Arctic Observation Integration Workshops Report

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Introduction

A series of three workshops was held 17–20 March 2008 in Palisades, New York, to advance implementation and further the development of an integrated Arctic Observation Network (AON) responsive to the critical scientific issues of environmental arctic change. Sponsored by the National Science Foundation (NSF), the workshop series included three interrelated meetings:

1. A 1.5-day NSF AON investigator meeting;
2. A half-day workshop, jointly sponsored by the AON and SEARCH for DAMOCLES (S4D) programs, on optimizing deployment of Lagrangian platforms for observations of the ocean-ice-atmosphere system; and
3. A 1.5-day workshop, jointly sponsored by the NSF AON program, the NSF Arctic System Science (ARCSS) Program, and S4D, to improve observing and modeling activities for understanding recent arctic sea ice change and its impacts throughout the arctic system.

An international group of over 70 participants with diverse disciplinary, geographic, programmatic, and institutional representation met to foster interdisciplinary and international integration of observing efforts. Participants included representation from the U.S and international arctic observational and modeling communities, including project representatives from AON, ARCSS-Synthesis of Arctic System Science (SASS), Study of Environmental Arctic Change (SEARCH), Developing Arctic Modelling and Observing Capabilities for Long-term Environmental Studies (DAMOCLES) program, Nansen and Amundsen Basins Observational System (NABOS), Canada's ArcticNet, Japan Agency for Marine-Earth Science and Technology (JAMSTEC), the International Study of Arctic Change (ISAC), and U.S. agency representatives.

Background and Motivation

Implementation of an Arctic Observing System is currently underway. Several significant observing efforts are building up to full scale, including NSF AON and DAMOCLES. In addition, groups within the U.S. arctic research community are working to understand arctic system change through SEARCH "Understanding Change" projects, SASS projects, and related efforts.

The extreme arctic sea ice retreat observed in 2007 underscores the immediate need for increased integration and coordination. The sea-ice cover retreated to well below its previous record minimum extent, with potentially substantial physical, biological, and socio-economic impacts on the Arctic. This event raises important questions about our ability to forecast similarly large events on short (i.e., this upcoming year), inter-annual, and decadal timescales, as well as strategies for combining observational efforts with modeling studies directed at improving our understanding of arctic change.

Against this backdrop, the Arctic Observation Integration workshop series was convened to advance planning and implementation of an integrated Arctic Observation System responsive to the critical scientific issues of environmental arctic change.

Specific workshop objectives included:

1. Evaluate the present observing system with respect to its ability to track rapid ongoing change;
2. Produce recommendations for optimization of observing systems and addressing gaps in 2008 and beyond;
3. Improve integration of cross-disciplinary and international observation efforts;
4. Evaluate existing observing technologies, platforms, and on-going development efforts in the context of potentially rapid changes in operating environments (e.g., dramatic decreases in summertime ice extent) and recommend possible adaptations.
5. Produce an integrated overview of the 2007 sea ice minimum, including prospects for continued decline or recovery; and
6. Develop a dialog on integration and long-term sustained arctic observing with relevant agency partners.

Recommendations from each component of the workshop series are summarized below as short-term and long-term activities. These recommendations underscore three central themes that emerged from workshop presentations and discussions: (1) understanding the extraordinary seasonal retreat of sea ice observed in 2007, (2) addressing the challenge of integrating different observation efforts into a system that serves science as well as broader society and key stakeholder groups, and (3) identifying scientific and programmatic gaps and next steps for observing, understanding, and responding to arctic environmental change with emphasis on high-amplitude, unexpected changes.

Summary of Recommendations

Arctic Observation Network (AON) Meeting:

Short-term (12 months)

1. Continue and expand the assessment of AON implementation status and the identification of gaps started during this workshop series. Specifically, this task should include assessment of how well AON addresses the scientific goals in the SEARCH and other AON planning documents (e.g., "Study of Environmental Arctic Change: Plans for Implementation During the International Polar Year and Beyond," "Toward an Integrated Arctic Observing Network," and "Arctic Observing Network [AON]: Toward a U.S. Contribution to Pan-Arctic Observing"). This activity should be led by the SEARCH Science Steering Committee (SSC), the SEARCH Observing Change Panel, and the Interagency Program Management Committee (IPMC), and could occur on a time-scale between short- and long-term. The

work should be done in close cooperation with the international arctic observing community, including the SEARCH for DAMOCLES effort.

2. Strengthen coordination of U.S. interagency observing efforts through the SEARCH IPMC and identify SEARCH/AON contacts within all IPMC agencies; this activity could be initiated though a joint SEARCH IPMC/SSC meeting focused on coordination of IPMC agency observing efforts.
3. Coordinate with Canada's ArcticNet program and other relevant international efforts through a Memorandum of Understanding (MOU) or similar coordination process.
4. Develop or assimilate tools to communicate and share information about different observing activities with respect to placement of instruments and planning of field campaigns.
5. Contribute to a collaboratory framework to advance scientific integration and exchange (cf. proposed 2008 Sea Ice Outlook effort, discussed in report Appendix B).
6. Explore how model output (e.g., the Intergovernmental Panel on Climate Change Fourth Assessment Report [IPCC AR-4]) can be examined in the same method as data provided through CADIS.
7. Pursue data coordination efforts amongst relevant national and international programs; this could be accomplished through CADIS and the SEARCH Data Management Working Group.
8. Implement an advisory group for CADIS that can serve as a community liaison (articulating the needs of both AON PIs and broader community); this advisory group could be created with the help of the SEARCH governance structure.
9. Identify and implement a process by which stakeholder priorities can be used to guide coordination efforts and demonstrate the utility and value of AON in a broader societal context (e.g., utilizing a tool such as a "Human Activities/Stakeholder Information Needs Matrix," Appendix A); provide structured guidance on how to acknowledge collaborators from local communities.
10. Convene the next AON meeting or follow-up workshop, focused on identifying cross-disciplinary scientific gaps and exchange within disciplinary working groups.

Long-term (2–5 years)

1. Develop a strategic plan for longer-term AON data management and coordination activities, including a funding mechanism to ensure balance and continuity.
2. Augment human dimensions and stakeholder-relevant (e.g., marine mammals) components of AON and strengthen interagency linkages to relevant ongoing observation efforts (e.g., through marine mammal commissions).
3. Coordinate with the International Study of Arctic Change (ISAC) to improve international exchange of information relevant for joint planning and coordination of observation programs.

4. Develop a process for balancing scientific and stakeholder information needs that identify measures of success for AON.

Autonomous and Lagrangian Platforms Workshop:
Short-term (12 months)

1. Sustain the present efforts using existing instrumentation to return detailed arctic atmosphere, ice, and ocean observations from arrays of autonomous instruments beyond the IPY period.
2. Refine and implement an "amphibious" International Arctic Buoy Program (IABP) buoy.
3. Work for improved access to eastern Arctic for IABP and others.
4. Harden Ice-Based Observatory (IBO) instrument designs to improve survivability during sea ice transition states.
5. Continue development of floats and gliders for work in ice-covered environments.
6. Produce white paper detailing a pilot (2–3 element) low-frequency acoustic navigation array.

