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REVIEW ARTICLE

Science in Antarctica and the role of the Scientific Committee on Antarctic Research (SCAR)

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Abstract

Scientific research in Antarctica requires international cooperation due to the magnitude of the objectives, the particular conditions of the Antarctic environment, and also because the Antarctic Treaty, signed in 1959 and entered into force in 1961, recognizes scientific research and international cooperation as important pillars. The Scientific Committee on Antarctic Research (SCAR), established in 1958, is the organisation responsible for promoting and coordinating scientific research in the Antarctic region (including the Southern Ocean) and for providing scientific advice to the Antarctic Treaty System and to other international bodies on Antarctica. This paper illustrates how SCAR operates to accomplish its mission and how it is organized to develop and coordinate the researches carried out by a large scientific community belonging to the - as of 2013 - 37 SCAR member countries. The five SCAR Scientific Research Programmes initiated in 2013 are a framework that will orientate a significant part of the research efforts during the next four to eight years. These programmes are highlighted in this paper, as well as other initiatives currently carried out by SCAR.

Keywords: Antarctica, SCAR, scientific research, international cooperation, policy advice

Introduction

Today the relevance of polar research is recognised because of the important role of these regions in the global Earth System. Antarctica is the coldest region on Earth, containing more than 90% of the existing ice, and about 75% of the fresh water in our planet. It influences sea level and the global atmospheric and oceanic circulations. It is also a favourable place to study the adaptation of life to extreme conditions; a privileged platform for astronomical observations and for measuring natural fields, a key place for understanding the continental

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break-up and the geological history, and an excellent place for detecting and following natural and anthropogenic environmental changes.

The study of Antarctica and the Southern Ocean, and their role in the Earth system, has become a topic of increased interest as the region experiences change that has global implications. The Antarctic region is a privileged location for scientific research of importance in its own right and impossible to achieve elsewhere on the planet.

The Antarctic region's unique geographic and environmental conditions as well as the administrative status granted by the Antarctic Treaty make international collaboration essential. With regards to scientific research, the body responsible for facilitating international scientific collaboration in Antarctica and the surrounding Southern Ocean is the Scientific Committee on Antarctic Research (SCAR). SCAR maintains close relationships with other bodies involved with the Antarctic Treaty System (ATS), in particular with the Council of Managers of National Antarctic Programmes (COMNAP), the Convention for the Conservation of Antarctic Marine Leaving Resources (CCAMLR) and the Committee of Environmental Protection (CEP), among others.

SCAR was formed in 1958, during the International Geophysical Year (IGY) by the International Council for Science (ICSU) and has made numerous contributions during more than 55 years (Walton and Carlkson 2011). As of 2013/14 SCAR's Members include 37 nations and 9 ICSU scientific Unions. SCAR is always open to incorporate new countries interested in Antarctic research. The application for becoming a new SCAR Member must be made by the official body representing the country in ICSU or by the organization in which it delegates. There is a category of Associate (non-voting) Member that normally is used for countries that are initiating the development of a national Antarctic programme and are showing an interest in Antarctic science. To become a SCAR Full (voting) Member requires demonstrating continuity of the scientific activities in terms of developing an active research programme. Both the scientific communities of Associate and Full Members of the SCAR countries are allowed to participate and contribute in the activities and initiatives promoted by SCAR. Detailed information about SCAR activities and rules of procedure can be obtained from its website (www.scar.org).

SCAR played a leading role in the organization and development of activities during the International Polar Year 2007-2008 (IPY) and has undertaken responsibility for maintaining much of the IPY legacy in the Antarctic region (Krupnik *et al.* 2011). For more information about the IPY see www.ipy.org.

SCAR's strategic vision is for a world where the science of the Antarctic region benefits all, excellence in science is valued and scientific knowledge informs policy. The main objectives of SCAR's mission are to (i) be the leading non-

governmental, international facilitator and advocate of research in and from the Antarctic region and (ii) to provide objective and authoritative scientific advice to the Antarctic Treaty and other bodies such as the Intergovernmental Panel on Climate Change, and to bring emerging issues to the attention of policy makers.

