology at all Australian stations and data are also collected from a number of automatic weather stations located throughout the AAT and from the Australian research and resupply ships operating in the Southern Ocean.

Key existing and potential partnerships

The work outlined in this plan will need to be undertaken by multidisciplinary consortia of researchers across a range of national and international organisations, including:

- the AAD and other Australian Government organisations (BoM, GA, CSIRO, CAWCR, IMOS, ANSTO)
- the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC) for the first five years of this plan
- Australian universities, research institutions, museums and state government agencies
- international research institutions, universities and other Antarctic nations, particularly those working in the region south of Australia and the Indian Ocean, as part of strategic bilateral collaborations.

Much of the research will be undertaken within the framework of larger international programs of research such as those of the World Climate Research Programme, the International Geosphere-Biosphere Programme, IWC, CCAMLR, Agreement on the Conservation of Albatrosses and Petrels (ACAP), Committee for Environmental Protection (CEP) and the Scientific Committee on Antarctic Research (SCAR).

Although Australia is a large and active Antarctic nation in the Southern Hemisphere, it must seek greater international collaboration with other nations in our region and beyond, as the significance of Antarctic research is truly global.

JOHN SMITH

Australia's Antarctic science capability

To achieve its goals over the next decade and into the future, it is essential that the program invests strategically in the development and maintenance of Antarctic science capability in its broadest sense (i.e. people and skills, infrastructure and key partnerships and collaborations). The responsibility for this must be shared across the broad Antarctic science community.

Through its support of the Space and Astronomy and Marine and Climate Super Science Initiatives, the National Collaborative Research Infrastructure Strategy, the ACE CRC and the Antarctic Airlink, the Australian Government has provided the potential for significant new investment in Antarctic and Southern Ocean science.

Australia's Integrated Marine Observing System (IMOS) has already invested heavily in observational facilities and data management infrastructure for Southern Ocean marine and climate science. The community challenge ahead is to make use of the existing resources and through leverage of the significant science support funding provided by the program, increase the total investment in this critical part of the national innovation system.

Part of the vision of this decadal plan is to see the formation of university centres of excellence on Antarctic and Southern Ocean research topics, greater training opportunities for the next generations of Antarctic scientists, particularly in disciplines in short supply (e.g. glaciology, numerical modelling, systems analysis, metagenomics) and for post-graduate and post-doctoral fellows; greater cohesion within the community and collaboration between universities and publicly funded research agencies in tackling the large-scale science questions; and sharing of national research infrastructure, analytical facilities and modelling frameworks.

Realising this vision will be essential if we are to achieve the ambitious science goals set out in this document. The intent is to build and fund the science themes and their component streams as communities of practice, thereby allowing planning, field campaigns, data synthesis and reviews of outputs to be conducted collaboratively. Annual Antarctic science symposia will be held to promote awareness in science and its use, and facilitate greater coordination and collaboration across the program.

There will always be limits on the amount of science that can be supported in the Southern Ocean and Antarctica, and hence a need to prioritise within and across themes. Field work in these remote, challenging and dangerous environments is expensive, and requires significant logistical support, and careful planning and coordination. The AAD will continue to drive towards increased efficiency in operations and support of science within the program, and in particular towards greater collaboration with other states operating in eastern Antarctica.

THEMES

1 Climate Processes and Change

Theme goal

To improve the understanding of the role of Antarctica and the Southern Ocean in the global climate system, with special focus on addressing critical gaps in knowledge identified by the Intergovernmental Panel on Climate Change (IPCC).

Key expected outcomes for this theme will be:

- enhanced detection and attribution of climate change in the Antarctic region, including ocean, ice and atmospheric processes
- enhanced performance of coupled earth system models through improved representation of the dynamics of Southern Ocean and Antarctic processes providing more robust analysis of climate change to guide domestic and international responses
- enhanced capability to adapt to the impacts of climate change through improved understanding of the nature and extent of change in ocean carbon sinks, sea level rise, regional climate variability, and Southern Ocean biophysical systems.

The theme will support regional observation systems collecting priority data on oceanic, cryospheric and atmospheric components of the earth system, with an emphasis on eastern Antarctica, by undertaking targeted process studies, contributing to development of coupled system models, publishing research papers, reviews and technical papers in the international peer reviewed literature, and conducting briefings on findings to key government and public stakeholders. Theme research will target key areas within IPCC assessment reports, in particular through contributions to, and support of, the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC).

The work of the theme will be organised into four streams:

1.1 The Antarctic ice sheet

1.2 Oceans and marine ice in the Southern Hemisphere

1.3 Atmospheric processes and change

1.4 Antarctic palaeoclimate.

Background

The Climate Processes and Change theme is concerned with the role of Antarctica and the Southern Ocean regions in the climate system; in climate variability and change in these regions; and in the processes that drive and cause changes and feedbacks in global climate.

Antarctica and the Southern Ocean are especially relevant to Australia because of their proximity and interconnections and their influence on regional climate processes. While the climate system must be analysed on a global scale, Australia's climate has characteristics influenced by regional climate drivers, including those in Antarctica and the Southern Ocean. Australia must undertake science that is needed to understand aspects of climate change relevant to us, and to inform effective policy responses appropriate to our nation.

The Fourth Assessment Report of the IPCC (AR4, 2007) concluded that the observed warming of the earth is unequivocal, and that this warming is strongest in polar regions. Surface temperatures over large areas of the Arctic and on the Antarctic Peninsula have risen considerably faster than the global average, and the vast Southern Ocean is warming more rapidly than the rest of the global ocean. These enhanced changes are a result of the ice-albedo feedback and other feedback[5] processes that amplify climate change in polar regions. At the same time, Antarctic and

5. A process in which warming leads to reduction in highly reflective (high albedo) ice, revealing a darker (low albedo) surface and consequential enhancement of warming.

Southern Ocean processes influence both regional and global weather and climate, and impact the wider environment and ecosystems. Impacts of warming in the high latitude Southern Hemisphere will be particularly evident in widespread shrinking snow and ice and the resultant consequences, including sea level rise.

Australia has a long and distinguished record of climate-related research in the Southern Ocean and the Antarctic. Most of this has been geographically focused in the region to the south of the Australian continent and in the Indian Ocean sector, the region with most direct impact on Australia, and which encompasses most of the Australian Antarctic Territory (AAT). The research has integrated multidisciplinary themes of ocean, atmosphere and ice, and also included palaeoclimate studies, to build an understanding of the complete high latitude climate system; this approach will be continued under the strategic plan for the next decade.

Major accomplishments of the program to date include confirmation that the Southern Ocean has warmed more rapidly than the global ocean average and that the dense bottom water formed near Antarctica has freshened in some locations and warmed in others. A new source region on the Antarctic coast, the Mertz Glacier Polynya, where cold dense bottom water is formed, has been located. Bottom water is a key driver of the global-scale overturning circulation of the ocean, and processes that form it involve complex interactions between ocean circulation, winds blowing off the ice sheet, and sea ice formation. These have been better understood through *in situ* measurements and mooring deployments, satellite remote sensing, and numerical modelling. For the past decade, Australia has been one of few nations undertaking major field research programs on Antarctic sea ice characteristics and processes and their potential response to climate change. Our marine science program has also made major advances in understanding ocean carbon uptake and its link to the biological pump[6], the circulation beneath ice shelves, processes and characteristics of basal freezing and melt, and their potential implications to ice shelf stability.

Extensive land-based surveys of East Antarctica have contributed to understanding the ice sheet mass budget and dynamics. Our participation in multi-national airborne surveys, using sophisticated ice-penetrating radar and other geophysical systems, enables us to map characteristics of the ice and underlying bedrock over vast areas of Antarctica. Results from this will be essential to produce accurate models to predict future changes to the ice sheets. Ice cores from coastal regions of the AAT have revealed the carbon cycle history, past sea ice extent and the links between sea surface temperature changes and the circulation of the Southern and Indian oceans and rainfall patterns in southern Australia. These ice cores provide the records of atmospheric greenhouse gas and ozone-depleting gas composition that are used in most climate and atmospheric chemistry

6. The biological pump removes carbon that is captured by biological processes from the surface ocean to the interior, through sinking of dead material and surface waters. The physical pump for carbon dioxide refers to the process of direct dissolution of carbon dioxide in sea water, driven by the concentration difference between atmosphere and ocean.

model simulations of past centuries. The extensive and long running network of surface monitoring stations across the Antarctic coast and Southern Ocean continues these records into the future and can provide a top down constraint on trace gas budgets, including trends in carbon dioxide uptake. Australian automatic weather station networks have defined the surface climate of large parts of the East Antarctic Ice Sheet; and changes to temperatures and winds in the higher atmosphere, and their coupling with tropospheric processes, have been monitored. Our Antarctic observations of the higher atmosphere have also revealed connections between ozone concentrations and the size and intensity of the polar vortex, characterised the winds and waves in the mesosphere, identified changes in atmospheric tides over the last three decades, and used the dust trail of a meteorite to verify atmospheric transport models.

Scientists from the program have contributed important research results to the assessment reports of the IPCC and have been represented as coordinating lead authors, lead authors, contributing authors and reviewers in the IPCC process.

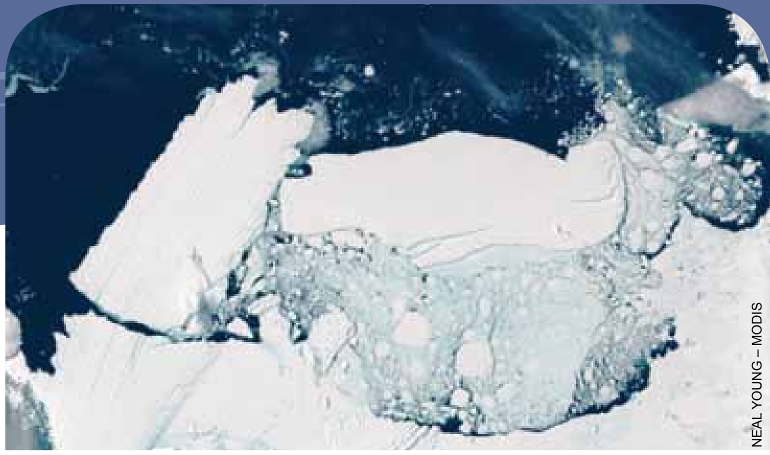
The program will build on this past research record which provides a solid background for addressing current uncertainties and questions. Antarctic and Southern Ocean changes are critically important because of the complex feedbacks involving ocean currents, sea ice and the carbon cycle, which have the potential to accelerate the rates of global changes. Elements of the climate system affecting our region that require focused attention via process studies include high latitude sea ice and ocean interaction, the dynamics of Antarctic ice sheets, deep ocean overturning, the uptake of carbon by the ocean, and the coupling between chemical, dynamic and radiative processes in the stratosphere and above with those of the lower atmosphere. It is essential that much of this research links across disciplinary streams.

Process studies and improved observations of the atmosphere, ocean, and cryosphere will support improvements to coupled modelling and to predictability of the climate system. Contributions to the development of Antarctic and Southern Ocean components of such models will be an important part of this 10 year plan.

Many of the streams will build on existing strengths within the program and on new capabilities that are being developed within the renewed ACE CRC (although only until 2014). In many cases, progress will be made from synthesis of existing data sets, as well as collection of new field data and the use of remotely sensed satellite data.

Sustained and systematic monitoring of the Southern Ocean and Antarctic climate system is fundamental to all the streams. This is dependent upon, and must be integrated with, both international (e.g. the proposed Southern Ocean Observing System, (SOOS)) and national (e.g. National Framework for Climate Change Science, Integrated Marine Observing System (IMOS)) efforts in the region. IMOS has recently made significant investments in Southern Ocean observations that are consistent with this plan, and with international programs.

Multidisciplinary links across streams, and with other themes defined in this plan, are essential. The individual streams must also be integrated within a total earth system science approach. Projection of future changes to the climate system requires improved models of components of the climate system and, in collaboration with the larger Australian climate modelling community, better fully coupled climate and earth system models. The model improvements need to be informed by field process studies, and the models must be validated against observations of recent and past climate in the Antarctic and in the Southern Ocean.



Key policy drivers and questions

The Climate Processes and Change theme focuses on a suite of research projects which contribute to setting Australia's policy position within the United Nations Framework Convention on Climate Change (UNFCCC), contribute significantly to the IPCC and advise the Australian Government's climate agenda.

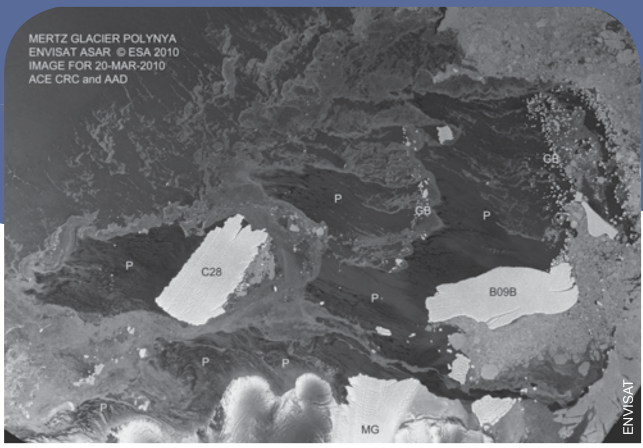
The UNFCCC provides the basis for global action 'to protect the climate system for present and future generations'. Australia ratified the convention in December 1992. Parties to the UNFCCC have agreed to work towards achieving the ultimate aim of stabilising 'greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system'. Australia is a signatory to the Kyoto Protocol, an international agreement under UNFCCC, and further protocols are expected to be negotiated during the time of this plan. Australia's position in protocol negotiations, and our involvement in other relevant international climate forums, must be founded on 'evidence-based' investigation which is underpinned by sound climate science.

The IPCC is the leading body for the assessment of the state of climate change and its potential environmental and socioeconomic consequences. The IPCC is acknowledged by the Australian Government as the authoritative source of advice on climate change science. IPCC bases its assessments mainly on peer reviewed scientific and technical literature, to which the program contributes. Research undertaken within this plan will aim to contribute to the body of scientific evidence that informs the IPCC Fifth Assessment Report, due to be finalised in 2013–14, and to other assessments which may follow.

The IPCC Fourth Assessment Report highlighted the lack of climate data from the Southern Ocean, the sea ice zone and Antarctica in general. The report also noted the need for greater understanding of the role the region may have in slowing the rate of climate change, and of the future behaviour of the ice sheet and its contribution to sea level rise. Australia has a pivotal position to play in research in this region, and in climate system connections at high latitudes.

The Australian Government has identified national research priorities for the fundamental science that is needed to provide knowledge essential to managing impacts, adaptation and mitigation strategies for climate change. The report, *National Framework for Climate Change Science*, highlights important knowledge gaps in Antarctic climate science, their relevance to global climate processes, and the benefit to Australia of addressing them. Australia's program for the next decade must deliver into this framework. Specifically, the Department of Sustainability, Environment, Water, Population and Communities (DSEWPAC) also has strong policy interests in Antarctic climate science. For example, the Environment Quality Division of DSEWPAC supports the continuation of ozone and atmospheric related research in Antarctica. Stratospheric ozone dynamics are emerging as an important determinant of climate in the Southern Hemisphere, and the importance of consistent, accurate and complete monitoring of ozone depleting substances in the atmosphere will increase over time because this monitoring in part reflects production data gathered under the Montreal Protocol.

Australia's influence in the Antarctic Treaty and other international forums is enhanced by leadership in relevant scientific research and by open exchange of the data and knowledge that result from this. We have had in the past, and should continue to have, an active and lead role in the major international programs that have a strong climate focus. These include the relevant initiatives of the World Climate Research Programme and the International Geosphere-Biosphere Programme.



There are a number of key scientific uncertainties that limit our ability to respond effectively to the challenges of climate change. Some of these scientific questions are particular to the Antarctic and Southern Ocean and include:

- What are the processes controlling dynamic ice discharge from the ice sheet in both East and West Antarctica, and how will these influence future sea level rise?
- Is the global overturning circulation likely to change with future warming, and what will be the impacts and consequences of this?
- What are the climate feedbacks involving ocean circulation, sea ice and the carbon cycle which may accelerate future climate change?
- How much heat and carbon will the Southern Ocean be able to uptake and store in the future?
- Is the development of better climate system models inhibited by inadequate understanding of some key high latitude atmospheric processes (chemical, dynamical and radiative)?
- What can the record of past climates tell us about current and future climate change?

