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A Roadmap for Antarctic Science: Assessing the Effectiveness of the Antarctic Roadmap Challenges

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Abstract/executive summary:

Between 2012 and 2014 the Scientific Committee on Antarctic Research, with input from the wider Antarctic community, carried out an inclusive and transparent horizon scan to identify the critical questions that Antarctic science will need to address in the next 20 years. To address the logistical and practical requirements to answer these questions, the Council of Managers of National Antarctic Programs undertook the Antarctic Roadmap Challenges (ARC) project to identify the corresponding technology, infrastructure, access, and logistical requirements. Together the two projects deliver the Roadmap for Antarctic Science, which sets the agenda for research and development by national Antarctic programmes in the medium-term future.

This report examines the development of the Roadmap for Antarctic Science and discusses potential ways to assess its success in influencing the policies and activities of national Antarctic programmes. It identifies several key opportunities and challenges in the implementation of the Roadmap, including the fostering of increased links between the Antarctic and wider scientific communities, shared infrastructure, effective public-private partnerships, substantial and stable funding, the impact of greater international interest in Antarctic affairs and the unique political environment regulated by the Antarctic Treaty System. It also considers the usefulness of the ARC Framework in assisting interested counties to develop national Antarctic programmes.

The report concludes that the significance of the Roadmap for Antarctic Science lies in its shaping of the discussion about the future of Antarctic science, and that continued and strengthened international cooperation remains key to Antarctic research.

Contents

Introduction

Antarctica and the Southern Ocean provides scientists with a unique environment for studying our world. Despite being perceived by many as being remote and distant from everyday life, Antarctica "provides exceptional insight into some of society's most pressing concerns" (Kennicutt et al. 2016, p. 11). Jane Lubchenco in 1998 called for a 'new social contract for science' to address increasing global environmental concerns (in Carlson 2015, p. 559). She challenged scientists in the 21st century "to address the most urgent needs of society, in proportion to their importance, to communicate their knowledge and understanding widely in order to inform decisions of individuals and institutions, and to exercise good judgment, wisdom and humility" (in Carlson 2015, p. 559). These challenges reflect global trends in science, which demands not merely curiosity-driven research but 'practical-instrumental' research, "where the goal is to solve current problems for their immediate application" (Elzinga 1992, p. 96). This shift is evident in the way Antarctic science is developing. Klaus Dodds suggests that science in Antarctica has historically been seen as a form of currency in Antarctic governance, whereby the production of scientific knowledge has been used to give credibility to states in influencing Antarctic affairs (2012, p. 75). As a result, governments of states involved in sponsoring the research" did not need to care so much about what they were doing, so long as they were there and the results of their preoccupations enhanced their countries' political credibility" (Elzinga 1992, p. 96). Science in Antarctica could be considered to enable domestic policy towards Antarctica, rather than policy being written to enable Antarctic science (1992, p. 96). The result, as Elzinga suggests, is that Antarctica has been less of a continent *for* science than a continent *by* science (1992, p. 96, italics in original). The publication of the Scientific Committee on Antarctic Research's (SCAR) Horizon Scan in 2014, followed by the Council of Managers of National Antarctic Programme's (COMNAP) Antarctic Roadmap Challenge in 2016, marks a refocussing on Antarctic as a continent for science. These projects reflect the emerging trend towards 'practical-institutional' research whereby scientists seek to answer key questions that have practical application to the development of society.

This report examines SCAR's Horizon Scan and COMNAP's Antarctic Roadmap Challenge (ARC), known collectively as the Roadmap for Antarctic Science. The first part describes and examines the processes followed in compiling the Roadmap for Antarctic Science, and discusses how the effectiveness of the Horizon Scan and the ARC project can be assessed. It compares the SCAR horizon scanning process with other key examples of horizon scanning, places it within a foresight process model, and uses this as the basis for assessing success. The second part addresses the opportunities and challenges in moving the ARC project forward. It identifies five main aspects: the fostering of increased links between Antarctic research communities and wider scientific communities, the need and opportunities for shared infrastructure, potential for public-private partnerships, the issue of substantial and stable funding, and the challenges and opportunities presented by increased interest in Antarctica and the Southern Ocean. The report suggests that the significance of the Roadmap for Antarctic Science lies in its ability facilitate discussion surrounding the future of Antarctic Science, while ensuring that international cooperation remains key to carrying out science in the extreme environment of Antarctica.

A Roadmap for Antarctic Science

The SCAR Horizon Scan

The Scientific Committee on Antarctic Research is the inter-disciplinary committee of the International Council of Science (ICS) responsible for initiating, developing, and co-ordinating independent scientific research on Antarctica and the Southern Ocean, and the role of Antarctica in the Earth system. It provides scientific advice to the Antarctic Treaty Consultative Meetings (ATCM) and to other organisations, such as the United Nations Framework Convention on Climate Change (UNFCCC) and Inter-Governmental Panel on Climate Change (IPCC). Recommendations provided by SCAR have informed many of the international agreements that provide protection for the ecology and environment of Antarctica. Formed in 1988, the Council of Managers of National Antarctic Programs brings together managers of National Antarctic Programmes (NAPs). It is charged with developing and providing best practice in managing the support of scientific research in Antarctica. Like SCAR, COMNAP provides advice to the Antarctic Treaty System, drawn from the experience and expertise of its members. Its role includes facilitating collaboration between national programmes, and providing opportunities and systems for information exchange.

Since 1882 there have been 4 International Polar Years (1882-3, 1932-33, and the International Geophysical Years of 1957-8 and 2007-8). Each of these has achieved major advances in scientific knowledge and involved a significant degree of international cooperation. The IPY of 1957-8 can be regarded as the trigger for the current Antarctic Treaty System. For a number of countries, including New Zealand, it also marked the beginning of a permanent presence on the continent. The SCAR Horizon Scan project recognised both the infrequency of IPYs, and the major impact that they have had upon the progress of Antarctic science, and set out to create further opportunity for planning and collaboration.

