Setting a Course for Antarctic Integrated System Science

Based on a workshop

held in Arlington, Virginia,

13 - 15 June, 2007

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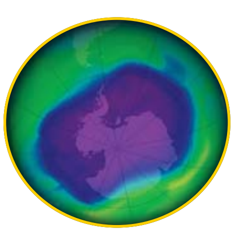

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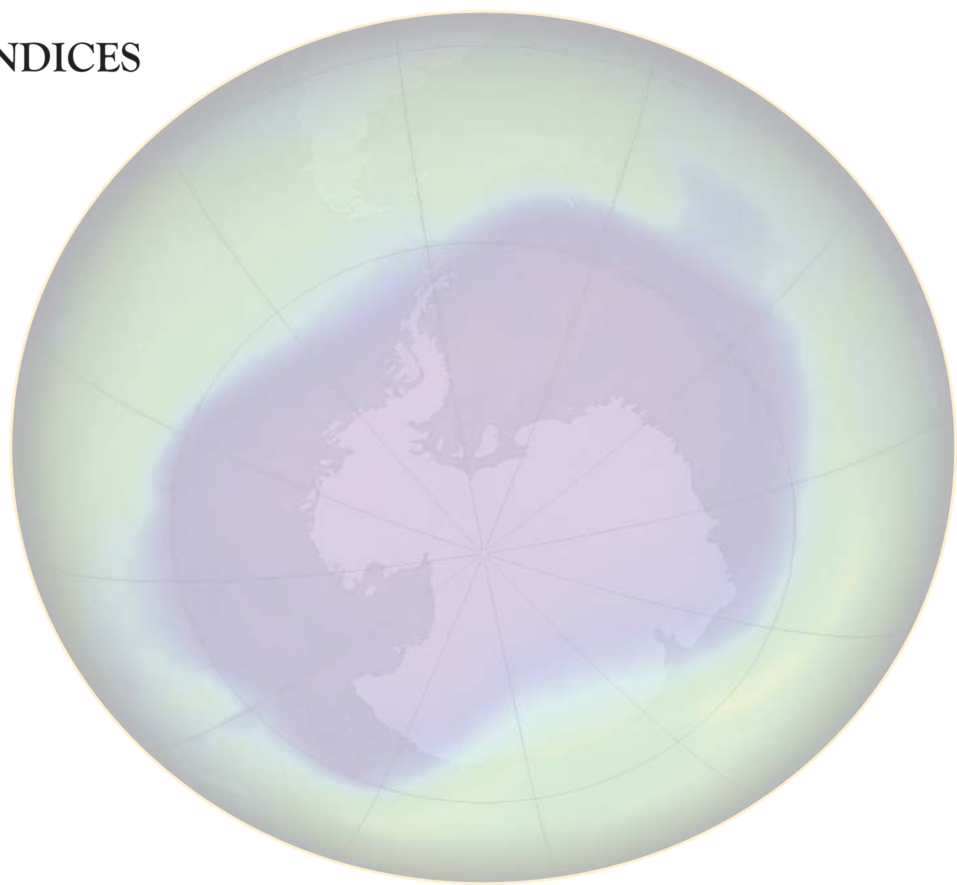


ANTARCTICA - A PLACE FOR SCIENCE

The National Science Foundation (NSF) administers programs that encourage, nurture, and deliver substantive and compelling scientific inquiry at the boundaries of our knowledge. Dating back to the International Geophysical Year (IGY 1957-58), scientists who study Antarctica have addressed a wide range of questions that inform our understanding of natural processes including linkages to human activities. This rich legacy is illustrated by findings from research supported by the Office of Polar Programs (OPP) and its predecessor programs. Antarctic research has contributed to our understanding of the functioning of organisms and ecosystems in the cold and dark, the role of the polar regions in Earth's climate, the evolution of the Antarctic continent and its ice sheets, the origins of the Universe, and the interplay of nature's forces in shaping one of our planets most captivating regions.

The promise of Antarctica as a catalyst for path-breaking science goes far beyond its uniqueness as a remote and harsh environment.

Findings in recent decades have illuminated Antarctica's importance in harboring distinctive organisms and ecosystems, storing paleoclimate records, influencing oceanic and atmospheric chemistry and circulation, and contributing to sea-level change over geological time. These discoveries have revealed that Antarctica not only responds to, but can be a driver of worldwide change. Antarctic science is inextricably linked to the challenges facing humanity in a changing global environment. An innovative approach to foster progress on complex questions regarding the future of our planet is essential to assuring that the research community quickly responds to the most recent paradigms. While the need for strong disciplinary science remains paramount, renewed efforts are needed to continue to minimize barriers between scientific disciplines. More effective integration across disciplines and consideration of Antarctica as an interconnected system of energy, materials and information exchanges is required to understand Antarctica and its role in future regional and global change.

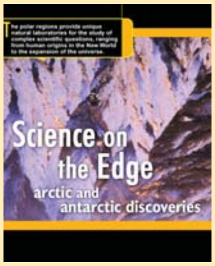
The research science community was asked to advise the NSF on future directions for an Antarctic Integrated System Science (AISS) program:

- Is a dedicated program the best approach to facilitate research that crosses disciplinary boundaries?
- What types of research might be included within such a program?
- How will this program interface with disciplinary programs?

THE IMPERATIVE……

The National Science Foundation (NSF) supports basic research at the frontiers of discovery through competitive, merit-based review. The nation's investment in NSF fuels important innovations that stimulate economic growth, enhance U.S. competitiveness, and improve the quality of life and health for all Americans. Scientific discoveries are emerging at an accelerating pace transforming the scientific landscape. The opening of new territories for exploration includes path-breaking investigations that were unimaginable only a few years ago. Investigators are creating models of complex systems across multiple disciplines and scales providing a deeper understanding of the physical forces that govern earth systems.

NSF investment priorities include promoting transformational, multidisciplinary research. These investigations emphasize research that crosses disciplinary boundaries and requires a systems approach to address complex issues at the frontiers of discovery. Fostering research that improves our ability to live sustainably on Earth, NSF research strengthens our understanding of the links between human behavior and natural processes.