Uncertainties underpinning these questions are addressed in the streams associated with this theme. Central to resolving these uncertainties is an urgent need for additional and sustained climate observations in Antarctica and the Southern Ocean.

Science streams

1.1 The Antarctic ice sheet

Stream goal

To significantly improve the estimates of ice loss from the Antarctic ice sheet, for incorporation in sea level projections for 2050, 2100 and beyond.

Key research questions

- What are the processes controlling dynamic ice discharge from the Antarctic ice sheet, and how will this influence future sea level rise?
- What is the present state and rate of change of Antarctic ice mass, including key observables, snow accumulation and melt?

Overview

There is an increasing body of evidence that mass loss from the ice sheets of Antarctica and Greenland is contributing to sea level rise, and doing so at an accelerating rate. Much of this loss is due to increased discharge of ice by the large glaciers draining the ice sheets rather than by surface melt. The nature, rapidity and extent of the ice sheet response to climate change are poorly understood and result in large uncertainty in projections of sea level rise over the next century and beyond. More reliable estimates of ice sheet contributions to present-day sea level rise are required based on field and satellite observations. These need to identify the regions where changes are most pronounced. The accuracy of satellite estimates of Antarctic mass balance change is presently limited by inadequate knowledge of the rate of glacial isostatic uplift, and research is needed to improve glacial isostatic adjustment models for Antarctica.

Improved understanding is required of processes that might drive rapid dynamical change in polar ice sheets and of their geological, meteorological and oceanographic context. These include the boundary conditions at the ice sheet bed, including the role of liquid water in subglacial streams and lakes; atmospheric processes that control the spatial and temporal variability of snow accumulation; and the interactions between the ocean, ice shelves and outlet glacier streams. Quantitative computer models which incorporate improved treatment of these and other processes, and which can reproduce the observed variability and history of the major ice sheets, are needed to project future change.

Detailed reconstructions of the ice sheet in the past are required to place modern observations (including ICESat and GRACE data) in context, to understand its response to former climate changes, and to verify the accuracy of the quantitative computer models. The region around Prydz Bay into which the Lambert Glacier system drains an immense area of Antarctica is a critical one. Research in this region should tell much about the early evolution of the East Antarctic Ice Sheet.

Scientific approaches and required capabilities

- Improved estimates of the overall mass budget of the ice sheet require longer term satellite measurements and new remote sensing technologies and techniques. Calibration and validation field experiments to provide ground-truth data to support the satellite observations will also be needed.
- Better projections require improved ice sheet models, accounting for the full stress configuration in the ice to correctly account for transitions between ice shelves, ice streams and ice sheets; higher resolution; and better driving fields (e.g. accumulation) and boundary conditions (e.g. basal conditions).
- Improved knowledge of wide-scale boundary conditions beneath the ice sheet and ice shelves, and over the continental shelf, as well as layers within it, requires a sophisticated airborne geophysical capability and international collaboration. Airborne geophysical surveys in the AAT might be achieved through extension of international partnerships (e.g. the ICECAP and AGAP projects) or by development of a national facility based on AAD-operated intracontinental aircraft. Airborne geophysical data and geophysical profiling techniques that can provide information on basal boundary conditions beneath ice sheets will also provide data on the crustal architecture of the AAT that enable comparison with the Australian continent. However, ongoing and proposed aerogeophysical surveys of the AAT are at comparatively low spatial resolution and further surveys will still need to be undertaken to achieve a reliable picture of the entire AAT.
- Improved modelling of ice shelf evolution requires *in situ* and remote studies of rifting and calving processes and direct measurements of sub-shelf ocean interaction. Reconstruction of past ice sheet configuration requires terrestrial campaigns to collect geological and geomorphic evidence of ice sheet positions, including sample collection for dating and other analyses. This is complemented by standard marine geological and geophysical studies which reveal past ice sheet bed and subglacial water drainage features exposed on the continental shelf by recent retreat.

1.2 Oceans and marine ice in the Southern Hemisphere

Stream goal

To understand the extent of large-scale physical, biological and biogeochemical change occurring in the Southern Ocean and marine ice environment (including ice shelves, sea ice and icebergs), and to attribute the cause(s) to anthropogenic emissions or natural variations for inclusion in IPCC models.

1.2.1 Sea ice interactions with the climate system and ecosystems

Key research questions

- How is the Antarctic sea ice physical environment changing on regional scales?
- What is the impact of changes on Southern Ocean primary production and ecosystem dynamics?

Overview

Antarctic sea ice forms a complex boundary between the Southern Ocean and the atmosphere, modifying and complicating interactions between them. High latitude Southern Ocean ice–algal biomass and primary production are also determined by factors including sea ice and snow cover extent and thickness. Changes to the regional distribution and timing of the seasonal advance and retreat of Antarctic sea ice are already occurring. Under future climate change scenarios, further significant changes are predicted, with potential feedbacks on the climate system and ecosystems.

Sophisticated new space-borne instruments, and advances using *in situ* observational techniques, are becoming available for use in the poorly observed sea ice zone. These offer new scope to monitor sea ice thickness and extent, and to investigate the interactions between the atmosphere, sea ice, and ocean on synoptic and local scales.

Better understanding of processes affecting sea ice formation, drift and deformation, and decay will require targeted field process studies within the sea ice zone at all times of the year. Better models will provide tools to assess regional scale interactions in the Southern Ocean and the implications of a changing environment on weather systems affecting Australia.

Sea ice affects Antarctic biological production at the primary and secondary level, and higher order predators will be affected by changes in the direct physical environment that the sea ice provides, as well as by consequent changes to the overall productivity of the system. Hence, it is important that studies of the sea ice environment include multidisciplinary links to coupled physical and biological processes. These will include consideration of the way that physical parameters such as ice extent, thickness, snow cover, the distribution of ice ridge keels, the distribution and thickness of fast ice, and the timing and interannual variability of the formation and break up of both fast and pack ice, are linked to the primary production in sea ice and in the water column.

Scientific approaches and required capabilities

- Satellite systems (such as CryoSat-2 launched in April 2010) can now measure sea ice parameters such as ice thickness from space, but field campaigns using an icebreaker will be required to calibrate and validate these.
- New analytical techniques need to be developed to provide a capability for regional sea ice thickness mapping and for assessing changes to total Antarctic sea ice mass.
- Improved numerical modelling of the coupled atmosphere–sea ice–ocean system, for both weather forecasting and climate studies, require models of higher complexity and better horizontal and temporal resolution.
- New technologies, such as autonomous underwater vehicles and ice capable Argo floats, can be used to fill gaps in existing ocean observations. This includes observing the ocean under the sea ice and monitoring key gateways in the Southern Ocean circulation.

1.2.2 Southern Ocean processes, variability and change

Key research questions

- How and why are the Southern Ocean circulation and water properties changing?
- What is the impact of changes on other parts of the climate system?

Overview

The circulation of the Southern Ocean strongly influences climate, sea level, biogeochemical cycles and biological productivity at both regional and global scales. A more complete understanding of Southern Ocean processes is needed to improve model parameterisations and to determine the response of the circulation to changes in forcing. Fundamental dynamical issues requiring more attention include the magnitude and distribution of mixing, the role of eddies, air-sea-ice interaction, water mass formation and the structure and variability of major circulation features like the Antarctic Circumpolar Current, the slope currents and deep boundary currents. The exchange between the Southern Ocean and lower latitudes needs to be measured to determine the meridional transport of heat, freshwater and other properties.

Changes in the circulation of the Southern Ocean can be expected to have large and widespread impacts. In particular, coupling between ocean circulation, sea ice and biogeochemical cycles can result in positive feedbacks that drive further climate change. Reductions in sea ice extent will drive further warming through the ice-albedo feedback. Models suggest that the ability of the Southern Ocean to absorb carbon dioxide will decline with climate change, providing another positive feedback. The magnitude of these impacts is unlikely to be foreseen by simply extrapolating present trends because of the potential for feedbacks that will alter the pace of change, possibly abruptly. The pervasive and strong links between Southern Ocean processes and the earth system mean that sustained observations of the Southern Ocean circulation are critical to detecting and interpreting future change.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The paucity of observations makes it difficult to document and interpret the patterns of change in the Southern Ocean. In particular, we are not yet able to distinguish the effects of natural changes from the effects of human-induced climate change caused by emission of greenhouse gases, as well as the impact of ozone depletion causing stronger winds over the Southern Ocean.

Observations of change provide a particularly relevant and rigorous test for models: if models can replicate current conditions and reproduce patterns of past change, we have more confidence in their ability to project the future. Recently, new tools have been developed to detect the 'fingerprint' of anthropogenic climate change. Formal climate change detection and attribution methods need to be applied more rigorously to the Southern Ocean; recent improvements in both observations and models of the Southern Ocean mean that formal, quantitative approaches to the comparison of modelled and observed patterns of change are now feasible.

Scientific approaches and required capabilities

- A mix of sustained multidisciplinary Southern Ocean observations and process-focused experiments will be needed to detect ocean changes and to attribute the drivers and causes.
- Integrated observations, analysis and model simulations are required to detect and interpret change.
- Southern Ocean observations using remote sensing, ship transects (using an ice strengthened or ice breaking ship), robotic platforms and moorings have been well defined internationally, and projects contributing to this stream should be integrated with the recommendations from SOOS.

1.2.3 Ice-ocean interaction and the Southern Ocean freshwater budget

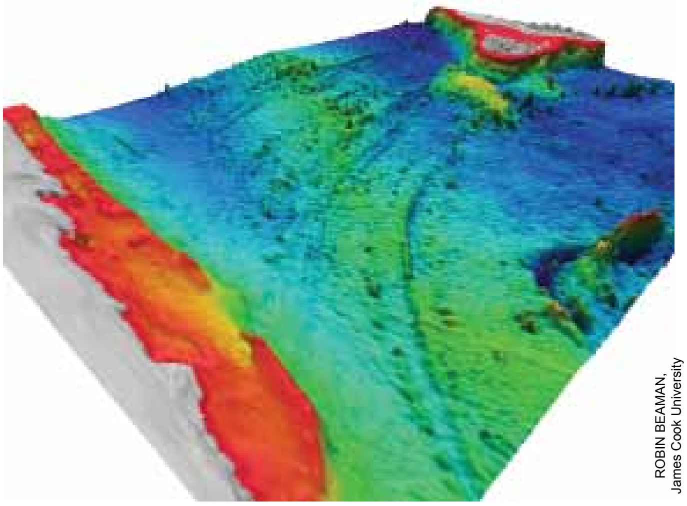
Key research questions

- How will a warming ocean affect floating ice shelves, ice tongues and sea ice around Antarctica?
- How will changes in ice melt and other processes affect ocean stability and the overturning circulation?

Overview

Changes to the high latitude ocean freshwater balance as a result of changes in sea ice, precipitation, or interaction between the ocean and ice shelf, as projected for a changing climate, may influence the strength of the global ocean overturning circulation. The overturning (or thermohaline) circulation is the dominant mechanism responsible for ocean heat transport and has a strong influence on global and regional climate patterns. There is a possibility that increased freshwater input to the high latitude ocean could cause a slowing of the thermohaline circulation, driving an abrupt change in climate.

The Southern Ocean plays a crucial role in the thermohaline circulation: the circumpolar flow of the Southern Ocean allows a global-scale circulation to exist; southern and northern sources of dense water make similar contributions to the ventilation of the deep ocean; and water mass transformations in the Southern Ocean connect the deep and shallow limbs of the overturning circulation. The Southern Ocean overturning circulation also plays a key role in the ocean carbon system. About 40% of the total ocean inventory of anthropogenic carbon dioxide is found south of 30°S, with carbon carried into the ocean interior by the upper limb of the overturning circulation and by the biological pump.



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James Cook University

Projects addressing this question need to focus on:

- ice shelf – ocean interaction – ice shelves, which are massive regions of glacial ice floating on the ocean, fringe 44% of the margins of the Antarctic continent and the basal melt processes couple them strongly to the ocean climate. This should include obtaining new bathymetric data over the Antarctic continental shelf at an accuracy adequate to determine how ocean water masses will mix and circulate over the shelf and carry extra heat to the base of the ice.
- sea ice formation in polynyas (localised regions of very high ice production and salt input to the underlying ocean).
- changes to precipitation and evaporation over the Southern Ocean.

Scientific approaches and required capabilities

- Improved understanding of ice shelf – ocean interaction and ice shelf evolution from oceanographic measurements adjacent to, and beneath ice shelves is required.
- Bathymetric mapping, including knowledge of the grounding line of ice shelves, together with measurements of ice shelf and cavity geometry, and melt and accretion rates at the shelf base can be achieved by drilling through ice shelves and suspending instruments in the cavity below.
- Moored instruments and satellite observations are required to monitor polynya processes and changes in ocean properties.

1.2.4 Southern Ocean biogeochemical processes in the climate system

Key research questions

- How do Southern Ocean biochemical and ecosystem processes feed back to the climate system?
- How will changes to these affect the rate of carbon dioxide uptake by the ocean?

Overview

The Southern Ocean absorbs about one sixth of our current annual emissions of carbon dioxide. This uptake will not continue at current rates if climate change reduces the rate of overturning circulation which moves atmospheric carbon dioxide into the deep ocean. The Southern Ocean is also the place where changes in biological processes have the greatest capacity to affect carbon dioxide uptake (e.g. in response to changes in sea ice cover, ocean warming and stratification) and supply of the limiting trace nutrient iron. Estimates of the ability of the Southern Ocean to draw down atmospheric carbon and of future changes in this draw down are crucially important for understanding and projecting future atmospheric carbon dioxide concentrations under various anthropogenic emissions scenarios. This understanding is required to guide global mitigation strategies.

Assessing the ability of Southern Ocean carbon pumps to continue contributing to the control of atmospheric carbon dioxide levels is a major uncertainty in assessing future global carbon budgets. This is particularly difficult because the response of the physical and biological pumps to climate change


WENDY PYPER


DOUG THOST

is likely to be different, but linked. Most of the uptake of anthropogenic carbon dioxide to date has been mediated by the physical pump, which responds directly to increasing atmospheric carbon dioxide. Biological pump responses are less clear and less direct, driven more by changes in climate and iron supply. A decline in the efficiency of the Southern Ocean uptake over the past few decades has been suggested on the basis of atmospheric observations and ocean models. However, observations of oceanic stratification are at odds with this view. *In situ* ocean observations of carbon dioxide concentrations, particularly to redress the paucity of winter observations, are required to determine the current and to project the future response of Southern Ocean uptake of carbon dioxide.

The uptake of carbon dioxide may itself influence future carbon dioxide air–sea exchange. First, uptake of carbon dioxide brings the ocean closer to equilibrium with the atmosphere, reducing the driving force for uptake. Second, the ocean acidification that accompanies carbon dioxide uptake reduces the extent of biogenic carbonate shell formation by many pelagic phytoplankton and zooplankton. Carbonate minerals are considered to be important in ballasting particle aggregates that transfer organic carbon to the deep ocean, and this may reduce the strength of the biological carbon pump. Measurements and process experiments examining these processes are needed.

There is also a need to address controls on the transfer of other gases between the ocean and atmosphere. This includes the transfer of oxygen into the ocean interior, which is expected to weaken in response to ocean stratification, leading to the expansion of suboxic regions, particularly in eastern boundary currents along the coasts of India, Africa and South America. These regions may then emit more reduced gases with significant greenhouse warming potential (e.g. methane and nitrous oxide) or gases that influence cloud formation (e.g. dimethyl sulphide (DMS)). In particular, methane emissions from subglacial and shelf margin environments may result from warming, and DMS emissions may increase in response to changes in phytoplankton and bacterial community compositions. The Southern Ocean is central to ventilation of the global ocean, so tracking and understanding these changes is especially important. Many of these gases can be measured in ice and snow cores, and understanding the conditions that control their formation and air-sea exchange may also allow better interpretation of past climate states.

Many of these feedbacks can be assessed from trace gas measurements and ecosystem studies. To detect changes early and unambiguously, the current network of atmospheric composition measurements will require upgrading. Continuous and exact monitoring of more gases and isotopes at more locations will take advantage of emerging technologies such as cavity ring down spectroscopy. But prediction of the future role of the Southern Ocean in biogeochemical feedbacks to climate change also requires understanding of how changes in atmospheric and ocean circulation will influence the delivery of iron, the limiting micronutrient that affects the magnitude and distribution of phytoplankton production. Iron delivery is expected to be modulated by a wide range of processes, including terrestrial aerosol production, wind variations, subglacial and sea ice melting, shelf productivity and iceberg ploughing of shelf sediments, hydrologic cycle changes and run-off from subantarctic islands.

