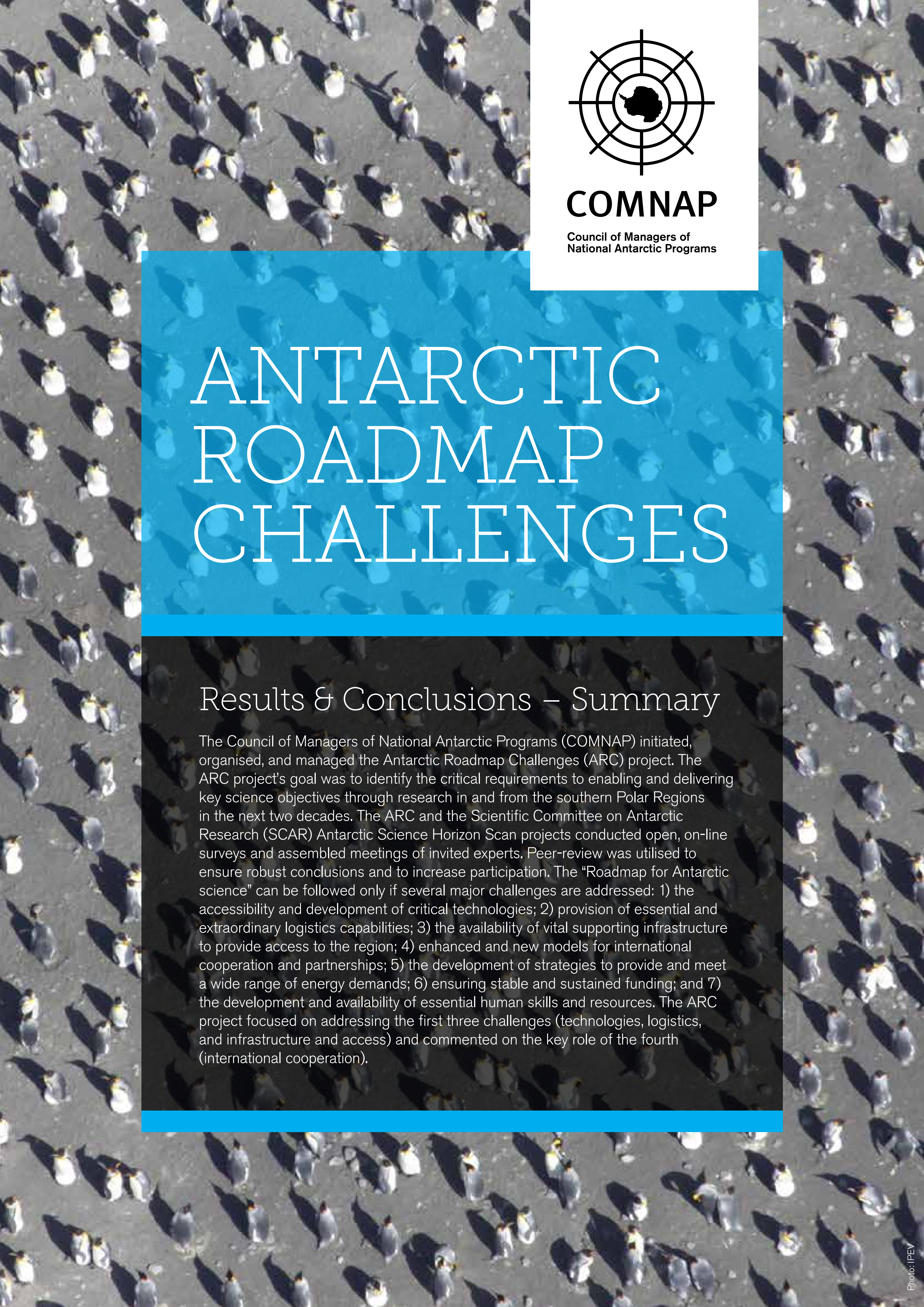

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COMNAP

Council of Managers of
National Antarctic Programs

# ANTARCTIC ROADMAP CHALLENGES

## Results & Conclusions – Summary

The Council of Managers of National Antarctic Programs (COMNAP) initiated, organised, and managed the Antarctic Roadmap Challenges (ARC) project. The ARC project's goal was to identify the critical requirements to enabling and delivering key science objectives through research in and from the southern Polar Regions in the next two decades. The ARC and the Scientific Committee on Antarctic Research (SCAR) Antarctic Science Horizon Scan projects conducted open, on-line surveys and assembled meetings of invited experts. Peer-review was utilised to ensure robust conclusions and to increase participation. The "Roadmap for Antarctic science" can be followed only if several major challenges are addressed: 1) the accessibility and development of critical technologies; 2) provision of essential and extraordinary logistics capabilities; 3) the availability of vital supporting infrastructure to provide access to the region; 4) enhanced and new models for international cooperation and partnerships; 5) the development of strategies to provide and meet a wide range of energy demands; 6) ensuring stable and sustained funding; and 7) the development and availability of essential human skills and resources. The ARC project focused on addressing the first three challenges (technologies, logistics, and infrastructure and access) and commented on the key role of the fourth (international cooperation).