National Science Foundation, Strategic Plan, 2006-2011

To address these questions, a workshop was held in June 2007. Attendees included practicing Antarctica scientists and leading investigators from related, but non-polar disciplines and programs. Workshop invitees were chosen to represent a broad spectrum of earth and environmental sciences, institutions and career phases. This report is an executive committee synthesis of discussions during the workshop, material provided by attendees, community comment on the draft report (see Appendix V for details), and the planning documents of the International Polar Year 2007-2008 and the National Science Foundation. The workshop consensus was that AISS is a welcome development that will foster compelling cross-disciplinary Antarctic research.

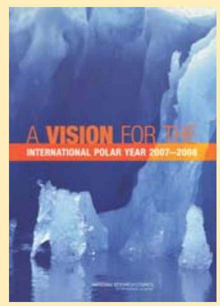
Recent advances and demonstrated linkages within Antarctica and to the rest of globe provided the impetus for a program to facilitate Antarctic science focused on questions that transcend disciplinary boundaries - Antarctic Integrated System Science (AISS).

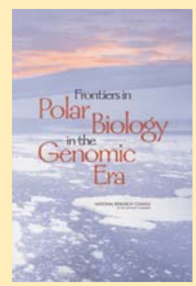
This report contains four sections; “Antarctic Science in the 21st Century” highlights research themes as examples of the potential for ground-breaking integrated system science research. “Antarctic Integrated System Science” summarizes historical precedents that lay the foundations for AISS, presents examples of similar efforts, and describes the characteristics of AISS projects. “Ensuring Participation in AISS” recommends philosophical guidelines for implementation of the AISS program that will encourage broad-based participation. Workshop participants held a diversity of views on the advantages and disadvantages of various approaches to prioritizing AISS science while assuring fair competition and broad participation. The lengthy discussions of the concerns of the community are captured in the guidelines proposed for managing AISS. The “Conclusions” section describes the essential ingredients and next steps necessary to realize the potential of the AISS program.

THE URGENCY…..

Environmental changes currently witnessed in the polar regions are vivid and in many cases greater than changes observed in the mid-latitudes or tropics. Some ice shelves in Antarctica are retreating and thinning, glaciers across the globe are shrinking, and ecosystems are shifting. We must understand these changes in the context of past changes to make informed choices about the future. Yet we do not fully understand how or why many of these changes are occurring. Exploration of new scientific frontiers in the polar regions will improve our understanding of Earth’s environment leading to new discoveries, insights and theories important to all peoples.

A Vision for the International Polar Year 2007-2008



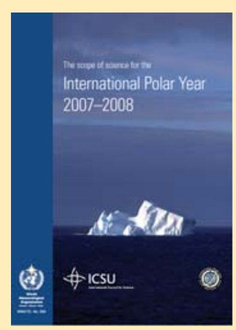


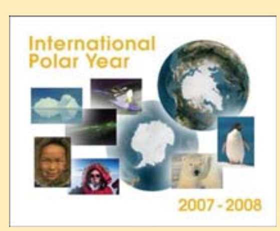
THE OPPORTUNITY................

Since changes in the polar regions can be harbingers of change elsewhere, intensive activity during IPY 2007-2008 will include linked physical, geological, biological and chemical observations of the atmosphere, ocean, ice, and land. Multidisciplinary observations will improve spatial and temporal coverage and new observational systems will enhance and expand existing networks.

Interdisciplinary studies are fundamental to building a global understanding of the Earth system. IPY projects address questions lying beyond the scope of individual disciplines through collection of samples, data and information regarding the state and behavior of the polar regions and their linkages to the rest of the planet. These projects will provide a reference set to understand past change and gauge the likelihood of future change scenarios.

The Scope of Science for the International Polar Year 2007-2008





ANTARCTIC SCIENCE IN THE 21st CENTURY

Knowledge gained from the study of Antarctica has proven indispensable to understanding our planet and the impact of humankind on it. With its encapsulating cryosphere, surrounding ocean, dynamic atmosphere and cold- and dark-adapted organisms and ecosystems - Antarctica harbors the collective outcome of complex interactions and processes. These relationships span spatial scales from the molecular to the continental and temporal scales from fractions of seconds to 100s of millions of years. Despite the growing awareness of the role of Antarctica in global systems, it remains one of the least-sampled regions on Earth. Recent and continuing observational programs have made unexpected discoveries demonstrating how much we have yet to learn about Antarctica. Due to the sparseness of observations, our understanding of the changes that are occurring today is incomplete. To understand natural variability and the role of human perturbations in planetary change, we must also understand how Antarctica is changing and why.

Building on past and current programs and efforts during the IPY 2007-2008, Antarctic science is poised for a "leap forward". The lessons learned in Antarctica will inform global-scale questions about our planet's functioning as a suite of co-dependent systems. The breadth of science investigations necessary to address such fundamental questions is indicated by the scope of IPY programs. IPY "Status" and "Change" research is investigating the atmosphere, ice sheets and glaciers, oceans, and ecosystems that dwell in these environments. "Global Linkages" research is investigating climate processes, thermohaline circulation, terrestrial and marine biogeochemical cycles, and solar-terrestrial linkages. "New Frontiers" research is studying biological adaptations and biodiversity on the land, beneath ice sheets and shelves and within polar oceans. Data collection, synthesis and dissemination, on the unprecedented scale proposed during the IPY, will inspire new discoveries, explore disciplinary frontiers, and provide a training ground for the next generation of scientists and engineers.

There were numerous potential cross-disciplinary ideas presented at the workshop illustrating directions that AISS might take. In general, but not exclusively, the discussions focused on three overarching scientific themes: Antarctica as a region in transformation, Antarctic ice and global water, and Antarctic environments and the response and impact of life processes. These illustrative themes are described below, unanswered questions are posed, and topics that address aspects of these questions are described as examples of what AISS projects might look like. These, however, are only examples of possible AISS themes and are not intended to limit the scope of future AISS projects or proposals. AISS should remain flexible so that it can be responsive to evolving or emerging paradigms that are best addressed by an integrated systems approach. Ultimately the portfolio of AISS projects will be determined by the proposals submitted, the peer review process, available NSF resources, and funding decisions.

ANTARCTICA – A REGION IN TRANSFORMATION

Landscapes hundreds of millions of years old jutting out from under ancient ice washed by ocean waters that have not seen the sun for a millennium might suggest that Antarctica is frozen in time. To the contrary, change proves to be the one constant, and wherever and whenever we look, transformations are evident. In this section, examples are summarized that illustrate questions about changes in Antarctica that are most effectively addressed by cross-disciplinary research.