Scientific approaches and required capabilities

- *In situ* ocean observations of carbon dioxide concentrations are required, particularly to address the paucity of winter observations. These, and observations that resolve the strong seasonal cycles in thermal and biological controls on air–sea gas exchange, will require use of autonomous systems such as buoys, profiling floats, and gliders with biogeochemical sensors.
- Continuous, precise monitoring technologies for atmospheric greenhouse gases and isotopes are becoming available for remote installations. Interpretation of the observed changes will be best achieved with atmospheric and ocean models, coupled to climate and biogeochemical processes.
- An integrated approach is required to estimate biogeochemical feedbacks to climate change.

1.3 Atmospheric processes and change

Stream goals

To improve understanding of teleconnections between Antarctic and Southern Ocean weather systems, to provide data for use in weather predictions and climate projections for Australia.

To understand the connections between ozone concentrations and characteristics of the polar vortex that will enable improved projections of the climate system response to ozone recovery, and particularly of changes to winds and storm frequencies at high southern latitudes.

To improve representation in numerical models of radiative, dynamical and chemical coupling processes throughout the atmosphere, focusing on energy and momentum transfer, chemical transport and links between regions and hemispheres.


GREG STONE

1.3.1 Characterising atmospheric processes, variability and change

Key research questions

- What are the patterns of variability and change at all levels in the high latitude Southern Hemisphere atmosphere?
- What are the processes which drive change and variability?

Overview

A better understanding is needed of the drivers of regional and hemispheric modes of climate variability such as the El Niño Southern Oscillation (ENSO), the Southern Annular Mode (SAM), and the Pacific Decadal Oscillation in our region. These are primarily associated with redistribution of energy in the lower atmosphere through the action of the hydrological cycle on meteorology and radiative contrasts between land, oceans and ice. The SAM variability also has components associated with atmospheric wave-driven dynamics and radiative coupling from the Antarctic ozone hole and tropospheric climate trends near Antarctica.

Enhanced emissions of greenhouse gases and ozone depleting substances resulting from human activity are significantly influencing climate. Whereas the global troposphere (0–10 kilometres) is radiatively warming, a near-global cooling of the stratosphere (10–50 kilometres) is occurring due to ozone depletion over Antarctica in spring, and increased radiative losses associated primarily with enhanced levels of stratospheric carbon dioxide. This stratospheric cooling is influencing circulation near the surface at high southern latitudes and thus mitigating greenhouse warming. It is expected that future ozone recovery will influence the future climate of the Southern Hemisphere, although the precise nature of this influence is still not clear. Attribution of climate response to restored ozone levels requires quantification of factors, including stratospheric temperatures and dynamical variability, trace gas transport, changes in chemical cycles, effects from the solar activity cycle and aerosols of tropospheric origin (e.g. from volcanoes and biomass burning). Research is required to develop a greater understanding of stratospheric changes due to increases in well mixed greenhouse gases, and possibly other causes. A particular focus should be on characteristics of the winter polar vortex and the structure of the upper troposphere lower stratosphere (UTLS) region, and the coupling between changes there and long-term ozone recovery and climate of the lower atmosphere.

The middle atmosphere (encompassing the stratosphere, mesosphere and lower thermosphere), particularly in the polar regions, is a natural laboratory for attributing anthropogenic change. Extreme physical conditions occur in the Antarctic and Arctic middle atmosphere, and these conditions lead to unique phenomena and processes that are sensitive indicators of the atmospheric state. There are significant differences between the northern and southern hemispheres, and interhemispheric coupling plays an additional role in interannual variability of

the stratosphere and mesosphere. Investigation of changes in the thermal and dynamical state of the Antarctic atmosphere over many seasonal cycles and several solar activity cycles are required to validate climate simulations and to separate out sources of natural variability from anthropogenic change.

Scientific approaches and required capabilities

- Physical measurements throughout the full depth of the Antarctic atmosphere are required.
- Measurements in the stratosphere and above should centre on the multi-instrument atmospheric laboratory capability at Davis, and partnerships with operators of similar facilities elsewhere in the Antarctic (and also in the Arctic).
- More emphasis is also required on high latitude tropospheric processes and on atmospheric chemistry (including chemistry–climate modelling).
- Monitoring programs should include observations of temperatures, winds, moisture, aerosols, ozone, and clouds from the surface to the mesopause. These will use disparate observational techniques such as satellites; automatic weather stations and drifting buoy networks; surface-based radar; and techniques for combining multiple stations.
- An extensive and freely available Australian Antarctic automatic weather station data set (extending back more than 20 years in some cases) can be used for studies of surface meteorological processes, and the existing mesosphere–stratosphere–troposphere (MST) radar facility at Davis could provide frequent and high vertical resolution tropospheric wind profiles.

1.3.2 Model development for weather and climate predictions

Key research questions

- What high latitude processes need to be better characterised to improve atmospheric models for weather and climate prediction?
- What atmospheric observations are required to better validate the next generation of models?

Overview

Antarctic and Southern Ocean research should include a focus on the application of observational and model-based studies to gain a better understanding of high latitude atmospheric processes and feedbacks. It should also focus on the resolution of global problems in modelling and on understanding our atmosphere. These are required to improve climate projections (and are also prerequisites for improved weather forecasting in support of high latitude operations). Better understanding, for example, is required of the evolution of Southern Hemisphere polar lows and their impacts on weather and climate; of processes and variability of Southern Hemisphere frontogenesis and frontal activity; of cloud and aerosol parameterisation in models; and on the impact of the Antarctic continent on Southern Hemisphere meteorology. On the local scale, ice–atmosphere interaction is influenced by the unique Antarctic boundary layer and investigation of near-surface turbulent processes, surface energy exchanges and katabatic wind processes will contribute to the larger picture.

A whole-of-atmosphere approach is needed to answer key questions. For example, the UTLS region (typically 6–15 kilometres height) is of importance to feedbacks and impacts of climate change at polar latitudes. It is a highly coupled atmospheric region that is influenced by interactions between radiation, dynamics, chemistry and microphysics. Ozone and water vapour are the most significant greenhouse gases in the UTLS, and are controlled by stratosphere–troposphere exchange, and by chemical processes associated with multiphase chemistry and cloud microphysics.

Atmospheric waves are another key dynamical driver of large-scale circulations and are significant in defining the thermal state of the atmosphere. They include gravity waves, tides and planetary waves and they manifest themselves on different horizontal and temporal scales. Atmospheric waves control long-range energy and momentum transfers which affect radiative and chemical processes in the atmosphere. Their correct representation in global computer models is critical for accurate predictions under changing conditions. The prime source of gravity waves is in the lower atmosphere from whence they propagate upward through an environment set by circulations and other waves. Investigations of the life cycle of gravity waves are needed but, because of their small horizontal scale, they present significant observational and modelling challenges.

JOEL PEDRO

Scientific approaches and required capabilities

- There needs to be a focus on observations that will contribute to improved representations of key atmospheric processes in models.
- Stronger links between the Antarctic atmospheric research community and the Australian and international climate modelling and weather prediction communities need to be developed to improve the resolution of high latitude processes in climate models.

1.4 Antarctic palaeoclimate

Stream goals

To produce high resolution reconstructions of East Antarctic climate and climate forcings over the last 2000 years, and Southern Hemisphere and global climate reconstructions over the last 2000 years from collaborative synthesis products.

To better understand and quantify links between high latitude climate and Australian climate, and improve our ability to define long-term variability for key climate variables (e.g. ENSO, SAM, regional rainfall and temperature).

To improve synchronisation and understanding of coupling of hemispheric climate and the role of abrupt changes in the global climate system.

To examine long-term ice and sediment records that cover key periods of climatic variation, particularly the last 1.4 million years.

1.4.1 Palaeo records of Southern Hemisphere climate variability and teleconnections

Key research question

- What does the high resolution, well dated climate record from Antarctica show over recent millennia?

Overview

Reconstructions of past climate that provide data on variability and change are needed to assess current climate change and better manage adaptation measures. High resolution ice core and other proxy records are needed to characterise natural climate variability and forcings and to provide a baseline against which anthropogenic change can be assessed. The records will better define the role in the region of natural variability and processes like the SAM and ENSO over the longer term. These new records of past climate will help address shortcomings noted by IPCC regarding data sparsity for the Southern Hemisphere. They will need to be well enough dated so that they can be synthesised into regional reconstructions and compared to models.

There are connections between Australian and high latitude climate, and highly detailed ice core records covering recent centuries to millennia will provide information on these. These records need to be combined with other proxy climate and meteorological data to reconstruct past climate parameters. They will also help to address questions about the extent of observed changes in Australian climate. Well controlled

climate reconstructions will provide information on past sea ice and ice sheet extent and on volcanic, solar climate and greenhouse gas forcings.

Scientific approaches and required capabilities

- Recovery of short to medium length ice cores in single-season campaigns from locations in East Antarctica that provide well dated (annually resolved) records at spatial density required for reconstructing climatological patterns and regional climate variability is needed. These locations are typically separated by hundreds of kilometres and concentrated toward the coastal region where snow accumulation is higher. However, cores from further inland at the limit where accumulation rates allow for good dating (such as Aurora Basin) are currently not available.
- The Holocene provides information to test model simulations of climate forcings and atmospheric feedbacks that are likely to occur in the future. Well resolved and high quality ice core sites are known in the AAT.
- Construction of records requires ice core analytical facilities. Base capability exists nationally and collaborative links provide access to an expanded range of techniques. Maintenance of local capability to undertake targeted drilling and analyses to provide key data streams underpins the collaborative reach and provides a basis for future collaborative access to larger international projects.
- Process studies at sites with special properties (e.g. the high accumulation Law Dome 'laboratory') allow detailed comparison of ultra high resolution parameters with meteorological and model data sets. This provides calibration and process understanding that can be extrapolated to other sites and could lead to more robust proxies. For example, continuous field measurement of atmospheric water vapour isotopes now looks feasible and could allow improved calibration of the ice core isotopic thermometer.
- Ice core records are integrated into networks within the framework of established large international efforts to gain continental-scale reconstructions. This requires active exchanges of data sets, field and analysis expertise.

1.4.2 Processes of climate evolution

Key research questions

- What changes have occurred in Antarctic and Southern Hemisphere climate on glacial-interglacial timescales and what are the forcings and feedbacks responsible?
- What are the processes that link hemispheric climate variations, especially during periods of abrupt climate change?

Overview

Ice core records provide a window into previous periods when climate was changing rapidly and climate forcings were significantly different from the pre-industrial or present. The program has characterised sites that could provide ice cores which provide evidence of past abrupt change, and which have better age resolution than existing Antarctic ice core records. During the last glacial period, when the northern hemisphere was punctuated with abrupt millennial-scale changes, the Antarctic response was quite different, albeit clearly coupled. Long-term palaeo records will provide better constraints on climate sensitivity and a test for models across a broader range of forcing conditions.

There is currently insufficient knowledge of the climate system to allow models to reproduce past glacial cycles from orbital inputs alone. Very old ice cores could provide the answer to a key puzzle: why glacial-


MIKE CRAVEN

interglacial cycles occurred with 41 thousand year periodicity prior to one million years ago and gradually shifted to a strong 100 thousand year periodicity for most of the last million years. Currently the longest ice core records extend to around 800 thousand years, but if ice over a million years can be drilled, this will help assess the role that carbon dioxide feedback played in this shift. This is relevant to understanding whether the current human-driven rise in carbon dioxide beyond past interglacial levels will drive the earth system into another semi-stable state that does not involve glacial advances and retreats. If it is established that sufficiently old ice exists in Antarctica to study this transition, it is almost certain to be within the AAT.

Changes in greenhouse gases through the Holocene are evidence of natural feedbacks between climate and atmospheric composition. Suggested causes of these changes include biomass burning, high latitude ocean dynamics, and changes in the terrestrial ecosystems. The extent to which these feedbacks will operate in the future is a large source of uncertainty in climate model predictions. Well resolved ice core material is available through this period at several sites in the AAT that will improve our understanding of how the feedbacks operate so that they can be represented in coupled carbon-climate models.

Ocean sediment cores are a primary source of information on how the Southern Ocean responds and drives climate and biogeochemical cycles. Geophysical data and deep drilling suggest that major regime changes have taken place around the Antarctic margin. Similarly, geological research around the continent has identified areas where there has been negligible change to ice configuration in the last five million years, and other places where major fluctuations have taken place even up to the Last Glacial Maximum. The Antarctic ice sheets do not behave uniformly and have variable sensitivity to sea level rise and warming, which adds uncertainty to projections of the future contribution of Antarctica to sea level change. Existing ocean sediment cores in the Australian and international archive can be further exploited by development of new techniques to derive additional information. In particular, high resolution cores could provide further insight into marine biological responses to past climate changes and oceanic processes such as sea ice changes and carbon uptake and release. Integration of these data with complementary data from ice core records gives a broader understanding of the linkages and feedbacks in the cryospheric system.

Onshore outcrops and the sea floor in and around

Antarctica provide additional insights into the history of the ice sheet margins. Further work on these records will provide a history of ice margin changes for the AAT.

Scientific approaches and required capabilities

- Long-term climate records from existing ice cores and marine sediment records provide a resource to investigate larger climate shifts on glacial timescales. The high precision with which the Law Dome deep core can be synchronised to Northern Hemisphere ice cores and West Antarctic records is a tool for ongoing investigation of changes well into the last glacial period.
- For investigations beyond the last glacial, deeper inland drilling projects are under international consideration. A deep ice core taken from a moderate accumulation site inland (e.g. Aurora Basin) could provide the best Antarctic record of the last interglacial period for comparison with the longest Greenland ice core records. A deep ice core taken from a low accumulation site could yield a record up to 1.3 million years. Logistical capability, drilling expertise and ice core analysis capabilities in Australia could be used as a basis for collaborative partnership in such deep drilling.
- The measurement of air composition in ice bubbles is a key capability for analysis of cores. This has been done in the past by CSIRO and also with overseas collaboration. High frequency measurements of methane concentrations can be used for dating of deep ice cores and would benefit from the development of field-deployable techniques that are emerging with cavity ring down systems.
- There are also potential drilling targets within the AAT to obtain sediment records that complement ice core records. Australia does not have deep ocean drilling capability so engagement with the Integrated Ocean Drilling Program, ANDRILL or the US Shaldrill programs is needed.

Terrestrial and Nearshore Ecosystems: Environmental Change and Conservation

Theme goal

To investigate the effects of environmental change, caused by local and global processes, on key Antarctic and subantarctic terrestrial and coastal[7] ecosystems and provide the scientific basis to guide enhanced environmental protection for these ecosystems.

Key expected outcomes for this theme will be:

- identification of key ecosystem sensitivities and vulnerabilities to environmental stressors
- identification of signals of ecosystem change caused by human pressures, both from local activities and from global processes
- scientific foundation for a system of spatial management and area protection that takes into account the particular characteristics of Antarctica
- scientific and technical foundation for practical measures to prevent, mitigate or remediate detrimental change caused by human activity.

The theme will support regional observation systems collecting priority data on terrestrial and nearshore ecosystems; undertake targeted process studies; provide environmental management advice; publish technical papers, reviews and background papers in the international peer reviewed literature; and conduct briefings on findings to key government and public stakeholders. Theme research will target key areas identified within the Committee for Environmental Protection (CEP) and the Intergovernmental Panel on Climate Change (IPCC) assessment reports.

7. Coastal in the context of this plan is the marine area extending from the coast to a depth of 200 metres

The work of the theme will be organised into three streams:

2.1 Trends and sensitivity to change

2.2 Vulnerability and spatial protection

2.3 Human impacts: prevention, mitigation and remediation.

Background

Antarctica's natural values, including its biodiversity, geology and landscapes and the ecosystem processes that link the living and non-living elements of the environment all contribute to making it a special place. Many Antarctic species are of iconic status, there are very high levels of endemism and many geological features are globally rare or unique to the region. These natural environmental values and the associated scientific values are the reasons why Antarctica has been accorded special status internationally; they are also among the least well understood in the world.

Geographic areas of interest for research coincide with those of the CEP, namely the Antarctic continent, particularly ice-free land, lakes and coastal marine waters, and Australia's subantarctic islands.