The Frauenhofer Institute (2015) defines forward-looking activities as those aiming “to better anticipate future opportunities or threats, and to identify issues that are of major importance for the future and the present." Horizon scanning is one such activity, and is defined by the Organization for Economic Co-operation and Development as a method to systematically examine and detect the early signs of potentially important developments (OECD 2016; HM Government 2014).

The SCAR Antarctic and Southern Ocean Science Horizon Scan project was initiated in July 2012. The project was designed to be inclusive, democratic, and transparent (Kennicutt et al. 2016). It adapted the methodology developed by Sutherland, Felishman, Mascia, Pretty and Rudd (2011) to take into account both the regional nature and high multi-disciplinary nature of Antarctic and Southern Ocean science.

To facilitate the Horizon Scan, an International Steering Committee (ISC) was formed with 25 Antarctic experts from 14 states. Two open on-line solicitations were used to gather opinions about the most important science questions expected to be answerable in the next 20 years. A total of 866 scientific questions were collected from a broad range of communities including Antarctic experts, scientists, and policy-makers. A 4-day retreat was planned to condense and organise these questions, with an open process to determine the attendees. An on-line nomination yielded approximately 500 suggestions. These were sorted into 5 subject-related groups (geoscience, life science, physical science, social sciences and policy making), and selected per group by voting in the ISC, paying attention to balance and representativeness. This resulted in the choice of 75 participants for the retreat. A pre-retreat online survey asked invitees to rate the existing questions and provided the opportunity to add further ones.

The retreat, which was held over four consecutive days, set out to identify the highest priorities among the initial 955 questions through a process of debate, discussion, revision and voting. The result was an agreed set of 80 scientific questions. These were categorised into 7 different clusters, and cluster summaries were written. Appendix 1 contains a list of the clusters and an example of the science questions selected. The end result of the SCAR Horizon Scan was a list of the 80 highest priority questions to be addressed by Antarctic research programmes over the next 20 years and beyond.

The Antarctic Roadmap Challenge (ARC) Project

The SCAR Horizon Scan project delivered agreement on the 80 most important research questions related to Antarctica, with the intention of defining a scientific roadmap for the next 20 years. As a follow on, COMNAP initiated the Antarctic Roadmap Challenge (ARC) Project, which sought to answer the question of how National Antarctic Programmes (NAPs) can meet the challenges of delivering the science defined in the roadmap. NAPs are the primary funding and support organisations for Antarctic science, and the ARC provides them with the required information regarding the likely requirements placed upon them by the science community.

The ARC Project sought from the outset to be inclusive, transparent, and democratic. Oversight was provided by an 11-member international and multidisciplinary steering committee, together with the chair of COMNAP and the president of SCAR. Two on-line surveys were used to engage with the global Antarctic community. The first survey asked respondents to identify the technologies required to answer the science questions, where and when each technology would be used, and for which of the 80 science questions it applied. A total of 453 people participated in the first survey, which ran between March and May 2015, with 230 completing the survey. This survey resulted in a list of technologies required, and another list outlining the main requirements for access, infrastructure, and logistics.

A second survey was used to gather further information relating to these lists. For the second survey respondents were asked to assess the current development status of the listed technologies, and to provide a high-level estimate of the associated development costs. In addition, for each of the requirements for access, infrastructure, and logistics, respondents were asked to provide their assessment of the current state of planning, the ability to deliver through a single NAP acting alone, and an estimate of the cost. The second survey ran on-line between July and August 2015, with 257 people participating. Of these, 108 completed it in full and 149 finished a portion of the survey.

Following the completion of the surveys a three-day workshop was held in late August in Tromsø, Norway, where 60 experts from logistics and operations, research science, and national programmes were gathered to consolidate the results of the ARC surveys together with other material such as white papers, summaries of the Horizon Scan, and planning documents. Five writing groups, each addressing one of the seven clusters of questions from the Horizon Scan, were responsible for the workshop's main output. The groups were allocated two leaders: a scientist and a national Antarctic programme expert. Each group was given a form with a standardised set of questions asking them to prioritise the technology required to address the science questions in that cluster, and assess the corresponding development status and high-level costs. The group was also asked to assess the ability of individual NAPs to deliver the technology, and whether the technologies were already available but not yet applied in the Antarctic context. Similar questions addressed the requirements for access, infrastructure, and logistics. The wording of each report was agreed on by the members of the group, and the draft reports were further reviewed and revised by external experts who did not attend the workshop.

The findings from the workshop, together with the detailed results of the two surveys, were developed into the official Antarctic Roadmap Challenge report, also known as the ARC Framework (Kennicutt, Kim, and Rogan-Finnemore 2016). This framework, together with the SCAR Horizon Scan, constitutes the Roadmap for Antarctic Science. To summarise, the Roadmap for Antarctic Science consists of:

- the 'what?', or the Horizon Scan consisting of the 80 biggest questions that Antarctic science needs to answer, and
- the 'how?', or the ARC framework, which describes the requirements of National Antarctic Programmes if they are to deliver the answers.

The ARC Framework gathers the requirements into 4 groups:

1. the observation **technologies** required by scientists to be able to collect data, the current state of development, and the likely future timeframes as well as ballpark estimates of the costs to develop them
2. the **infrastructure** requirements of the Antarctic science community such as stations, vessels, and data links from the field in Antarctica to home research institutions
3. the various forms of **access** required to Antarctica and the Southern Ocean, and
4. the **logistics** of getting science teams there and back safely and efficiently.

A number of important requirements were highlighted as being beyond the capability of any one NAP to supply. Therefore, a significant challenge identified by the ARC is collaboration between NAPs to assist with delivery.