Long-term (2–5 years)

1. Implement pilot navigation array and use it to support float and glider operations for the Arctic Observing Network, including a science program that exploits the array.
2. Expand plans to provide basin-wide navigation based on the pilot design.
3. Define and transition to operational status an arctic-wide atmosphere-ice-ocean observing system that includes IBOs, floats, gliders, and the infrastructure (acoustic navigation) needed to support such operations.

Lessons from the 2007 Arctic Sea-ice Minimum Workshop:
Short-term (12 months)

1. Develop and implement a process that tracks, summarizes, and integrates ongoing developments and provides a consensus outlook for May–September 2008 sea-ice extent and characteristics. Toward this goal, develop an organizational structure and process for collecting information, moderating, and issuing information on a monthly basis (See Appendix B, 2008 Arctic Sea Ice Outlook).
2. Summarize retrospectively the results of the 2008 Arctic Sea Ice Outlook. Who got it right and why?
3. Plan and hold follow-up workshops in fall 2008 after the upcoming field season and September 2008 ice minimum.
4. Develop and submit multi-authored synthesis papers targeted to high-impact journals—papers that integrate the impacts on the summer 2007 sea-ice retreat and linkages to multiple components of the arctic system and place the summer 2007 ice retreat in perspective given the eventual outcome of the summer 2008 ice retreat.

5. Develop a synthesis paper on existing ecosystem data, including paleo-records and more recent analogs that are useful for ecosystem reconstruction (beyond sediment cores and temperature reconstructions).
6. Synthesize existing ecological and human-dimensions information.
7. Identify other data sets needed to improve our understanding of potential changes within ecosystems and human systems (e.g., subsistence, tourism, resource extraction, fisheries, etc.) through a follow-up workshop.
8. Identify specific information gaps that are pertinent to science, policy, and human implications through a follow-up workshop (as above).
9. Undertake modeling efforts in order to explore possible scenarios given the state of our knowledge today, e.g., make preliminary projections for how arctic marine and terrestrial ecosystems might function in the immediate and distant future in order to inform management and policy. Build on ongoing modeling efforts through SEARCH and DAMOCLES (e.g., similar to modeling workshop held October 2007; workshop report at http://www.arcus.org/search/internationalsearch/meetings-and-activities.php).
10. Convene follow-up meetings to develop integration and modeling activities.

Long-term (2–5 years)

1. Continue observations (AON and other) and integrated analyses of the key parameters for documenting and understanding the sea-ice cover over the next several annual cycles.
2. Collect observations that are needed to assist in refining and validating scenarios.
3. Undertake data collection and research on the marine and terrestrial components for which there are major gaps in observations and understanding of change (e.g., including marine-terrestrial linkages) through research mechanisms such as a specific Announcement of Opportunity.
4. Undertake research activities using modeling together with other analytical methods to improve understanding and predictability on seasonal to interannual time scales.
5. Develop modeling efforts to explore possible scenarios for how the sea ice may retreat further on long time scales, and the consequent implications.
6. Look outside the Arctic for data relevant to understanding human implications.
7. Identify components of the arctic system that are more vulnerable to rapid change and the barriers to resilience and adaptation; this will involve research partnerships with local communities.

Overview

This meeting served as both an AON progress review as well as a planning meeting for developing cross-disciplinary efforts and pursuing focused integration activities. NSF's AON Program comprises more than two-dozen projects that are collecting and analyzing data from different components of the arctic system in response to the questions formulated by the scientific community in the context of SEARCH. The first AON investigator meeting in spring 2007, held immediately after announcement of the funded projects, primarily addressed implementation issues for individual projects. This second AON meeting focused on coordination of activities into an integrated network that is responsive to the needs of the scientific community and stakeholders. Representatives from DAMOCLES and other relevant observing efforts participated to strengthen collaboration.

Workshop presentations included brief status reports of AON projects and related national and international observing efforts, including DAMOCLES (through the SEARCH for DAMOCLES coordination activities), the Canadian ArcticNet program, Japan Agency for Marine-Earth Science and Technology (JAMSTEC) observing efforts, and the Nansen and Amundsen Basins Observational System (NABOS) program. Workshop discussions focused on a number of issues central to development of coordinated, integrated arctic observation efforts. Working groups explored in more detail three key topics (1) data management and integration, (2) observing system/network design and coordination and integration through observations and modeling, and (3) interactions between human activities and sea, land, ice, and atmosphere. The meeting was concluded with a plenary discussion that identified next steps and provided input to the subsequent two workshops.

Plenary discussions, working group discussions, and recommendations and action items are summarized below. Workshop presentations, working group materials, and additional background information on participating projects and programs are available for download from the SEARCH website at: http://www.arcus.org/search/Meetings/2008/aow/index.php.

Summary of Plenary Discussions

Plenary discussions addressed several issues for developing cross-disciplinary efforts and pursuing focused integration activities:

1. Gaps in Meeting Scientific Objectives of SEARCH

Based on working group discussions (below), a hierarchical approach in addressing AON disciplinary or sampling gaps emerged. At the highest level, a focus on overarching, tractable scientific questions (i.e., the SEARCH science questions), with guidance derived from stakeholder information needs, can help focus AON efforts and identify overarching gaps that cross disciplinary boundaries. Workshops such as the Lessons from the 2007 Sea-ice Minimum Workshop and survey tools such as the Human Activities and Stakeholder Data Needs matrix (Appendix A) can help direct high-level integration efforts. One such high-level gap identified at the workshop and in prior community discussions is the collection and coordination of marine biological data, in particular on species relevant to arctic communities.

At a more focused level is identification of broad disciplinary gaps. Two examples of disciplinary gaps identified are (1) observational data collection on arctic human dynamics, and (2) information on mountain glacier and ice cap melt, in the context of freshwater input and sea-level rise over the next century. Finally, there are more specific spatial and temporal sampling gaps within disciplinary groups, requiring meetings such as the Autonomous and Lagrangian Platforms Workshop and a higher degree of information sharing between different programs at the international level to coordinate deployment of instruments and sampling campaigns.

In identifying gaps in the context of SEARCH, it needs to be recognized that gaps may be addressed through coordination with ongoing related efforts. For example, coordination of AON's meteorological observation activities with large operational programs such as the network of meteorological observations maintained by various weather services, as well as NOAA- and NASA-supported efforts at comprehensive reanalysis of atmospheric fields. Similarly, marine biological data gaps may be partially addressed through closer collaboration with various U.S. agencies, such as NOAA and the U.S. Fish and Wildlife Service, to build on efforts that are already underway but that are not currently integrated into a coordinated observing system.