Research under this theme is focused on identifying the ecosystem effects of global change and providing support for environmental management and protection in Australia's Antarctic and subantarctic areas of interest. Applied environmental research, designed to support environmental management of the human presence in Antarctica, has been a core component of the program since the early 1990s when Australia established the world's first dedicated Antarctic human impacts research program, and will continue to be so in the foreseeable future. The research contributes to Australia's commitment to comprehensive environmental protection under the Madrid Protocol and to fulfilling its obligations under other international agreements, national legislation and government initiatives and policies.

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The Antarctic environment is subject to human pressures at global, regional and local scales. Despite its geographic isolation, the connection between the Antarctic and other regions via atmospheric and oceanic circulation means that human activities outside the Antarctic region are affecting the Antarctic environment through processes such as climate change, ocean acidification, ozone depletion and atmospheric transport of persistent organic pollutants. Regionally, harvesting of marine living resources and the human introduction of non-native species has the potential for the most significant impacts. Local scale impacts include habitat destruction, contamination and disturbance through the conduct and support of national Antarctic research program activities, and through tourism.

The program has carried out ground-breaking environmental research in several key areas, leading to practical mitigation and remediation strategies. Rigorous experimental studies of disturbance to Antarctic wildlife from visitors, vehicles and aircraft have been used as the basis for guidelines for minimising disturbance. Experimental studies of incursion pathways and survivability have been included in systematic risk assessments of introduced non-native species, including plant propagules, marine fouling and microbial pathogens, and used as the basis for protocols to reduce risks and develop response plans. Ecological risk assessment has been used to prioritise contaminated site clean-up and remediation, and technologies developed for excavation, remediation and site stabilisation under freeze–thaw conditions experienced in Antarctica.

Many of the approaches initiated by Australia have been adopted by other countries for their national Antarctic programs and for use in the Arctic. Australia has also contributed significantly to international programs of longer-term foundation research designed to provide the theoretical basis for sound environmental management in the region, such as the Scientific Committee on Antarctic Research (SCAR) Regional Sensitivity to Climate Change program, which focused on climate sensitive aspects of Antarctic and subantarctic terrestrial and lake ecosystems and their implications for management.

Research in the program will continue to build the foundations for understanding the environment, particularly focusing on the special features of the region. This will be used as the basis for environmental risk and vulnerability assessments, for the development of mitigation strategies and remediation procedures, and for environmental targets and guidelines specific to the Antarctic and subantarctic region. The approach aims to both identify and resolve environmental problems.

The Terrestrial and Nearshore Ecosystems: Environmental Change and Conservation theme will also focus on the implications of climate change to governance and management of the Antarctic and identification of climate change effects on highly sensitive components of ecosystems. These may be important as sentinels providing early indications of ecosystem responses to change in both the Antarctic and in other parts of the world. Building the projections of climate change into Antarctic environment management is now recognised as an international priority bringing new scientific challenges.

It is clear that in meeting these challenges we will need to confine our efforts to a subset of the systems within the AAT and subantarctic islands. It is simply not feasible to cover all of them. In making these choices, we will be guided by Australian Government policy priorities and research community views, the latter an outcome of stream workshops to be held in the early stages of this decadal program. Theme and stream leaders will work closely with SCAR and other national programs to ensure that our initiatives and research fit well within the broader frameworks and context.


NATHAN SAUNDERS

Key policy drivers and questions

The Terrestrial and Nearshore Ecosystems: Environmental Change and Conservation theme focuses on research that contributes to protecting the Antarctic environment by supporting governance of the AAT, supporting Australia's policy positions at the Antarctic Treaty meetings, principally the CEP, and supporting international initiatives to better protect the Antarctic environment.

The Madrid Protocol provides a framework for comprehensive protection of living and non-living components of the Antarctic environment. Among other things, the Protocol creates an obligation to remediate environmental impacts from past activities; sets standards for ongoing activities which have the potential to create impacts, such as fuel handling and waste management; establishes procedures for the assessment of environmental impacts of planned activities; and sets requirements for preventing and dealing with environmental emergencies arising from activities in the Antarctic Treaty area. It also creates the framework for a comprehensive system of protected areas to ensure the full range of environmental values of Antarctica is protected.

It is Australian Government policy to maintain the Antarctic Treaty and its instruments as the primary regulatory mechanism for the Antarctic continent. Other international agreements to which Australia is a party, such as the Convention on Biological Diversity and World Heritage listings, apply directly to our subantarctic territories (Heard, McDonald and Macquarie islands).

Protection of these subantarctic islands lies exclusively within the jurisdiction of Australian Government agencies and the Tasmanian Government; as such their management must be consistent with Australian state and Commonwealth governance frameworks and supporting research must be prioritised accordingly.

The management plans for these areas include prescribed research and monitoring.

Science in support of environmental protection operates on two major time scales. In the short term, highly focused tactical research is required that addresses current pressing and emerging environmental threats; in the longer term, strategic and fundamental research is required to establish a sound information base to prepare environmental management in the region for a future which becomes increasingly more uncertain as we look further ahead. Immediate priorities for environmental research derive primarily from the CEP and the needs of the AAD as administrator of the AAT and the territories of Heard Island and McDonald Islands (HIMI). Priorities for longer term strategic and fundamental research reflect and contribute to Australia's broader research needs as articulated in the national research priorities.

Until recently the CEP has focused on addressing impacts arising from activities occurring within the Antarctic region; however the implications of global pressures such as climate change for governance of Antarctica are now recognised as an important emerging topic. Australia was instrumental in the CEP discussions that established current priorities, but, while seeking to ensure progress on them all, will tailor the nature and level of engagement on the basis of various factors including our geographic areas of interest, capabilities and national priorities. Additionally, we need not restrict our efforts to these collective priorities. For example, management of contaminated sites may not be a high priority for the other Treaty Parties, but is a field in which Australia has significant expertise and can provide leadership by developing and sharing site remediation technologies tuned for Antarctic conditions.

Science streams

2.1 Trends and sensitivity to change

Stream goal

To identify, track, attribute and predict ecosystem change as the basis for vulnerability assessments and adaptive management, and to provide sentinels of more widespread change in both the Antarctic and other parts of the world.

Key research questions

- Are changes occurring in Antarctic and subantarctic terrestrial and nearshore ecosystems that are attributable to global change?
- What are the key drivers and pathways of climate change impacts on Antarctic and subantarctic ecosystems?
- Which species, processes and/or systems are suitable for tracking the impacts of environmental change?
- What are the sensitivities of Antarctic and subantarctic biodiversity to environmental stressors and are there critical thresholds that would give rise to irreversible impacts?
- How has the biodiversity of Antarctic and subantarctic terrestrial and nearshore areas changed in the past and how can this help us predict future change in a changing world?

Overview

Antarctica and the subantarctic islands are currently undergoing measurable climate change; for example, the Antarctic Peninsula has experienced climatic warming greater than any other region on the planet. For a variety of physical, chemical and ecological reasons, some critical thresholds will be crossed first in polar regions. Thus, these regions have the potential to provide early warning of ecosystem impacts of climate change that may have implications well beyond the boundaries of Antarctica and the Southern Ocean. Understanding the likely trajectory of change is also essential for ensuring that environmental management measures for the region are designed to accommodate a changing environment. Changes to Antarctic ecosystems have already been attributed to climatic changes, most dramatically on glaciated subantarctic islands, such as Heard Island, where retreating glaciers are exposing new habitat, but the signs of change are also apparent elsewhere in the region. Antarctic terrestrial, lake and coastal marine ecosystems are likely to be particularly sensitive to climate change because they are closely coupled to climate and temperature-sensitive environmental processes such as insolation, snow and ice cover, precipitation, wind, drainage, soil compaction and erosion. They are also vulnerable to impacts from local activities (such as habitat loss, physical disturbance and locally sourced contamination), introduced non-native species and globally transported persistent pollutants, and are likely to show synergistic responses to multiple stressors. Because they are simple systems with few trophic links and limited functional redundancy, they are likely to have low capacity to resist change.

The only reliable way to test predictions of further ecosystem impacts in response to global change is to commit to a sustained effort of integrated observing of Antarctic terrestrial and nearshore biodiversity and ecosystem processes following the lead of the Southern Ocean Observing System and Australia’s Integrated Marine Observing System. Australian facilities in East Antarctic and subantarctic ecosystems are strategically located for determining whether changes being observed in the Antarctic Peninsula region are within the bounds of natural variability and can also provide important ‘longitudinal replication’ (at around 65–67°S) for internationally coordinated studies, testing the

hypothesis that the north–south gradient can be used as a proxy for future climate change.

Examples of ecosystems that would be valuable to include in a network of long-term observing sites designed to identify functional and structural ecosystem change include:

- The moss beds at Casey are among the best examples of terrestrial vegetation in Antarctica, and are highly sensitive to water availability, which itself is very climate sensitive.
- The nearshore marine environment at Casey is an ideal location for studying the effects of sea ice on coastal marine communities because within a few kilometres sea ice duration changes from less than two months per year to more than 10 months per year.
- The lakes of the Vestfold Hills, accessible from Davis, represent the most extensive range of lake types within a small area in Antarctica, and their ecosystems are intrinsically linked to climate-sensitive processes in their catchments and the overlying ice.
- Australia's subantarctic islands, Macquarie and Heard Islands, are in a zone of rapid environmental change and are each located in different positions relative to the climatically important ocean frontal systems.

The history of change in the Antarctic environment and how this has affected Antarctic biodiversity provides important clues to its ability to withstand future environmental change. The dating of exposures, genetic divergence and speciation and the ageing of key structural species can be used to better understand how long, in geological timeframes, the extant communities have had to colonise habitats and how long, in biological timeframes, individual species need to establish and grow. Together this will provide important information on the potential to adapt to long-term environmental changes and, over shorter periods, recovery times after transient disturbances.

Recent syntheses of Antarctic terrestrial biodiversity are beginning to question the established paradigm that ice cover during past glacial maxima left no refugia and resulted in almost complete extinctions followed by extensive recolonisation after the polar ice cap retreated. Sampling at carefully selected locations across East Antarctica and targeting potential refugia is expected to contribute significantly to understanding how the current terrestrial biota has evolved from that of the past, and in turn how it may respond to future environmental change.

Scientific approaches and required capabilities

- A fundamental requirement is accurate species identification and an understanding of gene expression and functionality, therefore conventional taxonomic expertise is needed in combination with molecular genomic techniques, including single species, whole community (metagenomics) and functional approaches (transcriptomics and proteomics).
- Development of an integrated observing system of key environmental parameters and ecosystem processes at locations that allow for sustained repeat measurements is needed to identify change against a background of natural variability.
- Experimental and field process studies are needed to understand the response of key Antarctic and subantarctic species to changes and extreme events in environmental conditions (e.g. temperature, wind/current speed, water availability, salinity, substratum (e.g. soil/permafrost or sand/silt), snow cover, dissolved/atmospheric carbon dioxide, and solar radiation, including UV), with an emphasis on determining critical thresholds.

In addition, modelling, data visualisation and synthesis of the environmental parameters and species thresholds will assist in making predictions of future change.

- Information on trophic pathways (e.g. stable isotope analysis) is also needed as the basis for prediction and modelling of downstream ecosystem vulnerability and also for tracing the accumulation of globally transported persistent pollutants.

2.2 Vulnerability and spatial protection

Stream goal

To provide the scientific foundation for spatial management and area protection in East Antarctica that takes into account the special characteristics of biodiversity and geodiversity, and the landscape and ecosystem processes that influence their vulnerability.

Key research questions

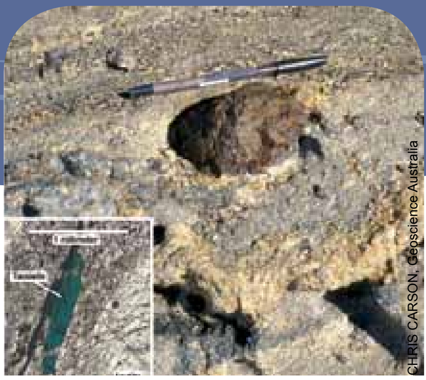
- How do spatial patterns and landscape influence vulnerability of the biodiversity of Antarctica and how must they be accommodated in spatial planning?
- How do we select areas to include in the series of Antarctic Specially Protected Areas (ASPAs)?
- How should the non-living values of Antarctica be included in spatial planning and area protection?

Overview

The Madrid Protocol requires the systematic identification of areas to be designated as ASPAs to protect outstanding natural values. The Protocol lists the range of values that might warrant protection, including biodiversity, geology, ecosystems and landscapes, but gives little guidance on criteria for inclusion, or what factors to consider when deciding on the appropriate size for protected areas. The principles for spatial planning developed for other parts of the world may be appropriate for the Antarctic but they will need fine tuning to accommodate the special characteristics of the region.

Factors such as uniqueness or rarity, special importance for life history stages, vulnerability, fragility, sensitivity or slow recovery are all used as criteria for identifying areas for special protection in other places. It is currently not possible to use these criteria in Antarctica because, despite more than 100 years of human activity in the region, scientific records (biodiversity, geology etc) are available for only a tiny fraction of the land and surrounding waters. East Antarctica in particular was recently singled out for special mention in an international review of the biodiversity of Antarctica by SCAR because the biodiversity of the region is so poorly documented; a recent report identified East Antarctica as the largest under-sampled region of continental shelf around Antarctica. Because of this information gap, secure protection through informed spatial management is not yet possible. Under the precautionary principle, spatial management should not be delayed by the absence of information; however, using a strategy of adaptive management, additional information should be used to strengthen and improve protective measures.

To date, most ASPAs have been designated to protect biodiversity values, with only a few established to protect natural non living values such as geological, glaciological or geomorphological features or non material values recognised as having standing (i.e. wilderness, aesthetic, intrinsic values). Research is needed on the geological processes and characteristics that influence conservation values and vulnerability of Antarctic landscapes and geological features. Research should focus on landscape stability and vulnerability to disturbance including rarity, fragility, sensitivity and ability to recover after disturbance. Methods are needed for predicting



the distribution of rare or high value features (e.g. mineralogy, fossil content, meteorites).

The lakes, ice-free land and coastal marine areas of East Antarctica and the subantarctic are among the most highly fragmented ecosystems on the planet; they have very high levels of habitat and community heterogeneity, and are among the least well documented of ecosystems. Few Antarctic lakes are interconnected, with most being isolated within their catchments on islands of ice-free land. In East Antarctica, patches of ice-free land may be separated by many hundreds of kilometres. This physical separation has important implications for connectivity and gene flow between populations, and creates the likelihood of genetically distinct populations. To ensure protection of the full range of genetic diversity, it is essential that landscape-scale factors which contribute to genetic separation are considered in spatial planning.

The ice-dominated environment of the Antarctic has several key habitat controlling processes that are additional to the processes found in other regions. On large spatial and long temporal scales these include the emergence of continental shelf and ice-free outcrops after periods of ice cap retreat following glacial maxima, exposure of seabed after retreat of ice shelves and changes in annual sea ice extent. On more local scales and more recent time scales they include disturbance by iceberg scour, seabed hypoxia caused by brine accumulations and the seasonal cycles of snow deposition and loss on land, and sea ice advance and retreat. On the smallest scales, patterns of frost heave caused by freeze–thaw on land and ice-rafted drop stones in the sea all create localised habitat patchiness by processes unique to ice-dominated environments. Important scales of habitat heterogeneity must be accommodated in any spatial planning scheme.

Scientific approaches and required capabilities

- Integration of existing data to identify predominant scales of geology, biodiversity, habitat patchiness and connectedness using spatial analysis and modelling tools, such as GIS is needed as a starting point for determining what effects these processes might have on susceptibility and resilience of Antarctic ecosystems. It will also indicate significant data gaps that should inform the prioritisation and planning of any future field surveys.
- Techniques are required to document landscape variability (e.g. geological analysis of sediment cores, seabed mapping using multibeam echo-sounders, satellite data of land and sea ice coverage) and to link these environmental drivers to measures of biodiversity as the basis for predictive models and potentially the identification of environmental proxies so that rapid survey techniques can be developed.
- Conventional taxonomic techniques are required, together with molecular genetic techniques including metagenomics, to better understand whole-of-system biodiversity, and phylogenetics to understand relationships between populations. These, together with spatially structured sampling techniques, will be needed to allow detailed analysis of phylogenetic relationships.
- Understanding key scales of temporal variability in biodiversity requires a range of geological (isotopic dating) and genetic techniques (population and molecular) to augment conventional survey. Together this information can be used to develop models to explain the current distribution of the biodiversity of East Antarctica and to inform predictions of how it might change in a changing world.