The key findings of the ARC project can be broadly described as "cross-cutting (community-wide)" and "science topic-specific" requirements.

Photo: AWI

## "CROSS-CUTTING" TECHNOLOGIES

The overarching cross-cutting items are those technologies, access, infrastructure, and logistics requirements that were identified as a high priority across all science topics. The highest-priority "cross-cutting" technological requirements were (order does not imply priority):

- Improved and expanded observing systems and sensor arrays that are interoperable, autonomous (can be sustained during long-term [years] deployments continent- and ocean-wide), are capable of meeting and managing growing and varied power demands, are stable and able to maintain long-term calibrations, and are capable of gathering and streaming or storing large amounts of data at finer and finer temporal and spatial scales.
- Advanced data analysis and computational capabilities based on the latest and developing cyber-information and communications technologies and high-performance computing.
- Enhanced satellite remote sensing capabilities with expanded and improved sensors, coverage, and availability that can provide integrated, synoptic region-wide measurements and that can capture diverse types of data.
- Improved coupled Earth System Models that integrate a wide variety of sub-system models and observations, and that include capabilities to handle diverse "big data" sets that will be produced by improvements in bandwidth and transmission capacities.
- Improved retrieval capabilities for all types of samples, including "clean" and "*in situ"* capabilities as well as the ability to provide ground-truth for remote and autonomous sensing arrays.

## THE STATUS OF CRITICAL TECHNOLOGIES

Approximately one third of the required technologies were identified as currently available but available only to a select set of scientists. Other technologies were considered to be currently available in one form or another but with the potential to benefit from improvements. In other instances, new technologies are required. Advancements in a number of technological areas will most likely come from outside of the Antarctic community and the challenge is to apply the latest developments in these areas to Antarctic science. Many of the required technologies are under continual improvement, and advances will incrementally occur over a number of years. Technological advances are critical to answering many high-priority scientific questions and can fundamentally change what questions are addressable, and even what scientific questions can be asked. The rate at which technological challenges will be addressed is in large measure controlled by the magnitude and rate of investments and the ability of the community to focus efforts on highest-priority needs.

## "SCIENCE TOPIC-SPECIFIC" TECHNOLOGIES

In most instances the cross-cutting technologies will benefit, and are essential to, the more specific requirements listed below. In many cases finer details about the cross-cutting requirements are provided by the science topic-specific needs. Key "science topic-specific" requirements were:

**Antarctic Atmosphere and Global Connections**

Continuous measuring sensors and remote weather stations with expanded and robust sensor arrays, technologies for "smart" (unattended) deployment, and improved models are some of the highest-priorities for the atmospheric sciences. The Antarctic community needs to more fully engage with national space agencies to ensure their needs are represented in planning efforts. Scientific advancement of Antarctic atmospheric sciences in the next two decades will be critically dependent on the improved exchange of people and information – including improved logistics coordination, technology transfer, and dissemination, and the availability and coordination of databases.

**The Southern Ocean and Sea Ice in a Warming World**

An overarching goal of ocean sciences research is much greater automation of measurements and lessening dependency on moored platforms to perform field work. Improved underwater and under-ice navigation and positioning are needed to accurately emplace autonomous platforms. Animal-based and other sustainable and deployable technologies need to be made more widely available and less expensive.

**The Ice Sheet and Sea Level**

The integration of models with a wide range of in-field observations will be critical to developing the next-generation ice-sheet models capable of describing and predicting realistic ice flow. Ice-sheet flow is critically affected by basal processes and ice rheology, both of which are not well described in models. To obtain the necessary observations, sampling of the subglacial environment and en-glacial environments is needed, including more-detailed geophysical imaging and mapping of the ice sheet and wider use of remotely deployed expendable instruments. Application of existing private sector 3-D seismic techniques would provide transformative insights into basal processes and ice structures.

**The Dynamic Earth Beneath Antarctic Ice**

Deployment of sensor arrays capable of acquiring continuous year-round data, as part of a sensor network capable of transmitting high volumes of data over long distances, is needed. These will require improvement of existing technologies for ice borehole drilling, sampling of subglacial sediments and rocks, and ocean drilling.