Why are some regions of Antarctica warming faster than the rest of the planet, and what are the implications for those regions, Antarctica more broadly, and Earth? Global warming is not uniformly distributed. Observations over the last decade have indicated that some of the more rapid warming on Earth is occurring in the Antarctic Peninsula region. Well-documented glacial retreat on the Antarctic Peninsula appears to be accelerating. Warming in the Peninsula region has important implications for the dynamics of ecosystems intimately tied to the waxing and waning of ice. The dramatic disintegration of the Larsen-B Ice Shelf has been attributed to regional atmospheric and/or oceanic warming. The biological communities sheltered for millennia beneath the ice shelf are experiencing altered environments and ecological adjustments are inevitable. At the same time, ice-shelf loss has freed tributary glaciers to flow up to eight-fold faster adding large amounts of freshwater to the ocean and altering oceanographic conditions. These are not abstract or projected trends - change is occurring in Antarctica.

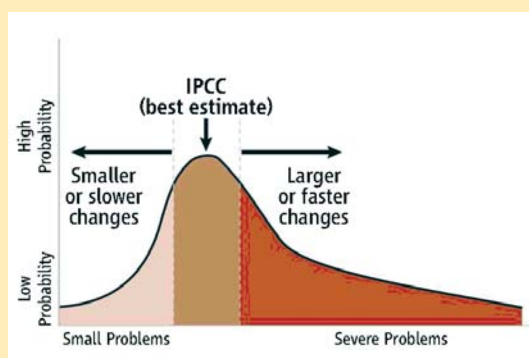
EXAMPLE - While the Antarctic Peninsula is one of the more rapidly warming parts of the Earth, the continent as a whole has experienced little change over the past five decades. Projections of continental climate change in Antarctica by the end of this century exhibit considerable variation. Deficiencies in climate models lead to large uncertainties in climate forecasts at high latitudes. If the projections of greatest change prove accurate, Antarctic ice sheets and shelves will experience substantial melting. A key question is whether rapid climate change is imminent in Antarctica. Addressing this question requires an understanding of the factors that govern the evolution of Antarctic climate such as stratospheric ozone depletion, greenhouse gas increases, forcings from the tropical Pacific Ocean, air-sea-ice interactions in the Southern Ocean, and non-linear interactions and feedbacks (for details see the inset box below).

Will synergistic effects from ozone depletion, climate change, and other anthropogenic perturbations alter Antarctic and Earth systems? A striking instance of human intervention on a planetary scale is diminution of the ozone layer above the poles by chlorofluorocarbons. Recent studies suggest that unforeseen effects related to ozone depletion may be altering the environment in unpredicted ways. Are the ozone hole and global warming combining to cause changes in greenhouse gas storage in the oceans and atmospheric pressure patterns that determine weather? The cold, elevated Antarctic ice sheet enhances the large temperature contrast between the equator and the pole intensifying circumpolar westerly winds over the Southern Ocean. Strengthening of the westerly winds may be linked to both stratospheric ozone depletion and greenhouse gas increases. These climate changes may affect ecosystems and the sequestration of carbon dioxide in the deep ocean while accelerating the seaward flow of continental ice contributing to sea-level rise.

EXAMPLE - The Southern Ocean south of 40^{o} S is estimated to account for ~20% of the global ocean CO_2 uptake. To explore the accuracy of these estimates and to predict how the Southern Ocean will change in a warming world require an understanding of ocean circulation, hydrological cycles, sea ice dynamics, ice sheet mass balance, the biogeochemistry of ecosystems, and the carbon cycle of the oceans (for details see the inset box at the bottom of the next page.)

Is rapid climate change imminent in Antarctica?

Rapid warming of the Antarctic Peninsula over the last 50 years is one of the more pronounced climate changes on Earth. Temperature increases on the west-side of the peninsula are most marked in winter and linked to sea ice and sea surface temperature changes in the Bellingshausen Sea. Summer warming on the east-side of the peninsula is more subdued but has had profound impacts on the fringing ice shelves. This warming is associated with the strengthening of westerly winds over the Southern Ocean since the 1960s. Ice shelves in the Pine Island Bay-Thwaites Glacier drainages of West Antarctica are thinning. In contrast, mainland Antarctica has shown little overall change in annual snowfall or near-surface air temperature since the International Geophysical Year. However, the troposphere appears to have warmed markedly in the winter. The sea ice cover around Antarctica has exhibited little net change since reliable satellite monitoring began in the late 1970s despite large compensating regional changes. What is the cause of the striking difference between the Peninsula and the majority of Antarctica? Will all of Antarctica undergo dramatic climate change in the near future? Are there climate surprises in the offing? These questions are of global significance because there are tens of meters of potential sea-level rise stored in Antarctic land-based ice. To understand current and past climate change the role of Antarctica's ice sheets must be defined. The adjacent figure illustrates how the climate debate so far has focused on the most likely scenarios but the greatest risk is at the extremes which are less likely but possible. The causes and consequences of Antarctic climate variability and change require coordinated studies of the atmosphere, ocean, land-based ice, floating sea ice, and terrestrial and marine ecosystems.



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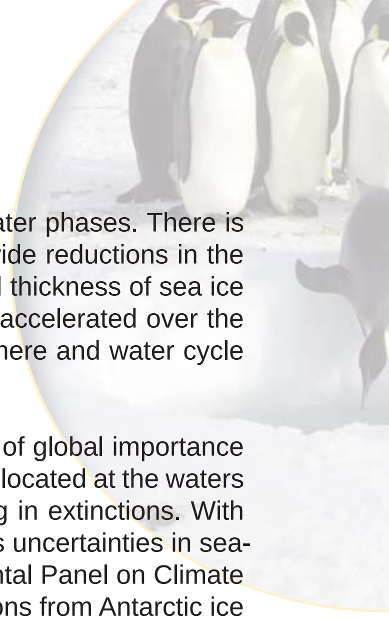


ANTARCTIC ICE AND GLOBAL WATER

An intrinsic element of Antarctic change is the balance between gaseous, liquid and solid water phases. There is an urgent need to better understand the rapid loss of snow and ice in polar regions. Worldwide reductions in the extent and mass of glaciers; the area, timing, and duration of snow cover; and the extent and thickness of sea ice have been documented. There are indications that the global rate of snow and ice loss has accelerated over the past decade. Critical questions about the role of Antarctic ice and snow in the global cryosphere and water cycle remain to be answered.