2.3 Human impacts: prevention, mitigation and remediation

Stream goals

To provide the scientific basis for procedures, technologies and environmental guidelines to reduce environmental impacts that would be applicable for all Antarctic Treaty Parties.

To finalise research in support of remediation of all high priority contaminated sites for which Australia is responsible. These sites will be prioritised on the basis of ecological risk assessment, including factors such as nature of contamination, mobility and off-site migration, and vulnerability of the receiving environment.

To produce a synthesis of human impacts research and mitigation in support of environmental protection in Antarctica based on developments over the 20 years since the Protocol was agreed. This synthesis will provide a benchmark for future research, will reduce the chance of unnecessary duplication and will result in more cost-effective environmental management by bringing together information from the many disciplines that have contributed to Antarctic human impacts research in a single, accessible volume.

Key research questions

- What management technologies could be used to achieve zero waste discharge at Antarctic stations?
- What technologies are practical and effective for the containment or remediation of contaminated sites (e.g. tip sites, fuel spills) in cold climates?
- What are appropriate risk assessment, mitigation and remediation guidelines for the various pressures facing Antarctic and subantarctic terrestrial and marine environments, including contaminants, introduced non-native species and intra-site transfer of native species?
- What are the likelihood, immediacy and severity of potential and emerging environmental threats?

Overview

Observing change and understanding ecosystem vulnerabilities are important foundations for environmental protection but ultimately, benefits to the environment come only from specific actions to prevent, mitigate or remediate impacts. Conditions in the Antarctic are very different from those elsewhere – it is therefore not surprising that many well established environmental management procedures and technologies do not transfer easily to polar regions. Physical conditions, such as low temperatures, limited available water, regular freeze–thaw, highly seasonal daylight hours and frequent strong winds mean that procedures which are routine in other places may be difficult or ineffective in the Antarctic. Challenges also include the human dimension such as remoteness, seasonal access, a very limited labour force and harsh working conditions.

The weight-of-evidence approach to ecological risk assessment, bringing together multiple lines of evidence and taking into account the strengths and weaknesses of each and their level of uncertainty, is the basis for regulatory frameworks used in Australia and in the Arctic. Lines of evidence include sensitivity of species, populations and assemblages, characteristics of the stressors and the nature of the environment. This information is currently not available for the Antarctic region.

Technologies for waste management on Antarctic stations have developed little since comprehensive protection of the Antarctic environment was internationally agreed in the early 1990s. Developing and using technologies that move our operations in the direction of zero discharges is a very direct and

practical way to reduce environmental impacts of our presence in Antarctica. The discharge of secondary treated sewage effluent to the sea stands out as being the one activity permitted by international agreement knowing that it results in the introduction to the Antarctic environment of very large numbers of non-native microorganisms, including potential pathogens.

Past practices of waste disposal to open tips has left a legacy of contaminated sites in the vicinity of most of the older established research stations in Antarctica. Open disposal of waste is no longer permitted but accidental spills of fuel and oil still occur. Together these sources have created somewhere between one and 10 million cubic metres of contaminated material in Antarctica. Because of the limitations imposed by shipping, it is not practical to remove all such waste for disposal in the countries of origin, and indeed, removal of native soils, which are a rare commodity in parts of Antarctica, may not be the best environmental solution. Containment and remediation of contaminants on site offers the promise of cost-effective solutions but requires the development of techniques that work under Antarctic conditions.

The introduction of non-native species is internationally recognised as a very high-priority environmental issue associated with human activity on the Antarctic continent and on subantarctic islands. The risk of non-native introductions will increase with increasing numbers of visitors, and the risk of establishment is likely to rise if climate change causes the region to warm and increases water availability on land.

Prevention, mitigation and remediation technologies have the potential to address both local and global environmental issues. Impacts caused by local activities are clearly the responsibility of the Antarctic community, whether they are scientists and support people involved in national programs, tourism operators or the CEP or Antarctic Treaty Consultative Meeting (ATCM). The causes of these impacts must be recognised and managed by those involved. The impacts of global change, however, are a wider responsibility. Antarctic environmental managers must accommodate global change impacts in their approaches to management and to some degree may be able to mitigate impacts and reduce the carbon footprint of their operations, but in general it is not within their power to prevent anthropogenic global change.

Scientific approaches and required capabilities

- Development of suitable analytical and experimental methods to determine threshold sensitivities of Antarctic species and ecosystem processes to environmental stressors, together with measurement of contaminant levels and behaviour in the environment (from fugacity and fate modelling and prediction) will be needed to develop site-specific ecological risk assessment guidelines and trigger values for prioritising remediation efforts.
- On-site treatment of contaminated sites, sewage and waste water treatment that address the main environmental risks associated with effluent discharge may require development of novel technologies, based on experimental evidence.
- Procedures need to be developed to reduce the chance of unintentional introductions of non-native species, together with monitoring surveys to detect new colonisers and provide a scientific basis for appropriate management options.
- Social, political and economic studies of the changing pressures on the Antarctic environment are required to identify and predict the most significant threats.

3 Southern Ocean Ecosystems: Environmental Change and Conservation

Theme goal

To conduct the scientific research necessary for understanding the impact of global change on Southern Ocean ecosystems, the effective conservation of Antarctic and Southern Ocean wildlife and the sustainable, ecosystem-based management of Southern Ocean fisheries.

Key expected outcomes for this theme will be:

- significantly improved understanding of the impacts of ocean acidification on selected biota and ecosystems of the Southern Ocean, including assessment of their resilience to predicted change scenarios
- identification of sensitive marine indicator species or systems for tracking and understanding the impacts of environmental change
- assessment of the risks of global change impacts on Southern Ocean ecosystems and species of high conservation or fisheries value, including evaluation of the probability of different food web structures arising under predicted changes in the ocean and sea ice systems
- better knowledge about the status and trends of important Antarctic wildlife populations (whales, seals and seabirds), leading to improved conservation planning and management measures
- improved scientific information for fisheries managers (including improved mitigation strategies to reduce bycatch) and integration of fisheries data into ecosystem models to assist in management decisions
- the design of a comprehensive, adequate and representative network of spatial management areas, including marine protected areas (MPAs) in the Southern Ocean (and within the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) Area), particularly focusing on the marine biodiversity in the waters off East Antarctica.

The health and conservation of Southern Ocean ecosystems is important to a number of international treaty bodies and inter-governmental initiatives, including CCAMLR, the International Whaling Commission (IWC), Agreement on the Conservation of Albatrosses and Petrels (ACAP), and the Intergovernmental Panel on Climate Change (IPCC). This theme seeks to address strategic needs identified by these peak bodies, with particular emphasis on addressing those that meet identified national priorities.

The work of the theme will be organised into four streams:

3.1 Marine ecosystem change

3.2 Wildlife conservation

3.3 Southern Ocean fisheries

3.4 Protecting marine biodiversity.


DAVID LAMBERT

Background

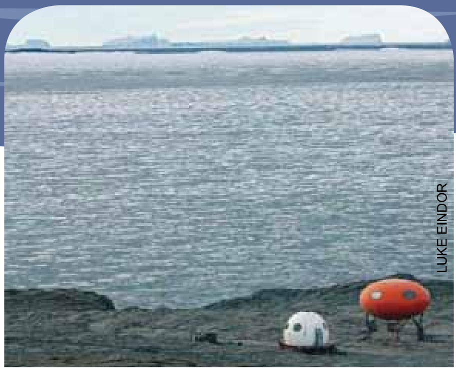
Australian research has made substantial contributions to understanding many elements of the marine ecosystems in the Southern Ocean and to the ecosystem-based management of the Antarctic region. These contributions include sustained multidisciplinary research into the ecosystem structure and function of the waters of the Southern Ocean, long-term monitoring of selected elements of the ecosystem, development of novel techniques to study ecosystem processes, significant contributions to the sustainable management of the fisheries of the Southern Ocean and research into reducing the incidental effects of fishing. These significant outputs and a wealth of highly cited publications in the international peer reviewed literature have contributed to Australia's position of influence within key international organisations. Continuation of this effort to address key conservation issues is needed.

There are a number of serious conservation issues that are likely to affect the marine ecosystems of Antarctica over the next 20 years. These result from changes in the physical, chemical and biological environment of the Southern Ocean, from past exploitation activities, from current or future fisheries, and from complex interactions between these factors. The scientific, management and policy implications of these issues are surrounded by considerable uncertainty and will require prioritised research over the next decade in order to improve our ability to understand and predict ecosystem change and its consequences and to inform management options and decisions.

Understanding and protecting the Antarctic environment, including that of the Southern Ocean, has been a major driver of research in the program for over 30 years. During the last decade, threats to the world's marine ecosystems have continued to escalate. These threats are primarily from anthropogenic changes to the physical, chemical and biological processes of the oceans and atmosphere and from increasing and unsustainable demand for protein from fisheries. Climate change and ocean acidification are likely to affect the structure and function of Antarctic marine ecosystems with implications for the Southern Ocean ecosystem's role in the global carbon cycle, for the conservation of threatened and depleted species and for the sustainable exploitation of fisheries.

Over the life of this plan the world's population will increase by approximately one billion people (UN figures). The requirements of this population for food will be exacerbated by the simultaneous decline of most of the world's largest fisheries. The increased demand for protein will put extreme pressure on the ocean's remaining marine stocks, some of which reside in the Southern Ocean, and thus fisheries-related conservation issues are likely to remain at the forefront of Antarctic research priorities. Over the same period, populations of several highly depleted species of whales and seals will show further evidence of recovery and their increasing populations will begin to exert ecological influences on both marine and terrestrial ecosystems. These ecological interactions will be occurring during a period of unparalleled physical and chemical change in the oceans and atmosphere and this altered environment will particularly affect the base of the food chain on which the entire ecosystem is dependent. It will be a challenging but essential task to understand better the combined effects of a highly dynamic environment on the region's ecosystems and to enable decision makers to manage and adapt to predicted changes.

The Southern Ocean marine productivity provides the food for the once vast populations of krill, fish, squid, seals, seabirds and whales. Food web linkages are complex and are affected by physical and chemical processes at a number of scales. Production is highly



seasonal and is spatially and temporally localised. For example, primary production in spring occurs in phytoplankton blooms associated with the retreating and disintegrating pack ice, whereas in winter it is mainly to be found in the microbial communities that are associated with the sea ice itself. Changes in the area, thickness and seasonality of sea ice are likely to have direct impacts on both the primary productivity of the system and on species higher up the food webs which use sea ice as a habitat. Southern Ocean ecosystems will be altered by other physical and chemical changes: ocean temperatures are rising, major frontal systems may have moved, circulation patterns are changing and oceanic carbon dioxide will continue to increase. Within this changing environment, the effects of local human-induced changes remain largely unknown: some species will be fished and others will recover from earlier exploitation. Developing procedures to understand and predict the ecosystem responses to the combined effects of multiple changes in the Southern Ocean will be fundamental for providing advice to bodies such as the IPCC and for developing effective management strategies for the region.

The process of monitoring is fundamental to all the streams of conservation-related research within this theme. Understanding change in key components of ecosystems and in ecosystem structure and function is essential for understanding past trends and for predicting future change. Recognising this, over the last two decades the program has supported a number of strategically focused monitoring initiatives targeted at individual species, communities or whole ecosystems (e.g. plankton recorder surveys, sampling from research vessels while underway, land-based monitoring of penguin populations, fisheries-independent surveys of fish populations, and censuses of Southern Ocean humpback, minke and southern right whale populations). This has resulted in the collection of some valuable long-term data series that will provide the foundations for analyses and synthesis over the next few years. However, it is highly likely that these analyses and growing understanding of critical indicators or sentinels of change will create a need for an expanded and a refocused monitoring program into the future.

The design and support of an enhanced monitoring program, to service multiple priority science and management questions for the future, is therefore important. Such programs will need to effectively detect and distinguish between fishing and environmental impacts, as well as the demographically driven responses of recovering predators. This will require the development of an explicit spatial framework for monitoring, and may require an expansion in the spatial coverage of monitoring within that framework, and the ability to monitor across a broader range of ecosystem components than currently occurs. Indicators will need to be chosen for their diagnostic value to contribute to management and thus will need to be specific, sensitive, operationally practical, and have links to historic data.

Key policy drivers and questions

In the Southern Ocean and Antarctica, a number of international bodies have responsibility for the conservation of particular species or ecosystems in the region, including CCAMLR, IWC and ACAP. These bodies have considered the key threats to the species and ecosystems in their jurisdiction and have developed research plans to address many of these threats. In addition, within the United Nations Framework Convention on Climate Change (UNFCCC) the IPCC has identified a reporting mechanism for the ocean ecosystem including ecosystem services, sensitivity and exposure to change, vulnerability of species, communities and/or ecosystems to impacts/extremes, and climate feedback mechanisms. Southern Ocean ecosystem research will contribute

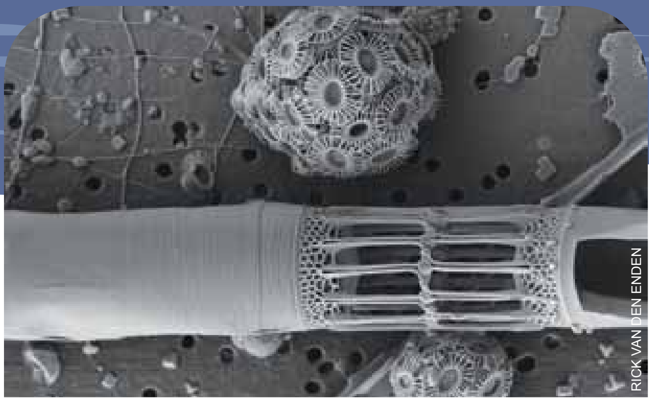
to setting Australia's policy position in these areas. In turn, the Australian Government has developed policies and research plans to address the subset of threats identified by the international bodies that are of particular interest to Australia. These considerations frame much of the research outlined in this document.

Australia has a number of domestic policy goals which also drive the prioritisation of Southern Ocean conservation research. These goals include the conservation of Antarctic marine living resources, the development of ecosystem-based management for fisheries, the conservation of high seas biodiversity incorporating MPAs, promoting non-lethal cetacean research, mitigation strategies for bycatch in fisheries, management and conservation of threatened species and adaptation/mitigation of effects of climate change on marine ecosystems.

The AAD's responsibility for managing the marine environment at Heard Island and McDonald Islands (HIMI) includes assessing the conservation values in the region and assessing and managing threatening processes to those values, such as the impacts of fishing. The AAD also provides the assessments for the Australian fisheries operating at HIMI and on the Antarctic continental shelf. This information is considered by national bodies such as the Australian Fisheries Management Authority's (AFMA) Subantarctic Research Assessment Group and CCAMLR's Working Groups before management decisions are made.

The AAD is formally responsible for conducting and coordinating Australian research into cetacean conservation and management, particularly in relation to the IWC. Whale research conducted within the program forms a core component of an integrated and planned research strategy that interacts with Australia's national and international priorities for cetacean conservation. Whale research activities are coordinated by the AAD's Australian Marine Mammal Centre (AMMC). The Southern Ocean-based whale research is a core component of the Australian-led international Southern Ocean Research Partnership (SORP)[8] which includes most nations engaged in Southern Ocean whale research and is directed towards agreed collaborative projects. The AMMC also coordinates research on Southern Ocean seals for the Australian Government and has broader national responsibilities that fall beyond the scope of the program.

8. SORP is a key Australian initiative within the International Whaling Commission. For more details see www.marinemammals.gov.au/sorp



Science streams

3.1 Marine ecosystem change

Stream goals

To identify the ecological responses and resilience of Southern Ocean ecosystems to the impacts of global change.

To develop cost-effective monitoring approaches to track the impacts of global change and the effectiveness of conservation measures on ecosystems.

Key research questions

- How have Southern Ocean ecosystems responded to environmental change in the past?
- What are the potential ecosystem impacts of observed and predicted physical (e.g. ocean currents, upwelling, sea ice) and chemical change (e.g. ocean acidification, salinity) in the Southern Ocean?
- What evidence is there that the biodiversity and structure of Southern Ocean ecosystems off eastern Antarctica is changing, and how much of this can be attributed to global change or past exploitation?
- How might these changes affect the productivity and sustainability of species and ecosystems?
- Which key pelagic species and communities are most vulnerable to the effects of ocean acidification, and what are the mechanisms of this effect?