Science in the Antarctic region and within SCAR

SCAR provides a forum for international scientific coordination, bringing together investigators from different countries and different disciplines to engage in coordinated and collaborative research activities. It enables research and links to international policy makers that would not be possible working solely through a single country and provides a medium for countries to expand their activities in the Antarctic and Southern Ocean.

SCAR accomplishes its work through a number of subsidiary bodies including Action, Expert and Advisory Groups, Standing Scientific Groups and Committees and Scientific Research Programmes. Action groups are formed to answer a specific question or carry out a specific task and have lifetimes of 2-4 years, whereas Expert Groups are formed to look at longer-term issues and have lifetimes of around 6 years.

Final decision-making authority rests with the SCAR Member countries and Unions through their Delegates by unanimous consent. An Executive Committee is empowered to act on behalf of the Delegates intersessionally. The business of SCAR is conducted at biennial meetings that include subsidiary body meetings, scientific group business meetings, an Open Science Conference and the Delegates' meeting. The SCAR biennial meetings during last decade have been in China (2002), Germany (2004), Australia (2006), Russia (2008), Argentina (2010) and USA (2012). The 2014 meetings are in New Zealand and in 2016 will be held in Malaysia.

The SCAR Scientific Research Programmes (SRPs) are SCAR's marquee science programmes. They carry out their work for periods of up to 8 years and they aim to answer or advance major cutting-edge research questions. In July 2012 SCAR Delegates approved five new SRPs that started in 2013. The new SRPs will continue the important scientific foci of SCAR, whilst expanding into newly identified high priority areas for research, including a stronger emphasis on scientific advice to the Antarctic Treaty. The new SRPs are:

State of the Antarctic Ecosystem (AntEco)
Biological diversity is the sum of all organisms that determine how ecosystems function, and underpins the life-support system of our planet. The SCAR SRP State of the Antarctic Ecosystem (AntEco) will be focusing on past and present patterns of biodiversity in the Antarctic, sub-Antarctic and Southern Ocean regions, to enhance scientific knowledge on biodiversity that, when coupled

with increased knowledge of species biology, can be used for the conservation and management of Antarctic ecosystems. The new challenges are to distinguish the impact of present processes from historical signals, and to develop scenarios of potential future states through interdisciplinary approaches. Key scientific questions include:

- How has Antarctic biodiversity evolved in response to past environmental change and what does this tell us about its capacity to respond to future change?
- What are the systematic and environmental geographic features of Antarctic biodiversity, and what mechanisms underpin the current distribution and abundance of biodiversity?
- Given the evolved geographic distribution of diversity and forecast threats, what conservation actions are required for mitigation of, and adaptation to, change?

The principal role of AntEco is to promote the use of established and innovative technologies in research and collaborations that will enable the synthesis and integration of biological, physical and temporal data at different resolutions in order to better understand the nature of Antarctic ecosystems.

Antarctic Thresholds - Ecosystem Resilience and Adaptation (AnT-ERA)
The SRP Antarctic Thresholds - Ecosystem Resilience and Adaptation (AnT-ERA) will examine the current biological processes in Antarctic ecosystems, to define their thresholds and thereby determine resistance and resilience to change. Stresses on Antarctic ecosystems result from global climate change, including extreme events, and from other human impacts. Consequently, Antarctic ecosystems are changing, some at a rapid pace while others are relatively stable. A cascade of responses from molecular through organismic to the community level are expected.

The differences in biological complexity and evolutionary histories between the polar regions and the rest of the planet suggest that stresses on polar ecosystem function may have fundamentally different outcomes from those at lower latitudes. Polar ecosystem processes are therefore key to informing wider ecological debate about the nature of stability and potential changes across the biosphere.

The main goal of AnT-ERA is to facilitate the science required to examine changes in biological processes, from the molecular to the ecosystem level, in Antarctic and Sub-Antarctic marine, freshwater and terrestrial ecosystems. Tolerance limits as well as thresholds, resistance and resilience to environmental change will be determined. AnT-ERA will be classified into 3 overlapping themes: i) molecular and physiological performance, ii) population processes, iii) ecosystem functions and services.