2. *Integration Among AON Projects and U.S. Efforts by Federal Agencies*

The focus on overarching scientific and stakeholder-driven questions and information needs was seen as a primary, discipline-transcending approach towards improved integration among projects and programs. In order to be successful, integration efforts need to interface and coordinate with federal agencies carrying out relevant programs (e.g., under the auspices of SEARCH). Workshop participants saw a substantial need for stronger coordination through existing channels, including the SEARCH Interagency Program Management Committee (IPMC), the Interagency Arctic Research Policy Committee (IARPC), and the U.S. Arctic Research Commission (USARC). Observation initiatives underway within the National Oceanic and Atmospheric Administration (NOAA) and Department of the Interior (DoI) also should be integrated into a coordinated framework. In addition, marine mammal commissions and fisheries boards are potentially important partners in addressing some of the stakeholder-driven scientific gaps. Entities such as the USARC may help integrate federal researchers into the planning process. To address overarching scientific questions, focused workshops (such as this workshop series) and approaches such as survey tools were seen as important models in this regard. Finally, CADIS, as the entity responsible for AON data management, can play an important role in fostering integration by providing an integrated data access and interpretation framework.

3. *Integration with International Programs and Efforts*

Efforts such as SEARCH for DAMOCLES, which was initiated through a Memorandum of Agreement (MOA) between the U.S. SEARCH and EU DAMOCLES programs, and related joint workshops appear to be successful in advancing international coordination and integration. This model of coordination should be explored to incorporate longer-term planning as well as broader international collaboration, in particular with Canada (e.g., ArcticNet), Russia, the Pacific Rim nations, and efforts such as NOAA's Russian-American Long-term Census of the Arctic (RUSALCA). In addition, coordination activities through entities such as the Arctic Council need to be explored. The International Study of Arctic Change (ISAC) will be of value in potentially leading the establishment of an international clearinghouse for information related to ongoing and planned activities on environmental arctic change.

4. Data Coordination

In the near-term, ensuring access to AON data is the primary goal, which requires coordination through CADIS with contributions from individual projects. In the mid- to long-term, steps need to be taken to ensure access to data and model output in a unified environment to help observing efforts within AON (e.g., placing of sites, motivation of research), as well as modeling efforts outside of AON (e.g., validation and understanding of change). At the international level, coordination with data management efforts by DAMOCLES and ArcticNet is key to a comprehensive and unified approach. In this regard, an advisory group to CADIS also can play an important role.

5. Observing Needs for Tracking and Projecting Rapid Change

The ice season of 2007 and other environmental arctic changes make clear the significant need to test the utility of the AON in tracking and anticipating rapid change, i.e., on seasonal timescales or less. Workshop participants stressed the need for an information and forecasting system that would serve the needs of the scientific community (e.g., in aiding siting of observation system components) as well as those of the broader public and stakeholders; this issue was discussed further in the Lagrangian and 2007 Sea Ice workshops. Tracking and projecting rapid change will require a combination of model output, examination of patterns in past observations, assessment of preconditioning, and consideration of impacts at the local level. Equally important are coordinated activities that capture and address public interest (e.g., activities such as the NSIDC "Arctic Sea Ice News & Analysis," see: http://nsidc.org/arcticseaicenews/).

6. Long-term Goals

In the longer term (i.e., several years), achieving continuity of the successful elements of AON and striking a balance between new and ongoing observing system components is essential as the coverage and sophistication of an integrated observing system improves. Data preservation and access in a unified environment, including relevant model output and tools relevant to stakeholder groups, are a priority for AON planning. Finally, striking the right balance between scientific and stakeholder information needs and assuring the relevance of data products for broader society are important goals for AON activities.

Summary of Working Group Discussions

Working Group 1: Data Management and Integration

The Cooperative Arctic Data and Information Service (CADIS) (see website at: http://www.eol.ucar.edu/projects/aon-cadis/) supports AON as a portal for data discovery and provides near-real-time data delivery, a repository for data storage, and tools to manipulate data. CADIS plays a key role in ensuring the longevity of AON data by obtaining and sharing metadata, preserving dataset lineages (attribution and sources), and performing curation and stewardship services. The primary goal of the CADIS archive should be to provide a single entry point for searching and browsing AON's distributed data holdings. Responsibilities of the AON project investigators include data quality control and providing metadata and data to CADIS in a timely manner. With regard to CADIS development and activities, workshop participants recognized the need for an Advisory Committee to act as a liaison to the scientific community and to guide science-driven data management priorities.

The value of cyberinfrastructure (CI) to facilitate integration efforts was recognized, which will require careful planning and strong partnerships between information technology (IT) researchers and domain scientists. In the near term, it is important to create tools that aid in interpretation and presentation of results for a broad range of scientists and stakeholders. In the longer term, the ability to rapidly interpret and synthesize data will be an important service to the scientific and stakeholder communities. This discussion informed the "Lessons from the 2007 Arctic Sea-ice Minimum" workshop and subsequent recommendations.

Working Group 2: Observing System / Network Design—Coordination and Integration Through Observations and Modeling

Working group participants stressed the importance of central, tractable science questions (e.g., causes and impacts of the 2007 sea ice minimum) in building an integrated observing network. Integration that focused around central science questions would assess past and current observational activities, linking across disciplines and arctic system components to guide design and development of an integrated observing system beyond the International Polar Year (IPY).

While identification of network gaps only may be possible after several years of observations, each discipline now can articulate gaps in cross-disciplinary information needs (e.g., atmospheric boundary fluxes, terrestrial runoff, coastal erosion). Several existing gaps and needs were identified by workshop participants, including:

- Terrestrial observational research appears to lack spatial coverage, both at the Alaska regional and the pan-Arctic scale.
- Lack of data over the seasonal ice zone (and continued dearth of sea ice thickness data) was seen as problematic.
- Potential gaps in satellite observing systems (specifically by NASA) were seen as a major concern.

- Concerns were raised with respect to the ability to track long-term change given the short timescale of funding schemes currently in place. The NSF Long-term Ecological Research (LTER) Program was seen as a potential model for support of a long-term Arctic Observing Network, which could serve as an umbrella to sustained long-term observations (through NSF) and monitoring (through agencies such as NOAA).

Models can guide the design of a network and spatial coverage of sensors (e.g., in DAMOCLES or buoy deployment), but the lack of accurate predictions of the 2007 sea ice minimum provided a note of caution on the utility of model output. Two significant outcomes of the implementation of the AON are its impact in bringing different disciplines together and its role as a legacy product of the IPY.

Working Group 3: Interactions Between Human Activities and Sea, Land, Ice, and Atmosphere

Studies of human dynamics in the arctic system and stakeholder information needs can help drive integration and coordination of AON. Local and traditional knowledge (such as that collected by the "Exchange for Local Observations and Knowledge in the Arctic [ELOKA]" or "Bering Sea Sub-Network: International Community-Based Observation Alliance for Arctic Observing Network [BSSN]" projects) can provide direction for AON, inform hypotheses, and contextualize research findings. With only one AON project specifically examining human dimensions research (i.e., "Is the Arctic Human Environment Moving to a New State?" project) and with a near-absence of biological observations of key species such as marine mammals that are of prime importance to arctic residents, this working group set out to identify potential starting points for improving cross-linkages to human dimensions topics. Critical issues include: identification of key stakeholders (local communities; fishing industry; oil, gas and mining; shipping and transportation; tourism; policy makers, regulators and enforcement; disaster response; broader public interests), their specific needs for information, and how this information can be provided. A "Human Activities and Stakeholder Information Needs Matrix" designed by the working group and circulated among workshop participants provided valuable input on stakeholder information needs that are already met or underway through funded AON projects (see Appendix A).