Overview

This stream focuses on research into the ecological responses, at all trophic levels, to predicted environmental changes in the Southern Ocean, including global warming and increasing ocean acidity. The complexity and scale of the challenge – to understand the nature and extent of change in Southern Ocean ecosystems – demands multidisciplinary input (including physical, chemical and biological oceanography, marine biology and ecology, taxonomy and mathematics) and a clear plan for how the results of field and experimental studies will be used. Our approach to synthesis and integration will be the development of spatially explicit biophysical ecosystem models designed to feed into the broad suite of conservation and management strategies in the Southern Ocean. The outputs of the research will also feed directly into the IPCC.

Southern Ocean ecosystems are threatened by global warming, ocean circulation changes, ocean acidification and sea ice retreat, as well as by invasive species and pressure associated with increased levels of exploitation. These pressures occur at a time when many higher predators are recovering from historic overexploitation, which will also impose strong influences on Southern Ocean ecosystems. Some species are vulnerable to habitat loss, particularly through loss of sea ice, or alterations in geographic range. Phytoplankton are particularly sensitive to all of these factors, with predicted alterations in the patterns of primary production (particularly the sea ice bloom) which will affect the structure and function of the ecosystem.

A number of biological responses to oceanic changes have already been reported, including:

- changes in phytoplankton community structure due to freshening and warming of surface waters
- thinning of foraminifera shells due to ocean acidification
- changes in zooplankton community composition with smaller species becoming more dominant
- southward extension of the range of more temperate species and contraction of the range of more polar species.

In future, predicted reductions in sea ice will cause a loss of habitat for ice-associated organisms, from microbes to seals. It will also cause profound changes in the light environment and melt-induced surface water stratification. These changes may diminish the extent of the ice edge bloom that is crucial to the productivity in the Southern Ocean and supports the specialised food chain linked to krill.

Ocean acidification will influence calcification and other pH sensitive biological processes and is likely to have widespread ecosystem impacts. Polar regions are likely to be amongst the first to be affected by ocean acidification because calcium carbonate is most soluble in cold acidic waters. In environments such as polynyas, in which surface water sinks rapidly, the earliest effects of increased carbon dioxide may be observed. Calcareous plankton and benthic calcifiers may be most vulnerable to ocean acidification and can provide model systems to study the effects of rising carbon dioxide levels.

Identifying how species and communities are coping with, and will respond to, physical and chemical changes in the Southern Ocean requires a means of identifying trends against the background of natural variability. The lower trophic levels are likely to be impacted directly by changes on relatively short time scales. Apex predators are sensitive to changes in the distribution and abundance of their prey, which in turn respond to changes in lower trophic levels and the physical environment. Krill, fish and squid remain the most difficult components of the Southern Ocean ecosystem to monitor, and information on these taxa is variable and in some cases very sparse. Many air breathing predators, in contrast, are more accessible to monitoring given many species' dependence on land or ice to breed or moult, or the use of near-shore migratory routes. The response of predators to changes in prey availability and behaviour can initially manifest as changes in their foraging locations or foraging success. Subsequently these changes emerge as demographic changes and eventually as abundance parameters. Understanding the responses of organisms and communities to oceanic change requires a commitment to strategic monitoring of Southern Ocean biodiversity and ecosystem processes.

From a national perspective – taking into account both user needs and resource constraints – developing an ability to detect and understand ecological changes in the Southern Ocean will require a carefully designed program of observations, experiments, monitoring and modelling. In the observation/monitoring arena, existing initiatives (e.g. CCAMLR Ecosystem Monitoring Program (CEMP); Australia's Integrated Marine Observing System (IMOS)) and emerging initiatives (Southern Ocean Observing System (SOOS); Southern Ocean Sentinel) provide a very useful foundation. Similarly, the Australian Antarctic Climate and Ecosystems Cooperative Research Centre and international Integrating Climate and Ecosystem Dynamics programs provide a framework for synthesis and modelling that will guide this stream over the next decade. Our challenge is to ensure synergy between the observational, synthesis and predictive modelling components of this stream, with strong feedback loops between these elements of the plan.

In summary, our aim in this stream is to determine the vulnerability of Antarctic ecosystems to global change, likely responses, and the implications for fisheries management and conservation.

Scientific approaches and required capabilities

- A model-based assessment of the risks of global change impacts on Southern Ocean ecosystems is required to evaluate the probability of different food web structures arising under predicted changes in the ocean and sea ice systems.
- An integrated observation and monitoring program, designed to meet the data requirements for national marine observing, IPCC and CEMP, based on a sound theoretical and practical foundation will permit an assessment of important drivers of change (e.g. climate, fishing) on key elements of the Southern Ocean and provide guidance to CCAMLR and other national and international bodies.
- Field-based multidisciplinary assessments of the regional and temporal variation in productivity of the Southern Ocean, including within the sea ice, and factors that contribute to that variation.
- A field-based assessment of the relative importance of food web relationships is required to identify the key alternative energy pathways and food web dynamics that might arise if krill and other key species are substantially negatively affected by global change.
- The identification of species, populations and communities most at risk from ocean acidification.
- Identification of sensitive marine indicator species or systems is required for tracking the impacts of environmental change.

3.2 Wildlife conservation

Stream goals

To undertake research that will inform the conservation management of whale, seabird and seal species with important ecological or conservation values. In particular:

- *To optimise the methodology and implementation of monitoring programs to measure the status, trend, distribution and relevant life history parameters for species of Antarctic wildlife for which such data have a clear management application.*
- *To determine the critical spatial scales over which changes will affect important ecological processes (e.g. foraging) of relevant vertebrates of high conservation value in the East Antarctic sector of the Southern Ocean.*
- *To integrate research on higher predators into broader international research efforts examining the potential effects of changing climate on ecological interactions.*
- *To undertake Australia's Antarctic research contribution to achieving the objectives of the IWC and collaborative projects of the Southern Ocean Research Partnership on whales.*
- *To demonstrate the effectiveness of non-lethal techniques to answer important conservation questions on whales and seals.*

Key research questions

- What are the status and trends of wildlife populations of ecological or conservation value in the Australian Antarctic Territory (AAT) and surrounding Southern Ocean, and what drives these trends?

- How do species and populations of key Antarctic wildlife utilise the various habitats available in the eastern sector of the Southern Ocean and what is the extent of spatial and trophic overlap between species?
- Will the ecological consequences of changes in population size and distribution of Antarctic wildlife lead to broader changes in ecosystem structure?
- What can the demographic processes of recovering populations of Antarctic wildlife tell us about decadal or greater temporal scales of changes in the Southern Ocean?
- How can we design an integrated long-term monitoring strategy for selected Antarctic wildlife in the eastern Antarctic and surrounding Southern Ocean that provides information on their population status, their ecological drivers and their vulnerabilities?
- How do changes in atmosphere and oceans affect the population status, distribution and behaviour of ecologically important Antarctic wildlife?

Overview

Whales, seals, penguins and seabirds face a number of threats to their long-term viability. Current threatening processes include oceanic and environmental changes on the feeding grounds, environmental changes at breeding sites, habitat degradation, direct and indirect interactions with commercial fisheries, and other human activities causing disturbance or interference. The effects of past over-exploitation of seals, penguins and whales also has implications for the current conservation status of these groups, as some species appear to show little evidence of recovery. In contrast, some species are recovering at rapid but variable rates and their recovery may have significant effects on the marine and terrestrial ecosystems of the region.

This stream will inform conservation and management options for Antarctic wildlife and focus on the status, population biology and ecology of whales, seals and seabirds and the threats these populations face. It will utilise the results of research delivered through other streams on important patterns of distribution and 'hot spots' of marine biodiversity.

The prioritisation of the wildlife conservation research will be informed by national initiatives such as the recovery plan process and bioregional protected area networks. Whale research undertaken within this stream will support Australia's role within SORP, which is an international collaboration to deliver conservation management research on Southern Ocean whales (humpback, blue, fin, minke, sei, southern right and sperm whales) to the IWC. As whales are highly migratory species that generally move between high latitude feeding grounds and tropical/subtropical breeding grounds, research activities relevant to SORP and other priority cetacean science issues are not limited to the Southern Ocean. The research within SORP focuses on two core themes: Post-exploitation whale population structure, health and status, and

Changing atmosphere and oceans – Southern Ocean whales and their ecosystems. SORP will sponsor a Year of the Whale project in 2013–14, a coordinated multi-vessel circumpolar synoptic survey program to address the major questions on whale distribution and abundance that cannot be addressed in a piecemeal fashion. This research will showcase the power of non-lethal research techniques and deliver priority science into the IWC and CCAMLR, and to multidisciplinary research programs such as the Integrating Climate and Ecosystem Dynamics program, SOOS and IMOS.

Scientific approaches and required capabilities

- Identification of a suite of wildlife species and populations of interest will be based on their ecological or conservation values.
- Quantification of the status, population dynamics and forcing factors (physical, biological) of the population structure, distribution and abundance of identified whales, seals and seabird populations is needed. This will require long-term abundance and trend estimation be continued and standardised, improved genetic and taxonomic distinction of key taxa and improved methods for studies that define habitat use and linkages between habitats.
- Identification and quantification of threats to Antarctic wildlife populations will need to focus on oceanic changes on the feeding grounds through studies of foraging ecology and distribution, environmental changes at breeding sites, direct and indirect interactions with commercial fisheries, and human activities causing disturbance or interference.


CHRIS WILSON

- There is a need to develop risk management and mitigation tools and strategies for Antarctic wildlife.
- Application of existing and development of new technologies (such as aerial surveys, tagging, acoustic monitoring, bio-logging, remote sensing, molecular and broad scale survey techniques) that best address the above objectives is required.
- Patterns of distribution and habitat utilisation by Antarctic wildlife, and 'hot spots' of marine biodiversity that might inform conservation and management options need to be identified.

3.3 Southern Ocean fisheries

Stream goal

To conduct strategic research to underpin the sound management of the Antarctic krill fishery and Antarctic and subantarctic fisheries on icefish and toothfish, including the development of ecosystem-based fishery management procedures and methods for reducing bycatch.

3.3.1 Krill and fish stocks

Key research questions

- What are the appropriate ecologically sustainable catch limits for krill and fish in the AAT and HIMI?
- Can estimates of krill biomass be significantly improved by revising estimates of key biological parameters (biomass estimates, growth, mortality and recruitment)?
- What is the stock structure of harvested species and the degree of interchange between regional populations?
- What are the potential effects of habitat change brought about by climate change and ocean acidification on the capacity of the krill and fish stocks to sustain current and projected harvesting levels?
- Can a modelling framework be developed to evaluate the impact and sustainable harvest levels of fishing in the Southern Ocean?

Overview

This stream will focus on strategic research needed to underpin the sound management of Antarctic and subantarctic fisheries including the development of ecosystem based fishery management procedures, options for spatial management and management of the incidental effects of fishing. In particular it will provide revised catch limits for the krill fishery off the AAT and design a feedback management regime for the Antarctic krill fishery. The stream will also provide regular assessments of the status of fish stocks in the Australian Exclusive Economic Zone (EEZ) off HIMI and incorporate regional-scale assessments into integrated management of the fish stocks on the Kerguelen Plateau.

Outputs from this stream will feed into Australia's domestic fisheries forums and into CCAMLR. Fishing in the Southern Ocean is managed by CCAMLR and ongoing scientific research is necessary to ensure that CCAMLR can achieve its three principles of conservation:

- Prevention of decrease in the size of any harvested population to levels below those which ensure its stable recruitment.
- Maintenance of the ecological relationships between harvested, dependent and related populations and the restoration of depleted populations.
- Prevention of changes or minimisation of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades.

These principles require scientific information on the species being harvested and on the marine ecosystem. Consequently, scientifically based management of the region's fisheries must adopt a more comprehensive approach than traditional single species fisheries management, an approach that has become known as ecosystem based fisheries management. In the absence of such information, CCAMLR has adopted a precautionary approach.

CCAMLR-focused research will concentrate on the species being commercially fished (krill, icefish and toothfish), and on ecosystems and species that are potentially vulnerable to the effects of fishing, or which have been selected by CCAMLR as indicator species. There is also a requirement for information on changes in elements of the ecosystems that are either dependent on the harvested species or which are vital to their success to reduce management uncertainties. CCAMLR has also emphasised the need for the development of ecosystem models for evaluating feedback management procedures and will require comprehensive and well coordinated monitoring to assist in this process.

In developing the ecosystem approach, CCAMLR has allowed for the needs of dependent species when setting catch limits and has specifically addressed issues such as bycatch and ecosystem monitoring but it is yet to develop the anticipated comprehensive feedback management approach. This management system, which is particularly warranted by the fishery on the region's keystone species – krill – has been endorsed by CCAMLR and will require research and development over the next decade.

The use of a management strategy evaluation framework for CCAMLR's fisheries will assist in targeting the most relevant areas for research. The framework involves assessing the consequences of a range of management options and outlining the trade-offs in performance across a range of management objectives. Key steps in the approach involve turning broad objectives into specific and quantifiable performance indicators, identifying and incorporating key uncertainties in the evaluation, and communicating the results effectively to client groups and decision makers.


TONY VENESS

The program has conducted most of the CCAMLR-related research in the East Antarctic and as such has developed considerable expertise in the development of sustainable resource management practices in the Southern Ocean. Due to a continued interest in the fisheries of this region, there is a need to continue this research, primarily within the Australian EEZ but there are opportunities to collaborate with other CCAMLR members to ensure that all fishing activities within the CCAMLR area are consistent with the aims of the convention.

There is a range of conservation issues that involve the biology of commercially harvested species. There are active fisheries targeting toothfish and icefish at HIMI, on the Kerguelen Plateau, on the continental shelf and slope of East Antarctica (off the AAT) and at Macquarie Island (outside the CCAMLR Area). Australian fishing vessels, which caught around 2500 tonnes of fish in the Southern Ocean in 2008, are the primary sampling platform for fisheries research in the Southern Ocean. These vessels conduct research as outlined in annual fishery assessment plans presented to AFMA. Much of this research occurs during routine fishing operations, and hence is a very cost-effective way of gathering data on fisheries dynamics, on the biological status of the fish populations and on the ecological effects of fishing. Fishing vessels can also serve as 'ships of opportunity' for the deployment of instruments in the region, and underway data collection.

The Antarctic krill fishery currently catches around 150 000 tonnes a year, yet the precautionary catch limits total some 6.5 million tonnes a year. This is the only fishery in the world that has such potential for massive expansion. There are signs that this expansion is underway, so the task of conducting the research to ensure sustainable management of this fishery is urgent. There is no current fishery for krill off East Antarctica and the catch limits off the AAT total three million tonnes. Re-commencement of a krill fishery off the AAT would require data collection and research to ensure that it remained within sustainable limits.

Scientific approaches and required capabilities

- Field-based studies will need to focus on a range of scales using a combination of complementary techniques and vessels (e.g. ranging from icebreakers, fishing vessels to small boats and inflatable rubber boats).
- Identification of the location of persistent ecological hotspots and low productivity areas in the Southern Ocean will assist future field work.
- A well focused and designed monitoring program is required; one that is capable of providing useful feedback to CCAMLR on the effects of fishing on key indicator species.
- Laboratory-based studies will utilise the unique aquarium and cold-room facilities at the AAD as well as ship and station-based research facilities.
- Some of the research outlined will also draw on the expertise in the fields of economics, policy and sociology to encompass the human dimensions of global fisheries which drive commercial activities in Antarctica.
- A coordinated approach for data collection and research from commercial fishing vessels is required.

3.3.2 Bycatch

Key research questions

- How effective are the seabird mitigation devices used by fishing vessels in the areas where seabirds are most vulnerable?
- What are the benthic ecosystem effects of different fishing techniques relative to their fishing efficiency in Antarctic waters?
- What are the effects of bycatch removals on the populations of vulnerable benthic species?

Overview

Seabirds, non-target fish species and marine benthos are impacted by fishing practices. Solutions to mitigate unsustainable impacts require distinct research approaches.

Several species of Southern Ocean seabirds have been severely depleted through their incidental mortality in longline fishing. CCAMLR manages Southern Ocean fisheries with the aim of reducing or eliminating seabird bycatch in the Southern Ocean and ACAP aims to achieve a favourable conservation status for the 29 species of albatrosses and petrels listed in the agreement. Because these species are highly migratory, their conservation requires a focus both within and outside the CCAMLR Area. Activities highlighted in the Australian Recovery Plan for Albatrosses and Giant Petrels include monitoring of breeding populations and related demographic research, elimination of introduced species at breeding sites, tracking studies to determine the overlap between the species' foraging range and longline fisheries, and bycatch mitigation research. Additionally, the recovery plan advocates the development of science based solutions to avoid or mitigate the incidental mortality of all seabirds in fisheries and to achieve greater use of seabird conservation measures by range states in national and high seas fisheries.