Assessing the effectiveness of the Roadmap for Antarctic Science

The reports delivered by the SCAR Horizon Scan and the ARC Project represent snapshots in time of the key questions for Antarctic science, and the technical requirements needed to deliver answers. The methodology used, adapted from Sutherland et al. (2011), focuses on the techniques and processes to deliver an output that is representative of the community. The methodology does not address the question of how the research output can be maintained over time, or how the effectiveness of the Horizon Scan and ARC should be assessed.

The results of the Scan and the ARC project were produced with considerable involvement and effort from many people in the Antarctic research community. The currency of these results, however, will inevitably decline with the passage of time, increasing scientific knowledge, and developments in technology and infrastructure; in short, with change. While the extensive consultation carried out during the Scan and the ARC project ensures that the resulting roadmap is of high quality, there remain unanswered questions about the need to maintain the roadmap in the face of future developments, and its contribution to the progress of Antarctic research. Key questions remain as to whether it will it be possible in future to look back and confirm that the consultation exercise was worthwhile, and how this might be measured. The next sections address the questions of managing change and assessing the value of the roadmap.

Experience of using Horizon Scanning in other contexts

While horizon scanning is a well-known technique for gathering predictive information in order to formulate policy for the future, it is not without issues. The UK Government institutionalised horizon scanning in 2005, but after an initial period of take-up its importance was downgraded, before it was revived again in 2013 (Rhydderch 2013), and refined in 2014 (HM Government 2017).

Horizon scanning is widely and successfully used in the health sector in many countries. An example of international collaboration resulting in the formation of a central organisation is the EuroScan International Network which was formed in 1997. Also known as the International Information Network on New and Emerging Health Technologies, its purpose is the exchange of information on new advances in healthcare. Euroscan (2014) has developed a Methods Toolkit which includes horizon scanning to identify and track promising new interventions or technologies. Its intention is to ensure that funding and policy decisions are made on the basis of reliable information and at a point in time when decisions can make the greatest difference.

The methodology has been adopted and adapted by a number of countries such as the US (Agency for Healthcare Research Quality 2015) and Malaysia (Malaysian Health Technology Assessment Section 2015). In each case, not only is there clear organisational responsibility for the scan itself, but also a process for carrying out regular updates over time. Furthermore, periodic reviews are built into the process, which use an expert group to assess the effectiveness of the scanning. The metrics used in the assessment of effectiveness include whether the interventions identified in the scan and tracked have fulfilled their promise, and whether the scanning process missed interventions that have subsequently been recognised as successful and requiring funding.

In a different context, the Frauenhofer Institute Report (2015) for the EU Commission investigates the effective use of horizon scanning in formulating policy for European research and innovation. It considers a range of models for horizon scanning, and analyses the experiences gained from successful case studies. One of the main recommendations is that ‘ownership’ of the scanning process be well-defined within the organisation, with clear responsibility being assigned for translating the results of the scanning into the form required for policy-making.

To understand how this might apply within the context of Antarctic science, it is useful to make use of the Foresight Cycle model introduced in the Frauenhofer report (2015), but originating from work by the European Forum for Forward-looking Activities (2013; 2014).

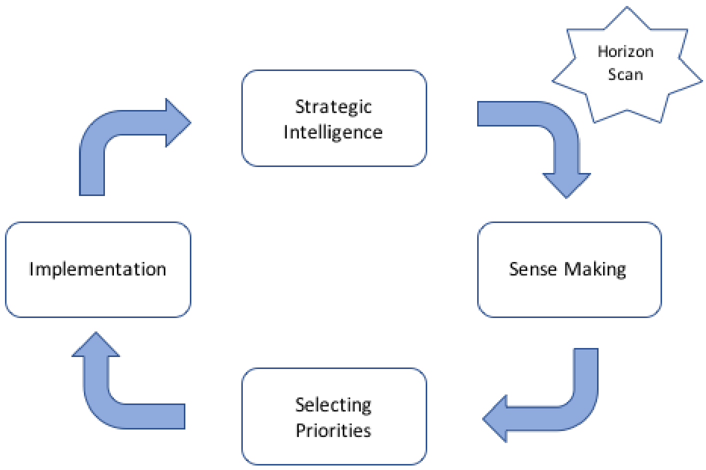

Fig 1: Horizon scanning in the Foresight Cycle, Frauenhofer (2015).

The horizon scan provides strategic intelligence with regard to possible future developments. Sense-making involves the analysis and organisation of that information, including the exploration of different scenarios. The resulting information forms the basis for setting priorities for policy and implementation. The cycle reflects the need to periodically review the progress achieved during implementation against the original intentions, and to adjust to developments in the environment.

Figure 2 summarises the application of the Foresight Cycle model to the SCAR Horizon Scan and the Framework from the ARC Project.

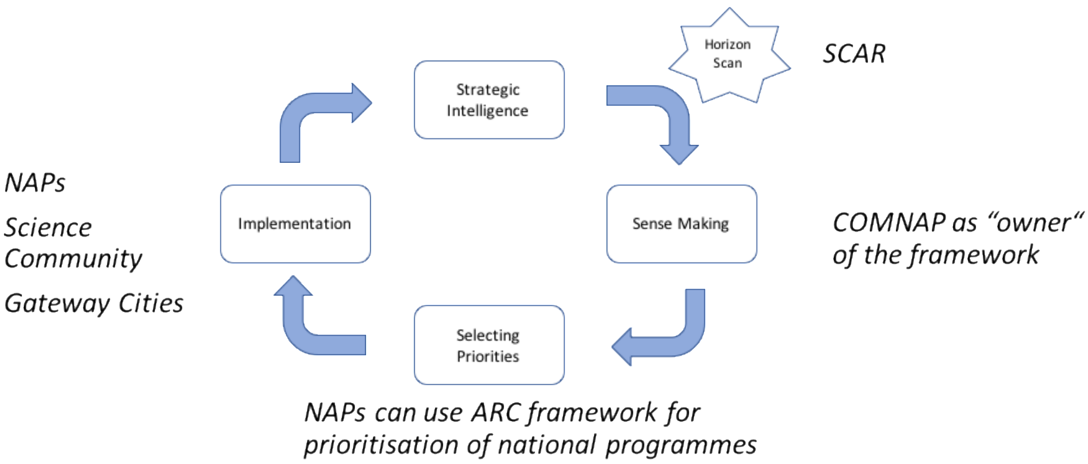

Fig 2: Application of the Foresight Cycle model to the SCAR Horizon Scan and the Framework from the ARC Project.