Specific examples of stakeholder information needs that could be met through AON include: information on terrestrial snow cover for use in community infrastructure design, search and rescue, transportation, and tourism and ecosystem services; and coastal sea ice information relevant for subsistence activities, marine shipping, oil and gas industry, and tourism. Preliminary findings from AON projects indicate, for example, that changing ocean conditions drive changes in fish distribution, run timing, and resilience. Fishers observe new opportunities and can adapt very quickly—if the regulations allow it. Hence, the observations of fishers, if recorded through AON, could provide information to managers and research scientists to guide rapid and effective research and regulatory responses.

Recommendations and Action Items

Short-term (12 months)

1. Continue and expand the assessment of AON implementation status and the identification of gaps started during this workshop series. Specifically, this task should include assessment of how well AON addresses the scientific goals in the SEARCH and other AON planning documents (e.g., "Study of Environmental Arctic Change: Plans for Implementation During the International Polar Year and Beyond," "Toward an Integrated Arctic Observing Network," and "Arctic Observing Network [AON]: Toward a U.S. Contribution to Pan-Arctic Observing"). This activity should be led by the SEARCH Science Steering Committee (SSC), the SEARCH Observing Change Panel, and the Interagency Program Management Committee (IPMC), and could occur on a time-scale between short- and long-term. The work should be done in close cooperation with the international arctic observing community, including the SEARCH for DAMOCLES effort.

2. Strengthen coordination of U.S. interagency observing efforts through the SEARCH IPMC and identify SEARCH/AON contacts within all IPMC agencies; this activity could be initiated though a joint SEARCH IPMC/SSC meeting focused on coordination of IPMC agency observing efforts.

3. Coordinate with Canada's ArcticNet program and other relevant international efforts through a Memorandum of Understanding (MOU) or similar coordination process.

4. Develop or assimilate tools to communicate and share information about different observing activities with respect to placement of instruments and planning of field campaigns.

5. Contribute to a collaboratory framework to advance scientific integration and exchange (cf. proposed 2008 Sea Ice Outlook effort, discussed in report Appendix B).

6. Explore how model output (e.g., the Intergovernmental Panel on Climate Change Fourth Assessment Report [IPCC AR-4]) can be examined in the same method as data provided through CADIS.

7. Pursue data coordination efforts amongst relevant national and international programs; this could be accomplished through CADIS and the SEARCH Data Management Working Group.

8. Implement an advisory group for CADIS that can serve as a community liaison (articulating the needs of both AON PIs and broader community); this advisory group could be created with the help of the SEARCH governance structure.

9. Identify and implement a process by which stakeholder priorities can be used to guide coordination efforts and demonstrate the utility and value of AON in a broader societal context (e.g., utilizing a tool such as a "Human Activities/Stakeholder Information Needs Matrix," Appendix A); provide structured guidance on how to acknowledge collaborators from local communities.

10. Convene the next AON meeting or follow-up workshop, focused on identifying cross-disciplinary scientific gaps and exchange within disciplinary working groups.

Long-term (2–5 years)

1. Develop a strategic plan for longer-term AON data management and coordination activities, including a funding mechanism to ensure balance and continuity.
2. Augment human dimensions and stakeholder-relevant (e.g., marine mammals) components of AON and strengthen interagency linkages to relevant ongoing observation efforts (e.g., through marine mammal commissions).
3. Coordinate with the International Study of Arctic Change (ISAC) to improve international exchange of information relevant for joint planning and coordination of observation programs.
4. Develop a process for balancing scientific and stakeholder information needs that identify measures of success for AON.

Overview

Motivated by promising advances in autonomous technologies for arctic observing and by the potential challenges presented by recent, rapid changes in summertime sea ice extent, the Autonomous and Lagrangian Platforms Workshop focused on understanding the role these platforms might play within a long-term observing system designed to track, understand, and ultimately forecast arctic change. Both DAMOCLES and SEARCH include efforts to develop autonomous floats and gliders capable of operating beneath the arctic ice and ice-tethered technologies—essentially inverted moorings suspended from buoys embedded in the drifting ice. Similar platforms have revolutionized ocean observing in the ice-free oceans, allowing the collection of cost-effective, persistent and long-term measurements with unprecedented spatial coverage. The NSF-sponsored Instrumentation for Arctic Ocean Exploration workshop (October 2002, Moss Landing, CA) assessed earlier observing capabilities while a workshop on Arctic Observing Based on Ice-Tethered Platforms (June 2004, Woods Hole, MA) focused on instruments suspended from drifting ice. The recent Acoustic Navigation and Communications for High-Latitude Ocean Research (ANCHOR) workshop (Feb 2006, Seattle, WA) explored two critical enabling technologies—acoustic navigation and communications—that are needed to provide services analogous to GPS navigation and Iridium satellite telephone communications for oceanographic instrumentation operating in the ice-covered Arctic. The Autonomous and Lagrangian Platforms Workshop participants focused on synthesizing and extending the results of these previous efforts to address the following questions:

1. How should autonomous and Lagrangian technologies and approaches be exploited to establish a system for tracking, understanding, and forecasting arctic change?
2. What adaptations will be required to compensate for and perhaps take advantage of rapid changes in arctic ice cover?
3. What technological and political challenges confront these platform development efforts, and how should the community prioritize its efforts?

Workshop presentations provided a brief summary of the science that is motivating efforts to develop a long-term arctic observing system, highlighting the need to understand the mechanisms behind observed mean sea ice draft reductions, the recent minimum in summertime sea ice extent, and variability in arctic water exports to the subpolar oceans. A series of plenary talks offered specific examples of autonomous and Lagrangian platforms applied to arctic research. Workshop participants remained in plenary for discussions focused on the questions enumerated above, concluding the day by developing a set of short- and medium-term recommendations for continued development of autonomous and Lagrangian technologies and their application within AON. Workshop presentations and additional background information are available for download from the SEARCH website at: http://www.arcus.org/search/Meetings/2008/aow/index.php.

Summary of Discussions

1. State-of-the-Art

Status reports summarizing accomplishments and current development efforts for autonomous and Lagrangian platforms provided essential background for understanding their potential roles in a long-term Arctic Observing Network and for prioritizing future research directions.