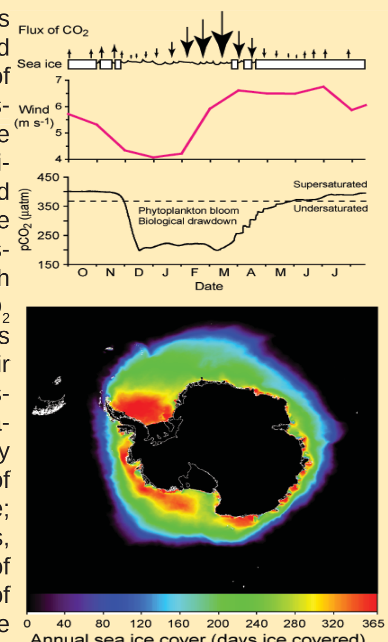
What is the likely contribution of Antarctic ice to global sea-level rise? Sea-level rise is of global importance due to the large human populations in coastal areas, the great value of land and infrastructure located at the waters edge, and the possibility that some biota may be unable to keep pace with change resulting in extinctions. With ice sufficient to raise sea level ~60 m, if complete melting were to occur, Antarctica dominates uncertainties in sea-level rise projections. In considering the potential for future sea-level rise, the Intergovernmental Panel on Climate Change (IPCC) concluded that model projections may not adequately estimate the contributions from Antarctic ice sheets. This is due to the sparseness of observations and data in the polar regions as well as deficiencies in ice-sheet modeling. Our understanding of these effects must be refined to provide a best estimate, or even an upper bound, on potential sea-level rise contributions from land-based Antarctic ice sheets.

EXAMPLE - It has been hypothesized that increased air and water temperatures in the Southern Ocean region are contributing to the instability and disintegration of ice shelves. These ice shelves once held back the ice sheets, limiting their contribution to sea-level rise. Determining if atmospheric and oceanic processes are destabilizing land-based ice sheets and in turn accelerating sea-level rise requires an improved understanding of the interactions among climate, atmospheric processes, ocean currents, and ice sheet dynamics (for details see the inset box at the bottom of the next page).

Are Antarctica's ice sheets stable, and if so over what time scales and under what circumstances might they become unstable? As described above, the dynamics of ice sheets are poorly understood. On the supply and redistribution side of the equation, atmospheric deposition and ice spreading rates are important controls. Little is

Is the Southern Ocean a source or sink for atmospheric CO_2?

The Southern Ocean occupies ~10% of the global ocean area, yet in some estimates accounts for ~20% of global ocean CO_2 uptake. Accurate quantification of this flux and how it will change in a warming world is hindered by an incomplete understanding of processes that regulate carbon sequestration among various liquid, solid and gas reservoirs. In the southern half of the Southern Ocean, remoteness and seasonal sea-ice cover have prevented the measurement of water column properties undermining reliable estimates of CO_2 fluxes in these regions. Water under sea ice is supersaturated with CO_2 due to winter transport of CO_2 from the deep ocean to the mixed layer. Ice is a barrier to CO_2 exchange with the atmosphere allowing for the build-up of dissolved CO_2 beneath ice shelves. The onset of the spring melt exposes these CO_2-rich waters to solar radiation triggering phytoplankton blooms that fix surface ocean CO_2 into organic matter through photosynthesis. Competition between these processes determines whether the Southern Ocean is a CO_2 source or sink. Net annual sea-air CO_2 flux values estimated for the Southern Ocean using independent methods disagree by as much as threefold. This discrepancy is due in part to the limited observations of under-ice waters, the complexity of biogeochemical cycles, and the variability of seasonal sea-ice formation. Progress will require targeted, coordinated studies of ocean circulation; hydrological cycles; the formation, melting and transport of sea ice; ice shelf dynamics; the rates of biological production and respiration in open waters, ice covered areas and marginal ice zones; the transport and transformation rates of biogenic particles; oceanic inorganic and organic carbon chemistry; and the effects of ice formation and melting on water column physical and chemical properties. It will be essential to synthesize all available observations and to integrate the synthesis with modeling efforts to bridge scales from regional to global.



K. Arrigo (pers.comm.)

known about these processes for several reasons. There are few direct measurements of geothermal flux; there are no comprehensive maps of frozen-versus-thawed ice sheet beds, the presence or absence of lubricating till, or the sedimentary basins that supply till; and the depth of water beneath ice shelves is unknown in many locations. Ice sheets flow to the marginal seas, forming ice shelves that are held back by friction with their sides or with local high spots on their bed. As observed after the Larsen-B ice shelf collapse, the frictional resistance provided by ice shelves is decisive in controlling the speed of continental ice sheet flow to the sea.

Ice-sheet responses to external forcings are highly variable. At one extreme the temperature at the ice-sheet bed in central East Antarctica has not yet responded to the end of the last ice age. At the other extreme, ice-stream flow velocity at some locations varies in response to diurnal tides. Understanding ice-sheet response requires knowledge of both short-term and long-term forcings and responses. *In situ* and satellite measurements are limited in coverage and duration, making paleoclimatic studies of ice and sediment cores essential. Capitalizing on the advances in understanding of ice sheet mass balance from the West Antarctic Ice Sheet initiative and research of the Science and Technology Center for Remote Sensing of Ice Sheets (CReSIS), we are poised to make major advances in our understanding of ice sheet dynamics.

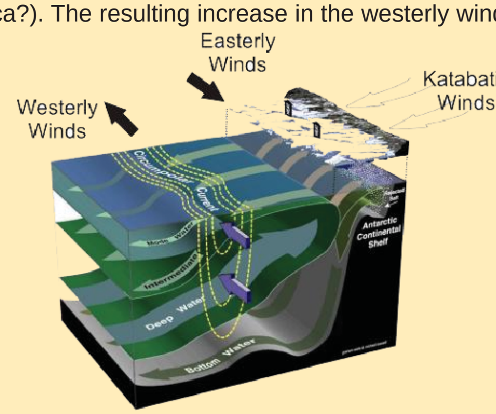
EXAMPLE - Recent studies of ice sheets have revealed the pervasive nature of liquid water in Antarctic sub-ice environments. Subglacial water is now recognized as central to many processes that have shaped the Antarctic continent and its ice sheets today and in the past. However, sub-ice water accumulations remain largely unexplored to the extent that even their geographic distribution has yet to be fully characterized and understood. Fundamental questions remain about life under the ice and how water influences the overlying ice sheets and ice stream dynamics. Answering these questions requires knowledge of climate, glaciology, geology, tectonics, limnology, and microbial evolution and adaptation (for details see the inset box at the bottom of the next page).

