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Antarctic Science in the 21st Century

This document is intended to catalyze a community-wide dialogue on the role of international cooperation in optimizing national investments in Antarctic science. Discussions will build on the long history of the Scientific Committee on Antarctic Research (SCAR) as a leader and coordinator of international Antarctic science and the Council of Managers of National Antarctic Programs (COMNAP) as an association of providers of Antarctic science logistical and infrastructure support. The impetus for discussions at this time is:

- the global financial crisis of 2008, especially rises in the price of fuel (which proved to be temporary), brought into sharp focus the economic imperatives for international coordination in support of scientific programs;
- improved coordination and partnerships have the potential to lessen environmental impacts and enhance the preservation of Antarctica; and
- SCAR and COMNAP, in partnership, will be stewards of one or more aspects of the legacy of the International Polar Year 2007-2008.

Due to Antarctica's remoteness, climate, and severe weather the costs of conducting science there have always been substantial. One way of lowering costs is the sharing of resources. Over the years, there have been numerous examples of shared infrastructure, coordinated logistics and partnerships in Antarctic science, so this is not a new concept but it is more relevant today than ever before. Sudden increases in fuel prices, despite recent declines, and other economic realities make it imperative that national programs increasingly work together to optimize utilization of facilities and "time on the ice". There has been a proliferation of field stations, support facilities, and vehicular traffic in Antarctica over the past 50 years widening the human "footprint" on the continent. Though this "footprint" remains small in absolute terms, it is increasing and this trend is expected to continue for the foreseeable future.

A critical element of a dialogue on international cooperation in Antarctica, is matching operational practices with the demands of today's science while considering how Antarctic science will evolve in the future. The advent of new technologies, shifts in scientific focus, and advances in knowledge are likely to change logistical needs and the mix of support required to conduct science in Antarctica. A clearer view and understanding of trends in Antarctic science will allow national programs and operators to plan for the future and allocate limited resources in anticipation of these developments. The growing demands of Antarctic science bring operational challenges for all nations but the opportunities for mutually beneficial partnerships and coordination are great.

Future Directions in Antarctic Science

Predicting future directions in Antarctic science is difficult at best, as investment in science is decided by each nation in very different ways. However, one can analyze trends and extrapolate where these trends may lead in the future.

The questions being asked by scientists and society are becoming more complex requiring investigations to be integrated and interdisciplinary. This reflects a holistic Earth system science approach and the recognition that, far from being isolated, Antarctica and its surrounding ocean are integral parts of the Earth system. Equally, studies within Antarctica recognize the co-dependence of and linkages amongst physical and living systems. Trans-continental observations and experiments have become an increasing feature of many programs, and access to all corners of the continent is desirable, if not required. In many instances large multi-national teams of scientists are involved, the range of disciplines and the supporting technologies are diverse, the volume of data and information collected is immense, and real-time internal and external communications are essential.

The Antarctic community is in the midst of a well-coordinated international effort and dialogue that in large measure will determine the future directions of Antarctic science. The International Polar Year (IPY) 2007-2008 has identified important scientific questions to be addressed and developed an extensive portfolio of projects. The IPY portfolio provides a unique "window" on the future of Antarctic science. Due to the short timeframe in which IPY projects were funded and implemented, many projects begun during the IPY will continue well beyond it. IPY scientific planning and outcomes have in many ways set a course for polar science for years to come. This community-wide effort, conducted over several years, can be used to inform discussions about the facilitation of international cooperation.

The IPY 2007-2008 Science Portfolio

There are limitations on information derived from the IPY program database. For example, not all projects were funded and, by design and process, larger multi-national programs were encouraged. The process used by the IPY Joint Committee to select "official" IPY programs influenced the characteristics of the science portfolio. IPY projects were required to be international in participation and similar projects were encouraged to merge into integrated programs. Projects address the IPY themes of status, change, global linkages, new frontiers, vantage point, and the human dimension. These themes are broad and include most elements of modern polar science. The information in the IPY project database has been analyzed based on classifying projects in various ways. Classification schemes and assessments of projects are to some degree subjective so these analyses are only utilized to detect major trends as absolute values and others may classify projects differently than this analysis. However, an overall analysis does yield important information about future directions in Antarctic science

IPY projects were classified by location: Antarctica, the Arctic, and bipolar. Seventy-six (76) projects were classified as either taking place in Antarctica or in both polar regions and the following analyses are restricted to these projects. Of these projects, 45% where indentified as Antarctic projects and 55% as bi-polar projects. The projects include almost 2500 participants. The projects were proposed by teams of researchers from 2 to 24 countries (average number of partner countries - 10) and team size varied from 4 to 188 scientists (average team size - 37).