Taking the components of the Foresight Cycle in turn:

- *SCAR is responsible for the Antarctic science vision, and for managing the cycle to review progress in the science questions*

  SCAR was responsible for the project that delivered the science vision developed through the Horizon Scan. SCAR's strategic plan (2017) for the period 2017 – 2022 states that the vision identified and codified in the 80 key questions will strongly inform and provide direction for Antarctic scientific research in the foreseeable future. The strategic report also notes that SCAR intends to review the results of the scan at 5-yearly intervals.

- *The ARC Project can be understood as the sense-making stage in the process.*

  If the SCAR Horizon Scan delivered the vision of "what science we should focus on", the ARC Project answers questions about the requirements needed to ensure the science can be delivered. It makes sense of the science questions by identifying the technologies needed, the infrastructure, access, and logistics required to enable scientists to gather the data, travel to Antarctica, get to the field and work there safely for the required duration. The framework provides indications of the current status and availability of technologies, the likely time required for further development, and estimates of the costs involved. It also identifies technologies and access requirements that the community feel are beyond the scope of any one NAP.

- *The selection of priorities for policy and implementation rests with the National Antarctic Programmes.*

  Situated at the hub of the network of NAPs, COMNAP's role is to facilitate information exchange, while decision-making lies with the members' national programmes. While the ARC Framework provides the basis for strategic and policy planning for NAPs, each programme is free to set priorities appropriate to its national interests and circumstances. The ARC Framework does, however, provide a ready-made basis for comparison of options, as well as a common language for discussions between programmes about collaboration and sharing of resources.

  The ARC Project report also highlights the need for the Antarctic research community to engage with wider scientific and technology communities. Key technologies such as satellite monitoring and remote sensing are used in many scientific disciplines and across many regions of the world. Making use of them in the extreme environments of Antarctica and the

Southern Ocean may involve additional requirements, but their development is not necessarily driven solely by Antarctic science. Similarly, the need to transmit large volumes of locally collected data from wilderness areas is not unique, although, once again, Antarctica brings particular challenges in terms of its isolation, environment and difficulties of access.

- *Implementation involves the science community, NAPs and Gateway cities.*

  The implementation of both the scientific research and the development of appropriate technologies, Antarctic infrastructure, means of access, and logistical capability, is primarily the responsibility of NAPs, working with the science community. Gateway cities play a particularly important role because they are the geographic focal points for access and logistics. Multiple national programmes make use of each Gateway City, providing opportunities to share capability, resources, and costs to the benefit of all. There are also opportunities for Gateway Cities themselves to develop and deliver services to the NAPs, and to develop new funding models (Antarctic Office 2017).

Assessing the success of the Horizon Scan and the ARC Framework

The SCAR Horizon Scan and the ARC Project were both conducted in a highly open, inclusive, and democratic manner. The methodology adapted from Sutherland et al. (2011) was designed to ensure that the results represented a consensus view of all participants. The diagrams below summarise the demographics of those involved in the ARC Project surveys, which prepared the material for the final on-site workshops.

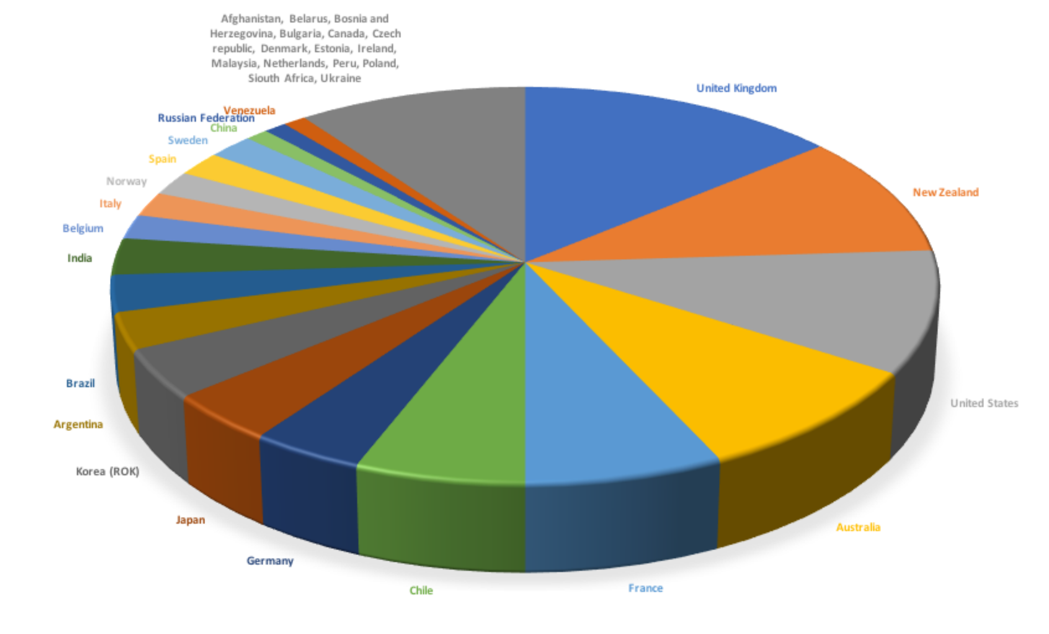

Fig 3: The main country of residency of participants in Survey 1 of the ARC Project