One class of measurement system is the Ice-Based Observatory (IBO), or Automated Drifting Station—an assemblage of autonomous instruments sampling the atmosphere, sea ice, and upper ocean and reporting their observations back to researchers on shore. In operation since 1979, the International Arctic Buoy Program (IABP) represents the most mature Lagrangian measurement system operating in the Arctic. This coverage is largely the product of extensive international collaboration, with instrument deployments occurring from ships of opportunity and aircraft. Additional instrumentation, such as the Cold Regions Research and Engineering Laboratory's (CRREL) Ice Mass Balance (IMB) Buoys, can be efficiently installed in conjunction with other ice-drifting sites to provide the detailed measurements needed for understanding the mechanisms behind observed changes in ice cover. The drifting ice provides a stable platform for supporting extensive instrumentation, but because IABP instrumentation relies on the ability to drift atop multi-year ice, rapidly decreasing summertime ice extent presents particular challenges. The IABP's response includes the design and testing of a new buoy hull capable of surviving breakup and re-freezing, exploiting low-cost, air-deployable drifters designed for use in the ice-free oceans, and seeking permission to deploy buoys into critical, but previously denied, sites within the Russian Exclusive Economic Zone (EEZ). Likewise, CRREL is developing a self-contained IMB buoy capable of operating in the seasonal ice zone.

Upper ocean observations are being acquired by Ice-tethered Profilers (ITPs, see www.whoi.edu/itp) developed at the Woods Hole Oceanographic Institution (WHOI) and Polar Ocean Profilers (POPS) developed by Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and the MetOcean company. These devices return high vertical resolution temperature and salinity observations. Systems have been deployed by U.S. investigators as well as Japanese and European scientists (the latter in association with the DAMOCLES program). Data from ensembles of ITP and POPS instruments are being used to construct true synoptic sections across the Arctic (by, for example, analyzing all the profiles obtained on a specific day) and map spatial fields such as fresh water anomalies. Another instrument contributing to the IBO concept is the Autonomous Ocean Flux Buoy (AOFB) developed by the U.S. Naval Postgraduate School. The AOFB makes high-frequency observations in the ocean surface layer just below the ice to estimate the heat, buoyancy, and momentum fluxes between the ice and ocean.

A common characteristic of these new IBO instrument systems is their reliance on the presence of perennial sea ice, but they are not currently designed to survive break-up, open ocean drifting, and re-freeze. Engineering work is now underway to improve survivability of IBO instrument systems in thin ice or open water, but alternate technologies not tied to the ice also are showing promise. Steady investments toward adapting floats and gliders to provide long-term persistence

(6–24 months), remote access, and wide coverage for arctic observing have produced some initial results.

Gliders developed at the Applied Physics Laboratory, University of Washington, have seen their first operations in an ice-covered environment, occupying a section across the wintertime Davis Strait. Arctic gliders incorporate additional autonomy to enable them to make unassisted decisions about when and where to surface, where to navigate, and how to respond to unexpected situations such as hardware malfunctions or severe navigational problems. Gliders possess the endurance to operate from one ice-free season to the next without servicing, and can thus conduct year-round surveys in the presence of seasonal ice cover.

Autonomous, Argo-style floats have been deployed in the Arctic by WHOI and by the DAMOCLES partners. The WHOI Polar Profiling Float (PPF) drifts and profiles beneath the ice but regularly attempts to locate open water by trying to surface, relying on a reinforced antenna to survive the resulting collisions. The float transmits data and receives a Global Positioning System (GPS) fix whenever it successfully reaches the surface, drifting without geolocation and storing data onboard for the periods between these surfacings. The DAMOCLES floats carry compact upward-looking sonars for measuring ice-draft along their drift path, and rely on acoustic contact with an array of ice-tethered platforms for geolocation and data telemetry. The PPF has seen limited arctic deployments that demonstrate proof of concept; DAMOCLES floats are being deployed now.

Faster, propeller-driven autonomous vehicles provide useful platforms for conducting short duration, rapidly occupied synoptic surveys and process studies. This class of Autonomous Underwater Vehicles (AUV) has been employed for tasks ranging from cable laying cables to collecting measurements of turbulence beneath the Arctic Ice. The newest AUVs (e.g., Hydroid Company’s REMUS AUVs) are compact and relatively easy to use, lowering the logistical barriers that have limited their application to arctic research.

In ice-free oceans, autonomous platforms rely on the GPS to provide geolocation and Iridium Satellite communications for telemetering data and instructions. These two backbone technologies allow efficient operation and maintenance of large arrays of low-cost autonomous observing assets. When ice cover denies access to the surface, these platforms must rely on acoustics for navigation and communications. Existing systems used to support float and glider operations in ice-free regions rely on “mid-frequency” (260 Hz or 780 Hz) acoustics to provide navigation for domains up to several hundred kilometers across. However, signal loss from reflections off the ice limits ranges, making larger domains impractical. Experiments demonstrate that low-frequency signals (10 Hz) offer a technology for supporting basin-wide navigation from a modest number of acoustic sources. Marine mammal concerns warrant careful consideration, though the depth and duty cycle of these sources should help mitigate impacts. Off-the-shelf technologies can provide short-range (0–1 km), high-rate acoustic communications, but acoustic communication over longer ranges, especially in the presence of overhead ice, would require dedicated development effort.

2. *How should Autonomous and Lagrangian Technologies and Approaches be Exploited to Establish a System for Tracking, Understanding, and Forecasting Arctic Change?*

Autonomous and Lagrangian platforms should be employed to strengthen the persistence and spatial coverage provided by AON. Floats, IBOs, and gliders excel at providing year-round measurements over extended time periods (years), while their relatively modest per-platform operating costs permit deployment in quantities that are large enough to provide unprecedented spatial coverage. Workshop participants agreed that AON should exploit the complementary nature of conventional (e.g., ship- and aircraft-based measurements, and moorings) and autonomous/Lagrangian platforms. Ship- and aircraft-based hydrography provides important tracer measurements (such as oxygen isotopes for attributing freshwater origins) that cannot otherwise be obtained, while moorings can provide detailed time series at critical sites where currents are well constrained by the bathymetry such as narrow, shallow gateways and along continental slopes and ridges. Floats and IBO clusters provide cost-effective, basin-wide coverage for gauging changes in water mass structure and integrated storage; IBOs can further provide information about the sea ice and atmospheric boundary layers. However, the nature of Lagrangian drifts can result in a concentration of platforms in convergence zones and limits their utility for resolving structure across boundary currents and frontal zones. Though more costly than floats and more lightly instrumented than ITPs, gliders possess the ability to navigate between waypoints and can thus repeatedly occupy strategic cross-basin surveys and critical sections across narrow boundary currents and frontal zones. Clearly, a mix of technology is optimal. Platforms and approaches also should be evaluated on the practicality of sustaining measurement activities over extended time frames (years to decades). Toward this end, workshop participants also stressed the importance of co-locating assets to ease the logistical burdens associated with extended maintenance.

Beyond the ideas expressed above, workshop participants identified three AON gaps that autonomous and Lagrangian technologies might help address: (1) atmospheric boundary layer measurements, (2) ice and ocean measurements within the seasonal ice zone, and (3) applying the new generation of biogeochemical sensors to arctic observing. Enhanced IABP or other IBO instruments could support additional meteorological sensors to augment sparse measurements within the atmospheric boundary layer. Gliders and PPFs can sample within the seasonal ice zone, though additional sensor development would be required to focus on the evolution of the ice itself. Gliders and floats can already carry a variety of bio-optical sensors, which will transition to arctic observing along with the platforms. New sensors are being actively pursued within the open-ocean glider community, and these developments can be directly applied to arctic observing.