Projects were secondarily classified by the portion of the earth system being studied: atmosphere - 15%, ice - 16%, land - 22%, oceans - 30%, space - 13%, and people - 7% (for Antarctica these projects are mostly education and outreach and require little logistical or infrastructure support). Classifying projects based on the SCAR science yields: life sciences - 30%, geosciences - 18%, and physical sciences - 52%. In the SCAR classification, climate and glaciology are physical sciences accounting for the large percentage of projects in this topical area.

More specifically, scientific topics addressed by these projects include:

- climate change and global warming (weather, UV radiation, and ozone depletion),
- ecosystem structure and functioning (pelagic, benthic, terrestrial, marine, and microbial),
- census of living resources and biodiversity (mammals, birds, penguins, vegetation, and fish),
- astronomy and near-earth space science,
- recovery of paleo-climate records (sediment and ice cores),
- ice and sea level (sea ice, ice sheets, and ice shelves),
- satellite observations,
- southern ocean and coastal oceanography,
- sub-glacial environments and hydrology,
- biogeochemistry, and
- geophysical remote sensing and mapping of the continent above and below the ice.

Science Support Requirements

Each IPY project described its logistical requirements in general terms. Quantitative estimates of the use of, and the need for, various support activities are not possible. The types of infrastructure and logistical support needed to support projects are:

- **Atmosphere -** air monitoring networks, standard meteorological observations, automatic weather stations, fixed wing geophysical and transport aircraft, multi-instrumented platforms, observatories, helicopters, research vessels for marine sampling, existing and new field stations, ship recovery of buoys, and snow terrain vehicles**.**

- **Ice -** ice strengthened research ships, fixed wing transport aircraft, snow terrain vehicles, icebreakers, existing and new field stations, multi-instrumented platforms, helicopters, ship recovery of buoys, Autonomous Underwater Vehicles, satellite data, and ice and rock-drilling capability**.**

- **Land -** helicopters, fuel depots, existing and new field stations, **r**ockets, spacecraft, snow terrain vehicles, ice and rock drilling capability, multi-instrumented platforms, observatories, fixed wing transport aircraft, geophysical aircraft, ice strengthened research ships, radars, and observatories.

- **Oceans -** icebreakers, ice strengthened research ships, helicopters, Autonomous Underwater Vehicle, snow Remotely Operated Vehicles, ship recovery of buoys, multi-instrumented platforms, ice drilling capability, fixed wing transport and geophysical aircraft, radars, submarines, ship-based drilling capability.

- **Space** - Ice drilling capability, existing and new field stations, fixed wing transport aircraft, ice-breakers, inland traverse support, automated observatories, multi-instrumented platforms, rockets, and radars (and, outside the remit of COMNAP, new sensors on space satellites).

- **People** – Existing field stations, helicopters, snow terrain vehicles, and GPS

Based on this information, projected logistical support needs include traditional sampling requirements but also new space-based sensors, AUVs, ROVs, robotic land-rovers, automated observatories and other advanced technologies:

- **Ships** – icebreakers, ice strengthened research vessels, marine research vessels (including deployment and recovery of buoys), inflatable boats, and ship-based drilling capabilities.
- **Field stations** –utilization of existing stations and new stations.
- **Air transportation** – fixed wing aircraft for transport and geophysical surveys and helicopters.
- **Land Transport** – snow terrain vehicles and inland traverse support.
- **Drilling capability** – ice and sediment drilling
- **Observatories** - multi-instrumented platforms, automated weather stations, air monitoring networks, AUVs, ROVs, submarines and satellites (rockets)
- **Others** – fuel depots, GPS, and radars

Increased utilization of automated observatories for collecting data is part of the evolution of coordinated observing systems to measure the effect and variability of climate change on short-term (minutes, hours, and days) and long-term timeframes (months, years, and decades). Logistical and operational support is necessary to deploy, maintain, and repair observing systems. In the future, these systems will become more autonomous, be outfitted with more complex arrays of sensors, and have ever increasing demands on power supplies. In addition, these systems will have increased needs for data collection and storage capabilities requiring real-time communications and data transmission to on- and off-continent receiving stations.