Antarctic Climate Change in the 21st Century (AntClim^{21})
The overarching question of the SRP Antarctic Climate Change in the 21st Century (AntClim^{21}) is: How will the Antarctic environment change over the 21st Century? This is an important issue both within Antarctic region and globally. To achieve this goal, AntClim^{21} will focus on three themes of research: i) Quantification of Antarctic climate variability, ii) Climate model verification for the Antarctic region, iii) Antarctic climate projection to 2100 AD.

The Antarctic region has already experienced substantial changes with impacts on global sea level and ocean carbon uptake. To understand the significance of recent trends in the context of natural variability, it is important to consider change on a multi-century time scale. This proposal will focus on the past 2,000 years. In addition, the group will take advantage of data and model outputs from earlier key time periods as they become available, such as the mid-Holocene, glacial terminations, warm interglacials, and the mid-Pliocene. Moreover, attribution of the causes of environmental change is a high priority. There needs to be an assessment of how realistically climate models capture key forcings to help constrain climate model projections of future change. The overall aim is to provide improved projections of the magnitude and patterns of change to Antarctica's physical environment as a result of global change over the next 100+ years. The assessment will be based on Intergovernmental Panel on Climate Change (IPCC) Assessment Report Five (AR5) Representative Concentration Pathways (RCP) and updated scenarios as they become available.

Past Antarctic Ice Sheet Dynamics (PAIS)
The overarching goal of the SRP Past Antarctic Ice Sheet Dynamics (PAIS) is to improve confidence in predictions of ice sheet and sea level response to future climate change and ocean warming. For this, PAIS aims to improve understanding of the sensitivity of East, West, and Antarctic Peninsula Ice Sheets to a broad range of climatic and oceanic conditions. PAIS builds on the success of former SRP ACE (Antarctic Climate Evolution), but with a new focus on the ice sheet rather than palaeoclimate reconstructions. Study intervals span a range of timescales, including past "greenhouse" climates warmer than today, and times of more recent warming and ice sheet retreat during glacial terminations.

The PAIS research philosophy is based on data-data and data-model integration and intercomparison, and the development of "ice-to-abyss" data transects, extending from the ice sheet interior to the deep sea. The data-transect concept will link ice core, ice sheet-proximal, offshore, and far-field records of past ice sheet behaviour and sea level, yielding an unprecedented view of past changes in ice sheet geometry, volume, and ice sheet-ocean interactions. These integrated data sets will enable robust testing of a new generation of coupled Glacial Isostatic Adjustment-Ice Sheet-Atmosphere-Ocean models that include new reconstructions of past and present ice bed topography and bathymetry.

PAIS will accomplish its objectives by: 1) facilitating the planning of new data-acquisition missions using emerging technologies; 2) encouraging data sharing and integration of spatially targeted transect data with modelling studies; and 3) initiating/expanding cross linkages among Antarctic research communities.

Solid Earth Response and Cryosphere Evolution (SERCE)
The Solid Earth Response and influence on Cryospheric Evolution (SERCE) SRP aims to advance understanding of the interactions between the solid earth and the cryosphere to better constrain ice mass balance, ice dynamics and sea level change in a warming world. This objective will be accomplished through integrated analysis and incorporation of geological, geodetic and geophysical measurements into models of glacial isostatic adjustment (GIA) and ice sheet dynamics. The programme is designed to synthesize and integrate the extensive new geological and geophysical data sets obtained during and subsequent to the International Polar Year with modelling studies, in a timeframe to contribute to IPCC AR6.

SERCE will provide the international collaborative framework and scientific leadership to investigate systems-scale solid earth–ice sheet interactions across Antarctica and relate these results to global earth system and geodynamic processes. A series of expert workshops and thematic symposia on improved data-modelling integration will propel the science of solid earth – cryosphere interactions beyond the current state of knowledge. The SERCE programme will conduct major efforts in capacity building, training and public outreach using complementary strategies to achieve technical capacity via information exchange, analytical capacity via training schools, engagement of new polar researchers via thematic science sessions, and public outreach via the world-wide web.

