Chapter 9

Towards SCAR's 60th Birthday (2008–18)

Introduction

By 2018 SCAR had been in operation for 60 years. Since its first meeting in The Hague, 3–5 February 1958, it has grown an international network of thousands of scientists who share a common ambition to carry out Antarctic science for the benefit of society. With a membership now representing the scientific communities of 43 countries, SCAR continues initiating, developing and coordinating high quality international scientific research in the Antarctic and the Southern Ocean. An inter-disciplinary committee of the International Council for Science (ICSU), SCAR continues to provide objective and independent advice to various international bodies, especially the Antarctic Treaty Consultative Meetings.

Antarctica and the Southern Ocean play a fundamental role in regulating processes such as climate and carbon uptake, and research in the Antarctic is crucial to understanding processes of global significance. Rapid changes are occurring in parts of Antarctica that could open the continent to a new level of activities in the coming decades. Antarctic governance, administration and environmental protection must be based on scientific data. Therefore, SCAR is more in demand than ever to deliver scientific input to international discussions and provide a platform for the growing international and interdisciplinary collaborations that are required. Since 1958, SCAR has been central to defining the vision and goals of science in Antarctica and has facilitated the implementation of Antarctic science by promoting international and trans-disciplinary collaborations. Providing scientific advice, identifying opportunities, and facilitating collaboration are the core elements of SCAR's mission.

In the last 60 years Antarctic scientists have made astonishing discoveries that have changed how we view our planet. These discoveries have influenced global policies to ban the use of ozone-depleting chemicals; to protect Southern Ocean ecosystems while managing sustainable commercial fishing; and to understand climate change. No one nation can achieve this alone. SCAR has played an international leadership role in shaping the Antarctic research agenda.

Sixty years ago it was the International Geophysical Year (IGY) of 1957–58 that drew world attention to the importance of continuing international Antarctic collaboration. Ten years ago it was the International Polar Year (IPY) of 2007–08. Today, Governments around the world are working together to combat climate change and adapt to its effects, and there are growing concerns about the decline in biodiversity wrought as we enter the Anthropocene, a proposed new geological epoch in which humans are shaping every aspect of the biosphere. SCAR is very well placed to inform and enable intergovernmental initiatives to chart a new course (in the global efforts on climate and biodiversity) through its continued ambition for a coordinated international approach to Antarctic science.

Antarctica is changing rapidly. An iceberg of the size of Luxemburg broke off from the Larsen C Ice Shelf in September 2017 - a prelude to the shelf's eventual disappearance. The Pine Island and Thwaites glaciers continue their rapid retreat, along with that of almost 90% of the glaciers of the Antarctic Peninsula and its nearby islands. Melting land ice contributes to global sea level rise. Antarctica may contribute more than a metre of sea level rise by 2100 and 13 metres by 2500. The area of Antarctic sea ice decreased by 20% below the mean for 1981-2010 in 2016, and stayed 10% below the mean in 2017. The shells of the plankton at the base of the food chain are at risk from spiralling concentrations of carbon dioxide, potentially harming Southern Ocean food webs. These current, worrying observations make SCAR's international research collaboration more urgent that ever. Antarctica is the world's freezer, but we are now holding the fridge door open and seeing the Anthropocene affect the region. At the end of 2017, Sir David Attenborough stressed the importance and urgency of research on Antarctica and the Southern Ocean, in the extraordinary BBC series *Blue Planet II*.

SCAR has reached its sixth decade and has grown substantially in membership – from 12 members in 1958 to 43 currently. It is now well-established as an internationally recognized and influential organization. This has only been possible through the engagement and support of the thousands of researchers from around the world that comprise the SCAR Antarctic scholarly community, together with the support of the SCAR member organizations. They will come together to celebrate SCAR's 60th year at its 35th Meeting and the Open Science Conference (POLAR2018) at Davos in Switzerland, 15–26 June 2018.

Overarching Influences and Developments

Exciting developments continued apace as SCAR entered the post-IPY era from 2010 onwards. Unique efforts began to bring the Antarctic science community and operators together to define the key scientific challenges for the next 20 years and how they might be met in the context of improving our understanding not only of the workings of the Antarctic and the Southern Ocean 'system', but also how what happens there affects and is affected by what is happening elsewhere on the planet. SCAR's emphasis on climate change has grown, echoing the call by the UN Framework Convention on Climate Change (UNFCCC) in Paris in December 2015 to limit the global rise in temperature to between 2.0 and 1.5°C. SCAR's emphasis on biodiversity and conservation grew too, in part responding to the need to meet some of the sustainable development goals promoted by the UN General Assembly in 2015 in their 2030 Agenda for Sustainable Development, which itself was a response to the fact that critical planetary boundaries were in danger of being breached [1]. The nature of science was changing too, with the increasing application of the holistic Earth System perspective that had been developed within the International Geosphere-Biosphere Programme (IGBP) of 1987-2015, and which recognized that everything is connected and that understanding the complexities of the natural environment requires complex interdisciplinary approaches. Those influences are leading SCAR to take an ambitious, wide-ranging, ocean- and/or continent-wide, integrated and interdisciplinary approach to the development of its flagship Scientific Research Programmes (SRPs). And all of these matters are of significant concern to SCAR's partners, especially the Treaty Parties responsible for managing Antarctica and the marine living

[1] Steffen, W, Richardson, K, Rockström, J, *et al.* 2015, Planetary boundaries: Guiding human development on a changing planet. *Science.* 347 (6223): 1259855. doi:10.1126/science.1259855

Mahlon (Chuck) C Kennicutt II, President 2008–12

Mahlon "Chuck" Kennicutt II was a founding member and former Director (1998-2004) of the Geochemical and Environmental Research Group (GERG) and is Professor Emeritus of Oceanography at Texas A&M University (TAMU). He received his BS degree in chemistry from Union College (1974) and a PhD in Oceanography (1980) from TAMU. At GERG he was involved in more than $100 million of research funding; spent more than 575 days at sea; mentored 21 MS and PhD graduate students; published over 130 scientific articles and nine chapters in books; and participated in submersible cruises on the Johnson Sea-Link, the *Diaphus*, the US Navy NR-1, and *Pisces II* submarines. In 2004, he was named Director of Sustainable Development in the Office of the Vice-President for Research at TAMU and continued to lead the Sustainable Coastal Margins Program created in 2000. In the Oceanography Department he taught oceanography, polar science, and science and policy. His research interests include environmental chemistry, organic geochemistry, the fate and effects of pollutants, environmental monitoring, ecosystem health, Antarctic environmental issues, and sustainability science.

He was involved in a number of breakthrough scientific findings. He was the lead author on the first discovery of cold-seep chemosynthetic communities in 1984 a few years after the discovery of hydrothermal vent ("hot vent") communities greatly expanding the habitats for organisms living without sunlight. He was co-author on papers that reported the first occurrence of thermogenic gas hydrates in nature, the first occurrence of gas hydrate structure H and the first marine molluscan symbiosis based on methane. He was a leading chemist on responses to several major oils spills including the IXTOC-1 blowout, the *Exxon Valdez* spill, and the *Mega Borg* accident. He was involved in developing molecular and stable isotopic fingerprinting techniques to trace the origins of oil and gas from anthropogenic releases and as a fossil fuel exploration technique (hydrocarbon seep detection). He also led major human impact monitoring programs in Antarctica for more than 20 years.

When he first went to Antarctica as a graduate student in 1977 it marked the beginning of more than 22 years of research on the impact of humans on Antarctica. He served as the US Delegate to SCAR for 14 years and was a Vice–President 2004–08 and President 2008–12. He was an *ex officio* member of the National Academy's Polar Research Board for 14 years, a science advisor to the US Antarctic Treaty Delegation for 7 years, and attended 10 Antarctic Treaty Consultative Meetings. He has served on numerous US National Academy committees including on the effects of oil and gas exploration on the North Slope of Alaska. He is currently a Trustee and Chair of the International Science Panel of the New Zealand Antarctic Research Institute. He has been named a National Associate of the US National Academy of Sciences for life and was awarded the US Antarctic Service Medal. Kennicutt Point in Antarctica was officially named in 2006.

Final meeting of the IPY Joint Committee, 7 June 2010, in Oslo.

Left to right: front row: Tillman Mohr, Michel Beland, Deliang Chen, Ed Sarukhanian, Volker Rachold, Robin Bell; 2nd row: Keith Alberson, Ian Allison, Helena Odmark (above) Eberhard Fahrbach, Colin Summerhayes, Takahashi Yamanouchi, Jerónimo López-Martínez, Grete Hovelsrud; back row: David Hik, Chuck Kennicutt, Igor Krupnik, David Carlson, Taco de Bruin, Paul Cutler, Vladimir Kotlyakov, Odd Rogne, Manfred Reinke.

resources of the Southern Ocean. SCAR continues to adjust its research profile to face these growing challenges and to stay at the scientific frontier.

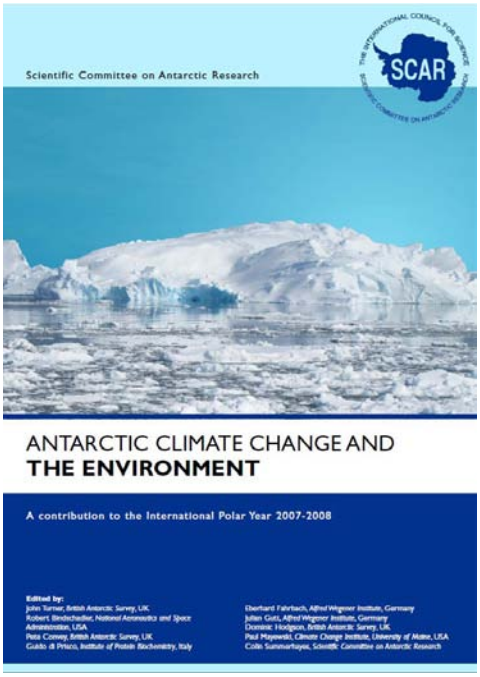
As we saw in Chapters 7 and 8, during the era of the first Strategic Plan (2004-2010) one of the most important external influences on SCAR and its science was the International Polar Year (IPY) (2007-2008), which changed the playing field for polar research. As the IPY management activities drew to an end in mid 2010, SCAR, which had played a key role with its Arctic counterpart, the International Arctic Science Committee (IASC), in taking the IPY forward to its successful conclusion, agreed to share the role of implementing the legacy of the IPY. Later in the text SCAR's role in winding down IPY activities is briefly explored.

As the IPY Final Report [2] published in 2011 observed, while a great deal had been achieved through the IPY, and many results were as yet forthcoming, many substantial challenges remained to be addressed in the Polar Regions. In the Antarctic (and elsewhere) they included: rapid climate change; diminishing snow and ice; sea level rise; changing ice sheet dynamics; changes to ocean circulation; loss of biodiversity; changing ecosystem patterns and ranges; melting permafrost; the need for improved projections and forecasts of climate and weather; and the transport of pollution and contamination to the Polar Regions and its effects. Evidently, there were ample challenges on the horizon for SCAR to pursue, not only for their intrinsic scientific interest, but also because they carried implications for policy-making bodies.

In the lead up to, and during, the IPY, SCAR put considerable effort into addressing the climate-related issues on that list in a major multidisciplinary study on Antarctic Climate Change and the Environment (ACCE) [3]. The cross-disciplinary ACCE report, published at the end of 2009 and outlined in Chapter 7, turned out to be one of SCAR's most important products, forming a south polar complement to the Arctic Climate Impact Assessment (ACIA) published in 2005 by the Arctic Council and the International Arctic Science Committee (IASC). The ACCE and ACIA reports provide essential multidisciplinary scientific bases for appreciating how the polar regions are responding, and may yet respond, to global warming, as well as providing advice on what new research needs doing to better understand and forecast climate change

[2] Krupnik, I, Allison, I, Bell, R, Cutler, P, Hik, D, López-Martínez, J, Rachold, V, Sarukhanian, E, and Summerhayes, C, (eds.). 2011. Understanding Earth's Polar Challenges: International Polar Year 2007-2008. *Occasional Publication Series* 69, CCI Press, Edmonton, 750 pp. Also at www.icsu.org/publications/understanding-earths-polar-challenges-international-polar-year-2007-2008.

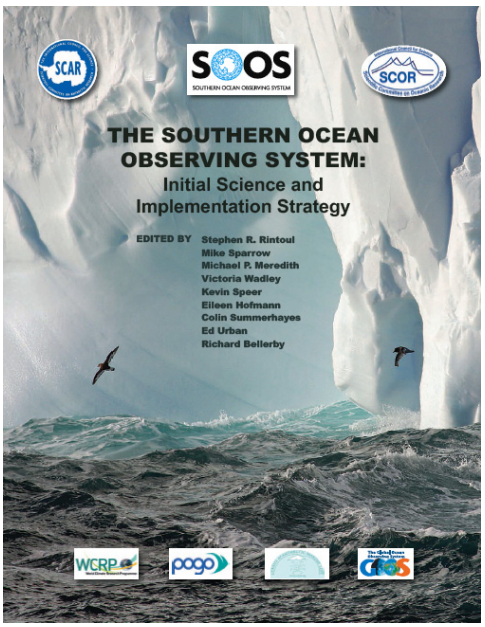
[3] www.scar.org/policy/acce-updates/.



The cover of the *Antarctic Climate Change and the Environment* book.

at the poles. The development of interdisciplinary efforts on a similarly grand scale would be encouraged as SCAR's second and third Strategic Plans developed.