3. *What Adaptations will be Required to Compensate for and Perhaps Exploit Potentially Rapid Changes in Arctic Ice Cover?*

IABP buoys and the other existing IBO instrument systems will require modifications to adapt to the rapidly changing summertime ice extent. For aircraft-based operations, decreased ice cover can narrowly constraint deployment sites and thus impact the spatial coverage offered by the drifting array. Existing IABP buoys and ITPs rely on perennial ice at their deployment site and were not designed for open-water operation or to weather the violence of break-up and freeze-in. The IABP is addressing these issues by: (1) adopting standard air-droppable, open-ocean surface drifters, fitted with pressure sensors, for flexible deployment over ice or open water, (2) implementing an air-droppable, "amphibious" buoy designed to survive break-up and freeze-in, and (3) negotiating with international partners to gain access to key deployment sites (e.g., the eastern Arctic). Work to modify IBO instrument systems to improve survivability during transition periods and enable continued operation in open water is underway.

Reduced summertime sea ice extent also has interesting implications for floats and gliders, as it provides large open-water expanses for at least a couple of months out of each year. If the trend is consistent, this new open water access might decrease the need for long-range acoustic telemetry, as floats and gliders could depend on at least one annual encounter with an ice-free region for data transmission. Although a low-frequency acoustic navigation array would still be required for geolocation during the ice-covered period, eliminating the need for long-range acoustic communication for data transmission greatly simplifies infrastructure requirements.

4. What Technological and Political Challenges Confront these Platform Development Efforts, and how should the Community Prioritize its Efforts?

Technological challenges include: (1) adapting IABP and other IBO systems buoys for "amphibious" operation, (2) continued refinement of float and glider systems to improve performance and reliability, (3) integration of new sensors, (4) development of autonomous sensors for characterizing the atmospheric boundary layer, and (5) the design and implementation of a low frequency acoustic navigation system, an underwater GPS to support autonomous and Lagrangian platforms for AON. Many of these were discussed above. Of the sensor developments, autonomous atmospheric instruments may prove the most challenging. Beyond relatively simple measurements such as pressure and air temperature, the harsh operating environment dictates that more sophisticated atmospheric observations be conducted using tended sensors.

Although the technologies for implementing the low-frequency acoustic navigation system already exist, technical hurdles remain related to the large power-intensive sources that the array would employ. Workshop participants suggested cabling sources in at least two sites: Barrow, Alaska and Svalbard. Moored sources would rely on large battery packs and likely require servicing once every 1–2 years. Maintenance costs would need to be considered carefully and economies, such as co-locating sources with existing science moorings, identified. Minimizing marine mammal impacts also would be a primary concern.

Political considerations constrain deployment sites for autonomous assets. The IABP lacks coverage in the eastern Arctic and would benefit from improved access to the Russian EEZ. In the lower latitude oceans, the ARGO program has negotiated a blanket agreement that provides permission to sample within the various national EEZs by simply informing the host government of the float's impending entry; advance permission is not required. Could we establish a similar agreement for buoys, ITPs, floats, and gliders operating in the Arctic?

International cooperation will be central to the success of the Arctic Observing Network, as the system is larger than any single national science organization could support. Such cooperation will provide the resources needed for the observing system and smooth access for drifting and gliding platforms. The envisioned basin-scale, low-frequency acoustic navigation array will include sources sited in a handful of EEZs, ideally with material support as part of the host country's contribution to the array.

Recommendations and Action Items

Short-term (12 months)

1. Sustain the present efforts using existing instrumentation to return detailed arctic atmosphere, ice, and ocean observations from arrays of autonomous instruments beyond the IPY period.
2. Refine and implement an "amphibious" International Arctic Buoy Program (IABP) buoy.
3. Work for improved access to eastern Arctic for IABP and others.
4. Harden Ice-Based Observatory (IBO) instrument designs to improve survivability during sea ice transition states.
5. Continue development of floats and gliders for work in ice-covered environments.
6. Produce white paper detailing a pilot (2–3 element) low-frequency acoustic navigation array.

Long-term (2–5 years)

1. Implement pilot navigation array and use it to support float and glider operations for the Arctic Observing Network, including a science program that exploits the array.
2. Expand plans to provide basin-wide navigation based on the pilot design.
3. Define and transition to operational status an arctic-wide atmosphere-ice-ocean observing system that includes IBOs, floats, gliders, and the infrastructure (acoustic navigation) needed to support such operations.

Overview

This workshop served as an international forum to exchange information and develop cross-disciplinary integration activities to better understand the reduced sea-ice cover in summer 2007, and to look ahead to summer 2008 and beyond. The workshop was organized as a rapid response to the drastic (1.2 ×106 sq. km) drop in the arctic minimum sea-ice extent observed in September 2007 relative to the previous minimum. The workshop follows upon activities within a working group at an NSF Arctic System Science (ARCSS) Synthesis of Arctic System Science (SASS) workshop in Washington, D.C. in October 2007 (see: http://www.arcus.org/ARCSS/2007_oct_sass/index.html). Participants of the workshop included scientists from SASS and AON projects, and EU DAMOCLES and other international and national invitees, including SEARCH and agency representatives. Workshop participants focused on assessing the efficacy and identifying gaps of current observing and analysis/modeling activities to understand and—to the extent possible—predict arctic sea ice and broader arctic system change.

Plenary presentations and discussion on documenting and understanding changes in several components and sub-systems of the broader arctic system, e.g., sea ice, atmosphere, ocean, terrestrial vegetation, the Greenland Ice Sheet, and the human response to the summer 2007 sea ice minimum were followed by presentatins and discussion on integration and synthesis to improve system understanding using observational and modeling approaches. Three working groups explored in more detail (1) documentation and understanding, (2) understanding and predictability, and (3) science, policy, and human implications of the 2007 sea-ice minimum. Presentations and discussion in the final plenary session addressed working-group findings and identified the next steps, focused on near-term efforts such as synthesis papers and assessing the summer 2008 sea-ice retreat as it develops.

The plenary and working group discussions and outcomes are summarized below. More detailed information on the proposed “2008 Sea Ice Outlook” effort is available in Appendix B. Workshop presentations, working group materials, and additional background information are available for download from the SEARCH website at: http://www.arcus.org/search/Meetings/2008/aow/index.php.

Summary of Plenary Discussions

Based on workshop presentations and discussions, it was generally agreed that we have (or soon should have, in the case of *in situ* mooring measurements) most of the ice-atmosphere-ocean observations needed to document how the 2007 sea-ice minimum unfolded. It also was generally agreed that our investigations of summer 2007 based on observations and modeling are substantial, as evidenced by the number of papers on summer 2007 recently published, submitted, or in preparation. Our present understanding, however, is too incomplete and not sufficiently interdisciplinary to predict changes, let alone the response of the arctic system to those changes.