Major Scientific Initiatives on the Horizon

Antarctic science priorities are many and varied and most are addressed in one way or another within the IPY science portfolio. The importance of any given theme or topic is highly variable among Antarctic Programs depending on national priorities and capabilities. The following are examples of important scientific initiatives on the horizon (the list is not intended to be exhaustive):

- Assessing the stability of the West Antarctic Ice Sheet (WAIS);
- Obtaining the longest possible ice core record of climate history (>1 myr);
- Determining detailed regional and temporal variability in Antarctic climate;
- Entry and sampling of subglacial environments;
- Establishing atmospheric and oceanic observing networks for forecasting the behavior of the coupled ocean-ice-atmosphere system;
- Discovering the nature and history of the sub-ice basement geology in East Antarctica;
- Investigating the relationships of upper atmosphere physics, the Earth's climate system over Antarctica and the Polar Vortex;
- Refining the pre-Pleistocene history of Antarctic climate from drill and piston cores;

- Determining ice sheet mass balance, stability, and its relationship to global sea level now, in the past and in the future;
- Recovering unique geological samples and paleo-records in the interior of Antarctica;
- Understanding evolution and biodiversity in the Antarctic;
- Investigating how life maintains and thrives in the cold and dark;
- Inventorying and mapping biological habitats, ecosystems and organism distributions in Antarctica and the Southern Ocean.

National and international projects will be addressing these and other scientific objectives over the next decade or more. Projects will necessitate ice core retrieval, entry into and sampling or sensing of subglacial environments, continental scale surveys and mapping, deep ice drilling, establishment of astronomical platforms, geological drilling and core recovery, trans-continental deployment of autonomous instrument packages, meridional ecological transects on land and in the ocean, long-term deployment of ocean observing equipment, deep sea and coastal organism collection, and earth system process modeling of all kinds.

Opportunities for Coordination and Partnerships

As Antarctic science becomes increasingly complex and expands in geographic coverage in the 21st century, there are many opportunities for cooperation and partnerships. These opportunities can be broadly categorized as: shared infrastructure and logistics, enhanced geographic coverage, common technologies, standardization of techniques and measurements, and international archives.

Shared Infrastructure and Logistics - Duplication of efforts or excess capacity in the infrastructure and support systems present a major opportunity for savings through joint efforts. Several examples are presented: stations, ships, access to the continent, and bi-polar deployments. Many more could be identified.

Stations- Growth in the numbers of science projects will almost assuredly result in increased demands on logistics and infrastructure. Countries could accommodate other country's nationals on an "as available" basis assuming that there is excess capacity in the geographic region where facilities are needed.

Ships - The ice breaking and ice-strengthened fleet of ships available to Antarctic scientists is aging and will be replaced over the next few decades. Several icebreakers are at or beyond their operational life-times and recommendations have been made for replacements. Given the timeframe of design and construction, the transition to the new ships will be difficult and the community may experience extended times of reduced ship-based capabilities. The employment of other nation's ships and long-term agreements is already being implemented. For maximum efficiency, countries need to consider the overall capabilities of the international fleet and work in partnership to avoid duplication. There is also an opportunity to build on the long history of cooperation with the tourist industry that has a fleet of ships in Antarctica during certain times of the year. "Ships of opportunity" may serve as transport to and from facilities and may also operate as platforms for the collection of oceanographic data while underway. There are many successful management models for sharing large facilities such as ship-time and these lessons could be more broadly applied in Antarctic science.

Access to the Continent - Facilitating access by one nation's scientists to another nation's facilities presupposes facilitating access by ship or air to the part of Antarctica in which land-based facilities are located. Once on the continent there are opportunities to share transport within the interior. Many IPY projects indicated a need for fixed-wing transport aircraft, geophysical survey aircraft and helicopter support. Air network systems are an example of how shared costs can optimize access and movement within the continent. Enhancement and extension of these types of systems will enable sharing of the costs of infrastructure and major equipment acquisition.