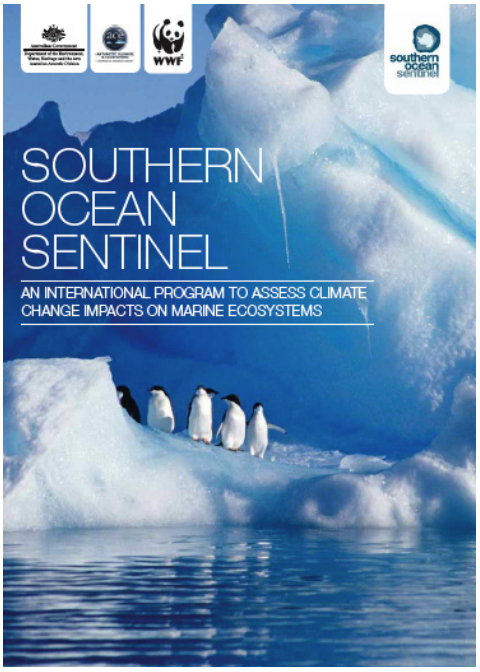
In parallel with the development of the wide-ranging and multidisciplinary investigation of the climate system, through the ACCE report and its aftermath, SCAR began in 2006, to develop plans for a wide-ranging and multidisciplinary Southern Ocean Observing System (SOOS) to monitor the physical, chemical and biological status and trends of the Southern Ocean, so as to underpin research into climate change and the evolution of biodiversity in the region. SOOS developed its key planning documents during 2012–15, and is now well underway, with international activities facilitated and coordinated through an International Project Office (IPO) at the University of Tasmania in Hobart. The SOOS-IPO is co-located with Australia's Integrated Marine Observing System (IMOS), and has been managed from August 2011 by an Executive Officer. A parallel initiative, the Southern Ocean Sentinel programme, which is being developed under the SCAR co-sponsored programme on Integrating Climate and Ecosystems Dynamics in the Southern Ocean (ICED), will provide much of the biological component of SOOS. ICED and SOOS are working together to support international conferences on Marine Ecosystem Assessment of the Southern Ocean (in April 2018), and Benchmarking Southern Ocean Ecosysems (in 2022), to build on the results achieved under SCAR's Census of Antarctic Marine Life, a contribution to the global Census of Marine Life, which came to and end in 2010. Together SOOS and ICED, are planning large-scale interdisciplinary initiatives to facilitate information flow and foster international collaboration on the status and trends of Southern Ocean ecosystems.



The cover of *The Southern Ocean Observing System* book.

SOOS has a much wider impact than the south Polar Region alone, forming a regional component of the Global Ocean Observing System (GOOS) co-sponsored by ICSU, the World Meteorological Orga-

The cover of *Integrating Climate and Ecosystems Dynamics in the Southern Ocean* book.



The cover of the *Southern Ocean Sentinel* book.

nization (WMO) and UNESCO's Intergovernmental Oceanographic Commission (IOC). SOOS is co-sponsored by SCAR, the Scientific Committee on Oceanic Research (SCOR), the Partnership for Observations of the Global Ocean (POGO) and two projects of the World Climate Research Programme (WCRP), namely Climate Variability (CLIVAR) and Climate and the Cryosphere (CliC).

On a separate major front, in early 2010, having recognized that efforts to conserve biodiversity in Antarctica remained distinctly *ad hoc*, despite the efforts of the Antarctic Treaty Parties, Professor Steven Chown, then the Chief Officer of SCAR's Standing Committee on the Antarctic Treaty System, convinced SCAR that it was time to take a long hard look at the state of biodiversity in the region, and proposed holding a ground-breaking workshop on Antarctic Conservation for the 21st Century to develop ideas. The workshop's core tasks were to review what was known and to undertake an 'Horizon Scan' (defined as a systematic means for identifying emerging trends and assisting decision-makers in identifying policies that address future challenges) of the issues facing conservation in the Antarctic. Its landmark recommendations were published in the journal *Science* in 2012 [4] to widespread acclaim. This topic has continued to grow in importance as noted below under Life Sciences.

Naturally, SCAR's Antarctic Treaty partners were keenly interested in this development, which led SCAR and its Antarctic Treaty partners to develop a wide-rang-

[4] Chown, S L, Lee, J E, Hughes, K A, *et al.* 2012. Challenges to the Future Conservation of the Antarctic. *Science*, 337, 158-159 and supplementary materials at www.sciencemag.org/cgi/content/full/337/6091/PAGE/DC1.

Jerónimo López-Martínez, President 2012–16

Jerónimo López-Martínez was born on 30 July 1951. After school he read geology at the University Complutense of Madrid for his BSc degree and continued at the University of Zaragoza to achieve a PhD in geology. His interests and research are wide-ranging and include geomorphology, neotectonics, quaternary geology, palaeoclimatology, karst geology, hydrogeology, geological hazards, environmental geology and geological heritage. Since 1989 when he first became involved with Antarctica he has added Antarctic geology to the list. All of these are evident by the breadth of more than 270 scientific publications. He has participated in about 30 expeditions to the polar regions and the world's main mountain ranges, including ten to Antarctica and eight to the Himalayas. He has a love of mountaineering and has made ascents of many high peaks including Mount Everest and, in 1990, the first Spanish ascent of Mount Vinson, Antarctica's highest summit at 4892 m.

He is currently Professor of External Geodynamics at the Autonomous University of Madrid and a senior figure in the Spanish geological community. He has taught, directed research projects and collaborated with scientists at many different institutions in Spain and abroad, including Argentina, Brazil, Britain, France, Germany, Italy, New Zealand, Portugal, South Korea, Sweden and the United States. He is a member of the editorial committee of several Spanish and international scientific journals. He has participated in the evaluation of projects and institutions, both in Spain as in other countries. In particular he was a member of the panel that evaluated the science and management of the British Antarctic Survey. He has been secretary of the Spanish Polar Committee and manager of the Spanish National Research Programme in Antarctica. He was in charge of adapting Spanish Antarctic activities to conform with the requirements of the

Protocol on Environmental Protection to the Antarctic Treaty, following its entry into force in 1998.

His participation in SCAR began in the early 1990s as the Spanish representative on the Working Group on Geology. Since 1996 he has been the Spanish Delegate at SCAR Meetings and was elected a Vice-President of SCAR 2002–06. He was a member of the SCAR delegation that received the prestigious Prince of Asturias Award for International Co-operation in Oviedo in 2002. At the XXXII SCAR Meeting in 2012 he was elected President of SCAR 2012–16. He presented the SCAR Lecture at the 35th ATCM (Santiago, Chile, 2016), on Exploring the Future of Scientific Research in Antarctica.

For 5 years, from 1998, he was the Spanish delegate to the Committee on Environmental Protection at Antarctic Treaty Consultative Meetings. He has also been a Vice-President of the European Polar Board and was a member of the Joint Committee for the International Polar Year 2007–08 from its first meeting in Paris in March 2005 until its ninth and last meeting in Oslo, at which he co-chaired the Committee.

ing Antarctic Conservation Strategy that by 2013 had been rebranded Antarctic Conservation in the 21st Century. The strategy is due for release soon. A key tool for implementing that strategy and providing Treaty Parties with up-to-date science information on key agenda topics is the Antarctic Environments Portal, a pilot version of which SCAR was working on with New Zealand and Australia in 2012–13, and which was launched in 2014. A substantial grant from the Tinker Foundation provided for its continued development through to 2020.

A further influence on SCAR's direction came from the strategic lead provided by its parent body, ICSU, which in 2010 had identified a suite of five Grand Challenges for global sustainability [5], which would form the core of its own Strategic Plan for 2012–17. Meanwhile, under President Chuck Kennicutt (2008–12), SCAR had been developing its second Strategic Plan, for 2011–17. Clearly there was a need to see how ICSU's Strategic Plan, SCAR's Strategic Plan and the plans of SCAR's polar counterpart, the International Arctic Science Committee (IASC), might together indicate the best way forward for the polar sciences in the next decade, and that led to the participation of the three organizations in an ICSU-sponsored conference on Research urgencies in the Polar Regions and their links to the ICSU Grand Challenges in Global Sustainability, in Sienna, Italy, in September 2011.

Recognizing the urgencies identified by the participants in Sienna, along with SCAR's responsibility for both carrying forward the legacy of the IPY and meeting ICSU's strategic requirements, SCAR President Chuck Kennicutt decided that SCAR needed to undertake a comprehensive evaluation of research priorities for the next decade, and proposed to the Delegates meeting in Portland, Oregon, in July 2012, that SCAR should undertake an expanded Horizon Scan covering all Antarctic sciences. An Action Group was created to begin planning and fundraising for an Horizon Scanning activity that took place in 2014 under the subsequent presidency of Professor Jerónimo López-Martínez (2012–16).

The SCAR EXCOM meeting of July 2013, in Barcelona, Spain, agreed that the Antarctic and Southern Ocean Science Horizon Scan would assemble a group of the world's leading Antarctic scientists, policy-makers, leaders, and visionaries to identify the most important scientific questions that should be addressed by research in and from the south Polar Regions over the next two decades. Chuck Kennicutt was asked to arrange the Horizon Scan, an assembly that grew to 75 participants from 22 countries. They met in Queenstown, New Zealand, in April 2014, and identified a list of 80 key scientific questions that should be addressed by research in Antarctica and the Southern Ocean in the next 20 years and beyond. This was a highly significant development - the first time the international Antarctic community had formulated a collective vision through discussions, debate and voting. The 80 pressing questions fell into 6 scientific priority areas [6] defining the global reach

[5] **Forecasting:** improve the usefulness of forecast s of future environmental conditions and their consequences for people. **Observing**: develop, enhance and integrate the observation systems needed to manage global and regional environmental change. **Confining**: determine how to anticipate, recognize, avoid and adapt to abrupt global environmental change. **Responding**: determine what institutional, economic and behavioural changes can enable effective steps towards global sustainability. **Innovating**: encourage innovation (coupled with sound mechanisms for evaluation) in developing technological, policy and social responses to achieve global sustainability.

[6] Kennicutt, M C, Chown, S L, Cassano, J L, Liggett, D, *et al.* 2014. Six priorities for Antarctic science. *Nature* 512, 23-25.

Participants in the Horizon Scan held in Queenstown, New Zealand, in April 2014.

of the Antarctic atmosphere and Southern Ocean; understanding how, where and why ice sheets lose mass; revealing Antarctica's history; learning how Antarctic life evolved and survived; observing space and the Universe from platform Antarctica; and recognizing and mitigating human influences.

In 2015, the organizers of the Horizon Scan set out a Roadmap for Antarctic science for the future, noting that: "Answering the questions identified by the horizon scan will require innovative experimental designs, novel applications of technology, invention of next-generation field and laboratory approaches, and expanded observing systems and networks. Unbiased, non-contaminating procedures will be required to retrieve the requisite air, biota, sediment, rock, ice and water samples. Sustained year-round access to Antarctica and the Southern Ocean will be essential to increase winter-time measurements. Improved models are needed that represent Antarctica and the Southern Ocean in the Earth System, and provide predictions at spatial and temporal resolutions useful for decision- making. A co-ordinated portfolio of cross-disciplinary science, based on new models of international collaboration, will be essential as no scientist, programme or nation can realize these aspirations alone" [7].

The challenge of addressing the five priority science areas identified in the Horizon Scan was addressed by the Antarctic Roadmap Challenge (ARC) project, led by the Council of Managers of National Antarctic Programmes (COMNAP) and sup-

[7] Kennicutt, M C, Chown, S L, Cassano, J L, Liggett, D, *et al*, 2015, A roadmap for Antarctic and Southern Ocean science for the next two decades and beyond. *Antarctic Science*. 27(1), 3-18.

The Antarctic Roadmap Challenges

ported by SCAR from 2014 onwards. Professor Kennicutt for SCAR and Dr Yeadong Kim for COMNAP co-chaired an International Steering Committee to organize the ARC project. The Roadmap [8, 9], outlines key future scientific priorities, along with their associated challenges and the means to achieve them, as shown under COMNAP, later in the text.

Aside from considering how it might respond to major scientific challenges, SCAR also needed to review its performance in facilitating science and providing independent scientific advice to governments. The SCAR-sponsored external review of 2009 (see Chapter 8) provided useful background for SCAR's development of the 6-year Strategic Plan for 2011–16 (Antarctic Science and Policy Advice in a Changing World). That development began under President Chuck Kennicutt (2008–12), as the first Executive Director, Dr Colin Summerhayes, was about to retire (in April 2010), and continued under its second Executive Director, Dr Michael Sparrow, formerly SCAR's Executive Officer. The Delegates meeting in Buenos Aires in August 2010 approved the plan, which took effect on 1 January 2011. Its inspiring preface (see Text Box below), penned by Chuck Kennicutt, encapsulates many of the key drivers that have shaped SCAR over the last 60 years.

The responsibility for implementing the SCAR Strategic Plan for 2011–16 rested subsequently with President Jerónimo López-Martínez (2012–16). Under his leadership, the Delegates meeting in Auckland, NZ, in 2014, asked Dr Terry Wilson to chair an *ad hoc* Committee to review SCAR's structure, to see what changes could be made to improve SCAR's overall performance. Delegates meeting in Kuala Lumpur in 2016 agreed with most of the key recommendations [10], which included: asking SCAR groups to provide more data to populate the SCAR web pages; getting SCAR to explain what it does in more accessible ways; making it easier for outsiders to join SCAR groups; increasing the SCAR profile at the national level; and continuing to focus SCAR's scientific efforts on a small number of SRPs, along with a few smaller Expert and Action Groups (EGs and AGs), all with clearly specified remits and life times.

ICSU's own independent 2015–16 review of SCAR, which was the first for over a

[8] Kennicutt, M C, Kim, Y, and Rogar-Finnimore, M. 2016. *Antarctic Roadmap Challenges*. COMNAP, 140pp. ISBN 978-0-473-35673-6 (PDF)

[9] Delivering 21st century Antarctic and Southern Ocean science. 2016. *Antarctic Science*, 28(6) 407-423. [10] reported in *SCAR Bulletin* 192 in November 2015.

[11] FutureEarth is a flagship 10-year project of the Science and Technology Alliance for Global Sustainability. It builds on the success of existing global environmental change programmes (Diversitas, IGBP, IHDP, WCRP and ESSP). It was launched at the UN Conference on Sustainable Development in Rio de Janeiro in July 2012, and transitioned to full development in May 2014. Its Secretariat is at ICSU's Paris headquarters. The Alliance's partners include the Belmont Forum and International Group of Funding Agencies for Global Change Research (IGFA), the International Council for science (ICSU), the International Social Science Council (ISSC), the United Nations Environmental Programme (UNEP), the United Nations Educational, Scientific and Cultural Organization (UNESCO), the United Nations University (UNU), the World Meteorological Organization (WMO), the Scientific Committee on Oceanic Research (SCOR), the Intergovernmental Oceanographic Commission (IOC), and the World Climate Research Programme (WCRP).