Research conducted in collaboration with fishing industries provides effective solutions to the problem of seabird bycatch in fisheries. Research projects aim to determine the effectiveness of avoidance measures, including new technologies, in reducing the mortality of seabirds that interact with fisheries. These projects save the lives of thousands of seabirds annually.

Commercial fishing gear not only collects the target species but has effects on the ecosystem that are detrimental both to biodiversity and to fisheries themselves, but these effects are yet to be quantified.


ROGER KIRKWOOD

Benthic trawls, and demersal longlines, may cause significant damage to the seafloor communities and can harvest high quantities of bycatch; pelagic trawls can yield significant bycatch of vulnerable early life history stages of fish and other invertebrates, and there can be significant mortality of the target species that does not result in their harvest. All of these effects could lead to failure to meet CCAMLR's conservation principles. Incidental effects of fishing have been internationally highlighted as an area where quality scientific observations can result in changes in fishing practices and/or spatial management measures which can have direct conservation outcomes. Better information on Antarctic and subantarctic marine biodiversity is required to underpin this bycatch research.

Scientific approaches and required capabilities

- Design and engineering capability to develop bycatch mitigation technology is needed.
- Ship-based research using a combination of research and fishing vessels will be required to trial and assess impacts of bycatch mitigation gear and approaches.

3.4 Protecting marine biodiversity

Stream goal

To develop efficient and effective methods to deliver a comprehensive, adequate and representative system of marine protected areas in the Southern Ocean.

Key research questions

- Which marine areas need most protection in East Antarctica?
- What methods and data are required to define marine areas for protection?
- Can we better identify effective stocks, or meta-populations of harvested species to assist with the development of spatial management procedures?
- Can areas of high conservation value in the Southern Ocean be identified using proxy data (e.g. sea surface temperature or remotely sensed ocean colour)?

Overview

Spatial protection for marine biodiversity has been identified as a priority issue by both the CEP and CCAMLR. Therefore, this research stream aims to support the development of a comprehensive, adequate and representative candidate network of MPAs within the CCAMLR Area, particularly focusing on East Antarctica and including identification and conservation of biological hotspots and vulnerable marine ecosystems.

CCAMLR has managed fisheries using area-based approaches on a very large scale but is moving towards a more specific spatial management framework at smaller scales. This shift in scale will require research to identify the appropriate spatial scales at which management actions will occur, in particular when implementing the conservation of representative areas, scientific areas, vulnerable areas, and areas where important ecosystem processes occur.

As is the case for many areas of the Australian EEZ and high seas, substantial uncertainties surround the biodiversity and spatial heterogeneity of Southern Ocean marine ecosystems. This science strategy will address some of these uncertainties through targeted field campaigns. However, a comprehensive field-based survey of biodiversity and evaluation of conservation values is not feasible. Thus, a combination of synthetic and modelling approaches using currently available data will be needed to produce robust strategies for the conservation of Southern Ocean biodiversity in the face of threats from fishing activities and global change. An initial bioregionalisation of the Southern Ocean has already been produced. This will be used to further define management areas. MPAs (two of which already exist in Australia's EEZ in the Southern Ocean; namely HIMI and Macquarie Island), and a vulnerable marine ecosystem have already been defined off the AAT.

Scientific approaches and required capabilities

- Synthesis and modelling of existing data sets (e.g. Census of Antarctic Marine Life) is required.
- A strong relationship between science and policy needs to be maintained to deliver a representative system of MPAs by the 2012 deadline.
- Field studies will be required to determine how effective the defined protected areas are in achieving their management goals.

AFMA OBSERVER PROGRAM

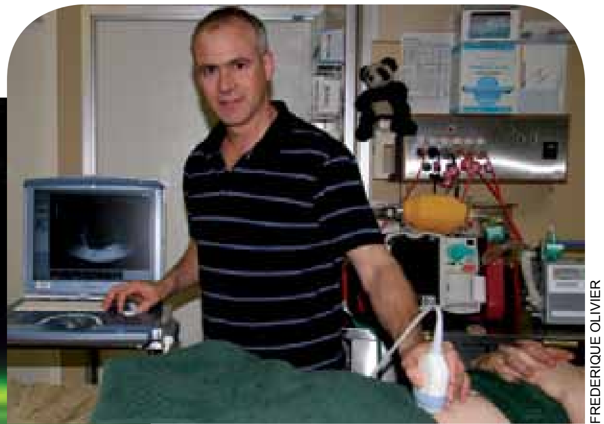
4 Frontier Science

The Frontier Science theme has been developed to encourage and support research that falls outside of the priorities within the other thematic areas, but within Australia's national science priorities. As discussed previously, while the focus on environmental policy-related science in the first three themes is driven by government needs, the program will continue to support excellent new science.

It is envisaged that some Frontier Science areas will grow in significance – as a result of their scientific impact and/or policy relevance – and thus a key role of the Antarctic Science Advisory Committee (ASAC) will be to maintain a watching brief on the Frontier Science portfolio, the national policy drivers and the national and international innovation horizons, and identify new priorities for thematic science.

A number of science areas that have had a long and very successful history of engagement in Antarctica will be considered under the banner of Frontier Science – examples of these are given on the following page. The examples given are neither exhaustive nor intended to be prescriptive. Frontier Science projects will be chosen on scientific excellence.

Most Frontier Science projects are likely to have a low demand on logistic support, but there may be some that are major initiatives, requiring a substantial allocation of logistic support, greater than that readily available within the program. While it may be possible to undertake a pilot study for a major initiative within existing logistic resources, the full implementation of such a project would require significant new and/or external resources to undertake the research. Major initiatives will be considered on a case-by-case basis by the program, in collaboration with partner agencies and ASAC.



EXAMPLES OF FRONTIER SCIENCE

Astronomy

Sites within the Australian Antarctic Territory (AAT) may soon become the focus of major international investment in astronomical infrastructure. There is thus an opportunity for Australian astronomers to continue to play a leading role in the characterisation and understanding of these sites and continue to engage with the international community to ensure that the advantages of Antarctica as a platform for scientific observations can be fully realised.

Geosciences

Geosciences play a critical role in addressing a number of questions already outlined within the other themes in this plan. In addition, there is scope to further explore the geological and geophysical characteristics of the AAT.

Human biology and medicine

Future priorities for research in this field, set by the Scientific Committee on Antarctic Research (SCAR) Expert Group Human Biology and Medicine (part of the SCAR Standing Scientific Group on Life Sciences), focus on research on and healthcare of humans in Antarctica (e.g. biomedical sciences, social and behavioural sciences, and medicine). Areas of particular interest include research into the effects of isolation, cold, altitude and light and dark. In addition, the use of the Antarctic as a space analogue has recently become of interest to the international polar medicine community.

Space weather

While routine measurements are made at all stations (part of underpinning science activities), a full understanding of space weather impacts at high latitudes is a complex evolving science task. Research in this area is of high value to Antarctic air, sea and land operations via continuity of communications and navigation right across the polar region.

Fundamental biology and physiology

The unique attributes of Antarctic biota mean that there will always be fundamental questions of scientific interest.

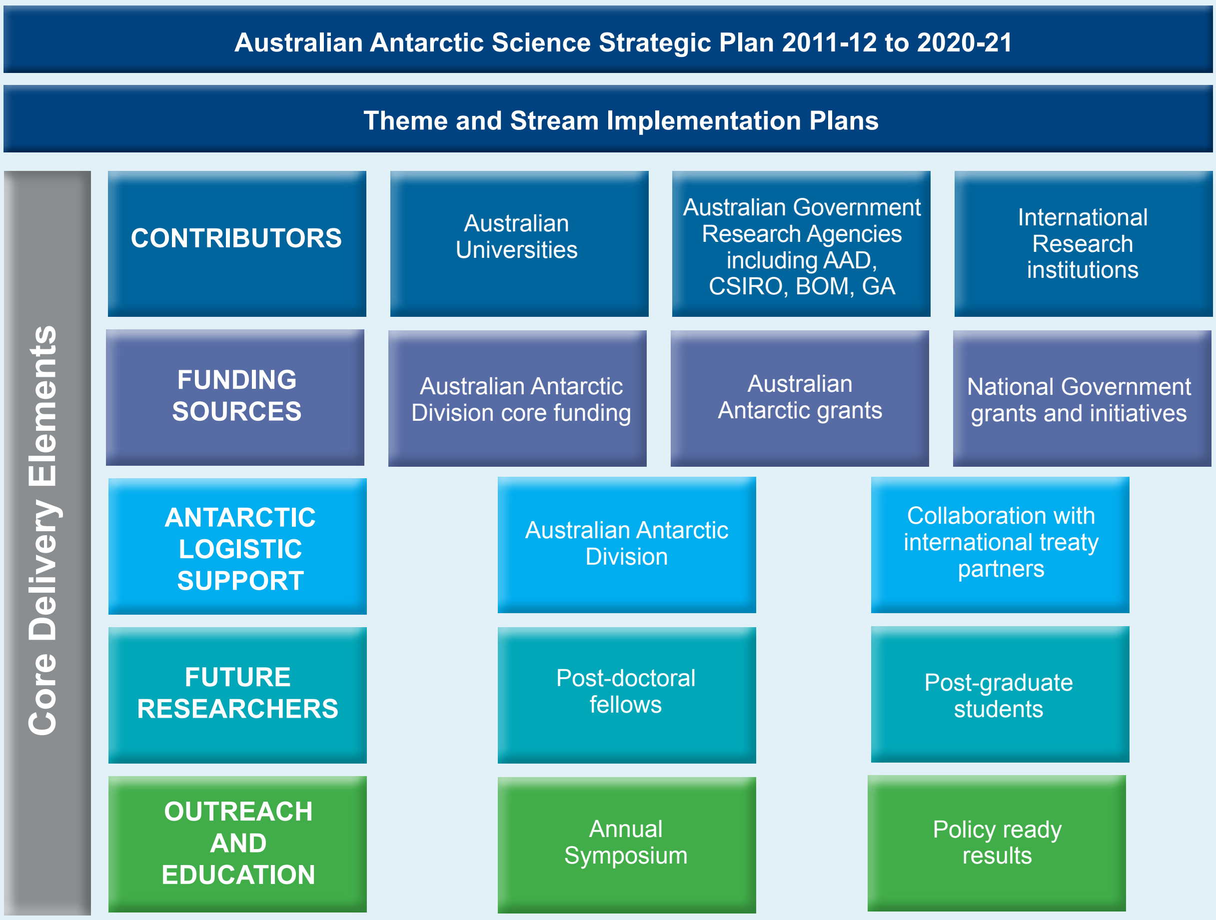
Implementation

This plan has provided an articulation of the theme and stream goals together with the planned outcomes for the program. Central to the plan is the need for scientific excellence in delivering these outcomes. The AAD will provide leadership, coordination and management to ensure the accomplishment of the science outcomes outlined within this plan, with oversight from Antarctic Science Advisory Committee (ASAC).

To implement this plan, a number of changes are required to the current administration of the program.

The following section outlines the guiding principles, leadership and governance for delivery of this plan (including the role of theme and stream leaders), development of implementation plans, the new two-stage application process, grants, transition arrangements, monitoring and reporting of projects, and outreach. New features such as post-doctoral fellowships and an annual symposium are also outlined below. The most up-to-date information on the implementation and application processes, throughout the life of this plan, will be available on the AAD web site.

CORE ELEMENTS OF THE PROGRAM



GUIDING PRINCIPLES

- **The AAD leads and manages the program and ensures that the scientific research undertaken is in accordance with this plan.**
- **Sustained progress in advancing Australia's Antarctic interests requires investment across a broad range of scientific activities.** The program will support a wide spectrum of scientific projects including tactical, strategic and fundamental research in the priority areas identified in this plan.
- **Scientific quality will remain a key determinant of project selection.** The program will use open competition and scientific peer review as a key means for establishing merit for selection of research projects. Note that the recognition of a 'fit-for-purpose' approach will be an important consideration in project selection.
- **Active participation by the research community outside AAD is critical to success**. The AAD will seek to engage actively with the external research community to maximise the scientific output possible from the program.
- **The program will continue to offer a competitive grants scheme.**
- **Partnerships are essential to achieving Australia's Antarctic science objectives.**

  The program will partner actively with international organisations to leverage Australia's Antarctic investment and achieve national goals through the outcomes of this plan.
- **Broad and easy access to research data.** Data acquired will be made publicly available within two years of collection or as soon as possible after scientific validation.
- **The program will invest in the next generation of polar scientists.** The program will seek opportunities to promote interest in Antarctic science to the next generation of polar scientists, including supporting post-graduate top-up scholarships and post-doctoral fellowships.
- **The program will engage in broad public outreach to promote Australia's investment in Antarctic science.** The need for public outreach will be built into all projects undertaken within the program.
- **The AAD will provide clear guidance on the logistic capability available to support priority research outlined in this plan.**

Leadership and governance

ASAC advises the Minister responsible for the Department of Sustainability, Environment, Water, Population and Communities on the areas of research that the program should undertake. Their primary role is in developing Antarctic science strategic plans, conducting reviews of each plan and advising the Australian Government of any changes that should be made. In particular they will advise if any additional theme should be included.

The Chief Scientist of the program provides day-to-day leadership to ensure the achievement of science outcomes within this decadal plan. The Chief Scientist will also act as the primary contact for the Frontier Science theme.

The Climate Processes and Change, Terrestrial and

ROLE OF THEME LEADERS

- Lead the implementation of research identified under their theme and manage stream development.
- Provide leadership and support for stream leaders within their research theme.
- Provide ongoing support and communication on a regular basis to all researchers participating in the program under their theme.
- Assist in the development of the overall implementation plans for the program to utilise resources as efficiently as possible for the highest priority research projects.
- Assess the progress of continuing projects and advise the research assessment committee of any issues, including change of investigators, changes in requested logistic support, and lack of expected progress.
- Identify areas of research requiring particular attention and establish collaborative links with researchers with the capability to address these areas.
- Coordinate and where appropriate lead delivery of core theme outputs to government stakeholders.
- Report annually to the program's Chief Scientist and ASAC on progress in relation to the plan.

Nearshore Ecosystems: Environmental Change and Conservation, and Southern Ocean Ecosystems: Environmental Change and Conservation themes will have a leader appointed from within the AAD. The theme leader will be the champion and primary point of contact for their theme.

Theme leaders will be supported by stream leaders who will do the day-to-day management of stream research activities. Stream leader positions will be open to a competitive process of selection. These leadership positions will be honorary appointments within the program and could be held by a researcher from any Australian research institution. Stream leaders will be responsible for developing implementation plans for and monitoring progress within their stream. Stream workshops will be held as required to design coordinated and integrated research plans. Funding will be available from the AAD to assist with funding for stream workshops. The AAD will offer financial support to stream leaders to attend stream workshops and maintain regular contact with researchers within their stream.

The day-to-day governance of the program and grant scheme will be managed by the AAD.

Implementation plans for the strategic plan

Implementation plans for three year blocks of time will be developed with clear priorities for the research identified within each of the broader themes. There will be a mixture of field-based studies, remote sensing, laboratory analyses, process and modelling studies undertaken within each theme, requiring detailed planning of the research required to meet the outcomes of each theme and stream.

A major part of the implementation planning phase is to develop effective and efficient field plans to accommodate as much field science as possible each year within resource and capability constraints (e.g. station beds, ship time, inter and intracontinental flying season). To facilitate logistic planning and maximise the ability for researchers to plan their research with certainty, stream implementation plans will be used to develop more of a ‘campaign style’ approach to scheduling and coordinating field activities. This will see groups of stream projects and scientists sharing logistics support where practical and generally working as a coordinated team. This has proven successful in the past and will allow more science to be conducted than if projects draw independently on transport and other logistics support.

The detailed theme and stream planning phase will commence during 2010 with stream workshops held to develop the research plans of each stream outlined in this plan. The timing of the workshops will be advertised and researchers interested in participating in the program will be encouraged to attend. The first implementation block of the plan will be focused primarily on high priority research, some of which will continue from projects approved under the previous Science Strategy 2004–05 to 2010–11. The second and third block of implementation plans will be outlined in decreasing degrees of detail. The final year of the plan will include finishing off field projects, writing up results, and developing the next strategic plan for 2021–22 and beyond.