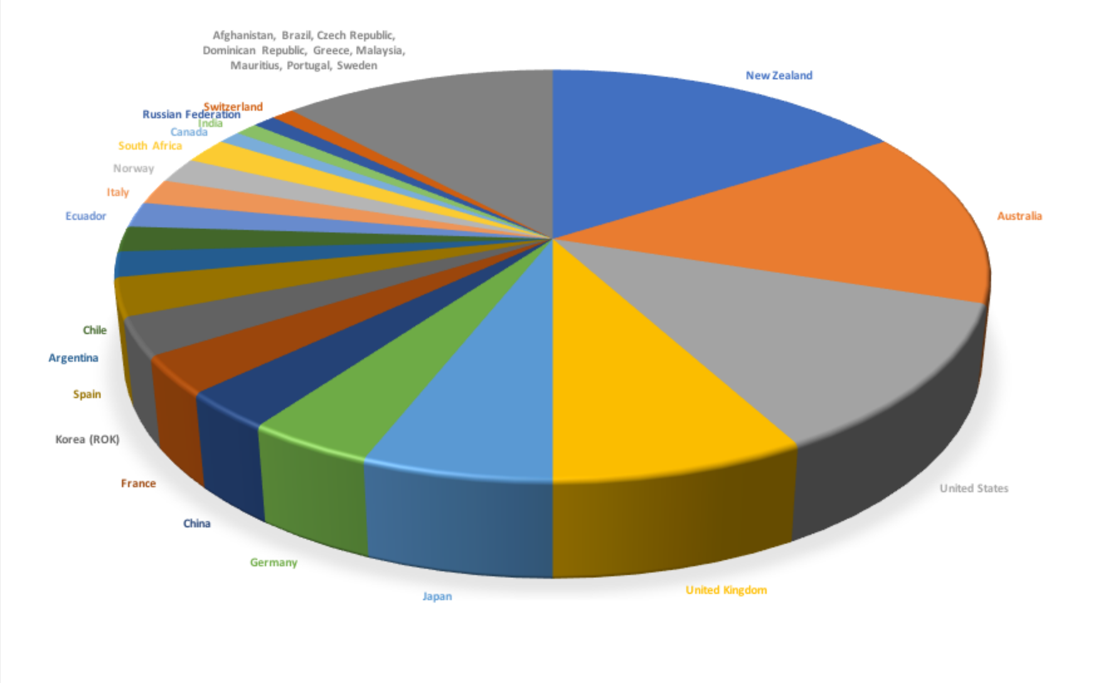

Fig 4. The main country of residency of participants in Survey 2 of the ARC Project

It can be seen that the survey participants came from a wide range of countries. However, it is also apparent that some countries contributed more participants, and could be viewed as dominating the discussions. This may be inevitable because of the wide range in the size of NAPs, as well as their differing degrees of experience. However, it does highlight the challenge faced by the Antarctic community in terms of supporting the development of new national programmes.

COMNAP supports the development of new Antarctic Programmes for members through mentoring. (Rogan-Finnemore 2017). The ARC Framework can serve as a toolkit for this process, by providing an outline of the components of a programme, a basis for selecting priorities, and an indication of the necessary budget. The Antarctic asset database currently in development will also provide information about potential collaboration and sharing of resources.

In seeking to assess the degree of success of the SCAR Horizon Scan and ARC projects, it is important to note that the context is similar to that of both the Euroscan International Network and the European Commission. The bodies setting priorities for policy are national agencies, which are autonomous agents and collaborate with others in the network on a voluntary basis. The hub of the network has the role of facilitating information exchange. It can facilitate the process of finding consensus, but has no authority to impose any specific direction upon the members. This means that the use of target metrics to measure and direct progress is of limited value.

The Scar Vision and the ARC Framework are best understood as toolkits, and a means of promoting the adoption of a common view. They derive their authority from the openness and inclusiveness of the process which delivered them. For example, the final report from the ARC Project was reviewed by all the NAPs prior to publication (Rogan-Finnemore 2017).

The true success of the vision and the ARC Framework will be measured by the extent to which the plans and policy-making of the NAPs for the next period are based upon them. A future piece of work could be to map the contents of NAP strategic plans to the 80 questions highlighted by SCAR (in terms of the science questions asked), and to the ARC Framework (in terms of technology, infrastructure, access, and logistics planning).

Carrying the Roadmap for Antarctic Science forward: opportunities and challenges

The SCAR Horizon Scan and COMNAP Antarctic Roadmap Challenges are both forward-looking projects that set out the ideal conditions for Antarctic science to realise its potential over the next two decades. While the ARC framework identifies the logistical requirements for Antarctic science to be carried forward, the question remains of who is responsible for this. COMNAP was responsible for authoring the ARC reports, but its role as a forum and advisory body to national programmes does not include responsibility for implementing the project. This is largely the responsibility of national programmes themslves, who must decide how to move it forward. While the ARC project highlights ways in which national programmes can structure their research and logistics, the project is a framework for development. While offering advice on the types of research and logistics required, it does not act as a mandate or bind national programmes into a fixed course of action. As the authors state in the forward to the document: “The goal of the ARC project is not to tell governments what research to do or to support,” but rather “to contribute to our understanding of the technical and practical challenges associated with future Antarctic science” (Kennicutt et al. 2016, p. 9). This means that if a national program feels that its recommendations are not in their best interests, it does not have to follow them. Given that the ARC project reflects the priorities of the international Antarctic research communities, this is unlikely. The crucial question, then, is how national Antarctic programmes can implement the suggestions identified in the ARC.

This section will highlight several of the opportunities for Antarctic research identified by the ARC, while also examining some of the political and institutional challenges in implementing them. The opportunities identified by the Roadmap Challenge include fostering greater links between Antarctic communities and wider national and international scientific communities and technology developers, the possibility of greater international and interdisciplinary cooperation around Antarctic ‘supersites’, and the potential for more effective and efficient public-private partnerships.