Extract from 'Preface to Antarctic Science and Policy Advice in a Changing World', SCAR's Strategic Plan 2011-2016

"The realities of conducting research in the southern polar regions bring with it great challenges but also great opportunities. The questions being asked by those with interests in Antarctica, the Southern Ocean and the Earth system are more complex and demanding than ever before. The critical role of scientific knowledge developed from the study of Antarctica and the Southern Ocean has never been more important in discerning the future of our planet. Antarctica and the Southern Ocean are a natural laboratory where global forces play out in ways not experienced or observable elsewhere on the planet. Antarctica also serves as a unique vantage point to look outwards from our planet to observe near-Earth space, our solar system and beyond. In a time of economic stress, it is important that resources be utilized to optimum affect, that investments in science in Antarctica be justified, and that the community develops and shares a collective vision of future scientific directions. A well-conceived strategy is not only essential but critical.

The strength of an organization can best be judged by the dedication and participation of its members. To ensure the highest level of contributions, those involved must feel genuine ownership of an organization's vision, mission and goals. This can best be accomplished by involvement in developing plans for the future. This is especially important for an organization whose success is dependent on membership fees and volunteers, such as the Scientific Committee on Antarctic Research (SCAR). The process of developing this strategic plan has been inclusive, consultative and iterative, aiming for a consensus view of how best to accomplish SCAR's vision and mission over the next six years.

SCAR has a special place amongst international scientific organizations, in that its focus – Antarctica – invokes the best of human emotions – wonder, awe, inspiration and even joy! Since its inception, more than 50 years ago, SCAR has greatly benefited from the support of a dedicated community of "true believers" in the uniqueness and grandeur of the southern Polar Regions. It is a privilege to conduct science, to work and to learn in one of Earth's remaining wildernesses. With this privilege, there is a responsibility to act as environmental stewards of the last great under-explored continent on our planet.

... [Antarctica] evokes a sense of discovery as [a location] of unexplored places and the origin of surprising findings that inspire unconventional thinking. Now is the time for the Antarctic science community to build on its past accomplishments and elevate their presence and importance in the global conversation. SCAR is uniquely positioned to foster and lead these efforts. It is not just for the future of SCAR that we must think and act strategically, but for the greater good of the place we cherish, the societies we live in and the planet we inhabit."

decade and which included a detailed interview in Potsdam with the SCAR leadership, concluded that SCAR was performing well but would benefit from: simplifying its structure; better defining its role and niche; further expanding its links to global science (including engaging with FutureEarth) [11]; further expanding its membership; building capacity in Asia, Africa, South America and other developing areas (with the help of ICSU's Regional Offices); increasing the participation of women; developing a fundraising strategy; embracing technology for virtual meetings; improving communications; and providing key performance indicators along with plans to achieve them.

The various topics mentioned above were addressed in the development of the Strategic Plan for 2017-2022 (Connecting and Building Antarctic Research) [12], which began during the presidency of Jerónimo López-Martínez and concluded under President Steven Chown (elected in 2016), with the assistance of the third Executive Director, Dr Jenny Baeseman, who took up her appointment in July 2015 following the departure of Mike Sparrow in May that year [13]. On the research front, SCAR had maintained its regular turnover of flagship SRPs, and SCAR's EXCOM meeting in Brno in July/August 2017, under President Steven Chown (2016–), had decided to encourage the development of one or more wide-ranging and challenging interdisciplinary research programmes, for example to understand the past and future behaviour of ice sheets and their implications for global sea-level rise. SCAR is uniquely positioned to facilitate a project of that nature [14].

By early 2018, the most prominent among the emerging ideas for such programmes, reflecting the outcomes of the Horizon Scan, were: (i) understanding the biodiversity and functioning of marine and terrestrial biological systems and how to protect them; and (ii) understanding ocean-cryosphere-atmosphere interactions, the behaviour of ice sheets, and global sea-level variation.

On the gender front, SCAR had encouraged the participation of women in Antarctic science, through the *Wikibomb* launched in Kuala Lumpur in 2016 [15]. On the membership front, SCAR had gained several new members since 2008, including Monaco (2010), Venezuela (2012), Iran and the Czech Republic (2014), and Colombia, Austria, Thailand and Turkey (2016). On the funding front, from 2015 onwards, SCAR began using a Development Council to advise it on potential external sources of funds.

SCAR also took steps to further enhance its interactions with partner organizations having a direct involvement in the Antarctic, like the Antarctic Treaty's Committee on Environmental Protection (CEP) and the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), as well as other organizations with a global remit including polar interests, like the World Meteorological Organization (WMO), the World Climate Research Programme (WCRP), and other polar organizations, like the International Arctic Science Committee (IASC), with which SCAR shared common interests.

Throughout the period 2010–18, SCAR's Strategic Vision evolved to reflect both internal and external changes. It was reframed in the Strategic Plan for 2017–22 as being "to be an engaged, active, forward-looking organization that promotes, facilitates, and delivers scientific excellence and evidence-based policy advice on globally significant issues in and about Antarctica, so as to create a legacy of Antarctic research as a foundation for a better future. In line with this vision, through scientific research and international cooperation, SCAR will establish a thorough understanding of the nature of Antarctica, the role of Antarctica in the global system, and the character and effects of environmental change and human activities on Antarctica."

SCAR's Mission, as specified in the 2017–22 Strategic Plan remained: "to advance Antarctic research, including observations from Antarctica, and to promote scientific knowledge, understanding and

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[12] www.scar.org/scar-library/other-publications/strategic-plans/774-2017-strategic-plan/file/.

[13] Dr Baeseman left SCAR in mid-November 2017, and was replaced by the new Executive Director, Dr Chandrika Nath, in July 2018.

[14] for an example of how SCAR might proceed, see the Past Antarctic Ice Sheet Dynamics project under the Geosciences section.

[15] www.scar.org/antarctic-women/

Women in Antarctic Research Wikibomb [16] celebration at XXXV SCAR Open Science Conference, Kuala Lumpur, Malaysia, in 2016.

Left to right: Dr Terry Wilson (US Delegate), Dame Jane Francis (UK Delegate), Dr Carlotta Escutia-Dotti (leader of SCAR's PAIS SRP) with President Jerónimo López-Martínez at the Women in Antarctic Science meeting in Tromsø, 2015.

education on any aspect of the Antarctic region. To this end, SCAR is charged with the initiation and international coordination of Antarctic and Southern Ocean research beneficial to global society. SCAR provides independent and objective scientific advice and information to the Antarctic Treaty System and other bodies, and acts as the main international exchange of Antarctic information within the scientific community."

SCAR's vision and mission are entirely consistent with the vision and mission of its parent body, ICSU [17]. For example, in August 2010, to meet ICSU's requirements of its interdisciplinary bodies, SCAR became a fully independent body, a Company Limited by Guarantee, with its own Articles of Association. While still remaining an interdisciplinary body of ICSU, SCAR now operates as a UK Charity (because its Secretariat is located in Cambridge). The members of EXCOM are the Trustees of the Charity.

During 2009-2018, SCAR continued to organize its biennial Open Science Conferences (OSCs) as a forum for the community of polar scientists, researchers, and students to report on the latest science, exchange ideas and explore new opportunities. Attendances average around 1000. The 4th OSC took place in Buenos Aires, Argentina (August 2010), the 5th in Portland, Oregon (July 2012), the 6th in Auckland, New Zealand (2014), the 7th in Kuala Lumpur, Malaysia (2016) and the 8th in Davos, Switzerland (June 2018), this latest one being a joint SCAR-IASC Conference (POLAR2018).

As a measure of its standing in the international community, SCAR was awarded the Prince Albert II of Monaco Foundation's 2013 Prix Biodiversité in recognition of its contribution to science and its work to improve understanding of the environment. SCAR also continued to manage for the Tinker Foundation the process for awarding the prestigious US$100,000 Muse Prize (formerly the Martha T Muse Prize) (see Appendix 7), whose contribution for the first 10 awards amounts to US$1,800,000, excluding administrative costs.

This chapter covers the work carried out under three SCAR Presidents, Professor Mahlon 'Chuck' Kennicutt (2008–12),

[16] https://en.wikipedia.org/wiki/Wikipedia:Meetup/SCAR_2016
[17] www.icsu.org/about-us

Professor Jerónimo López-Martínez (2012–16), and Professor Steven Chown (2016–), and through four Delegates' meetings: Buenos Aires, Argentina, in 2010; Portland, Oregon, in 2012; Auckland, New Zealand, in 2014; and Kuala Lumpur, Malaysia, in 2016; leading up to the 60th birthday meeting in Davos, Switzerland in 2018. SCAR's regular process of strategic planning involved the plans being developed initially by EXCOM, with the aid of the Chief Officers of the SCAR subsidiary groups and the leaders of the SRPs, along with the Executive Director, under the leadership of the President of the day, for approval by the Delegates. Professor Kennicutt oversaw the completion of implementation

SCAR EXCOM meeting in Tromsø, 2015, including Chief Officers (COs) of Science Groups. Left to right: Azizan bin Abu Samah (Vice-President), Jenny Baeseman (Executive Director), Jesus Galindo (Deputy CO Geosciences), Eoghan Griffin (Executive Officer), Terry Wilson (Vice-President), Jerónimo López-Martínez (President), John Storey (CO of AAA SRP), Carlota Escutia-Dotti (CO of PAIS SRP), Daniela Liggett (Co-Chair Humanities and Social Sciences), Aleks Terauds (CO of SCATS), Bryan Storey (Vice-President), Karin Lochte (Vice President), Yan Ropert-Coudert (Secretary of Life Sciences), Huw Griffiths (Co-CO AntEco), Julian Gutt (CO AnT-ERA), Anton Van de Putte (CO SCADM).

SCAR President Jerónimo López-Martínez opening the XXXIV SCAR Meeting and OSC, Kuala Lumpur, Malaysia, 2016.

Prince Albert II of Monaco presenting the 2013 Prix Biodiversité Award to SCAR President Jerónimo López-Martínez

Logo for XXXI SCAR meeting and Open Science Conference, July–August 2010, Buenos Aires, Argentina.

Logo for XXXIII SCAR meeting and Open Science Conference, July 2014, Auckland, New Zealand.

Logo for XXXII SCAR and Open Science Conference, July 2012, Portland, United States.

Logo for XXXIV SCAR meeting and Open Science Conference, August 2016, Kuala Lumpur, Malaysia.

Logo for the joint SCAR–IASC Science Conference at the POLAR2018 Meeting in June 2018, Davos, Switzerland.

Steven L Chown, President 2016–20

Steven Chown was born on 27 June 1964 in Pretoria, Gauteng, South Africa. He studied entomology at the University of Pretoria and graduated with a BSc in 1985. He stayed until 1989 to complete a PhD on the ecology and systematics of sub-Antarctic weevils involving field work on Marion Island. He was employed by the University in 1989 as a lecturer and then in 1997 as Professor of Entomology. In 2001 he became Professor in Zoology at Stellenbosch University. In 2004 he was appointed the first Director of the DST-NRF Centre for Excellence in Invasion Biology.

He was Chairman of the Prince Edward Islands Management Committee 1996–98. In 2002 he was elected Chief Officer of the SCAR Life Sciences Standing Group. He was the SCAR Delegate for South Africa (2002–12) and Chairman of the SCAR Standing Committee on the Antarctic Treaty System (2006–14) where he was the primary interlocutor between the science community and the Treaty.

In 2012 he moved to be Professor of Biology at Monash University in Melbourne and within a year was promoted to Head of School of Biological Sciences. This was a major increase in his management responsibilities as Monash was revitalizing the School. In 2017 he stepped back to his original professorship.

He has worked across a wide range of fields, from basic insect physiology to the ecological implications of animal physiological variation. With others he was instrumental in developing the field of macrophysiology to provide much insight into the responses of organisms to environmental change at global scales. Most of his work has focused on insects and other invertebrates but he has also worked on mammals, birds, reptiles and plants. Antarctic and sub-Antarctic systems and their biodiversity have formed a significant focus and he has been heavily

involved in both science and conservation policy development for the region.

He was the inaugural recipient of the Martha T Muse Prize for science and policy in Antarctica and has also received the SCAR Medal for Excellence in Antarctic Research, the South African Antarctic Gold Medal, and the Zoological Society of Southern Africa Gold Medal.

He has published more than 440 peer-reviewed scientific papers and several scientific and popular books. He has been Editor-in-Chief of Functional Ecology, and on the editorial boards of several learned journals.

His work has had substantial impacts on conservation and science policy. Much of this has been delivered through interactions with the Antarctic Treaty System and has resulted in policy progress on invasive species, climate change adaptation and conservation management of the Antarctic.

Since becoming President Steven has embarked on major changes to increase the efficiency of SCAR, enhance its connectivity with a wider range of other partners and develop an active and topical output to ensure it remains at the forefront of Antarctic science worldwide.

SCAR Cross-Programme Workshop on interdisciplinary Antarctic and Southern Ocean Research, Barcelona, Spain, September 2015.

Incoming SCAR President Steven Chown (left) and outgoing President Jerónimo López-Martínez (right) at the SCAR meeting in Kuala Lumpur, 2016.

of the first Strategic Plan (2004-2010) and the development and start of implementation of the second Strategic Plan (2011-2016). Professor López-Martínez oversaw completion of the implementation of the second Strategic Plan and began development of the third Strategic Plan (2017-2022). Professor Chown oversaw the further development and initial execution of the third Strategic Plan (2017-2022), and will be responsible for developing the fourth one. These key documents, approved following discussion and input from the Delegates, set the pace and direction of SCAR's continued evolution.

Advances in Science Delivery

The main vehicles for delivering SCAR's scientific outcomes throughout the 2009–18 period continued to be its SRPs, organized by the scientific community operating under the aegis of SCAR's Geosciences, Life Sciences and Physical Sciences Groups (the 'Standing Scientific' part of each group's name was dropped in 2016), and approved by the SCAR Delegates. A key role for the SRPs is to facilitate collaboration on important scientific questions through workshops and conferences that maximize international and multidisciplinary involvement.

During the 2009–18 period the five original SRPs came to their expected end at different times, and were replaced by new SRPs addressing different challenges. The progress of each SRP is reviewed regularly by EXCOM and the Delegates, the last such review being completed in 2016.

Life Sciences

Highlights from the SRPs operating under the aegis of Life Sciences included the following selected key findings whose publications are grouped by year.

For 2010 it was observed that:

1. the Southern Ocean was the centre of evolution for octopuses;

2. at least 200 invasive species have become established on the continent and the sub-Antarctic islands. The SCAR-led IPY project 'Aliens in Antarctica' showed that many species were introduced inadvertently on the clothing or equipment brought to scientific stations (more so than through tourism);
3. onshore, warming has led to an increase in some indigenous species, like springtails. Vascular plants have increased by 1-2 orders of magnitude on Alexander Island over the past 40 years, and field experiments suggest that small temperature changes will create large responses of vegetation and insects.