1. Gaps in Understanding Sea-ice Loss and Related Changes

The three working groups presented a number of gaps in understanding, which are listed in their respective summaries. In addition, the importance of improved understanding of the role of the ocean in sea-ice loss was discussed, e.g., the mechanisms through which warm Atlantic and Pacific water inflows into the Arctic may affect the sea ice, as well as the oceanic influence on the overlying atmospheric modes-of-variability in the Arctic. Another uncertainty is whether earlier analogs may be found in the 1920–1930's warming and modes-of-variability, including the linkages between sea ice and the Arctic Oscillation. There also was general agreement that the largest uncertainties may be in the nature and magnitude of the feedbacks and linkages between system components, including marine-terrestrial linkages. The need for more extensive datasets on marine and terrestrial ecosystem variables was stressed.

2. Integration Efforts to Improve Understanding and Prediction

The exchange of information across different disciplines and approaches that was made at the workshop appear to be successful in compelling new ideas and potential efforts for integration and collaboration—collaboration beyond the within-institution research papers on summer 2007 that have been produced thus far. Two near-term efforts for integration and synthesis that were proposed are (1) synthesis papers on summer 2007 that are inter-disciplinary and international, and (2) an international, collaborative, integrated outlook for the summer 2008 sea ice (Appendix B).

Summary of Working Group Discussions

Working Group 1: Documenting and Understanding Sea Ice Change

The central issue addressed was identifying the aspects of the summer 2007 sea-ice minimum that we do understand and the key remaining uncertainties, including those that are due to observational gaps.

Basic variables such as sea-ice extent and motion, surface air temperature (SAT), and wind fields are reasonably well observed or estimated for summer 2007 and over the preceding 2–3 decades. Important basic oceanic variables (e.g., heat fluxes) are being measured in part, although the time-series are shorter and measurement strategies are still being assessed. From these observations, the basic conceptual model to understand the summer 2007 event is to distinguish between two categories of processes: (1) long-term processes ("pre-conditioning") and (2) short-term processes (e.g., anomalies or weather events) that are responsible for the interannual variability, which are highly non-linear and can activate or "trigger" a number of positive feedback loops. In terms of pre-conditioning, the story of the summer 2007 event likely started much earlier, in that it was strongly and intrinsically connected to what happened during preceding years.

Long-term tropospheric warming, characterized mostly by reduced winter cooling and a longer melt season, is most probably related to global greenhouse-gas warming, which together with long-term atmospheric circulation and sea-ice motion patterns has reduced mean sea-ice thickness on the order of one meter compared with 20 years ago. Year-round *in situ* oceanic measurements suggest increases in the input of heat from the south, especially via Fram Strait and more recently via Bering Strait.

In the context of triggers, variability in the Arctic is capable of creating extreme events such as the 2007 summer sea ice minimum. The trigger for summer 2007 was very unusual high pressure over the Beaufort Sea, which provided strong southerly winds blowing from Bering Strait across the North Pole. Due to long-term weakening (thinning), the sea-ice pack is becoming more mobile and more vulnerable, such that the interannual variability has much more severe impacts (and vice versa). This connection between long-term and short-term processes also is due to positive feedbacks between the two types of variability—processes related to the long-term variability becoming more active, and short-term processes becoming more active due to the preconditions created by long-term variability.

Uncertainties and needs with regards to understanding the state of the atmosphere include: (1) improve understanding of (and possibly predict) the atmospheric circulation at the seasonal scale, in particular sea-level pressure (SLP) and SAT, which are critical in summertime; (2) improve understanding of SLP and SAT interactions, including the need to improve SAT observations; and (3) identify the ability of winds to break up the sea-ice cover, thereby enhancing penetration of incoming solar radiation into the ocean and leading to increased sea-ice melting; and (4) improve our knowledge of the various modes of atmospheric circulation and oscillations, including the sensitivity of the polar vortex to external influences (e.g., possible role of tropics and stratosphere).

Sea-ice understanding uncertainties and needs are related to both thermodynamics and dynamics, including: (1) how sea ice (frazil) forms in winter, rejects brines, and enhances the shallow cold halocline and the deep thermocline that protect sea ice from bottom melt during summer; (2) sea-ice drift, in particular in sea-ice source areas (e.g., Siberian shelves), sinks (e.g., Fram Strait), and regions with extensive rafting and ridging (north of Greenland and Canada); (3) the factors that led to the observed increase in sea-ice mobility, i.e., is it caused by sea-ice mechanics (rheology), sea-ice thinning, or something else?; and (4) distinguishing between specific age classes, in particular for multi-year ice (MYI).

Oceanic understanding uncertainties and needs relate to both required measurements and understanding processes, including: (1) interannual quantification of the oceanic heat fluxes into the Arctic from the Pacific and the Atlantic, (2) quantification of the processes by which this heat may influence the sea ice (e.g., by upward heat flux either by diffusive or eddy processes, or by mechanical, topography-related processes, (3) the pathways for oceanic heat within the Arctic Ocean, and (4) feedbacks between oceanic circulation and inflows and changes in sea-ice cover.

Working Group 2: Understanding and Predictability

The emphasis on predictability in this working group was on the seasonal time scale, particularly the upcoming summer 2008 melt season. The initial issue addressed by the working group was to identify the "targets" or components on which prediction should focus. Potential targets for prediction include: (1) geophysical parameters (ice extent, ice thickness/morphology, age distribution); (2) practical aspects of sea ice extent and dynamics (e.g., stability and hazards from perspectives of key user groups); and (3) specific regions to target for prediction (e.g., Arctic as a whole, Northern Sea Route/Northeast Passage, Northwest Passage, and the Chukchi and Beaufort Seas), as well the probability of a particular event. The following data and information was deemed necessary for prediction: (1) sea-ice state (ice extent, ice thickness/morphology, ice age); (2) atmospheric state (seasonal forecasts from NCEP/ECMWF, atmospheric patterns or modes-of-variability, clouds); and (3) ocean state (SST, heat content, heat transport, processes of heat exchange, halocline variability, mixed-layer depth, oceanic heat pathways). The stated approach is to combine observations and models and to include experience from past perspectives. The working group addressed predictability limits as related to gaps in our present understanding. These include questions on the precise roles of atmosphere–ocean–ice forcing or preconditioning as well as the response of the ice to changes in atmospheric and oceanic forcing. Another key question concerns ice recovery vs. "tipping points" (which need to be carefully defined); that is, how readily—and under what forcing conditions—can the ice recover from a dramatic or abrupt change such as summer 2007? Further questions include: When, where, and how is the ice–albedo feedback most/least effective? What controls the heat buildup in the upper ocean? What is the role of oceanic heat from subsurface layers? What are the effects of the "memory" of the ocean and ice and how can they be quantified? What elements of the system lead to events such as the record retreat in 2007 and to what extent are they predictable or random? Can an ENSO/hurricane-type regression method be developed for prediction? What can we learn from other efforts to predict? What are the dynamic feedbacks in the system and how do they act? What is the sea ice thickness in the region north of the Canadian Archipelago (this will require sea ice thickness surveys in spring 2008)? What is the relationship between ice age and thickness and what is the real ice age distribution in the Arctic?