The need to ensure substantial and stable funding and challenging geopolitical circumstances are also discussed as potential difficulties to implementing the ARC vision.

Greater links between Antarctic communities and wider national and international scientific communities and technology developers

As already mentioned Antarctica has, at least since the fourth International Geophysical Year of 1957 – 1958, been the site of unprecedented international scientific cooperation (Elb 2011; Brady 2013). This is reflected in the science being conducted and published. In a comprehensive examination of academic articles published between 1980 and 2004, Prabir G. Dastidar (2007) notes that there has been a significant increase in the number of Antarctic papers with co-authors from two or more countries. There are also significant cross-national research expeditions carried out in the Antarctic. Examples are the Antarctic Geological Drilling (ANDRILL) project involving Germany, the United States, New Zealand, Italy and the United Kingdom, which studies the evolution of Antarctic ice sheets, and the Australian-led Census on Antarctic Marine Life (CAML), a project involving 17 ships and scientists from over 20 national to examine the distribution and abundance of marine life around Antarctica (National Research Council of the National Academies 2011, p. 115).

While this provides evidence of the degree of collaboration that already exists, successful implementation of the ARC requires substantial new forms of collaboration not only between national programmes but also across disciplines and research interests and areas (Kennicutt et al. 2016). This will require changes in conventional practices and assumptions. David Carlson notes that the evolution of science within disciplinary boundaries tends to cordon research in separate domains (2015, p. 550), and this is evident in the many 'communities' within Antarctic science noted by the authors of the ARC (Kennicutt et al. 2016, p. 15). As Carlson comments, "languages, habits, cultures and resource have developed strong conventions, either national or disciplinary" and he queries whether "science offer[s] a universal language, transcending national boundaries" (Carlson 2015, p. 550).

Another issue in fostering international and transdisciplinary science is the difficulty of moving funds between countries and institutions, a requirement if funding for trans-national programmes is to be fairly distributed (Liggett 2017, personal communication). Institutional changes, however, can be difficult for individual researchers to effect from 'the bottom up'. A lack of overall coordination can also make it difficult to match capacity building in different areas; for example, to ensure that opportunities for training are matched to future employment.

A further area of collaboration highlighted in the ARC involves links between the international Antarctic community and other non-Antarctic scientific programmes and technology providers. The increasing depth and breadth of science highlighted in the SCAR Horizon Scan and in the ARC project makes collaboration with the wider international scientific community and technology providers necessary if national programmes are to meet the research goals identified in the ARC. In particular, the ARC project highlights communication between the polar community and national space agencies and the remote sensing community as an example of collaborations that will enable 'big science' questions to be answered (Kennicutt et al. 2014, p. 47).

Shared infrastructure

The ARC project also proposes shared infrastructure between national programmes as a way to increase capacity. While cooperation between national programmes has historically been robust, several observers have noticed that this cooperation has not yet extended to the sharing of research facilities (Hemmings 2011; Elzinga 2013). Elzinga suggests that the lack of cooperation in this area stems from the perception among emerging Antarctic states that the establishment of a scientific base is necessary to demonstrate a commitment to Antarctic research, fulfilling a condition for becoming a full Antarctic Treaty Consultative Member (2013, p. 209). To date there have been few examples of bilateral collaboration in research stations, and none of genuinely multinational research stations (Hemmings 2011). The need for new research stations has also been questioned by the Antarctic and Southern Ocean Coalition, which has drawn attention to the cumulative environmental impacts of increasing numbers of stations (ASOC 2006, p. 4).

The ARC project identifies the need for the establishment of 'supersites' in areas of high scientific interest in order to facilitate interdisciplinary and cross-cutting science while minimizing logistical challenges (Kennicutt et al. 2016, p. 37). These supersites would be logical places to develop trans-national facilities, as financing and operating them would require significant international collaboration. There are precedents for such collaboration. As Elzinga notes, "In other realms there are research facilities that are funded and operated by a large number of nations for a common purpose with cost-sharing agreements and rules for use and time allocation for scientists from participating countries" (2013, pp. 211 – 212). Examples include the European Southern Observatory with its network of telescopes in Chile, and the European Synchrotron Radiation Facility at Grenoble in France.

International collaboration does not rely solely on joint facilities. However, a seeming reluctance to take up this opportunity may be indicative of broader geopolitical challenges to the development of truly trans-national Antarctic research. Hemmings notes that "the largest states still have no need for partners, and to the extent that their own Antarctic presence reflects their longer-term geopolitical interests, may be disinclined to complicate things by joining in joint facilities – which they may very well have to lead anyway" (2011, p. 13). The establishment of joint facilities is further complicated by sovereignty issues arising from territorial claims. Under the Antarctic Treaty territorial claims are frozen, but not eliminated. As the authors of the ARC state, "physical presence continues to be an essential expression of national geopolitical interests in the region" (Kennicutt et al 2016). Hemmings further suggests that the small number of genuinely shared bases to date reflects a reluctance to abandon national-based Antarctic science in favour of 'a genuinely trans-national science' because of its potential diminishment of sovereignty (2011, p. 16). Claimant states may see internationalizing an existing station or participating in the creation of a new joint station in their claimed territory as a "potential zero-sum game in terms of relative influence and profile within 'their territory'", and be reluctant to support international infrastructure within their claimed sector (2011, p. 13). As Hemmings comments, "having visitors is an altogether different proposition to adding their names to the deeds of the property, let alone pulling yours down and inviting colleagues to join you in building and running a new facility, particularly if you believe you still own the land" (2011, p. 13).