For 2013-14 it was observed that:

4. models suggest that continued warming could reduce productive krill habitat by 20% by 2100, with severe impacts on air-breathing predators that feed in the Antarctic Circumpolar Current during the summer breeding season;
5. the recovery of viable moss samples from 1600 year-old moss frozen in permafrost on Signy Island, shows the potential for long survival under glacial conditions followed by regrowth after ice retreat. Here is a new mechanism for terrestrial refugia from a glacial episode;
6. liquid water from subglacial Lake Whillans in West Antarctica proved to contain metabolically active microorganisms. The water was derived mainly from glacial ice melt, and contains a chemosynthetically driven ecosystem inhabited by a diverse assemblage of bacteria and archaea. Confirmation that aquatic sub-ice environments support viable microbial ecosystems also suggests that they contain globally relevant pools of carbon and microbes that can mobilize elements from the lithosphere and influence Southern Ocean geochemical and biological systems;
7. the first global census of the Adélie penguin, achieved using a combination of ground counts and satellite imagery, found a breeding population 53% larger (3.79 million breeding pairs) than the last estimate in 1993, and included 41 previously unsurveyed colonies, and reports on 17 previously unknown colonies. Declines in the Adélie penguin population on the Antarctic Peninsula are more than offset by increases in East Antarctica.

For 2015–16 it was observed that:

8. tracking King Penguins around Iles Crozet showed that their population declined as warming by 1°C pushed the Polar Front (a food source) southward, increasing the distance the birds must travel to feed. Climate models suggest that further warming will push the Front farther south, threatening the stability of this population;
9. experiments with Southern Ocean pelagic organisms found that food preferences change as oceanic CO_2 content increases, for example with copepod species grazing more on dinoflagellates rather than other phytoplankton species when pCO_2 was high – a response to ocean acidification. Such altered trophodynamic interactions will impact how carbon is channelled through polar food webs, and may increase the rate at which future anthropogenic CO_2 emissions can be absorbed;
10. the well-documented warming of the Antarctic Peninsula, by 1.2°C in summer air temperature since the 1960s, has led to significant increases in the distribution of the two native Antarctic vascular plant species: *Deschampsia antarctica* by 191%; and *Colobanthus quitensis* by 208%. Further increases in coverage are likely with continued regional warming;
11. a 10-year study showed that Southern Hemisphere humpback whales

are now at roughly 70% of pre-exploitation abundance, but recovery levels vary substantially between oceans, with strong recovery in the Indian Ocean but still low recovery in the southwest Atlantic and Oceania.

AnT-ERA investigations in the McMurdo Dry Valleys, Photograph: B J Adams.

In 2010 the main Life Sciences SRP was Evolution of Biodiversity in the Antarctic (EBA) which, until its discontinuance in 2013, had held several major workshops and contributed many papers to key international science journals. EBA was replaced in 2012 by two new SRPs: Antarctic Thresholds - Ecosystem Resilience and Adaptation (AnT-ERA) and State of the Antarctic Ecosystem (AntEco). AnT-ERA examines the current biological processes in Antarctic ecosystems, to define their tolerance limits and thereby determine resistance and resilience to change. It also works with the climate modelling community to assess how climate change may affect biodiversity. In contrast, AntEco focuses on the longer term, on the nature and evolution of patterns of biodiversity across terrestrial, limnological, glacial and marine environments, and provides the scientific knowledge of biodiversity that can be used for conservation and management. Its research encompasses topics like: spatial ecology; molecular ecology and evolution; ecoinformatics and systems biology; paleoecology; and impacts, trends and conservation. Among other things it organized a successful SO-Ant-Eco Expedition to the Marine Protected Area of the South Orkney Islands, with 22 participants from 9 countries and 16 institutions, in 2016. The goals were to find

SO-Ant-Eco Expedition to the Marine Protected Area of the South Orkney Islands aboard RRS J*ames Clark Ross* in 2016.

Above: trawling from the after deck; and

Below: participants in the laboratory.

out how the habitats around the islands relate to the types of animals that are found there, to identify areas that may be particularly vulnerable to the impacts of fishing in the future, and to find and describe new species.

The Life Sciences Group shared with Geosciences the management of the Subglacial Antarctic Lake Exploration (SALE) SRP, which came to an end in April 2010, following a Chapman Conference on SALE, in Baltimore. SALE's activities guided the development of clean drilling techniques, and led to a Code of Conduct for the exploration and research of subglacial aquatic environments. SALE's ef-

forts also led to plans for major drilling programmes for Lake Ellsworth and for the Whillans Ice Stream, and to the successful drilling into Lake Vostok by Russia initially in 2012, and again in January 2015. A SALE-led monograph on Subglacial Aquatic Environment Science was published in 2013.

A key Life Sciences subsidiary group is the Continuous Plankton Recorder EG (EG-CPR), which compiles data from member nations' ship tows every southern summer season, and issues standards to help those involved with CPR operations to maintain the correct methodology and taxonomic accuracy. The EG-CPR produced the Southern Ocean Zooplankton Atlas [18], which is a contribution to SOOS and to the activities of CCAMLR. By 2016 the EG-CPR had evolved into the Southern Ocean Continuous Plankton Recorder Database (SO-CPR) EG. CPR data and associated models show that the Southern Ocean hosts some persistent hot spots of high zooplankton abundance.

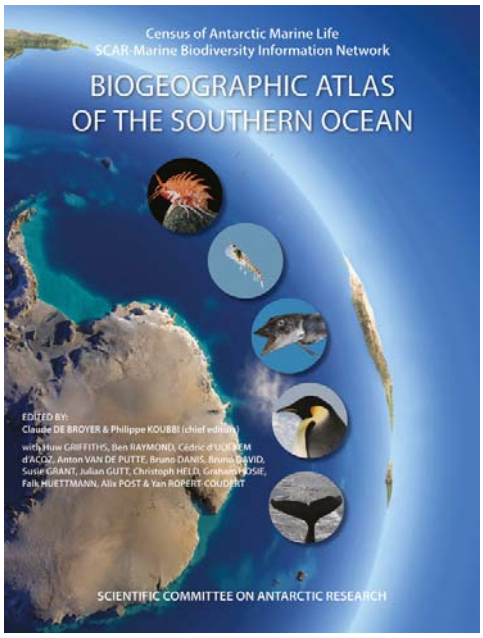
2010 saw the integration of SCAR's Marine Biodiversity Information Network (MarBIN) with the biodiversity databases managed by the Australian Antarctic Division to form the Antarctic Biodiversity Information Facility (ANTABIF). ANTABIF is a dedicated Antarctic biodiversity data portal giving access to a distributed network of contributing databases, following the principles of the Global Biodiversity Information Facility (GBIF). A key product is an Antarctic Field Guide to marine species. By 2012, SCAR's AG on ANTABIF evolved into the EG on Antarctic Biodiversity Informatics (ABI), with a goal of renewing the international Antarctic Biodiversity Portal for the benefit of the wider community.

During 2010, the Life Sciences Group was still heavily engaged in the concluding phase of the IPY Project on the Census of Antarctic Marine Life (CAML), a contribution to the global Census of Marine Life, (CoML), which ended in 2010. CAML participants summarized their findings in a special issue of *Deep Sea Research II* (2011), and the project left a significant legacy. The CAML-led barcoding campaign extended the number of Antarctic DNA barcodes, finding evidence of a high numbers of cryptic species (those that look alike but cannot interbreed) in the Antarctic benthos, especially among species previously thought to have circum-Antarctic distributions. Lasting legacies from CAML include a 30-year benthic dataset from Admiralty Bay; >20,000 barcode sequences for Antarctic marine fauna; contributions to SOOS (see Physical Sciences, below), with both physical and biological components including biologger data from marine mammals; taxonomic monographs, Antarctic Field Guides and pages for the *Encyclopaedia of Life*; more than 1,000 scientific papers published; and evidence provided in support of CCAMLR's bioregionalization programme and its declaration of two Vulnerable Marine Ecosystems. CAML's achievements provide a robust benchmark against which future change in the Antarctic marine ecosystems may be measured.

Life Sciences also continued contributing to the Latitudinal Gradient Project, showing how life changes as Antarctica is approached, and to the Integrating Climate and Ecosystem Dynamics programme (ICED), which had become co-sponsored by SCAR.

In due course these various marine biological studies led to production in 2014 of a landmark publication, SCAR's *Biogeographic Atlas of the Southern Ocean* [19], which presents the distribution patterns of over 9000 Southern Ocean species and represents the work of the Census of Antarctic Marine Life (CAML) and SCAR's Marine Biodiversity Information Network (MarBIN). The atlas, described as an outstanding contribution to Antarctic science and conservation, represents the

[18] McLeod *et al.* 2010, *Polar Science* 4, 353-385.
[19] http://atlas.biodiversity.aq/



The cover of the *Biogeographic Atlas of the Southern Ocean.*

work of 147 scientists from 91 institutions across 22 countries. It examines the evolution, physical environment, and genetics of these organisms and how they may be affected by climate change. It assists those involved in the science, conservation, monitoring and sustainable management of the Southern Ocean.

A new EG on Birds and Marine Mammals (EG-BAMM) was formed in 2010 to support research to quantify the role of birds and marine mammals in the Antarctic marine and terrestrial ecosystems. EG-BAMM established links with CCAMLR and SOOS through its top predator-tracking database, and provides an opportunity to develop new synergies across the Southern Ocean science community, especially in the area of ecosystem structure and dynamics (these predators can provide an integrated signal of changes in distribution and abundance of prey). In future the potential exists for collaboration with Oceanites, which has been collecting penguin data from the Antarctic Peninsula for 30 years, and with the Mapping Application for Penguin Populations and Projected Dynamics (MAPPPD) Project funded by NASA.

In 2010 Life Sciences also formed two new cross-linkage projects: an EG on subglacial lake exploration - Advancing TecHnological and ENvironmental stewardship for subglacial exploration in Antarctica (ATHENA), in association with the Geosciences Group, and an AG on Ocean Acidification, in association with the Physical Sciences Group, which planned to find out how acidification is progressing, and what are its effects on Southern Ocean organisms. This latter group was disbanded in 2016, but work continued on revising the SCAR Ocean Acidification Report for eventual issue.

Delegates recommended in 2016 that the new AG on Biogeochemical Exchange Processes at the Sea-Ice Interfaces (BEPSII) should work closely with Physical Sciences' ASPeCt study of sea-ice processes, though it was recognized that BEPSII had a bipolar focus. Life Sciences was also jointly engaged with Physical Sciences in trying to improve our ability to predict how the Antarctic environment will evolve over the next century, through a new EG on Prediction of Changes in the Physical and Biological Environment of the Antarctic (PCBEA).

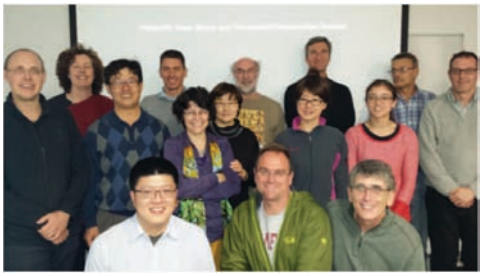
As mentioned above under Overarching Influences, concern was growing about conservation in Antarctica, in part stimulated by Life Sciences evaluations of the efficacy of protection measures provided by the current system for Antarctic Specially Protected Areas, as highlighted in 2010 by Kevin Hughes' and Peter Convey's contribution to an expanding body of literature and activity relating to quantifying and assessing human impacts and interactions of various types with the Antarctic environment [20]. By

[20] Hughes, K A, & Convey, P. 2010. The protection of Antarctic terrestrial ecosystems from inter- and intra- continental transfer of non-indigenous species by human activities: a review of current systems and practices, *Global Environmental Change* 20, 96-112.

Participants in The Monaco Assessment, June 2015.

2012, SCAR, COMNAP, New Zealand and the International Union for Conservation of Nature (IUCN) had agreed to formulate a strategy for the future based on the latest developments in conservation science and practice, and leading to development of a strategy for 'Antarctic Conservation for the 21st Century'.

Concerns about biodiversity continued to predominate, and in June 2015, together with the Government of the Principality of Monaco and other partners, SCAR organized a workshop on Antarctica and the Strategic Plan for Biodiversity 2011–20. Participants examined the extent to which conservation of the biodiversity of Antarctica and the Southern Ocean is contributing to realizing a set of ambitions agreed for the world as part of the Convention on Biological Diversity (CBD)'s Strategic Plan for Biodiversity 2011–20, which required that: "By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people." A key outcome of the workshop was The Monaco Assessment, indicating what could and should be done in south polar conservation [21].



Members of the new ANTOS Expert Group.

By 2012, Delegates had also approved formation of a new joint Life and Physical Sciences AG on Remote Sensing, to coordinate development and adaptation of remote sensing methodology and to promote new avenues of research. A key aim was to work on remote sensing techniques for gathering information on the variability of emperor penguin populations. The research required the use of high-resolution multispectral satellite images, and SCAR asked the European Space Agency (ESA) to extend the coverage of the Sentinel-2 satellite over Antarctica (up to 80°S) to meet this need.

Expanding on that concept, in 2014 Delegates approved the formation of a new AG entitled Antarctic Nearshore Terrestrial Observing System (ANTOS), to establish an integrated and coordinated transcontinental and trans-regional environmental surveillance system to identify and track environmental variability and change at biologically relevant scales. This provides a terrestrial biological partner to SOOS. ANTOS would have to include a satellite-based approach.

[21] http://www.scar.org/monaco-assessment.

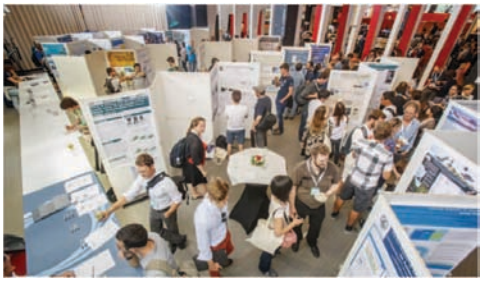
At the same time, to address concern about the lack of SCAR's involvement in the Sub-Antarctic, Delegates approved a new AG on Integrated Science for the Sub-Antarctic (ISSA) to provide a comprehensive overview of past and current Sub-Antarctic science; identify pressing science questions for current and future work; identify key lessons for science, conservation, and policy across the region; and develop a network of Sub-Antarctic scientists, including support for early career researchers.