These new SRPs join Astrophysics and Astronomy from Antarctica (AAA), which aims 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.

Other SCAR Action and Expert groups focus on issues such as ice mass balance and sea level, remote sensing of bird populations, polar atmospheric chemistry, ocean acidification, environmental contamination, permafrost and periglacial processes, and human biology and medicine to give just a few examples. These groups are under the umbrella of the three SCAR Standing Scientific Groups (Geosciences, Life Sciences and Physical Sciences). There are also Advisory groups that take an overview of important topics such as Climate Change and Capacity Building as well as Standing Committees with foci on data management, geographic information and SCAR's interactions with the Treaty.

SCAR also promotes and contributes to the development of Antarctic and Southern Ocean observation networks, and is involved in several initiatives related to atmospheric, astronomical, lithospheric, cryospheric and oceanic observation networks, for example, the Southern Ocean Observing System (SOOS), co-sponsored with the Scientific Committee on Oceanic Research (SCOR).

Scientific data and information are valuable and irreplaceable resources. SCAR recognizes the critical and essential importance of the stewardship of data and information within national and international programmes and its accessibility to all. Proper management of data and information is not an "add-on" or an additional task; it is a fundamental aspect of modern science. The management of data and information on behalf of SCAR's scientific community is carried out by the Standing Committee on Antarctic Data Management (SCADM) and the Standing Committee on Antarctic Geographic Information (SCAGI).

The Future of Science in Antarctica and the Southern Ocean
To sustain a position of leadership, SCAR must maintain a continually evolving vision of frontiers and emerging directions in Antarctic and Southern Ocean science. Over the short term this comes directly from the community of SCAR scientists, who are very much used to thinking in terms of the 5-10 year (typical funding) time scale. However, what will the main science questions be over the longer term? This is the question of the 1st SCAR Antarctic and Southern Ocean Science Horizon Scan "A View beyond the Horizon: Future Directions in Antarctic Science" is attempting to answer. The Scan assembled some of the world's leading Antarctic scientists, policy makers, leaders, and visionaries to identify the most important scientific questions that will or should be addressed by research in and from the southern polar regions beyond the next two decades. Previously the scientific community sent over 850 unique questions and nominated almost 500 scientists of which were selected the group of about 70 scientists that complete the job. The Scan outcomes will assist in aligning international programmes, projects and resources to effectively facilitate Antarctic and Southern Ocean science in the coming years. The results will be available in several publications and on the SCAR website.

SCAR scientific advice

SCAR provides objective and independent scientific advice to the Antarctic Treaty Consultative Meetings (ATCMs) and other organizations on issues affecting the conservation and management of Antarctica. SCAR also identifies issues emerging from greater scientific understanding of the region and brings them to the attention of policy makers.

SCAR provides advice to the Treaty Parties through its Standing Committee on the Antarctic Treaty System (SCATS). SCAR initiates advice as well as

responding to requests for information, mainly from the Committee on Environmental Protection (CEP). In recent times, advice has been in regard to the conservation, protection and management of Antarctica, as well as related to climate change and its impacts, among other scientific issues.

SCAR prepares papers for the ATCMs, in some cases in partnership with other entities (e.g. COMNAP and IUCN) and individual Treaty Parties. SCAR's status as an independent and objective scientific advisor in the Antarctic Treaty System is maintained at all times. To promote the presence of the science in the Treaty meetings, since 2003 SCAR has provided a SCAR Science Lecture as an ATCM agenda item, addressing the latest developments in Antarctic sciences and emerging issues.

SCAR, in collaboration with several partners, are developing a strategy entitled 'Antarctic Conservation for the 21st Century'. The activity will actively encourage participation from all stakeholders in the region. The approach will be structured to align with both the Protocol on Environmental Protection to the Antarctic Treaty and the Five Year Work Plan of the Committee for Environmental Protection. The Antarctic Conservation Strategy links closely with the Environments Portal being developed by New Zealand, SCAR, Australia and others. The portal will compile and share scientific information on, for example, the status and trends of species, emerging environmental concerns, threats to biodiversity or implications of climate change. Bringing together information in this way would support work on subjects such as the consideration of non-native species risks, threats to biodiversity and the implications of climate change. The portal will provide access to assessments and syntheses prepared independently by SCAR on priority issues.