Public-private partnerships

A further opportunity for national programmes to engage with the ARC Framework is in the development of public-private partnerships. While historically research work in Antarctica and the Southern Ocean has been carried out mainly by national programmes, private sector engagement can make major contributions both financially and through improved products and services (National Research Council of the National Academies 2011, p. 118). A key example of a public-private partnership that was heralded as a success was the establishment of Belgium's Princess Elisabeth Station, a joint venture between the privately owned and operated International Polar Foundation (IPF) and the Belgium government. The station was commissioned in 2004 after the IPF raised two-thirds of the funds, with the government contributing the remainder, and generated positive media coverage as the first zero-emission Antarctic station (Cheek, Huyge and de Pomereu 2011, p. 31). The station was to be owned by the Belgium government and operated by the IPF. Yet the station's recent history suggests the difficulties that may arise when infrastructure is no longer directly under the control of national programmes. In 2015 the Belgian government relieved the IPF of responsibility for managing the station, citing financial deception and mismanagement (Enserink 2017). The IPF won the right to run the station again after a lengthy court battle, but the Belgium government responded by instructing researchers not to travel to the Antarctic. As a result, scientists lost an entire season of research (Enserink 207).

Information-sharing is another area where there is potential for conflict between public and commercial priorities. Open science and sharing of data is mandated by the Antarctic Treaty and is an integral part of Antarctic Treaty System. In contrast, commercial applications of science, particularly by the powerful pharmaceutical industry, are conditioned by a different legislative regime, emphasising patent protection and the maximising of profits. An example is bio-prospecting. In the Antarctic region this generally involves research on extremophiles to obtain chemical properties that can be used to develop commercial products such as cold-resistant crop strains, pharmaceuticals, or cosmetics (Meduna 2015). Closely entwined with scientific research, bioprospecting is a development which, because of its commercial applications, can at the least be expected to place pressure on the free exchange of information. As Joyner asks with relation to bioprospecting: “Can the desire to ensure commercial confidentiality and patent protection be reconciled with the legal requirements of scientific exchange and cooperation in the Treaty’s Article III? . . . can intellectual property rights be preserved as a useful means for promoting and encouraging the exchange of scientific information?” (Joyner 2012, p. 205).

A further opportunity for public-private partnerships in the Antarctic involves the growing phenomenon of citizen-science, made possible by access to and sharing of data (Carlson 2015, p. 565). Generally involving members of the public working on projects often in collaboration with or under the direction of professional scientists, citizen science often takes the form of community-based projects that monitor, for instance, “birds, mammals, fish, plants and lakes and river ice,” and directly examine and report the health and conditions of animals (Carlson 2015, p. 565). Such monitoring projects already operate over a substantial part of North America and Eurasia. Examples of web-based citizen science projects for Antarctica include counting of penguins in pictures taken automatically by cameras placed in colonies (Zooniverse 2017), and counting Weddell Seals in satellite pictures (Scientific American 2013; LaRue et al. 2011). Citizen science projects can enable the general public to add value to scientific projects while simultaneously gaining direct experience and increased understanding of scientific research. In the Antarctic context the potential benefits include raising public awareness of issues relating to Antarctica, conservation, and Antarctic science, and in this way adding to public interest in and knowledge of the region.

Substantial and stable funding

A major motivation for seeking new partnerships is the need to spread the considerable financial costs of Antarctic-based science. To realise the ARC vision requires “substantial and sustained investments by governments to meet the challenges of conducting research in a remote and extreme environment” (Kennicutt et al. 2015, p. 409). This is particularly crucial if the goal of developing new technologies is to be realised, with ‘[t]he pace of technological investment . . . determined by the magnitude and rate of investment’ (2015, p. 416).

While the majority of funding for Antarctic research relies on national programmes, Antarctic research competes with other contenders for resources. The economic slowdown has resulted in many Western governments being reluctant to commit more funds or reducing budgets. The only countries to significantly increase their Antarctic budgets recently are China, India, and the Republic of Korea (Brady 2013, p. 16). The reliance of science funding on national agencies also makes this funding vulnerable to changing political priorities and election cycles. President Trump’s promise to refocus NASA on space exploration rather than earth science is a high-profile example of the vulnerability of science research programmes to changes of political agenda. Trump’s election campaign promise to "free NASA from the restriction of serving primarily as a logistics agency for low-Earth orbit activity [and] refocus its mission on space exploration”’ presaged what seemed to many an ominous sign of a turn away from climate-related science (Smith 2016). This was reinforced by the comments of Bob Walker, a senior Trump campaign advisor and fellow climate sceptic. The Guardian reported Walker saying that there was no need for NASA to do “politically correct environmental monitoring”. He further characterised climate research as ‘heavily politicised’ claiming that its political agenda had “undermined a lot of the work that researches have been doing”, and he concluded that “Mr Trump’s decisions will be based upon solid science, not politicized science” (Milman 2016). While scientists believe that their work is based on evidence rather than opinion, the comments cited above are a reminder that science takes place (or not) within a political environment. From its inception, SCAR has been independent of governments, with areas of interest defined by scientific rather than political agendas (Walton, Kennicutt and Summerhayes 2015, p. 576). Given the urgent need for global action on climate change and the importance of the Antarctic region and Antarctic research in providing evidence of its causes and likely effects, a key question is whether it is feasible for science to maintain a stance outside politics.

Increased membership of SCAR and the Antarctic Treaty System

A final opportunity and challenge for the implementation of the Roadmap for Antarctic Science is the increasing international interest in Antarctic activities demonstrated by the growing membership of key Antarctic institutions such as SCAR and the ATS (Brady 2013; Hemmings 2012). Increased international engagement with the continent demonstrates the growing recognition of the value and importance of Antarctic science. But while the growing number of new states signing up to the mechanisms of governance of the Antarctic is a positive, it is also not without challenges. As decision-making bodies, these institutions rely on consensus from all members, and while this ensures that all parties are satisfied with any agreement passed, it also gives individual members the power to veto any agreement (Haward 2012, p. 22). With increasing membership this could lead to a 'UN-type situation', whereby consensus on an issue is impossible due to the competing aims and agendas of different members (Brady 2012). This can lead to the weakening of agreements to the 'lowest-commnon demoninator'.