By 2017, following discussions with the International Association of Antarctica Tour Operators (IAATO), SCAR's science groups were also collectively considering the possibility of undertaking a holistic and wide-ranging study of the Antarctic Peninsula so as to understand better the interactions there between climate and biota. It could include, eg, the regional downscaling of climate model projections to the peninsula scale, as well as consideration of aspects such as fishing and biodiversity specific to the peninsula, and the effects of increasing levels of tourism.

Life Sciences proposed, in 2017, the establishment of new AGs on Plastics in Polar Environments, and on Input Pathways of persistent organic pollutants to AntarCTica (both joint with Physical Sciences), as well as one on Krill.

Life Sciences also provides an umbrella for the EG on Human Biology and Medicine, which after some years of discussion between SCAR and COMNAP, would by 2014 merge with COMNAP's Medical Network (MEDINET) to form a joint SCAR-COMNAP group addressing human biology and medical issues in the Antarctic.

The Life Sciences Group continued organizing SCAR's 4-yearly Biology Symposium. The 10th of these took place in Sapporo, in Japan, in 2009, with the theme of Antarctic Biology in the 21st Century - Advances in and beyond IPY, with the outcomes published in the journal *Polar Science* in 2010. The 11th took place in Barcelona, Spain, in 2013, with the theme of Life in Antarctica: Boundaries and Gradients in a Changing Environment, with the outcomes published in *Polar Biology* in 2016. The 12th took place in Leuven, Belgium, in 2017, with the theme Scale Matters, and the intention to publish a range of contributions in the journal *Frontiers*.



Participants viewing the poster session at the 12th SCAR Biology Symposium in Leuven, Belgium in 2017.

Geosciences

Highlights from the SRPs operating under the aegis of Geosciences included the following selected key findings whose publications are grouped by year.

For 2010 it was observed that:

1. the ACE-supported international ANDRILL project had recovered a sedimentary record of ice sheet advances and retreats back through Miocene times (23-5.3 million years ago), finding abundant sedimentary cycles representing periodic changes in the tilt of the earth's axis. The cycles from Pliocene times (5.3 to 2.6 million years ago) showed that the West Antarctic Ice Sheet (WAIS) and Ross Ice Shelf had melted periodically then, resulting in a switch from grounded ice and ice shelves to open water environments in the Ross Sea Embayment;
2. these new data provided numerical modellers with new constraints on ice sheet melting and Ross Sea conditions. A new ice sheet/ice shelf model that simulates fluctuations of the WAIS in response to ocean in-

duced melting suggested that such melting may generate up to 7m of sea level change, plus up to 3m from the East Antarctic Ice Sheet;

3. the ACE-led Integrated Ocean Drilling Program (IODP) Cruise 318, which drilled the Wilkes Land margin in January-March 2010 recovered 53 million years of Antarctic history, from an ice-free 'greenhouse Antarctica', to the first cooling, to the onset and erosional consequences of the first glaciation, and to the subsequent dynamics of the waxing and waning ice sheets, all the way to the thick, 'tree-ring style' records with seasonal resolution of the last deglaciation around 10,000 years ago.

For 2012 it was observed that:

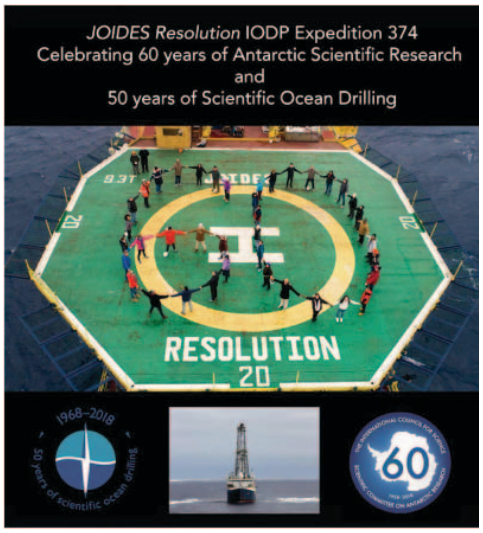
4. the Wilkes Land coast of East Antarctica had supported near-tropical forests including palms and equivalents to today's Baobabs during Antarctica's 'greenhouse' Eocene climate (see 3. above). Winters were mild (> 10°C) and frost-free;
5. the sea level contribution from the whole Antarctic ice sheet of +0.20 ±0.15 mm/yr, compares to +0.39 ±0.14 mm/yr from the Greenland ice sheet.

For 2013–14 it was observed that:

6. evidence spanning the early-to-middle Eocene transition from the Wilkes Land margin showed that the earliest through-flow of a westbound Antarctic Counter Current began 49–50 million years ago through a southern opening of the Tasmanian Gateway, together with the onset of regional surface water and continental cooling (2–4°C). The west-flowing current cooled Antarctic surface waters and coasts, invigorated deep convection, and spread globally through intermediate waters. The opening of the Tasmanian Gateway explains the cooling of the Southern Ocean surface water and global deep ocean water in the apparent absence of (sub-) equatorial cooling, indicating that the cooling that led to Antarctic ice was not a simple function of diminishing atmospheric CO_2, the effect of which would have been global;
7. the expansion of ice on Antarctica during the Eocene-Oligocene Transition 34 million years ago, induced crustal deformation and gravitational perturbations around the continent. Close to the ice sheet, sea level rose despite an overall reduction in the mass of the ocean caused by the transfer of water to the ice sheet;
8. under warm conditions in the early Pliocene, the East Antarctic Ice Sheet (EAIS) fluctuated substantially in response to small changes in atmospheric CO_2 concentration and mean global surface temperature. This demonstrably higher than expected sensitivity to climate change suggests that the marine margins of the EAIS, as well as the marine-based West Antarctic Ice Sheet, may become increasingly susceptible to ocean warming, with the potential for widespread mass loss raising sea level by metres over the coming centuries to millennia.

For 2015–16 it was observed that:

9. applying a simple Pliocene-like warming scenario incorporating the combined mechanisms of marine ice sheet instability, melt-driven hydrofracturing and cliff failure, shows that the West Antarctic Ice Sheet may collapse within decades rather than centuries, while the East Antarctic Ice Sheet will lose ice from its surrounding basins within several hundred to a few thousand years. The total modelled Antarctic ice loss corresponds to +17m of sea-level rise, in good agreement with high-stands of sea level identified in sea level records from Pliocene times;



RV *JOIDES Resolution* Leg 374

10. a new, highly detailed ice core from the West Antarctic Ice Sheet (WAIS) Divide project revealed a consistent pattern of climate changes that started in the Arctic and spread to the Antarctic during the last glacial period, tens of thousands of years ago. Sudden climate changes that began in the North Atlantic around Greenland circulated southward, appearing in the Antarctic some 200 years later, highlighting the importance of ocean currents for redistributing heat between the Northern and Southern hemispheres in a process called the bipolar seesaw;

11. new information from the ANDRILL-2A drill core and a complementary ice sheet modelling study showed that polar climate and Antarctic ice sheet margins were highly dynamic during the early to mid-Miocene some 17 million years ago, and sensitive to small changes in temperature stimulated by small changes in atmospheric CO_2 of between 280 and 500 ppm.

Continuing into 2010, the Geosciences main SRP was Antarctic Climate Evolution (ACE). ACE held the First International ACE Symposium, in Granada, Spain, in September 2009, with key papers published in 2012 [22]. ACE scientists led the Integrated Ocean Drilling Program (IODP) Cruise 318, which drilled the Wilkes Land margin in January–March 2010, and were also closely involved with the drilling programme of ANDRILL into the seabed beneath the Ross Ice Shelf.

In 2010, ACE began developing, with Physical Sciences, plans for a follow-up cross-disciplinary SRP to study Past and Future Change of the Antarctic Environment (PACE), to provide greater insight into the natural variability of the Antarctic climate system, understanding of the responses of the system to natural and anthropogenic forcing factors and improved regional predictions of key elements of the atmosphere, ocean and cryosphere, including changes in sea level. By 2012 PACE had evolved into the Past Antarctic Ice Sheet Dynamics (PAIS) SRP. PAIS scientists were instrumental in obtaining approval for two new IODP Antarctic margin drilling expeditions: IODP Cruise 374, to investigate West Antarctic Ice Sheet and Climate History, was drilled between 4 January and 8 March 2018 in the Ross Sea, and IODP proposal P839 covers Amundsen Sea–West Antarctic Ice Sheet History, and will be drilled in summer 2019. These PAIS-IODP expeditions will provide much needed evidence of marine ice sheet instability and sensitivity under various past high CO_2 warmer conditions for different subglacial basins under the West and East Antarctic ice sheets. Successful drilling depends on prior site surveys that will be or are being carried out by SCAR scientists, including a site survey from the RV *Polarstern* in 2017 for the Amundsen Sea drilling. In September 2017, PAIS hosted a conference in Trieste to assess the latest scientific results in re-

[22] Florindo, F, Escutia, C, DeConto, R, and Bentley, M (eds.). 2012. Cenozoic Evolution of Antarctic Climates, Oceans and Ice Sheets. *Palaeogeography, Palaeoclimatology, Palaeoecology Special Publication*, Elsevier, doi:10.1016/j.palaeo.2012.04.005

constructing Antarctic ice sheet response to warmer climates, and the development of models for predicting future ice sheet contribution to sea-level rise.

As implied above, reconstructions of past continental positions are critical for understanding the evolution of ocean circulation. As one move towards understanding the timing of the opening of the Drake Passage, a Symposium on The Scotia Arc: Geodynamic Evolution and Global Implications was held in Granada, Spain, in 2013, outcomes of which were published in a Special Issue of the journal *Global and Planetary Change* in 2014.

The Geosciences Group shared with Life Sciences the management of the Subglacial Antarctic Lake Exploration (SALE) SRP [see Life Sciences for a report].

At the Delegates meeting in 2012, the Delegates approved plans to develop a new SRP on Solid Earth Response and Cryosphere Evolution (SERCE), with the goal of synthesizing and interpreting the extensive new data sets obtained during the IPY by the international Polar Earth Observing Network (POLENET) geophysical sensor deployments. SERCE promotes communication and coordination with other international groups investigating polar ice mass change, glacial isostatic adjustment, and ice sheet contributions to global sea-level rise, so as to improve the understanding of the interaction between the solid earth, cryosphere and climate as a contribution to sea-level change. Among its activities are thematic workshops, facilitating data exchange, and training schools like the one in Goa, India, in September 2015, on Glacial Isostatic Adjustment, which attracted 45 participants from 30 countries, and a workshop on Glacial Isostatic Adjustment (GIA) and Elastic Deformation which took place in September 2017 in Iceland.

At the 2010 SCAR meeting the AG on Sub-Ice Geological Exploration ended, and a new one began, on Acquisition of Multibeam Bathymetric Data. It ended in 2014. The ongoing AG on Cold Seeps and Hydrothermal Vents in the Antarctic (SAVANT) AG, shared with Life Sciences, had developed methods for detecting and classifying deep ocean seeps and vents, and prepared a field guide for seep and vent organisms. It ended in 2013. The AG on GPS for Weather and Space Weather Forecasting AG (GWSWF), shared with Physical Sciences, was making steady progress in 2010. By 2012, it had morphed into an EG on the Global Navigation Satellite System (GNSS) Research and Application for Polar Environment and Weather and Space Weather Forecasting (GRAPE/WSWF). During 2017, the GRAPE community prepared a new SRP proposal for 2020, on Radio Sciences Research on AntarctiC AtmospherE (RESOURCE).

Other ongoing Geoscience initiatives in 2010 included the Geodetic Infrastructure of Antarctica (GIANT) EG; the Permafrost and Periglacial Environments EG, which evolved into the EG on Antarctic and sub-Antarctic Permafrost, Soils and Periglacial Environments (ANTPAS); the EG for the ongoing Antarctic Digital Magnetic Anomaly Project (ADMAP) (jointly managed by SCAR and IAGA (the International Association of Geomagnetism and Aeronomy), which contributes data to the World Magnetic Anomaly Map; and the EG for the International Bathymetric Chart of the Southern Ocean (IBCSO). The IBCSO EG achieved the first release of the Southern Ocean chart (IBCSO v.1.0) in 2013 [23], followed by the publication by the British Antarctic Survey and the Geological Survey of Spain of a new Antarctic map, Bathymetry and Geological Setting of Drake Passage, created under the aegis of SCAR's IBCSO programme, in December 2016 [24].

[23] www.scar.org/news-from-ibcso-2/.

[24] Bohoyo, F, Larter, R D, Galindo-Zaldívar, J, Leat, P T *et al.* 2016. *Bathymetry and Geological Setting of the Drake Passage*. BAS GEOMAP 2 Series, Sheet 7, 1:1,500,000. British Antarctic Survey, Cambridge, UK. ISBN: 9780-85665-199-1

The Drake Passage map involved compiling data collected over the last 25 years on more than one hundred oceanographic cruises onboard six different Antarctic research vessels from different countries.

A new EG was established in 2014 to investigate Antarctic Volcanism, to address the growing realization that there was a great deal more sub-ice volcanism in Marie Byrd Land in West Antarctica than had been expected. At the same time a new AG on Geological Mapping Update of Antarctica was endorsed to capture existing geological map data, update its spatial reliability, improve representation of glacial sequences and geomorphology, and enable data delivery via web-feature services. Another new AG approved in 2014 covered Geoheritage and Geo-Conservation in Antarctica, a topic of interest to the Committee on Environmental Protection (CEP) of the Antarctic Treaty. By 2017, after a successful workshop in Edinburgh, Geosciences applied to establish a new AG (AntArchitecture) to examine radar-imaged ice profiles, ie the internal architecture of the ice sheet, to inform palaeoclimatic reconstructions and ice sheet modelling.

Among Geosciences' responsibilities was planning for SCAR's 4-yearly International Symposium on Antarctic Earth Sciences (ISAES), the 11th of which took place in Edinburgh (10–16 July 2011), and the 12th of which took place in Goa, India (13–17 July 2015). The 13th meeting will take place in Incheon, South Korea, in 2019. The Group also plans SCAR's contributions to the 4-yearly International Geological Congress, including the 34th, in Brisbane, Australia (2012) and 35th, in Cape Town, South Africa (2016). It will contribute to the 36th Congress, in Delhi, in 2020.