Bipolar Coordination- There is a growing interest in comparative studies in both polar regions. Based on the high percentage of bipolar IPY programs and recent developments in bringing these two communities closer together, this trend can be expected to continue in the coming years. Cooperation between SCAR and its northern counterpart IASC (International Arctic Science Committee) provides further opportunities for partnerships in logistics and infrastructure. Large infrastructure items, such as ships, can be effectively managed in the context of bipolar missions. Long-term scheduling is necessary to move assets from one polar region to another, and extended stays may be required. This has been accomplished in the past and is currently occurring with various ships spending time in both hemispheres. When a country's assets are primarily deployed in one or the other polar regions, but that country has scientific interests in both regions, there is an opportunity for partnerships. Working together, one country might accommodate another country in exchange for equivalent utilization of assets in the polar region where their infrastructure is limited or non-existent.

Enhanced Geographic Coverage - Many IPY projects indicated that new facilities would be needed. While it was not always evident what these new facilities might be, in many instances they appeared to be related to increased geographic reach. As noted above, the growing need for trans-continental research and demands for access around the continent provide an opportunity for improving synergy without each country having to establish permanent or summer field support camps to increase geographic reach. The increasing use of observatories, autonomous monitoring stations and multi-instrument platforms brings with it a growing need for deployment, servicing, and maintenance, which could be facilitated by coordination among national operators with established facilities in different geographic sectors. The development of such coordination will obviate the need to mount independent field efforts for such activities, which are costly and time consuming. Future research and observational needs will call for distributed observing systems across the continent, the surrounding ice and through out the ocean. It is expected that AUVs and ROVS will see increased utilization as well. Increased technological support by personnel will be necessary to operate, maintain, and repair sophisticated instrumental packages and robotics over broad geographic ranges. Coordination of the activities may be the only way to economically maintain these systems.

Common Technologies - Making technologies widely available is another opportunity for partnerships. Technologies include observatories, multi-instrument platforms, and ice and sediment drilling capabilities, to name a few. International collaboration might include: sharing of technologies and making instruments available for use at multiple locations. Programs are already considering ways of sharing drilling equipment to enable a coordinated approach to building a sub-ice geological history database for Antarctica. Deep ice drilling to reach the oldest ice would benefit from shared infrastructure.

Standardization of Techniques and Measurements - Increasing pan-Antarctic collaboration requires standardization of techniques and measurements to add value to projects and to increase geographic coverage beyond that feasible by a single researcher or a single nation. In addition, those who lack the wherewithal to collect data everywhere would benefit from wider sharing of data and information. Data management, archiving and accessibility have to be major considerations and national operators will inevitably play an increasing role in this regard. Collection of standard measurements at the many stations across Antarctica, such as weather measurements, brings added power to research from a continent-wide observing system. Standard techniques, agreed data quality objectives, and open access to data are essential. There are also opportunities to add observing elements to on-going programs at minimal additional cost on a non-interference basis. For example, if a traverse is occurring for glaciological research, additional value can be (and sometimes is) derived from adding a series of meteorological measurements, since most of the cost of being on site has already been incurred. Standardizing approaches and sharing data will require coordination and the communication of needs among scientists, national programs and funding agencies. Existing international partnerships provide models for coordinating projects and major infrastructure and field support.

International Sample Archives - International archives need to be expanded so that a larger community can benefit from samples that were expensive to acquire, and examples of how these facilities might work already exist. Preservation of samples and future access to sample banks would decrease the need for new sample acquisition.

Summary

The nature and conduct of Antarctic science is rapidly evolving. This evolution is closely linked to more sophisticated scientific objectives and technological advances. These changes and increasing costs for all elements of science support, logistics, and infrastructure have important implications for the future success of Antarctic science. While a spirit of cooperation, partnership, and coordination has always been part of Antarctic science, current economic realities provide an even greater impetus for nations with Antarctic programs to capitalize on the benefits derived from international coordination and partnerships. It is recommended that COMNAP and SCAR in partnership, poll operators, national programs, and national committees to more completely identify programs and projects either planned or on the drawing-board. This would allow the general trends in Antarctic science identified in this report to be more rigorously quantified in terms of usage, needs and gaps while also allowing for the development of a more detailed time-line of when these trends will become reality.