ANTARCTIC ENVIRONMENTS AND LIFE'S ROLE

At first glance, Antarctica might seem to be beyond life – icy, treeless, and hostile - but on closer examination, Antarctica hosts a striking abundance and diversity of life, ranging from the microscopic to some of the largest marine animals on the planet. As noted above, and especially true from the perspective of understanding life in these

What is the contribution of Antarctica's Ice Sheet to global sea-level rise now and in the warmer world of the future?

Recent changes in Antarctic ice-sheet flow suggest that sea-level might rise substantially faster than our best models now predict. Surprising flow acceleration has occurred in some places, as additional heat delivered from the Southern Ocean melted ice shelves that held back the ice sheet. Processes extending from the stratosphere to the ocean may be affecting ice sheet stability. It has been hypothesized that Antarctic stratospheric cooling, due to ozone loss and/or rising greenhouse gases and other processes, has contributed to an increase in the pressure difference between mid- and high latitudes (see inset box - Is rapid climate change imminent in Antarctica?). The resulting increase in the westerly winds around the continent intensifies the Antarctic Circumpolar Current. The Coriolis force steers surface waters more strongly northward to be replaced by waters up to several degrees warmer from intermediate-depths in the ocean. This water is funneled across the continental shelf and beneath floating ice shelves in submarine troughs eroded into the sea floor by formerly more-extensive glaciers. Ice sheet melt rates of tens of meters per year can result, thinning ice shelves and reducing their ability to buttress the export of continental ice to the oceans. This in turn leads to accelerated ice sheet flow, ice-sheet mass loss, and rising sea-level. Making accurate predictions of future sea-level require that these processes and interactions be understood, quantified and related in an interdisciplinary framework.



Southern Ocean Circulation

Image adapted from the LARA, Report

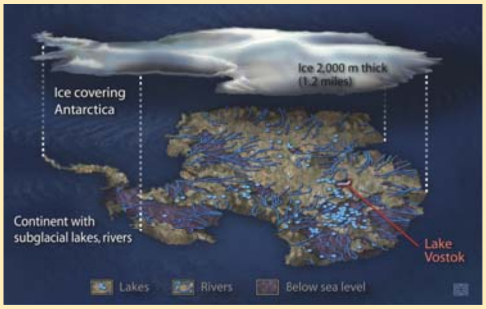
environments, observations are sparse and fundamental knowledge of Antarctic biodiversity and the distribution of organisms on the land and in the ocean and their role in elemental cycles are lacking. An ominous consequence of climate change and human presence in Antarctica is the prospective ecological impacts of the migration or introduction of non-Antarctic species into the region. Ocean warming is expected to result in a southward extension of low to mid- latitude organisms and human transport of non-indigenous organisms into the region has been documented. Invasive species, natural and anthropogenic, threaten to compromise Antarctica's relative isolation of more than 20 million years. A corollary to concerns about effects of ozone depletion on climate is biological effects related to UV-B exposure. How external factors such as climate change, ozone depletion, UV exposure, and organism invasions will interact with the cold and restricted-light adapted life of Antarctica is largely unknown.

How have Antarctic organisms and ecosystems responded to or influenced past physical environmental changes and how will future change be expressed? Environmental change and the evolution of life have long been studied within a context of the inter-relationships of atmospheric, oceanic, terrestrial, and biological systems. In Antarctica, current models that link physical changes in environmental states to species' survival, adaptation, and evolution are limited by a lack of fundamental knowledge regarding rates of evolution in the cold, mechanisms of adaptation, and biological tolerance to the rate of environmental change. A better understanding of the mechanisms and evolution of low-temperature adaptation is needed to predict how organisms will respond to environmental change. These complex questions require long-term studies of ecosystem-level species function and diversity and new approaches such as physiological genomics and quantitative genetic analyses of the rates of biological evolution and adaptation.

EXAMPLE - The potential impact of primary production in the upper ocean on climate, which in turn impacts marine ecology, provides an example of the complexity of connections between physical processes and biological responses. It has been hypothesized that phytoplankton exudates contribute to atmospheric aerosols that in turn affect the optical properties of clouds altering incident solar radiation influencing climate. The testing of this hypothesis requires knowledge of phytoplankton ecology and physiology, oceanography, biogeochemistry, nutrient dynamics,

How does subglacial hydrology influence life beneath the ice and the dynamics of ice sheets?

The ice sheets of Antarctica conceal unique and widespread subglacial environments that have not directly contacted the atmosphere or ocean for tens of millions of years. It has been shown that life exists in the melt water that lubricates ice-sheet flow. Subglacial water is now recognized as central to many processes that have shaped the Antarctic continent and its ice sheets recently and in the distant past. Subglacial environments include a range of features that differ in geologic setting, age, evolutionary history, limnology, and size. These environments are "natural" earth-bound macrocosms that in some instances trace their origins to a time before Antarctica became encased in ice. The isolation of subglacial environments from the weather, ocean currents, or other mechanisms of fast exchange has established fundamental constraints on the structure and functioning of microbial communities in these environments. In contrast to other habitats, where solar energy is a primary influence, processes in subglacial environments are mediated by the flow of the overlying ice and the flux of heat and possibly fluids from underlying strata. Recent findings suggest that a third control is subglacial hydrology, which establishes water residence time controlling delivery of water, heat, and materials to and through subglacial systems. Water pooled in lakes or spread out beneath the ice efficiently lubricates the motion of the overlying ice but moves little sediment. Water concentrated in sub-ice streams can move sediment but localizes lubrication effects. Subglacial lakes appear to occur coincident with the "head waters" of ice streams, possibly influencing variations in ice stream velocities. The spectrum of sub-ice environments that occur across the Antarctic continent provides an unparalleled opportunity to explore and study one of earth's last frontiers and decipher fundamental earth and life processes. The exploration and study of subglacial environments will advance our understanding of how life, climate, and planetary history have combined to produce the Antarctic continent as we know it today informing the search for life elsewhere in our solar system.