XII International Symposium on Antarctic Earth Sciences, July 2015, Goa, India.

Physical Sciences

Highlights from the SRPs operating under the aegis of Physical Sciences included the following selected key findings whose publications are grouped by year.

For 2010 it was observed that:

1. the strengthening of circum-polar winds caused by the ozone hole led to the areal increase in sea ice in recent decades (the opposite of the Arctic, where there is no shielding wall of wind). These strong winds also limited the impact of global warming on Antarctic climate;
2. Southern Ocean bottom waters and intermediate waters have freshened in recent decades due to increased melting of land ice;
3. there was a surprisingly rapid causal link between changes in winds over the Weddell Sea and the warming of the Antarctic Bottom Water.

For 2012 it was observed that:

4. the strengthening of Westerly Winds (the positive trend of the Southern Annular Mode), caused stronger southerly winds in the western Ross Sea, increasing sea-ice extent and duration there;
5. the changed atmospheric circulation enhanced the wind-driven inflow of warm ocean water onto the Antarctic continental shelf, causing ice shelves to melt from below;
6. the more northerly warm winds running down the Antarctic Peninsula and West Antarctica caused sea-ice cover to decline in the Amundsen–Bellingshausen seas.

For 2013–14 it was observed that:

7. deep convection in the giant polynya in the Weddell Sea ceased following the formation of a fresh water cover created by melting ice in response to global warming, hence reducing the rate of production of Antarctic Bottom Water and affecting the oceanic storage of heat and carbon;

8. a new era in astronomy opened with the first solid evidence for astrophysical neutrinos from cosmic accelerators, made by the IceCube project.

For 2015–16 it was observed that:

9. 18 years of continuous satellite radar altimeter data showed that on average ice-shelf volume change had accelerated from negligible loss ($25 \pm 64 km^3/yr$) for 1994–2003 to rapid loss ($310 \pm 74 km^3/yr$) for 2003–12. West Antarctic losses increased by ~70% in the past decade, and earlier volume gain by East Antarctic ice shelves ceased. In the Amundsen and Bellingshausen regions, some ice shelves have lost up to 18% of their thickness in less than two decades;
10. Thwaites Glacier, one of West Antarctica's most prominent, rapidly evolving, and potentially unstable contributors to global sea-level rise, is actively melting partly in response to a geothermal heat flux associated with sub-ice magma development and volcanic activity, as well as to sub-ice erosion caused by incursions of warm seawater. Thwaites Glacier featured prominently in international news media in May 2018;
11. 7000 years ago, during the Holocene thermal maximum, the Mackay Glacier of East Antarctica thinned rapidly in a climate like that of today, linking geological evidence of rapid ice surface lowering to marine ice sheet instability;
12. the direct detection of gas clouds in our Galaxy via observations of carbon has been made using the HEAT telescope at Ridge A in Antarctica, the driest location on Earth. One third of the molecular gas along the sightline studied was estimated to be 'dark', a form of cold gas that can only be traced by observing the carbon atoms with terahertz instruments.

The Physical Sciences Group was responsible for three SRPs in 2010: Antarctica in the Global Climate System (AGCS); Astronomy & Astrophysics from Antarctica (AAA), which was established in that year, and Interhemispheric Conjugacy Effects in Solar-Terrestrial and Aeronomy Research (ICESTAR), which ended in 2010 and was replaced by an Expert Group.

The primary product of the AGCS SRP in 2010, with contributions from Life Sciences and Geosciences, was the ACCE report referred to above and mentioned in Chapter 7. AGCS incorporated SCAR's International Trans-Antarctic Scientific Expedition (ITASE) project, which collects short cores for analyzing past climates, and SCAR's EG on Antarctic Sea Ice Processes and Climate (ASPeCt) project, which collects information on sea ice. AGCS and its sub-programmes were cosponsored by the World Climate Research Programme (WCRP).

By 2012, AGCS was being replaced by a new SRP, on Antarctic Climate in the 21st Century (AntClim21), with the aim of: quantifying variability, verifying model outputs, and projecting climate to 2100 and beyond, culminating in producing an ACCE style synthesis report entitled 'Antarctica 2100'. By 2016, AntClim21 was planning the Great Antarctic Climate Hack to encourage people in the wider community who are not modellers to learn to use the ESMValTool of Phase 6 of the international Coupled Model Intercomparison Project (CMIP-6) to assess the application of models for their own purposes. By 2017 AntClim21 was developing plans for Antarctic Climate Indicators for climate monitoring. Some aspects of AGCS's work were also incorporated into PAIS, another successor SRP, shared with Geosciences [see Geosciences, above].

SCAR's involvement in climate change led it to become an Observer to the UN Framework Convention on Climate Change (UNFCCC), and SCAR sometimes uses the Observer status of ICSU to attend rele-

vant working group or other meetings of the Intergovernmental Panel on Climate Change (IPCC), where SCAR can present information on climate change and its effects in Antarctica and the Southern Ocean. For example, in 2016 Tim Naish (NZ) and Rob DeConto (US) of SCAR's ACE SRP attended a scoping meeting in Geneva for the IPCC special report on limiting warming to 1.5°C, and Rob DeConto (US) and Andrew Mackintosh (NZ) of the ACE SRP were selected as Lead Authors on the IPCC special report on the Cryosphere and the Ocean.

These various lines of research are supported by the READER databases for Met-, Ocean-, and Ice- data. MetREADER has recomputed all its climate data; IceREADER compiles short ice core data. Ocean data will be collated through the Southern Ocean Observing System (SOOS).

The AAA SRP was established in 2010 to coordinate astronomical activities in Antarctica in a way that ensures the best possible outcomes from international investment in Antarctic astronomy, and maximizes the opportunities for productive interaction with other disciplines. It was setup:

i. to undertake quantitative assessments of the potential of each Antarctic plateau station to contribute to astronomy;

ii. to advances in understanding Antarctic meteorology as it applies to astronomical observations;

iii. to improved coordination between atmospheric and ionospheric researchers;

iv. to archive sets of site-testing data (eg testing the qualities of the atmosphere and the thickness of the turbulent boundary layer as the basis for deciding what kinds of equipment are needed to take best advantage of the sites); and

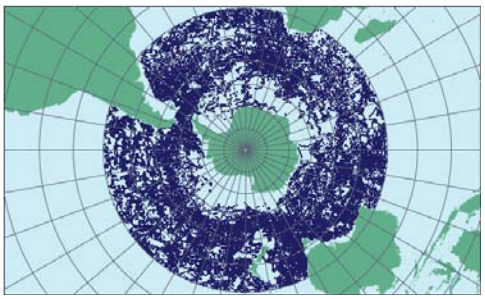
v. to get people to work together to create common facilities, eg the Polar Large Telescope (PLT).

AAA held its first meeting in Sydney, Australia, in June–July 2011, and by 2016 had clearly demonstrated how Antarctica can be used as a platform to look outwards from Earth. It had successfully supported collaboration between national programmes, and lowered the barrier to participation for less-developed programmes, encouraged participation through AAA workshops, and developed a roadmap for high plateau astronomical research. Astronomical researchers can now access existing data through a dedicated portal on the SCAR AAA website.

Under the ICESTAR SRP, virtual observatories were developed of auroral image data as the basis for future studies. ICESTAR's autonomous observatories provided the first critical year-round space-weather data from the continent, in conjunction with the THEMIS satellites, revealing new information about magnetospheric substorms - the sudden releases of energy that cause auroral displays. By 2010, ICESTAR scientists had published more than 200 papers and hosted and convened scientific sessions at several international conferences. ICESTAR was replaced in 2010 by an EG to provide a better scientific understanding of the polar atmosphere, and to develop further a data portal to facilitate this research. The EG was disbanded in 2014 and replaced by an AG on Sun Earth Relationships and Antarctica (SERAnt).

The Physical Sciences Group also hosts the joint SCAR-SCOR Oceanography EG, whose prime product was the development of SOOS (see earlier). The EG now acts as the Scientific Steering Committee for SOOS, which produced its Initial Science and Implementation Strategy in 2012, its Implementation Plan in 2015, and a Database of Upcoming Expeditions to the Southern Ocean (DueSouth) in 2017. SOOS's objectives are: to design and implement a comprehensive and multi-disciplinary observing system for the Southern Ocean; to advocate for and guide the development of new observation technologies; to unify current observation efforts and leverage further

resources; to integrate and coordinate national and international projects and programmes, across disciplinary boundaries and between nations; and to facilitate and develop a data system that provides seamless access to essential data products for the Southern Ocean. Among its initial tasks, set in 2014, were: to identify Essential Ocean Variables, including ecosystem ones; and to develop a strategy for under-ice observations. During 2016–17, SOOS: identified and made discoverable a network of over 600 current and historical moorings in the Southern Ocean; rescued 20 years of data from 63 international moorings; developed four regional networks to coordinate Southern Ocean observational efforts; published eight peer-reviewed strategic and/or review publications; brokered an agreement for delivery of an interactive map of Southern Ocean observing platforms (SOOSMap); held 11 meetings/workshops, with significant international sponsorship of these events; supported the development of the CCAMLR Marine Protected Area monitoring plan; and delivered a five-year Business Plan. Among other observing systems, SOOS depends upon vertical profiles through the water column of temperature and salinity, collected by the international Argo float programme.



Argo 03/2007 – 03/2009
61965 profiles from 1353 distinct floats
http://argo.jcommops.org

Among the other Physical Sciences subsidiary groups, SCAR's Ice Sheet Mass Balance and Sea Level (ISMASS) EG was jointly co-sponsored by IASC in 2010 and finalized its new Science Plan [25] in July that year, aiming to assess how both the Antarctic and Greenland Ice Sheets were contributing to global and regional sea-level rise. By 2012 it had extended its focus to include mountain glaciers, and by 2013 it had also been co-sponsored by the Climate and Cryosphere (CliC) programme of the WCRP. ISMASS recognized that past ice-sheet models had been constrained to use overly simplified physics, limiting our ability to simulate accurately the important coupling between ice sheets, ice streams and ice shelves. By 2013, that was no longer the case, and significant advances were being made in the monitoring and modelling of ice-sheet mass balance. ISMASS researchers also discovered that 8,000 years ago, in the Holocene thermal maximum, Pine Island Glacier had thinned as fast as it was now doing, and would likely continue to do so.

Physical Sciences hosted a joint AG with Life Sciences on Environmental Contamination in Antarctica (ECA), to cover biological aspects of Antarctic pollution. ECA integrated its database on Organic Pollutants into the Antarctic Master Directory [see Data and Information Management, below], and by 2012, had merged with the former AG on Antarctic Fuel Spills (AGAFS).

The AG on Polar Atmospheric Chemistry at the Tropopause (PACT) developed a database relevant to their new definition of the chemical tropopause and was disbanded. A new EG was formed in 2010 on Operational Meteorology in the Antarctic (OPMet) along with an AG on Antarctic Clouds and Aerosols (ACA).

The AG on GPS for Weather and Space Weather Forecasting (GWSWF) began exploring synergies with the GIANT and POLENET groups of Geosciences, and aimed to establish a suitable GNSS re-

[25] *SCAR Report* 38.

ceivers network over the Arctic and Antarctica with the scope to develop a 3D image of the upper atmosphere as well as to develop algorithms for water vapour retrieval over Antarctica. In 2016 Delegates approved formation of an EG on Forum for Research into Ice Shelf Processes (FRISP), and an AG on Tropical Antarctic Teleconnections (TATE).

Meanwhile, the long-running EG on the International Partnership in Ice Core Sciences (IPICS) planned extension of the scope of the North Greenland Eemian Ice Drilling (NEEM) project to encompass the last interglacial period in ice cores from both hemispheres, and saw the US West Antarctic Ice Sheet (WAIS) Divide drilling project reached its target depth of 3330 m. IPICS remains committed to obtaining an ice core representing more than 1 million years of ice accumulation in Antarctica, and to obtaining high resolution records of change from ice cores covering the past 2,000 years as a contribution to the international Past Global Changes (PAGES) project.

SCAR Social Sciences

By 2010, SCAR boasted an EG on the History of Antarctic Research, and had established a new AG on Social Sciences whose goal was to advance our understanding of human values associated with Antarctica, and to establish a network of Antarctic social scientists and humanities researchers. Among the Social Sciences concerns were new security threats, including the impacts of climate change and the issues arising from increased human traffic to Antarctica by scientists, tourists, and mariners. The Social Science AG became an EG in 2014, and began working with the History EG to develop a consolidated approach to Antarctic humanities, retitled as the Humanities and Social Sciences Expert Group (HASSEG). A series of workshops and conferences has steadily expanded the membership and encompassed such topics as Antarctic Wilderness, and Linkages between environmental management and value systems: the case of Antarctica.

A key product in 2016 was the book *"Exploring the Last Continent: An Introduction to Antarctica"*, edited by D. Liggett, B. Storey, Y. Cook and V. Meduna, which tells students, and those who want to have a more critical look behind the scenes of Antarctic science, about the systems approach to providing insights into Antarctic ecosystems and the geophysical environment, along with discussions of current issues like climate change, bioprospecting, environmental management and Antarctic politics. A related publication reviewed the Antarctic Treaty Parties' engagement with the concept of wilderness in Antarctica and the governance of wilderness areas [26]. Many HASSEG members have also contributed to other recent books, such as *Handbook on the Politics of the Antarctic* and *Antarctica: a continent for the Humanities*, and there is a growing output of papers in international journals as the topic grows in interest.

Provision of Advice to the Antarctic Treaty

One of SCAR's key roles is to provide independent scientific advice to policy-makers, primary among them being the Parties to the Antarctic Treaty. For this purpose, SCAR maintains a Standing Committee on the Antarctic Treaty System (SCATS), chaired during this period by Professor Steven Chown (2006–14), then by Aleks Terauds (2014–18), through which SCAR presents both Working Papers and Information Papers to the annual Antarctic Treaty Consultative Meeting (ATCM) and the associated meeting of the Committee on Environmental Protection (CEP), as well as interacting with the Commission

[26] Deary, H and Tin, T. 2015. Antarctic Treaty Consultative Parties' engagement in wilderness protection at home and in Antarctica. *The Polar Journal.* doi:10.1080/2154896X.2015.1068537.

for the Conservation of Antarctic Marine Living Resources (CCAMLR). A great deal of work is required by both SCATS and the SCAR Secretariat for preparing for Treaty meetings. For example, in 2017 SCAR led the production of 5 Working Papers and 6 Information Papers, and shared in the production of 3 co-sponsored Working Papers, 4 co-sponsored Information Papers, and 2 Background Papers. SCAR's submissions can be seen on both the SCAR and ATCM web sites.