Where this is likely to have the strongest ramifications is on the environmental protection of Antarctica and the Southern Ocean. Strengthened environmental protection is a crucial part of the vision outlined in the ARC: "A recurring and underpinning guiding principle is to achieve the wished-for outocmes within a framework of environmental stewardship (Kennicutt et al. 2015, p 421). However, as witnessed in the creation of the recent Ross Sea Marine Protected Area (MPA), decision-making by consensus gives states individual power to block proceedings. During the planning of the Ross Sea MPA both Russia and China vetoed any agreement for a considerable period, due to their interest in marine resources in the area (McKie 2016). It was only after intense diplomatic efforts that these states agreed to the MPA.

This raises further questions about the potentially different motivations for activity in the Antarctic (Hemmings 2012). For example, Anne-Marie Brady notes that "Chinese-language polar-science discussions are dominated by debates about resources [in the broadest sense] and how China might gain its share (Brady 2013, p. 42), topics that are virtually absent from the Antarctic discourses of Western nations, where scientific collaboration and environmental stewardship are emphasised. In this context it is worth noting the disproportionate representation in the Roadmap for Antarctic Science process of participants from Western countries (highlighted in Figure 1 and 2). Going forward, a key challenge for the Framework will be to ensure that it speaks to an international audience and engages with both existing and new Antarctic states.

A key element of the philosophy of a horizon scan is to set aside self-interest and short-term needs, and to focus on the future of the science a whole (Kennicutt et al. 2015). The ARC vision is founded on the conviction that Antarctic and Southern Ocean science objectives and questions should be globally connected rather parochial. However, the authors also note that improved technology and climate change are likely to increase the number and diversity of actors in the region, and they note that "external pressures and changing global geopolitical configurations may adversely affect Antarctic governnance and the conduct of science" (Kennicutt et al. 2014, p. 12). At a time when global issues require, more than ever, co-ordinated global responses, a key question for successful implementation of the ARC vision is whether "more defensive, national strategies gather momentum, or whether the countervailing impulse towards global collaboration will prove stronger" (Royal Society 2010, p. 20).

Conclusion

The past two decades have seen an increasing recognition of both the important role that Antarctica and the Southern Ocean play in global weather and oceanic systems and the vulnerability of the region itself to climate change (Kennicutt et al. 2015). This has fuelled further scientific interest in the polar continent which has resulted in an increasing number of states conducting research there. At the same time global scientific trends have moved away from basic curiosity-driven science towards practical-instrumental research that can be used to answer the most urgent global scientific questions. The Roadmap for Antarctic Science sets the agenda for on-going research in the next 20 years by identifying the key science questions, and the main technology, infrastructure, access, and logistical requirements required to answer them. It places Antarctic science at the centre of issues of global scientific interest, and provides an overview to facilitate discussions of interdependencies across national, disciplinary, and technology boundaries.

It remains to be seen whether the Roadmap for Antarctic Science will be incorporated into the aims and goals of national Antarctic programmes. The current significance of the project is its contribution to discussions about the future of Antarctic science. By establishing the key science questions to be answered in the next 20 years and the logistical requirements for addressing them, COMNAP and SCAR have taken the lead in directing the conversation and influencing the agenda. The implementation of the Roadmap itself will take place within the complex political environment that has been successfully regulated over the past half-century through the ATS. Despite the political sensitivities and the very high importance of protecting the Antarctic natural environment, Antarctic science has made remarkable progress with levels of cooperation and collaboration rarely seen elsewhere. The Roadmap challenges the Antarctic community of scientists, technologists, and logistical experts to extend that collaboration not only among national programmes, but also among the wider science and technology communities.

This report has examined SCAR and COMNAP's Roadmap for Antarctic Science in two ways. The first part examined the process used to compile the Horizon Scan and discussed how the effectiveness of the Horizon Scan and the ARC project can be assessed. The second part addressed the opportunities and challenges involved in moving the ARC project forward and, in particular, the need for increased international cooperation. The report notes that while the overall process of generating the Roadmap was as open, transparent and inclusive as possible, it has been strongly shaped by traditional Antarctic states. The challenge remains of ensuring that its implementation, and Antarctic science more generally, is equally open, transparent, and inclusive.

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Appendix: The SCAR Horizon Scan Clusters and sample questions

1. The Antarctic atmosphere, ocean, ice, the solid Earth and its biotic systems

   HSC1Q1: How is climate change and variability in the high southern latitudes connected to lower latitudes including the Tropical Ocean and monsoon systems?

2. The interactions within and between Antarctic and global processes

   HSC2Q13: Why are the properties and volume of Antarctic Bottom Water changing, and what are the consequences for global ocean circulation and climate?

3. Critical couplings, feedbacks and thresholds that modulate and regulate these interactions

   HSC3Q28: What are the thresholds that lead to irreversible loss of all or part of the Antarctic ice sheet?

4. How Earth's polar regions have driven and responded to ongoing and past change

   HSC4Q37: What is the crust and mantle structure of Antarctica and the Southern Ocean, and how do they affect surface motions due to glacial isostatic adjustment?

5. The relationships between ecological and evolutionary processes and their roles in structuring biodiversity ad ecosystem service delivery

   HSC5Q43: What is the genomic basis of adaptation in Antarctic and Southern Ocean organisms and communities?

6. The origins of the universe and life

   HSC6Q70: What is the nature of the Dark Universe and how is it affecting us?

7. How the presence of humans in the region is changing and diversifying, and the ramifications of these changes for Antarctic governance regimes

   HSC7Q77: How will the use of Antarctica for peaceful purposes and science be maintained as barriers to access change?