Zina Deretsky, NASA, 2007

sea ice/biota interactions, air/sea gas exchange, atmospheric photochemistry, and aerosol and cloud chemistry and physics (for details see the inset box below).

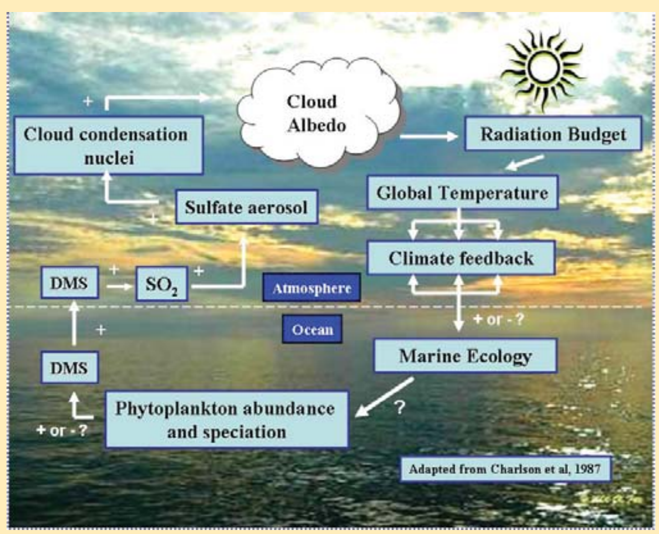
How will rapid climate change affect Antarctic ecosystem structure and functioning? Evidence from studies of temperate-climate terrestrial ecosystems suggests that global climate change has resulted in the mistiming of peak food availability and breeding times of flowering plants, insects and birds leading to population declines. In temperate marine ecosystems, a decoupling has been reported between peak availability of algal foods and zooplankton abundance. To more accurately forecast ecosystem response to climate change, we need an improved understanding of the constraints imposed by alterations in physical conditions on the timing and predictability of biological processes.

What do the records of past environmental change and biological succession and survival tell us about future change? Studies are needed to link the physical and life sciences over a range of spatial and temporal scales, to better understand the linkages between physical changes in Antarctica on geological timescales and biological evolution and adaptation. Biological systems in Antarctica are thought to have been isolated for millennia from the global oceans by currents that circumnavigate the continent, unchecked by land masses. Antarctica has been perennially cold and subject to long uninterrupted periods of darkness each year as the seasons wax and wane. Current hypotheses concerning the biological ramifications of a "snowball" earth and other extended global glaciations contrast with the apparent continuity of life over geological time scales. Integrated, cross-disciplinary studies are essential to resolve the apparent paradox of Antarctic geological and biological records throughout Earth history.

EXAMPLE - It has been hypothesized that geological processes are responsible for establishing near-shore topography in-turn influencing coastal currents, marine primary productivity and the ecology of seabirds. Understanding these interactions requires knowledge of geology, glaciology, paleoecology, organismal physiology, trophic relationships, oceanic circulation patterns, ice mass distributions in time and space, and sea-level change (for details see inset box at the bottom of the next page.)

Do phytoplankton metabolites moderate climate?

Certain species of phytoplankton produce dimethylsulfonopropionate (DMSP) that is enzymatically converted to the gas dimethylsulfide (DMS), a precursor to atmospheric sulfate aerosols. Aerosols nucleate the formation of clouds. Clouds affect incoming solar radiation and upper ocean ecology. These apparently disparate processes can be linked together in a feedback loop between biological and physical processes. The Antarctic is especially well-suited for the study of these interactions. The Southern Ocean is a major source of DMS and it is highly sensitive to changes in ocean circulation, climate, terrestrial-dust flux, and perhaps sea-ice cover. Antarctic ice core records of the sulfur cycle over glacial/interglacial time scales imply these processes have been operative for long periods of time. This hypothetical cycle suggests that change will propagate through the interacting components of the ocean and atmosphere. Testing this hypothesis requires the study of phytoplankton ecology and physiology, physical oceanography, biogeochemistry, nutrient dynamics, sea ice/biota interactions, air/sea gas exchange in open and ice-covered waters, atmospheric photochemistry, and aerosol and cloud chemistry and physics.



ANTARCTIC INTEGRATED SYSTEM SCIENCE (AISS)

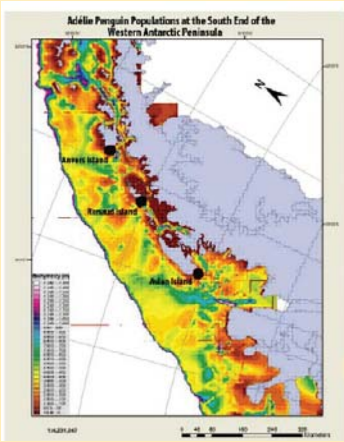
The discoveries of disciplinary science increasingly highlight the need for integrative research. Both multidisciplinary and interdisciplinary science is well established in the Office of Polar Programs. Ideas regarding the creation of an integrated program for Antarctic science were first discussed in 1993. In recent years, the Office Advisory Committee has made recommendations that such a direction be considered. In response to this, since 2005 annual Antarctic Science proposal solicitations from NSF explicitly encourage cross-disciplinary projects. Program directors have supported important interdisciplinary efforts while balancing a compelling agenda of disciplinary research. However, limited resources and a number of management questions and challenges delayed establishment of a dedicated integrated system science program until now.