SCAR's ACCE report of October 2009 stimulated the Antarctic Treaty Parties to organize an Antarctic Treaty Meeting of Experts (ATME) on Climate Change, held in Norway's Lofoten Islands in April 2010 and, at the ATCM that year, to welcome annual updates on climate change from SCAR as essential for their ongoing deliberations and those of the CEP. The Treaty Parties decided that Climate would become a regular agenda item for the CEP, and looked to SCAR for science leadership. In due course the CEP established a Climate Change Response Work Plan (CCRWP) and, in 2017, a Subsidiary Group on the CCRWP to which SCAR contributes. SCAR meanwhile provides annual updates on climate change to the ATCM and CEP, and works closely with the CEP's Intersessional Contact Group (ICG) on Climate Change, notably through the CEP's Subsidiary Group on Climate Change Response.

SCAR's 2010 papers on the introduction of non-native species, which drew extensively on the results of the IPY Aliens in Antarctica project, helped the CEP to set the stage for future research on non-indigenous species. SCAR planned to develop a guide to best practices for dealing with the introduction of such species. By 2012 SCAR had agreed to work with Treaty Parties to help develop a surveillance strategy for areas at risk of establishment of non-native species. And by 2015, SCAR was able to provide the CEP with a recently published framework (the Antarctic Biological Invasion Indicator - ABII) that applies global best practice to the problem of understanding, monitoring and managing biological invasions in Antarctica. This remains an important topic as recent studies show that human introductions of non-native species to Antarctica are becoming more frequent.

SCAR also showed in 2010 that data on biodiversity, including those on non-indigenous species, were crucial as the basis for developing a more regularized approach to selection of Antarctic Specially Protected Areas (ASPAs) and to Antarctic conservation in general, and agreed to continue working with Parties to evaluate conservation practices for Antarctica in the 21st century. In later years SCAR continued working with partners from the CEP to further develop SCAR's strategy for 'Antarctic Conservation for the 21st Century'. SCAR's independent work on Antarctica and the Strategic Plan for Biodiversity, published in 2017, the culmination of the Monaco Assessment of 2015, mentioned earlier, also makes a valuable contribution to the CEP's activities. SCAR continues to work with the CEP to identify the management actions needed to mitigate threats to terrestrial Antarctic biodiversity as the basis for producing a prioritized set of actions and/or management strategies for the CEP to consider. SCAR is also involved in discussions on the development of a comprehensive, representative and integrated network of ASPAs.

SCAR continues to work closely with Treaty Parties on the Antarctic Environments Portal, a key web-based facility, which informs the CEP about the changing state of the Antarctic environment. The main purpose of the Portal is to provide the CEP and the ATCM with easy access to up-to-date summary information on the current state of knowledge on all relevant aspects of the Antarctic environment that are of importance to policy-makers, so as to support decisions on Antarctic environmental management and make up-to-date information available equally to all Treaty Parties as well as to the public. From 2015 onwards, SCAR's SCATS, together with the Portal Editor, David Walton, have reviewed

numerous Information Summaries and Emerging Issues for the Portal. Alex Terauds, the SCATS Chief Officer, sits on the Portal's editorial board, and SCAR's Executive Director sits on the Portal's management board. SCAR may manage the Portal from 2020 onwards. Also on the biodiversity front, SCAR plans to reach out to the new Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES), the new 'IPCC for biodiversity issues', to help IPBES to address Antarctic issues.

The Treaty Parties have a considerable interest in SCAR's SOOS and ICED programmes for helping to establish the biodiversity of the Southern Ocean in the context of implementing the requirements of the Strategic Plan for Biodiversity 2011–20. As of 2016, the Southern Ocean was not adequately represented in global biodiversity assessments and conservation efforts. The Monaco Assessment, referred to above, and its associated activities will help to ensure that the biodiversity of the Southern Ocean and efforts to ensure its conservation are not omitted from any global assessment. Conservation of biodiversity in the Southern Ocean will be greatly aided by CCAMLR's 2016 declaration of the Ross Sea as a Marine Protected Area. Equally influential, for the recovery of seabird numbers, is the eradication of rats from South Georgia, the success of which was declared in 2018.

In 2012, responding to a question from the CEP about the extent to which marine noise affected marine mammals, SCAR established a new cross-disciplinary AG on Impacts of Marine Acoustic Technology on the Antarctic Environment. The ensuing report 'Anthropogenic Sound in the southern Ocean: An Update', drew the CEP's attention to a scientific synthesis on the subject by the Subsidiary Body on Scientific and Technological Advice of the Convention on Biological Diversity (The impacts of underwater noise on marine and coastal biodiversity and habitats, UNEP/CBD/SBSTTA/16/INF/12). Although the AG was then disbanded, SCAR agreed to provide an update on the state of knowledge of the impact of underwater noise on marine biota to CEP in 2018.

In 2015, SCAR and COMNAP provided the CEP with advice on wildlife approach distances in Antarctica, concluding that human disturbance has a significant negative impact on Antarctic wildlife. In particular it was important to take into account obscure, negative responses of wildlife to human incursion, an element not reflected in existing guidelines and therefore warranting further consideration. SCAR worked on this jointly with COMNAP, following the CEP's request for advice on the possible effects of Unmanned Aerial Vehicle (UAV) ('drone') operations in the Antarctic; the UAV term was later changed - in accordance with international practice – to Remotely Piloted Aircraft System (RPAS). SCAR suggested avoiding RPAS launches closer than 100 m to wildlife until more Antarctic-specific information was available. On the basis of SCAR's follow up report in 2017 on the State of Knowledge of Wildlife Responses to Remotely Piloted Aircraft Systems (RPAS), providing best-practice guidelines for RPAS use in the vicinity of wildlife, the CEP decided to establish an ICG to develop guidelines for the environmental aspects of the use of RPAS in Antarctica and invited SCAR to participate. One of the outcomes of this is agreement by SCAR to provide a summary of peer reviewed literature through the Antarctic Environments Portal.

Other advice to the ATCM and CEP included SCAR's 2010 report to the CEP on Bioprospecting, which revealed the extent of those activities, and the potential for future biotechnology based on Antarctic organisms. This continues to be a field of interest to both the CEP and the lawyers in Working Group 1 of the ATCM. In 2010, EXCOM also agreed to form a new EG on Protected Area Management Plans (EGPAMP) to improve provision of scientific advice on those plans to the ATCM. More recently, SCAR's AG on Remote Sensing began working with

Emperor penguins on Ekströmisen, Dronning Maud Land. Photograph: Peter Clarkson.

the UK and other Treaty Parties on remote sensing techniques for gathering information on the variability of emperor penguin populations. In 2016 SCAR reviewed for the ATCM the status of Antarctic Geoconservation, reporting on current threats to Antarctic geological features, and detailing existing systems for their protection, promising to provide a final report in 2019.

SCAR continues to provide the CEP and the wider community with codes of conduct for scientific activities in the Antarctic, including the Code of Conduct for Use of Animals for Scientific Purposes in Antarctica; the Code of Conduct for the Exploration and Research of Subglacial Aquatic Environments; and (with COMNAP in 2016) the Code of Conduct for Activity within Terrestrial Geothermal Environments in Antarctica. The Environmental Code of Conduct for Terrestrial Scientific Field Research in Antarctica was adopted by the ATCM in 2018. In 2017, the ATCM adopted as Resolutions both the SCAR Code of Conduct for Exploration and Research in Subglacial Aquatic Environments, and SCAR's revision (with Australia and NZ) of the Antarctic Conservation Biogeographic Regions.

Jerónimo López-Martínez presenting the SCAR Lecture on Exploring the Future of Scientific Research in Antarctica at XXXIX ATCM, Santiago, Chile, 2016.

In addition, SCAR continues to provide each ATCM with a SCAR lecture on some key scientific topic of potential interest to the work of the Treaty Parties [27].

SCAR's links with CCAMLR also continued to improve and strengthen, starting with SCAR contributing in July 2010 to a CCAMLR workshop on Marine Protected Areas (MPAs) in the Antarctic context. This would help to ensure that the conservation efforts on land (CEP) and at sea (CCAMLR) dovetailed with one another in a seamless manner. In 2012 SCAR and CCAMLR agreed to form a joint Action Group, which met in 2013 to work towards developing a more strategic partnership. One key objective is to ensure that SCAR science that is relevant to CCAMLR is communicated to CCAMLR scientists.

Links to COMNAP

In 2010 SCAR and COMNAP held a joint meeting at which SCAR lectures on SOOS and on SCAR's Strategy for Data and Information Management in the 21st Century served as the basis for discussion about how COMNAP might contribute to attaining SCAR's goals in these areas. SCAR and COMNAP EXCOMs agreed to form an Action Group (as done with CEP) to explore ways in which the two

[27] www.scar.org/antarctic-treaty/atcm-presentations/

organizations could work together more effectively and in a more strategic manner. This led to an agreement to jointly sponsor a fellowship starting in 2011, and to jointly work on: observing systems [28]; on non-native species; on data and information management; on future collaboration at the ATCM, including submission of joint papers when appropriate; on joint workshops; on King George Island coordination; and on possible joint sponsorship of the SCAR and COMNAP human biology and medicine groups, something that came to fruition in 2014. SCAR and COMNAP had traditionally worked jointly on advice to the CEP in several areas, for example including studies on invasive species - Aliens in Antarctica, concluded in 2014, and UAV ('drone') impacts on wildlife, concluded in 2015.

Left to right: COMNAP Chairman Heinz Miller, ATCM Executive Secretary Manfred Reinke, SCAR President Jerónimo López-Martínez, and CEP Chairman Yves Frenot at KOPRI, Incheon, Korea, in 2013.

Joint COMNAP-SCAR EXCOM meeting in Brno, Czech Republic, 2017.

Following the 2014 Horizon Scan, COMNAP led a second stage in the process (the Antarctic Research Challenges (ARC) Project), assisted by SCAR, to help national Antarctic programmes to understand and to develop ways to address the challenges identified by the Scan. The main outcomes of the ARC in terms of the 6 main scientific challenges were as follows:

The Antarctic Atmosphere and Global Connections challenge would need: optimally deployed observing technologies; improved satellite remote sensing; data transfer in real time; improved Earth System modelling; and improved exchange of people and information. It would focus initially on the Southern Ocean and sub-Antarctic islands, then the West Antarctic ice shelf.

The Southern Ocean and Sea Ice in a Warming World challenge would need: underwater (and floating) navigation and positioning; high bandwidth and continuity of data communication from remote locations; Autonomous Underwater Vehicles (AUVs) and Unmanned Aerial Vehicles (UAVs)('drones') with greater range and capacity; long-term ice and deep-water capable sensor platforms; and unmanned physical and biological sensors. It would need year- round access to the continental margin and shelf edge; under ice access; and circum-Antarctic coverage.

The Antarctic Ice Sheet and Sea Level challenge would need: process-driven numerical ice sheet modeling;

[28] SCAR's observing systems at present (2018) include its contribution to CryOS (the Cryosphere observing system), which is part of the Global Cryosphere Watch; OpMet (SCAR's Expert Group on Operational Meteorology); SOOS (which is a contribution to the Global Ocean Observing System); and, most recently, ANTOS (Antarctic Nearshore Terrestrial Observing System).

subglacial sampling, multiple geophysical measurements and sampling of ice; satellites collecting snow and ice data; autonomous sensors; and increased use of AUVs. It would focus initially on the Amundsen Sea Embayment, Thwaites Glacier and West Antarctica; the deep interior of ice sheets; coastal islands and rises; sedimentary basins; and ice shelf cavities.

The Dynamic Earth – Probing Beneath Antarctic Ice challenge would need: remote sensing data and remotely deployed sensors; subglacial access and down-hole sensors; drilling into sediments and rock; enhanced data communication; and new power sources along with instruments with low power demand. It would focus initially on: the deep interior of the continent; the ice sheet; ice margins at the coast; and coastal to deep-sea records.

The Antarctic Life on the Precipice challenge would need: improved sensors; robotic multi-purpose systems and vehicles; high performance computing; high volume automated platforms for phylogenetic and functional analysis of multiple large sample sets; and high volume satellite/microwave bandwidth. It would focus initially on coasts; access from ocean to land; deep-sea access; and extended temporal access.

The Near-Earth Space and Beyond challenge would need: high bandwidth networks; high performance computing; advanced data analysis; and remote robotic observatories across the plateau. It would focus initially on wide bandwidth; air access to the plateau; and power generation at remote sites.

The Human Presence in Antarctica challenge would need: advanced data analysis; improved ecosystem models; better sensing and surveillance technologies; and imaging and recording equipment suitable for extreme cold conditions.

Data and Information Management

Critical to the complete success of science is the archiving, management, and sharing of data, following the rubric 'collect once, use many times', and, one might add, 'by as many people from as many countries as possible'. All too often the practice falls short of the goal, despite continual stimulation by SCAR and the wording of the Antarctic Treaty, which calls on all Antarctic nations to share their data. To stimulate further progress, by 2010 SCAR had an agreed data and information management policy and strategy, originating in the Standing Committee on Antarctic Data Management (SCADM), which was briefly mentioned in Chapter 8. As part of implementing this strategy, SCAR began to build an Antarctic Data Management System (ADMS), capable of supporting interdisciplinary Antarctic science and SCAR activities within the Antarctic Treaty System. SCAR's data policy supports the data and information strategy, formalizing SCAR's approach to data sharing as being full, free and open, and requiring SCAR projects: to develop data management plans; to create metadata (descriptive) information for all datasets generated in the course of a project; and to deposit those metadata in the Antarctic Master Directory (AMD). A 2014 review of SCADM led to a new goal, to develop an Interoperable Data Repository Network. SCAR's EXCOM and Delegates emphasize the need for all Members to be involved in SCADM and to contribute their data to the AMD.