Implementation plan 1:
2011–12 to 2013–14 (Years 1–3).

The first three years of the plan will finalise projects from the previous science strategy, undertake commitments to the Antarctic Climate and Ecosystems Cooperative Research Centre and Australian Marine Mammal Centre and commence new projects under the themes and streams outlined in this plan.

Implementation plan 2:
2014–15 to 2016–17 (Years 4–6).

The second three years of the plan will primarily be in support of the newly developed streams of research described in this plan.

Implementation plan 3:
2017–18 to 2019–20 (Years 7–9).

The final three years of the plan will build on the research commenced during the life of the plan.

Final Year: 2020–21 (Year 10).

The final year of the plan will comprise finishing the research undertaken within this 10 year plan.

A mid-term review of progress will be undertaken by ASAC in 2015–16 to ensure the plan is delivering the desired outcomes for government.

Application process

All researchers seeking support from the program, and/or requiring grant funding will need to apply through an online project application form. This form will be different from the one used in previous years and researchers who apply should read the new conditions and questions carefully.

The aim of the new assessment process (Figure 4) is to streamline and simplify the application process for the benefit of applicants and assessors. Therefore a two-stage approach is planned with an initial expression of interest (EOI) required to outline why the project should be undertaken, demonstrating its fit to strategic theme and stream goals, and a brief explanation of project scope (where, how and who). Second, the applicant will be invited to complete a full application if (and only if) the EOI passes scrutiny by an assessment committee. This EOI step should reduce the amount of time spent by applicants and assessors on projects that are unlikely to be supported. Only the full application will be peer reviewed and assessed by an independently chaired research assessment committee.

Applicants should consider carefully what timeframe their research will deliver results and apply within the following categories: tactical, strategic and fundamental.

Figure 4: Application process

PLAN	• Theme and stream goals • Implementation plan developed at stream workshops • Clear priorities and timelines
APPLICATION	• Expression of interest – assessment of fit to theme and stream goals • Full application for EOIs that pass the assessment
ASSESSMENT	• Criteria-based assessment, peer review and rejoinder • Scientific assessment committee – score assigned
PROJECT IMPLEMENTATION	• Logistic and financial support finalised for each project • Research undertaken • Outreach and education
REPORTING	• Milestone progress reports for each project • Stream and theme reports each year to ASAC and the Minister • Final reports for all completed projects
REVIEW	• Regular review of project delivery against theme and stream goals • Annual symposium to review progress • ASAC will conduct a mid-term review of the strategic plan

Tactical research

Research that encompasses short-term projects (generally one year or less) designed to answer specific questions from policy makers, environmental managers and operational users of science data.

Strategic research

Research that encompasses projects of medium-term duration (2–5 years) that provide findings and data of direct relevance to achieving the projected outcomes of the plan within the timeframe of the plan (i.e. there is a demonstrated link between the output of the project and the outcomes we are looking to achieve).

Fundamental research

Encompasses longer term projects that reflect the high level goals of science priorities, but are not expected to provide outputs of direct relevance to projected outcomes of the plan within the life of the plan.

Assessment of the projects will be conducted using criteria-based scoring with scientific excellence as a key determinant. The strategic importance of the project will also be a major criterion. The quality and track record of the research team to deliver on time and on budget together with the outreach and education plan for the project will also be assessed. Instead of a purely additive series of criteria there will be threshold scores within criteria so that if a project does not demonstrate some key criteria at a high enough level, the project will not be given approval to proceed.

Applicants will need to articulate clearly how the expected outputs (including outreach activities and publications) of their project will contribute to the strategic goals and desired outcomes set out in the plan. As evaluation of the likely contribution of the research to achieving these outcomes will be an integral part of the assessment process, it will be important to look at the broad context of the work, and to understand where the project fits within stream project portfolios and plans.

For projects within the Frontier Science theme, the requirement for strategic relevance to theme and stream goals will not apply.

The full cost of logistic support offered by the AAD will be documented and provided in the letters of offer for all approved and supported projects, not just to those who are awarded a cash grant.

Grants

The AAD will continue to offer a competitive grants scheme to support research within the plan.

Transition arrangements

Continuation of existing projects into the term of this plan will be considered by theme and stream leaders, based on the priorities outlined in this plan. Projects due for completion in 2011–12 will be allowed to finish off and those that would extend longer will need to be considered more formally against the theme and stream goals in line with the new application requirements.

Project monitoring and reporting

Stream leaders will maintain contact with all project chief investigators in their streams on a regular basis to monitor progress. All projects will be required to provide progress reports against agreed milestones each year. The reports will be assessed by the research assessment committee to ensure progress is satisfactory against the project objectives, expected outputs and outcomes. Adequate progress must be maintained or the project may be removed from the program. The research assessment committee will make such a recommendation to the Chief Scientist based on its assessment of progress.

A final report will be required at the completion of each project. This report will also be assessed by the research assessment committee.

Outreach and education

In following the lead of the International Polar Year 2007–09 and the Australian Government's recent innovation report *Inspiring Australia: a national strategy for engagement with the sciences,* the program will incorporate outreach and education into each theme, stream and project. Projects will need to demonstrate the outreach and educational activities planned at the application stage of the project. Three main categories of activities will be encouraged:

- broad dissemination of research results
- increasing research capacity
- educational benefits.

Examples of these activities are given on the following page.

GLENN JACOBSON

SALLY CHAMBERS

EXAMPLES OF OUTREACH AND EDUCATION ACTIVITIES

Broad dissemination of research results

- Provide presentations at conferences, in broader community forums (such as through National Science Week, Antarctic Midwinter events, and the Australian Science Media Centre), and at schools.
- Identify research activities suitable for media events or other promotional activities and inform the AAD Corporate Communications area.
- Participate in media interviews.
- Provide to the AAD still images, video footage and research information in plain English, which can be used in various formats for government policy makers, Ministerial briefings, media events, educational material, public displays (such as in museums, science centres), public websites and other non-technical publications.
- Present research to government through appropriate forums.
- Make data available in a timely manner to the Australian Antarctic Data Centre.
- Publish in diverse media (e.g. non-technical literature, websites and CD-ROMS) to reach broad audiences.
- Participate in the development of video and podcasts for upload to public websites.
- Develop partnerships with, for example, Antarctic Arts Fellowships, individual artists and writers, museums, science centres and schools.

Increasing research capacity

- Identify and establish collaborations between disciplines and institutions, among the Australian research institutions and with international partners.
- Establish partnerships that enhance the overall access to scientific infrastructure.

Educational benefits

- Include post-graduate students in projects.
- Provide mentoring to post-graduate students and/or post-doctoral fellows.
- Participate in scientists in schools programs.

In particular the program provides three new initiatives for outreach and education.

1. Post-graduate students

The program has for many years attracted large numbers of students with around 130 post-graduate students involved in projects each year. While Antarctic research is popular with students, there are some clear gaps in Australia's Antarctic research capability that are needed and these areas will be targeted with top-up scholarships funded by the program. Theme and stream leaders will be responsible for identifying these gaps.

2. Post-doctoral fellowships

Post-doctoral fellowships in Antarctic and Southern Ocean science will be developed during the life of the plan.

Co-funded post-doctoral fellowships between the AAD and Australian research institutions will also be awarded.

AAD

3. Annual Antarctic and Southern Ocean symposium

The program will hold an annual symposium commencing in 2011–12. The timing of the symposium will be aligned with the application round to maximise opportunities for new collaborations to be established. Each symposium will include updates from theme and stream leaders on progress with the plan. Workshops will be held as required for each stream to enable design of coordinated and integrated research plans for identifying and assisting with collaborative opportunities. The intention is to hold the symposium in different Australian capital cities. A public lecture will be a feature of each symposium.

The cost of participation in the conference will be an eligible item within the Australian Antarctic grants scheme.

Further information

There are a number of changes to the administrative processes that will support this plan. The web site http://www.antarctica.gov.au will contain up-to-date details throughout the life of the plan.

Notes for page 71

9. Submission to the National Innovation System (NIS) Review
10. NCRIS Roadmap (available at http://ncris.innovation.gov.au/Pages/default.aspx)
11. SCAR Report No. 34 (2009) Data and Information Strategy (DIMS) 2009-2013, Scientific Committee on Antarctic Research, Scott Polar Research Institute, Cambridge, United Kingdom.

Data and information management

Solving complex scientific and societal problems requires collaboration across traditional silos in both science and government. Connecting these silos will rely on a more integrated approach to collecting, managing and accessing the fundamental currency in science, which is data and information. Nationally this position is well understood as evidenced by recent calls for development of a National Environmental Information System (DEWHA, 2008[9]).

As we improve our ability to aggregate multidisciplinary and disparate data, we also increase the potential for new, often serendipitous discoveries. It is only by actively encouraging unfettered, timely access to scientific observations and measurements at the local, regional and global scale that we can hope to understand ecosystem processes and the earth system more generally, predict and address the consequences of global change and manage our resources in a sustained way. By making the output of the program widely and globally accessible through multiple communication channels, the full impact of the program can be realised in helping to address these complex system questions. Program data and information will also continue to feed into national assessments of trends and pressures that provide benchmarks for evaluating environmental change and the effectiveness of change mitigation strategies (e.g. State of the Environment Reporting at www.environment.gov.au/soe/about.html).

Advances in communication technologies, particularly those underpinned by the internet, are providing new models for highly distributed, networked collaboration. Opportunities exist now to exploit the ballooning array of new and sophisticated sensors that collect data at micro and macro spatio-temporal scales. Collegially developed virtual observatories (e.g. those now forming under the National Collaborative Research Infrastructure program[10]) will be key science enablers of the future as well as being highly intensive generators of data. But extracting maximum value from these large-scale, high cost science programs will rely on effective storage, management and re-use of the data generated.

Recognising these factors, the program intends to build on the lead role it already plays in fostering data management best practice within the international Antarctic science community. As a signatory to the Antarctic Treaty, Australia actively promotes Article (III)(1)(c) of the Treaty, urging the free and open exchange of scientific observations and results. These principles are enshrined in the program's data policy (http://data.aad.gov.au/aadc/about/index.cfm). The program will play a strategic role, working with other ATS nations to build a pan-Antarctic Data Management System under the auspices of the Scientific Committee on Antarctic Research (SCAR, 2009[11]). This distributed, but federated system will evolve through national and international collaborations and will be aligned with Australian Government 2.0 Taskforce recommendations on the use of open standards.

The main outcomes that will be delivered through our approach to data and information are those that result in:

- efficient, interoperable and internationally networked data infrastructure delivered through collaboration
- enhanced public and researcher access to data
- minimisation of restrictions on data exploitation
- preservation of source data in a manner that permits long-term re-usability
- increased reliance on open source technologies and methodologies
- improved capacity to integrate multidisciplinary data to help derive innovative products and/or drive new scientific discovery
- maximised knowledge of the topographic, habitat and bathymetric characteristics of Antarctic and subantarctic territories and seas at regional and local scales.

APPENDIXES

Appendix 1 – Acronyms

AAD ....Australian Antarctic Division

AAT ....Australian Antarctic Territory

ACAP..................Agreement on the Conservation of Albatrosses and Petrels

ACE CRC ....Antarctic Climate and Ecosystems Cooperative Research Centre

AFMA..................Australian Fisheries Management Authority

AGAP..................Antarctica's Gamburtsev Province

AGCS ....Antarctica and the Global Climate System

AMMC.................Australian Marine Mammal Centre

ANDRILL ....Antarctic Drilling Project

ANSTO ....Australian Nuclear Science and Technology Organisation

ANU ....Australian National University

ASAC..................Antarctic Science Advisory Committee

ASPA ....Antarctic Specially Protected Area

ATCM..................Antarctic Treaty Consultative Meeting

ATS ....Antarctic Treaty System

AWS ....Automatic Weather Station

BoM ....Bureau of Meteorology

CAWCR ....Centre for Australian Weather and Climate Research

CCAMLR ....Commission for the Conservation of Antarctic Marine Living Resources

CEMP ....CCAMLR Ecosystem Monitoring Program

CEP ....Committee for Environmental Protection

CliC.....................Climate and Cryosphere project

CLIVAR...............Climate Variability and Predictability

CSIRO ....Commonwealth Scientific Industrial Research Organisation

DAFF ....Department of Agriculture Fisheries and Forestry

DCCEE ....Department of Climate Change and Energy Efficiency

DFAT..................Department of Foreign Affairs and Trade

DMS...................Dimethyl Sulphide

DPIPWE ....Department of Primary Industries, Parks, Water and Environment

DSEWPAC..........Department of Sustainability, Environment, Water, Population and Communities

EEZ.....................Exclusive Economic Zone

ENSO ....El Niño Southern Oscillation

EOI ....Expression of Interest

GA.......................Geoscience Australia

GLOBEC.............Global Ocean Ecosystem Dynamics

GRACE...............Gravity Recovery and Climate Experiment

HIMI ....Heard Island and McDonald Islands

ICECAP ....International Climate and Environmental Change Assessment Project

ICED ....Integrated Climate and Ecosystems Dynamics

ICESat ....Ice, Cloud and Land Elevation Satellite

ICSU ....International Council for Science

IGBP ....International Geosphere-Biosphere Programme

IMO ....International Maritime Organisation

IMOS ....Integrated Marine Observing System

IPCC ....Intergovernmental Panel on Climate Change

IPS ....Ionospheric Prediction Service

IPY ....International Polar Year

IWC ....International Whaling Commission

MPA ....Marine Protected Area

MQ ....Macquarie University

NWP ....Numerical Weather Prediction

PAGES ....Past Global Changes Project

RMIT ....Royal Melbourne Institute of Technology University

SAM ....Southern Annular Mode

SARDI ....South Australian Research and Development Institute

SCAR ....Scientific Committee on Antarctic Research

SOLAS ....Surface Ocean Lower Atmosphere Study

SOOS ....Southern Ocean Observing System

SORP ....Southern Ocean Research Partnership

UNEP ....United Nations Environment Programme

UNFCCC ....United Nations Framework Convention on Climate Change

UNSW ....University of New South Wales

UNSW@ADFA....University of New South Wales (Australian Defence Force Academy campus)

UQ ....University of Queensland

UTAS ....University of Tasmania

UTLS ....Upper Troposphere Lower Stratosphere

WCRP ....World Climate Research Programme

WMO ....World Meteorological Organization

Appendix 2 – Acknowledgements

Thank you to the following organisations and individuals who took the time to provide formal submissions on the plan.

Astronomy Australia Ltd – Antarctic Astronomy Advisory Committee

Bureau of Meteorology

Bureau of Rural Sciences

Department of Climate Change (at the time of submission, now the Department of Climate Change and Energy Efficiency)

Department of the Environment, Water, Heritage and the Arts (at the time of submission, now the Department of Sustainability, Environment, Water, Population and Communities):

- Approvals and Wildlife Division
- Australian Antarctic Division (Territories, Environment and Treaties section)
- Environment Quality Division
- Environmental Research and Policy Coordination Division
- Marine Division

Department of Innovation, Industry, Science and Research

Geoscience Australia

Office of National Assessments

University of Newcastle Centre for Space Physics

WWF–Antarctic and Southern Ocean Initiative and the Antarctic and Southern Ocean Coalition

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Professor Michael Ashley

Dr Jeff Ayton

Professor Michael Burton

David Doley

Dr David Etheridge

Professor Neville Exon

Dr Iain Field

Dr Jo Jacka

Professor Jamie Kirkpatrick AM

Dr Des Lugg AM

Dr Dave Neudegg

Professor Patrick G Quilty AM

Professor Alan Rodger

Dr James Smith

Professor Michael Stoddart

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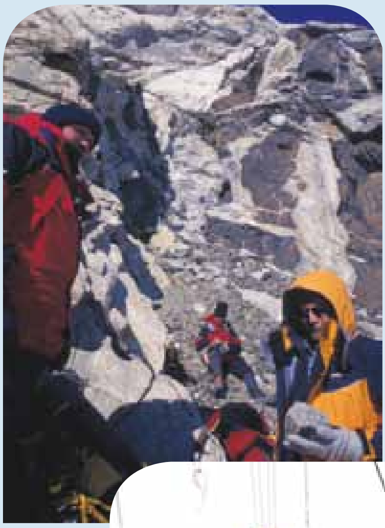
KRISTIN YATES



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