Large interdisciplinary programs supported by the Office of Polar Programs include the Arctic System Science (ARCSS) program, the Long-Term Ecological Research (LTER) at Palmer Station and the McMurdo Dry Valleys, and the West Antarctic Ice Sheet (WAIS) initiative, to name a few. ARCSS has extended the frontiers of knowledge of Arctic paleoclimate and the biological and societal impacts of land-ocean-ice-atmosphere interactions in a warming environment. The Antarctic LTERs have contributed to fundamental knowledge of life in terrestrial and aquatic environments in the ice-free regions of Antarctica, the ecology of the southern oceans, and the biogeochemical and physical factors that influence the distributions and survivability of flora and fauna in Antarctica. The long-term standardized observational datasets produced by the Antarctic LTERs have allowed the detection of subtle effects due to climate warming at locations that are a continent apart. The long-standing coordination of WAIS researchers has assured organized multi- and interdisciplinary approaches to community-defined questions about potential ice sheet contributions to sea-level rise. Smaller interdisciplinary efforts have also been sponsored within and jointly by existing Antarctic Science programs. Even with these successes, it has been recognized that some scientific issues require even broader integration. IPY augmentations in NSF funding provide an opportunity to build an integrated system science program while minimizing impact on OPP disciplinary programs.

The Antarctic Integrated System Science (AISS) program administers projects that transcend disciplinary boundaries. AISS projects are intended to develop a deeper understanding of the complex interactions that govern Antarctica and its past, present, and future roles in the Earth system. Investigations that cross disciplinary boundaries can contribute significantly to research addressing fundamental questions about our planet.

Are glacial scouring of basins, upwelling, productivity, and seabird population dynamics coupled?

The heterogeneous distribution of top predators in marine environments has puzzled ecologists for decades. An example of this heterogeneity is the breeding distribution of Adélie penguins (Pygoscelis adeliae) on the Western Antarctic Peninsula. The evolutionary loss of flight severely constrains the feeding territories of Adélie penguins. It can thus be hypothesized that penguin populations are restricted to marine regions where primary production, and the prey linked to that production, is predictable on ecological time scales. Adélie penguin populations at the southern end of the Western Antarctic Peninsula are associated with deep, glacially incised basins and cross-shelf canyons that enhance upwelling and prey retention near breeding colonies. The Western Antarctic Peninsula is changing due to climate warming presenting an unprecedented opportunity to identify and understand how interactions between physical and biological processes drive ecosystem responses. Achieving a mechanistic understanding of seabird population dynamics will require integration of studies of geology, glaciology, paleoecology, prey and phytoplankton ecology, ocean circulation, and ice mass and sea-level change.



(•) Adelie penguin colonies

AISS projects are highly integrated, involve more than one discipline, and address questions broader in scope than those typically supported by disciplinary Antarctic programs.

By virtue of the nature of logistical support, scientists from diverse disciplines often work side-by-side in Antarctica. AISS can take advantage of relationships developed in the field by encouraging and supporting cooperative research projects. Cross-cutting scientific questions necessitate resources and talents from multiple disciplines and institutions acting in concert. Our ability to address complex issues will depend on the breadth, depth, and connectivity of teams and investigators assembled to undertake such projects. Questions focused on processes spanning wide-ranging spatial and temporal scales often require a diverse set of technological tools.

Scientific questions demand an integrative approach when progress hinges on knowledge and resources that exceed those available within a single discipline.

AISS projects must have compelling intellectual merit, broad impact and expand the frontiers of our knowledge. Research becomes integrative as communities of experts develop strategies to address interdisciplinary questions. These strategies often enlist diverse disciplines, investigators, instrumentation, and institutions. The AISS program complements science being pursued by NSF disciplinary programs and these programs provide the fundamental advances upon which AISS research is built. AISS should not fund projects that recast disciplinary questions into a form requiring minimal expertise from other disciplines when progress is possible within a discipline. Projects that are so broad in scope that tractable research strategies are impractical should also be discouraged.

ENSURING PARTICIPATION IN AISS

Integrated system science in Antarctica will flourish if there is a community of scholars willing to formulate innovative and broad-based questions and research strategies. Wide participation in AISS is most likely if community expectations are met and all aspects of the management of the program are transparent. It is expected that AISS will attract “new” funds and not adversely impact existing, successful programs. Transparency in how priorities are set, teams are formed, and projects are organized and selected is essential. Unambiguous guidance must be given regarding what constitutes an AISS project as opposed to those that would be considered by disciplinary programs. AISS should include a blend of “open solicitations” driven by investigator-selected topics and “directed solicitations” targeted at high-priority, urgent research topics. Directed solicitations should stem from community input. Workshops to develop solicitations would be one way to acquire such input. A balance between proposal opportunities by teams of investigators and single investigators must be maintained to ensure opportunities for all. Reviewers must be well informed about AISS goals and evaluation criteria and procedures must be clear to ensure that the outcomes of reviews are in concert with these goals. Novel review procedures should be explored and projects should be considered for funding for five (5) years when warranted.

Experience indicates that newly evolving communities of scientists need to be nurtured if strong interconnections are to be built.

AISS community-building efforts must engage all interested parties in identifying promising scientific directions. Resources must be made available for “all hands meetings”, town hall meetings at national conferences, forums to present the latest information, and science sessions in national and international venues. These activities will contribute to a sense of community. In the longer term, a National Academies/National Research Council “frontiers” or “grand challenges” report should be commissioned to set strategic directions for AISS based on broad community input. AISS must make special efforts to involve and inspire the next-generation of researchers to ensure continuity in the program over the years and to bring new ideas into the discussion.

CONCLUSIONS

Continuing study of Antarctica will produce transformational advances in our understanding of the Earth's historical, present and future changes. Research to discern the importance of human involvement in a naturally varying world must consider the co-dependence of physical, chemical, geological, biological, glaciological, oceanic and atmospheric systems. Cutting-edge investigations have been a feature of Antarctic science for over 50 years. The Antarctic Integrated System Science (AISS) program is the latest demonstration of the Office of Polar Program's commitment to advance the frontiers of knowledge in the province of cross-disciplinary research. The promise of the IPY 2007 - 2008 makes this initiative especially timely and the AISS program is poised to build on this momentum.

The time to grow the AISS program is now.

In summary, the creation of AISS as a dedicated program to foster cross-disciplinary research is welcomed and justified. It is expected that the AISS program will encourage urgently needed research that might not otherwise be performed. There are abundant, compelling scientific questions that would contribute to a diverse and robust portfolio of AISS projects now and in the foreseeable future. AISS will complement and create synergy with on-going and future OPP disciplinary programs and should rely on "new" funding avoiding diminished support for existing programs. OPP discipline-based programs provide the fundamental knowledge necessary to plan future AISS directions.

AISS will flourish if there is a community dedicated to formulating innovative cross-disciplinary questions and research strategies.