Challenges for SCADM remain: working with SCAR Members to ensure that they align their data and information management practices to feed data into the AMD; getting Members to appoint data and information managers and enable them to attend SCADM meetings; and helping smaller national programmes to set up data practices that will feed into the AMD. In future, SCADM will meet with its Arctic counterpart to consider the best practices for Polar data, including harmonizing metadata standards, for the benefit of all science users. SCADM

is working closely with early career researchers via the Association for Polar Early Career Scientists (APECS), and with ICSU's World Data Centres.

SCAR's Marine Biodiversity Information Network (MarBIN), mentioned above and in Chapter 7, provides a good example of a successful approach to data management. SCAR-MarBIN's data are globally available through the Ocean Biodiversity Information System (OBIS) and the Global Biodiversity Information Facility (GBIF). SCAR-MarBIN forms just one of SCAR's long list of data products for the wider community [see SCAR's Partners and Products, below].

SCAR's information management includes geographic information, which is handled by the Standing Committee on Antarctic Geographic Information (SCAGI). SCAGI delivers a range of geographic information products including: the Antarctic Digital Database (ADD); Air Operations Planning Maps; the Composite Gazetteer of Antarctica (CGA); and the SCAR MAP Catalogue. The challenges for SCAGI resemble those for SCADM: ensuring that all Members have an active representative; encouraging national representatives to become involved with and contribute all new data to SCAGI products; and ensuring that retiring national representatives are replaced with successors.

Follow Up to the International Polar Year (IPY)

To ensure the legacy of the IPY, ICSU began working with SCAR, IASC and WMO to develop plans for an International Polar Partnership Initiative (IPPI), which was taking shape by 2014. It aimed to bring together stakeholders with interests in coordinating work on both human and biophysical systems, so as to improve understanding of the human and natural processes at the poles. Among other things, this would involve SCAR working closely with the WMO's Global Integrated Polar Prediction System (GIPPS), Polar Climate Predictability Initiative (PCPI), and Year of Polar Prediction (2017–19), which aim to reduce uncertainties in weather and climate forecasting in Polar Regions.

The IPY had identified the need for Observing Systems to provide regular and routine measurements of status and change in the polar environment, on land, in the sea, and in the air, encouraging development of both an Arctic Ocean

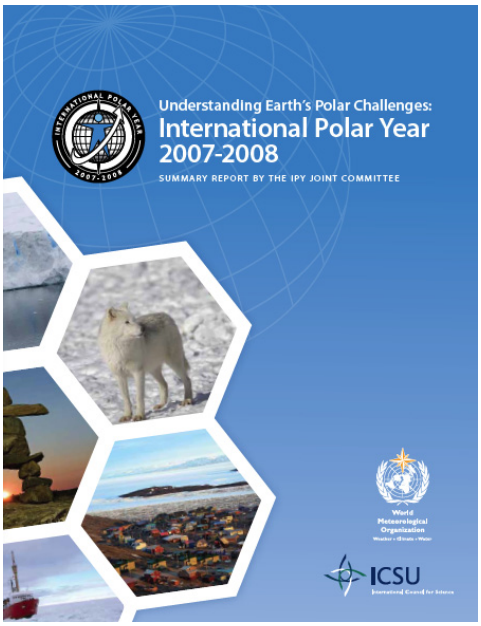
SCADM meeting in Tokyo, with SCAR President Jeronimo Lopez-Martinez and COMNAP Chairman Kazuyuki Shiraishi.

Observing System and a Southern Ocean Observing System (SOOS), along with a global Cryosphere Observing System (CryOS), in addition to the ongoing polar meteorological observing systems of the World Meteorological Organization (WMO). SCAR used the IPY as an opportunity to develop SOOS (see earlier), had already helped to develop the CryOS programme of the Integrated Global Observing Strategy (IGOS) of the space agencies and UN agencies, and had put in place an Operational Meteorology group. Given the example of IASC's attempt to develop a Sustained Arctic Observing Network (SAON) in the north, SCAR considered it wise to attempt something similar in the south, and by 2013 had set in train plans for an EG to develop an Antarctic Nearshore and Terrestrial Observing System (ANTOS) as a counterpart to SOOS. Delegates approved ANTOS in 2016.

With the retirement of Colin Summerhayes as the *ex officio* SCAR representative on the IPY organizing committee (the ICSU-WMO Joint Committee - JC) at the beginning of April 2010, Chuck Kennicutt took on that responsibility, with Summerhayes rejoining the JC in a personal capacity. The IPY–JC completed its task at the end of June 2010, handing over the responsibility of organizing the two follow-up IPY conferences to an International Steering Committee (ISC), chaired by Olav Orheim of Norway and supported by a Norwegian Secretariat. SCAR nominated Summerhayes as its representative on the ISC. Planning for the 2nd IPY conference began at the JC meeting in Longyearbyen, Svalbard, in September 2006, and the conference was duly opened by HRH Crown Prince Haakon of Norway on 8 June 2010, at Lillestrøm, just outside Oslo. It attracted 2323 people from 53 nations. The third and final IPY conference was first discussed at the JC-6 meeting in Quebec, Canada, in 2007, following an offer by Canada to host the 3rd conference in Montreal. It was organized by the ISC, now chaired by Peter Harrison, with Canadian support, and duly took place in Montreal in April 2012, with the theme From Knowledge to Action. Both Summerhayes and Sparrow served on the ISC for the Montreal conference, representing SCAR's interests.

In June 2009, the IPY-JC appointed an editorial team, including Summerhayes to represent SCAR, to produce a final IPY report under the leadership of Igor Krupnik (USA) and David Hik (Canada), which appeared in 2011. The report noted that the IPY had developed into the largest internationally coordinated planetary research effort of the preceding 50 years, making it a worthy successor to the 3rd IPY – otherwise known as the International Geophysical Year (1957-58). As the IPY Report points out, the IPY: "... marshaled the intellectual resources of thousands of scientists from an unprecedented number of fields and from more than sixty nations. It has already advanced our understanding of the complexities

BipAG members meeting in Oslo in October 2009; Left to right: Fridtjof Mehlum, Masaki Kanao, Colin Summerhayes, Jenny Baeseman, Heinz Miller (Chairman), Chris Rapley, Volker Rachold, Elena Andreeva.



Cover of the IPY Final Report: *International Polar Year 2007–2008*.

of the polar regions and of the range of global linkages, geophysical, biological and societal, of polar processes.

IPY 2007-2008 also generated a widely anticipated 'pulse' (momentum) in the form of substantial new funding for polar research and monitoring programmes, new observational and analytical programmes; technologies, integrated system-level approaches, and a remarkably broadened circle of stakeholders in polar science. By the official closing date of June 2010, the field had been rejuvenated by almost a decade of planning, organization and implementation of IPY, as well as by the entry of many new players. Also the general public had been kept more abreast about the significance of polar scientific and environmental science than ever…".

IPY contributed not only to the theoretical and organizational strengthening of polar research, it also created a powerful legacy in our understanding of polar processes and their global linkages. Large-scale data sets were established in many fields, against which future change can be assessed. Novel and enhanced observing systems were launched that will eventually produce long-term benefits to many stakeholders, including polar residents. And IPY trained a new generation of scientists and leaders who will carry this legacy into the future.

SCAR and IASC jointly established a Bipolar Action Group (BiPAG) in 2008 to consider how best to implement the legacies of IPY (see Chapter 7), and among other things agreed to co-sponsor IPY's Association of Polar Early Career Scientists (APECS). The responsibility for overseeing the IPY legacy passed from BiPAG to the SCAR and IASC Executive Committees in 2010, leaving BiPAG to focus on identifying science issues of mutual interest to SCAR and IASC. BipAG was dissolved in 2014, with the proviso that the potential for developing bipolar activities should be routinely considered by each science group. Taking a bipolar approach to key scientific issues, including those identified in the Horizon Scan, was the focus of a joint SCAR-IASC Think Tank meeting in Potsdam in February 2016, which involved the EXCOMs of both groups and some invited experts.

Capacity Building, Fellowships, and Awards

SCAR's Advisory Group on Capacity Building, Education and Training (CBET) helps Members with less well-developed scientific programmes to develop their expertise. Among other things, it manages the process through which SCAR provides 4 to 6 annual fellowships to early career scientists wishing to broaden their experience by working in a polar research laboratory in a different SCAR Member country. SCAR's fellowship funding has been independently supported by India, Italy, Norway and Switzerland. By 2012 COMNAP had agreed to co-sponsor one of the fellowships, and independently sponsored one fellowship itself. In 2016 the award scheme was fleshed out with funds from the Prince Albert II of Monaco Foundation's 2013 Prix Biodiversité.

SCAR also provides funds, mostly from SRP budgets, to fund travel grants for early career scientists to attend the Open Science Conferences or the Biology or Earth Sciences Symposia. SCAR also promotes the development of early career scientists through APECS, via mentoring, and encourages APECS scientists to become involved in its SRPs and other activities. To cement linkages, an APECS member sits on the CBET Committee.

By 2015, SCAR had begun a Visiting Professorship scheme to enable experienced researchers to teach or carry out research at major laboratories in a different SCAR Member country for 2–4 weeks. The first two professorships were awarded that year.

SCAR continued with its round of awards for Scientific Excellence, for International Scientific Coordination, and for Outstanding Scientific Achievement (see Appendix 8).

On behalf of the Tinker Foundation, SCAR continues to manage the process for awarding the prestigious Martha T Muse Prize (later the Muse Prize) for Science and Policy in Antarctica.

The Muse Prize

Photographs and the principal research areas of the winners of the Muse Prise in subsequent years are shown in the following columns.

Steven Chown (South Africa) receiving the first Martha T Muse Prize from Renate Rennie for Antarctic Biology in 2009 .

Helen Fricker (USA) recipient of the Muse Prize for Glaciology in 2010.

José Xavier (Portugal) for Southern Ocean Biology in 2011.

Steve Rintoul (Australia) for Southern Ocean Circulation in 2012.

Valérie Masson-Delmotte (France) for Palaeo-hydrology in 2015.

Martin Siegert (UK) for Glaciology in 2013.

Rob DeConto (USA) for Palaeoclimatology in 2016.

Tim Naish (NZ) for Palaeoclimatology in 2014.

Matthew England (Australia) for Physical Oceanography in 2017.

Michael Meredith (UK) for Physical Oceanography and Climatology in 2018.

SCAR's Partners and Products

As explained and tabulated in Chapter 7, SCAR works with a number of partners and has a wide range of scientific products, which continued with minor change through to 2018. SCAR cements its partnerships through a Letter of Agreement or a Memorandum of Understanding (MoU) [29]. In 2014, SCAR and IASC signed an additional MoU with the European Polar Board (EPB), and in 2016 one with the Asian Forum for Polar Sciences (AFoPS). By 2016, SCADM had become an Associate Member of the International Oceanographic Data and Information Exchange (IODE) programme of UNESCO's Intergovernmental Oceanographic Commission (IOC). And in 2017, SCATS was holding discussions

Signature of the SCAR-IASC-AFoPS agreement, Kuala Lumpur Malaysia in 2016. Left to right: SCAR Vice-Presidents Terry Wilson and Karin Lochte; Yeadong Kim (AFOPS Chairman), Susan Barr (IASC President) and Jerónimo López-Martínez (SCAR President) with joined hands; the representative of the Malaysian Science Ministry, and SCAR Vice-Presidents Azizan bin Abu Samah and Brian Storey.

[29] www.scar.org/partnerships/agreements.

with IAATO on potential collaboration related to IAATO's Systematic Conservation Planning Project. Through its partnership with WCRP, SCAR co-sponsors the Climate and Cryosphere (CliC) Project, the International Programme for Antarctic Buoys (IPAB) and the CLIVAR/CliC/SCAR Southern Ocean Implementation Panel.

ICSU Bodies	Antarctic Treaty System	Organizations with a Polar Focus	Programmes with a Polar Interest
International Association of Cryospheric Sciences (IACS)	Agreement on the Conservation of Albatrosses and Petrels (ACAP)	Southern Ocean component Global Ocean Ecosystem Dynamics Programme (SO-GLOBEC)	Global Biodiversity Information Facility (GBIF)
International Astronomical Union (IAU)	Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR)	Integrating Climate and Ecosystem Dynamics in the Southern Ocean Programme (ICED)	Integrated Global Observing Strategy Partnership (IGOS-P)
International Arctic Science Committee (IASC)	Council of Managers of National Antarctic Programmes (COMNAP)	International Permafrost Association (IPA)	Past Climate Changes (PAGES)
Scientific Committee on Oceanic Research (SCOR)	Committee on Environmental Protection (CEP)	International Partnerships in Ice Core Sciences (IPICS)	Global Ocean Observing System (GOOS)
Scientific Committee on Solar Terrestrial Physics (SCOSTEP)		Association of Early Career Scientists (APECS)	Partnership for Observation of the Global Oceans (POGO)
World Climate Research Programme (WCRP)			
Committee on Data for Science and Technology (CODATA)			

Table of SCAR's partners.

A SCAR product is defined as being 'a resource that needs ongoing maintenance'. SCAR's data products were reviewed internally in 2011 to ensure that they were regularly updated, and that each had a clear line of management responsibility. Highlights of the current decade include: the publication of IBCSO Version 1.0 (the bathymetric map of the Southern Ocean) in 2013, and the Bathymetry and Geological Setting of the Drake Passage in 2016; the publication of BEDMAP 2 (updated map of the depressed land beneath Antarctica's ice) [30] in 2013; the amalgamation of SCAR-MarBIN and AntaBIF into Biodiversity.aq, which brings together biological data from marine and terrestrial realms; the publication of the Biogeographic Atlas of the Southern Ocean; and the publication of ADMAP-2012, the latest compilation of the Antarctic Digital Magnetic Anomaly Project (ADMAP).

[30] Fretwell *et al.*, 2013, in *The Cryosphere* 7, 3775-3793.

Antarctic Data Directory System (ADD)	Antarctic Digital Magnetic Anomaly Project	Antarctic Biodiversity Database	Antarctic Map Catalogue	Antarctic Bedrock Mapping (BEDMAP)	Composite Gazeteer of Antarctica (CGA)
Continuous Plankton Recorder Database (CPR)	Geodetic Data	International Bathymetric Chart of the Southern Ocean	Reference Antarctic Data for Environmental Research	Seismic Data Library System	Tide Guage Data

Table of SCAR's data products.

The Executive Directors of SCAR: from the left Dr Colin Summerhayes (2004–10), Dr Chandrika Nath (2018–), Dr Michael Sparrow (2010–15), and Dr Jenny Baeseman (2016–17).