SCAR also provides scientific advice on the role of the Antarctic and associated systems in global climate change to the Intergovernmental Panel on Climate Change (IPCC) and the UN Framework Convention on Climate Change.

Building capacity in Antarctic research

To enable all in the SCAR family to participate in, contribute to and benefit from SCAR's activities, SCAR works to enhance the capacity of all of its members and the Antarctic community, including early career scientists and students.

The National Antarctic Programmes of SCAR Members vary greatly in size and capacity. Some have large scientific communities that are well funded and long standing. Others have relatively small and/or new Antarctic science communities that are just developing. SCAR runs several Fellowships and Prizes, including the Fellowships (jointly with COMNAP), the Martha T Muse Prize for Science and Policy in Antarctica and a Visiting Professor Scheme.

SCAR/COMNAP Fellowships
The SCAR/COMNAP Fellowships are designed to encourage the active involvement of early career scientists and engineers in Antarctic scientific research, and to build new connections and further strengthen international capacity and cooperation in Antarctic research. The Fellowships allow researchers from any country to undertake short term visits to major international laboratories, field facilities, and/or home institutions of a SCAR/COMNAP Member country. The awards are up to US$ 15,000 each and are announced annually.

SCAR Visiting Professor Scheme
The Visiting Professorship Scheme is directed at mid- to late-career scientists and academics whose work contributes to the scientific objectives of SCAR, offering the opportunity for them to undertake a short-term visit (from one to four weeks) to another SCAR member country to provide training and mentoring. Awards are granted to individuals based on competitive criteria and enable successful candidates to contribute their experience towards strengthening the scientific research capacity of nations with smaller or less well-developed Antarctic research programs. The ultimate goal of the scheme is to promote capacity building in the host institute and to develop long-term scientific links and partnerships leading to advances in Antarctic research. The awards are up to US$ 2,500 each and are announced annually.

Martha T Muse Prize for Science and Policy in Antarctica
Sponsored by the Tinker Foundation, the "Martha T. Muse Prize for Science and Policy in Antarctica" is a US$ 100,000 unrestricted award presented to an individual in the fields of Antarctic science or policy that has demonstrated potential for sustained and significant contributions that will enhance the understanding and/or preservation of Antarctica. The Tinker Foundation's goal is to establish a prestigious award that recognizes excellence in Antarctic research by honoring someone in the early to mid-stages of his or her career. The prize-winner can be from any country and work in any field of Antarctic science or policy. The goal is to provide recognition of the important work being done by the individual and to call attention to the significance of understanding Antarctica in a time of change.

Concluding remarks

The global relevance of Antarctic research, in particular in the context of the climate change, is globally recognised. This paper has highlighted the need and advantages of international cooperation in order to be more efficient and effective as well as because of the requirements of the Antarctic Treaty. The role of SCAR is to promote international scientific research in the Antarctic region, and identify programmes, fora and actions to coordinate the efforts of different countries to contribute to increase efficiency, avoid repetitions and facilitate

mutual knowledge. All this reinforce the values of the Treaty and also can help the national Antarctic programmes to orientate their activities. The countries that conduct more and better coordinated scientific research contribute in a greater measure to the aims of the Treaty and have a more influential role in the system. Scientific research in Antarctica contributes to increase our knowledge about local and global status and processes. SCAR, with its advisory role in the Antarctic Treaty System, works to ensure this knowledge is transmitted to policy makers and promotes environmentally responsible decisions affecting the greatest under-explored continent on our planet.

For further information on SCAR please consult the SCAR web site (www.scar.org). SCAR Member countries also have their won SCAR National Committees, which are responsible for national activities within SCAR. Their activities, contact details and links are also indicated in the SCAR web site.

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