To be most effective, AISS projects must be of compelling intellectual merit, have broad impact, and focus on topics at the frontiers of our knowledge. Sustained efforts to build an AISS community of scientists are needed to foster the intellectual leadership required to formulate scientific investigations that span disciplinary boundaries producing path-breaking and transformational knowledge.

The enriched polar science landscape that AISS is poised to foster, promises to be an important legacy of the IPY 2007-2008.

A vigorous AISS program will create knowledge that is exciting, transforming and critical in informing some of society's most pressing issues. Antarctic integrated system science will catalyze the formulation of the next generation of scientific questions, attract people to science and engineering careers, and recruit early-career investigators to the polar sciences. Investment in the AISS program now takes advantage of an unparalleled focus on our planet's polar regions afforded by the International Polar Year and the intense public debate about climate change and its ramifications for our society, the international community, and the future of our planet.

Appendix I

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Appendix II

Revised Agenda

Wednesday, June 13, 2007

- Introductions – Kelly Falkner, Program Director AISS, Scott Borg, Antarctic Science Division Director, NSF, OPP
- "Lessons Learned from the Arctic ARCSS Program" – Josh Schimel, University of Southern California (Remarks – Neil Swanberg, OPP Arctic Division
- Edges of Disciplines Presentations
    - "Future Life Sciences Research in the Antarctic -- Challenges and Opportunities" - Donal Manahan, University of Southern California
    - "Unknowns About the Role of Antarctic Ice Sheets in Global Climate and Sea Level Rise" - Robert Bindschadler, NASA/GODDARD
    - "Some Thoughts on Policy-Relevant and Paleo-Related Antarctic Integrated and System Science" – Richard Alley, Penn State
    - "Integrated Science for Society and the Environment" - Scott Collins, University of New Mexico
    - "EDGES of Long-term Ecological Research in Antarctic" - Hugh Ducklow, Marine Biological Laboratory
    - "Global Warming and Antarctica: Happening, Imminent, or Lost in the Climatic Noise?" – David Bromwich, Ohio State University
    - "Subglacial Water in Antarctica at the Intersection of Many Disciplines" - Robin Bell, Lamont Doherty Earth Observatory (presented June 14, 2007)
- Discussion of the Definition of "Integrated and System Science" – Robert Bindschadler, NASA/GODDARD
- Charge to the Workshop – Kelly Falkner, NSF OPP
- Discussion Group Breakout Sessions
- Discussion Group Reports to Plenary

Thursday, June 14, 2007

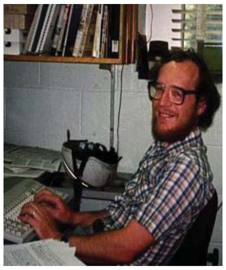
- Recap of Day 1 – Richard Alley, Penn State
- Plenary General Discussions
- Participant Brief Presentations – 2 slides, 2 minutes
- Reconvene Discussion Group Breakout Sessions
- Discussion Group Reports to Plenary

Friday, June 15, 2007

- Recap of Day 2 – Doug Martinson, Lamont Doherty Earth Observatory
- Plenary General Discussion
- Convene Writing Group – annotated Table of Contents and writing assignments
- Adjourn the Workshop

Appendix III

Organizing Committee



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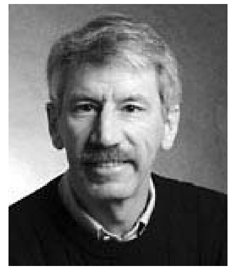

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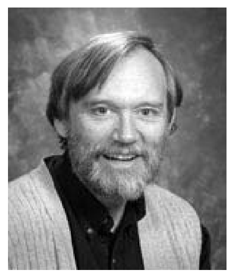

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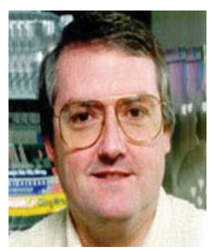

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Appendix IV

Questions, Objectives and Discussion Group Guidance Questions

Workshop Questions:

- Are there Antarctic research themes and topics that would be better served by integration and a systems approach to their organization?
- Are there lessons to be learned from the Arctic System Science experiences that would facilitate an integrated and systems science approach in Antarctica?

Workshop Objectives:

- Identify compelling Antarctic science questions that are best addressed in an integrated and/or systems approach building on the momentum of the IPY and other on-going projects.
- Develop a rationale/approach for setting priorities and assessing which topics are scientifically mature enough to be addressed in a timely manner.
- Determine whether, and if so how a longer term (5 to 10 years) science plan for an Antarctic Integrated System Science program should be established.
- Provide the NSF with initial justification for requesting resource allocations for Antarctic Integrated System Science.

Discussions Group Guiding Questions:

- Interdisciplinary
    - What are the most compelling Antarctic science questions that are best addressed by an integrated and/or systems approach? Are there specific examples from the IPY or other on-going programs and projects that are exemplary?
    - How should AISS set priorities and assess whether topics are intellectually, scientifically, and technologically mature enough to be addressed in a timely manner?
    - What are the most compelling reasons for a new Antarctic Integrated and System Science program that would justify a request for new resources?

- Disciplinary
    - From what you have heard from the presentations and in the interdisciplinary group discussions, what are the research topics at the "edges" of your discipline that can only be accomplished in coordination other disciplinary experts?
    - Within your discipline, what are the most compelling science questions that are best addressed by an integrated and/or system science approach?
    - From the viewpoint of your discipline, what are the most compelling reasons for the continuation of the new Antarctic Integrated System Science program?

Appendix V

Workshop Participants and Community Comment

The Organizing Committee solicited wide input and comment to ensure that an accurate depiction of the diverse views of the Antarctic research community was presented. Workshop participants were instructed to act as representatives of their communities and to consult with their peers regarding their views on all aspects of AISS before the workshop. Participants were asked to develop two slides summarizing example science themes best addressed by an integrated system approach. One of the slides was based on consultation with their peers and one was based on personal opinion. Each participant was given the opportunity to present the slides to the workshop. A draft copy of the AISS report was made available for four (4) weeks on the workshop web site (*http://cresp.tamu.edu/AISSWorkshop*). A call for comment was widely announced on polar list serves and email digest mailings. Workshop participants were also asked to solicit comment from their peers. All workshop related materials were available at the same site.

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