**Life on the Precipice**

The key technologies for the life sciences include improved and more-robust sensors with automated calibration, sensor networks, and higher sensor resolution for monitoring the *in situ* structure and function of living systems. High-volume automated multi-omic platforms for phylogenetic and functional analysis of multiple large-scale meta-omic sample sets, including automated *in situ* meta-genomic analysis and integrated bioinformatics analysis, are critical.

**Near-Earth Space and Beyond – Eyes on the Sky**

Next-generation large single-dish telescopes will require novel designs in order for the telescopes (including optical/infrared telescopes deployed to the interior of Antarctica) to be transportable to remote locations. A broad range of geophysical phenomena, spanning magnetic and geographic latitudes from the sub-aurora zone to the polar caps, at altitudes from the troposphere to near-Earth space, are observable but will require the development of autonomous measurement systems that can operate unattended for long periods in severe environments.

**Human Presence in Antarctica**

New and better sampling and handling technologies and better sensing and surveillance technologies and tracking systems are needed, including autonomous tracking devices and smart technologies. For many of the humanities- and social science-focused questions access to information is a critical limiting factor.

## Access, Infrastructure and Logistics

The majority of Antarctic research is field-based and will continue to be so for the foreseeable future, and access is often a critical limiting factor in conducting research. While many of the identified access needs can be met by the national Antarctic programmes, greater access is required over longer periods of the year. The preponderance of observations and measurements to date, other than those by satellite-based sensors and autonomous observatories, have been made during the austral summer, due to the difficult operating environment during other times of the year. Many scientific questions will require year-round continent- and ocean-wide access. High-priority areas for expanded access include coastal areas (including beneath ice of all kinds – floating and grounded), the interior of Antarctica (including deep field camps), and the Southern Ocean. Three of the seven science topics noted the importance of access to West Antarctica.

The optimal locations for measurements, experiments, and observations may be remote from permanent stations. Greater geographical access without additional permanent stations can be provided by the deployment, servicing, and retrieval of automated observatories and platforms, the development of modular and relocatable laboratories/facilities, temporary stations, and expeditionary-style field programmes. An ability to rapidly deploy teams of scientists to rapidly changing regions to collect benchmark observations was seen as a priority as well.

## The Costs

The costs associated with provision of technologies and support requirements vary over a wide range. At the lower-cost end of the spectrum (tens of thousands to hundreds of thousands of US dollars) is advancement of data-handling and analysis techniques. At the higher end of the cost spectrum (tens of millions to hundreds of millions of US dollars) is permanent infrastructure, such as ships and stations and dedicated satellite missions. Major technological needs may require pooling of resources for greatest effect. Partnerships, sharing of facilities and technologies, and coordination of efforts maximise return on investments and reduce impacts on the environment. The cost analyses indicated a wide range of opportunities for scientists and nations to contribute to the collective effort, within resource limitations and national interests.

## International Collaboration

The ARC project reaffirmed that no one country has the wherewithal to simultaneously pursue all aspects of the highest-priority Antarctic science. Continuing and enhanced cooperation in the spirit of the Antarctic Treaty remains a high priority and an ever increasing financial reality for national programmes. In a number of critical areas, such as satellite remote sensing, development of sensors and automated and robotic platforms, computing and information technologies, and advances in power technologies, it is expected that advances will occur outside of the Antarctic community. If it is to remain relevant, the community needs to be ever vigilant and must capitalise on advances in mainstream science through their application to the research conducted in the Antarctic. The availability and production of "big data" are a modern scientific phenomenon that has wide-ranging implications, and this massive flow of data can be optimally utilised only by applying the latest technologies in information, communications, and computation. The remoteness of the Antarctic introduces special challenges to addressing these issues.

The ARC and SCAR Antarctic Science Horizon Scan projects have provided a unique and rare opportunity for the international Antarctic community to come together to speak with one voice. In a world of competing demands on national resources it is more critical than ever that the Antarctic community communicate to funders and the public on why what we do is important to larger global debates. Through these two projects, the community has collectively laid out an ambitious vision of one possible path to the future. ARC points the way to what it will require to enable the far-reaching scientific agenda envisioned. Ultimately, success will be dependent on national investment in technological advances, provision of greater access region-wide and year-round, and the availability of logistics and infrastructure that allows researchers to do their best work where it must be performed. This vision reaffirms that the underpinning philosophy of Antarctic science remains international cooperation, coordination, and partnerships. It has never been more important that the global Antarctic community find new ways to work together that leverage national assets and investments in Antarctica.

Photo: Tarnow, US National Science Foundation

Photo: KOPRI

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Full ARC outcomes are available to download as a PDF document from https://www.comnap.aq/Projects/SitePages/ARC.aspx or printed copies can be requested by emailing sec@comnap.aq.

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