Questions focused on predictability were discussed. There is agreement that the sea-ice cover has very strong interannual variability about a longer trend, with an approximately normal distribution of positive and negative ice anomalies (at least until 2007), implying equal probabilities of extremely heavy or light ice years. In the past, there is no year-to-year correlation apparent in ice extent; however, does this vary regionally, and has this changed with a thinner and dramatically less extensive ice pack? Are ice thickness and age perfectly correlated? If the answers to the previous questions are negative, then prediction needs to be prefaced by acknowledging that past evidence suggests limited predictability, but that extreme events such as that of 2007 may be associated with conditions that hold promise for empirical predictions.

The working group developed a process to address the issue of translating our understanding into predictability through a collaborative, integrated outlook for the summer 2008 season (see Appendix B: Proposed 2008 Sea Ice Outlook).

Working Group 3: Scientific, Policy, and Human Implications

The fundamental point of departure for identifying the science, policy, and human implications of faster-than-forecast changes can be found in the following statements posed by the Working Group: (1) results from the Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCC AR4, 2007) combined with the subsequent drastic ice reduction in 2007 provide confidence that arctic climate change is here—and even faster than the IPCC models have predicted; (2) the convergence of rapid climate-change events, socio-economic change, and political change has come to create a kind of "perfect storm," especially for Arctic Peoples; (3) change is so rapid that we need to know what the potential alternate ecosystem states might look like; and (4) the problem needs to be dealt with now on multiple levels, starting with the science that informs decision making and conducting research on components of the system that immediately impact people and with which people interact.

Two key aspects of general science questions were identified. First, assuming that arctic ecosystems will be replaced by subarctic ones, what does that mean specifically with respect to spatial distribution and temporal and seasonal variability? Second, can we predict the cumulative effects of ecosystem change, threshold events, and the ensuing feedbacks? For both questions, there are significant implications for policy and human systems.

Recommendations and Action Items

Short-term (12 months)

1. Develop and implement a process that tracks, summarizes, and integrates ongoing developments and provides a consensus outlook for May–September 2008 sea-ice extent and characteristics. Toward this goal, develop an organizational structure and process for collecting information, moderating, and issuing information on a monthly basis (See Appendix B, 2008 Arctic Sea Ice Outlook).

2. Summarize retrospectively the results of the 2008 Arctic Sea Ice Outlook. Who got it right and why?

3. Plan and hold follow-up workshops in fall 2008 after the upcoming field season and September 2008 ice minimum.

4. Develop and submit multi-authored synthesis papers targeted to high-impact journals—papers that integrate the impacts on the summer 2007 sea-ice retreat and linkages to multiple components of the arctic system and place the summer 2007 ice retreat in perspective given the eventual outcome of the summer 2008 ice retreat.

5. Develop a synthesis paper on existing ecosystem data, including paleo-records and more recent analogs that are useful for ecosystem reconstruction (beyond sediment cores and temperature reconstructions).

6. Synthesize existing ecological and human-dimensions information.

7. Identify other data sets needed to improve our understanding of potential changes within ecosystems and human systems (e.g., subsistence, tourism, resource extraction, fisheries, etc.) through a follow-up workshop.

8. Identify specific information gaps that are pertinent to science, policy, and human implications through a follow-up workshop (as above).

9. Undertake modeling efforts in order to explore possible scenarios given the state of our knowledge today, e.g., make preliminary projections for how arctic marine and terrestrial ecosystems might function in the immediate and distant future in order to inform management and policy. Build on ongoing modeling efforts through SEARCH and DAMOCLES (e.g., similar to modeling workshop held October 2007; workshop report at http://www.arcus.org/search/internationalsearch/meetings-and-activities.php).

10. Convene follow-up meetings to develop integration and modeling activities.

Long-term (2–5 years)

1. Continue observations (AON and other) and integrated analyses of the key parameters for documenting and understanding the sea-ice cover over the next several annual cycles.

2. Collect observations that are needed to assist in refining and validating scenarios.

3. Undertake data collection and research on the marine and terrestrial components for which there are major gaps in observations and understanding of change (e.g., including marine-terrestrial linkages) through research mechanisms such as a specific Announcement of Opportunity.

4. Undertake research activities using modeling together with other analytical methods to improve understanding and predictability on seasonal to interannual time scales.

5. Develop modeling efforts to explore possible scenarios for how the sea ice may retreat further on long time scales, and the consequent implications.

6. Look outside the Arctic for data relevant to understanding human implications.

7. Identify components of the arctic system that are more vulnerable to rapid change and the barriers to resilience and adaptation; this will involve research partnerships with local communities.

V. Workshop Series Summary and Conclusions

The Arctic Observations Integration workshop series achieved stated goals and resulted in vigorous and productive exchange on both organizational issues and scientific content. The international coordination was advanced but coordination efforts must be expanded to include other members of the international community active in arctic research. In this regard, as the International Study of Arctic Change (ISAC) develops, it may provide the mechanism to ensure continuity and expansion of international collaboration.

Three central themes of the meetings were:

1. Understanding the extraordinary seasonal retreat of sea ice observed in 2007,
2. Integrating different observation efforts into a system that increases our scientific understanding as well as serving broader society and key stakeholder groups, and
3. Identifying key scientific and programmatic gaps and next steps for observing, understanding, and responding to arctic environmental change.

Working groups and plenary discussions arrived at a number of promising approaches addressing these challenges using unifying questions (such as the evolution and aftermath of the 2007 record ice minimum) to advance integration of observing system activities. The scientific community and funding agencies clearly have a significant amount of work to do towards developing a sustained, advanced observing system capable of taking the “pulse” of the entire arctic system, while at the same time translating and disseminating information relevant to the scientific community and stakeholders. Workshop discussions identified many steps necessary to achieving this goal, including activities already in place, gaps and next steps, and processes for coordination and integration. The international arctic research community has a long history of successful scientific collaboration and exchange, which were well reflected in the outcomes of the meeting. The challenge now is to expand these efforts to arrive at an effective, integrated approach of observing, understanding, and responding to arctic environmental change.

Appendix A: Human Activities and Stakeholders Needs Matrix

Examples of completed Human Activities and Stakeholder Needs Matrix completed by several AON projects.

Human-Ecosystem Interactions	Terrestrial Permafrost		
Who are the stakeholders?	**Why do they care about [AON category]?**	**What do they need to know?**	**How can we provide it?**
Communities	subsistence - animal distribution		
	subsistence - hunters access		
	travel & safety		
	cultural value		
	infrastructure	Understanding changes in permafrost state	websites & outreach (K-12)
Fishing Industry (small local vs. big)	resource abundance and distribution		
	weather/safety/access		
	planning for the future/ investments		
	regulations		
	operating costs		
	infrastructure		
Oil and Gas	infrastructure	impact of warming permafrost on roads	reports (such as ISER report on infrastructure & climate change in AK)
	access window	reduced window of tundra access & travel	publications & joint projects
	development and operating costs		
	env hazards, risks		
Shipping	env hazards & risks		
	access window		
	infrastructure		
	operating costs		

Human-Ecosystem Interactions	Terrestrial Permafrost		
Who are the stakeholders?	**Why do they care about [AON category]?**	**What do they need to know?**	**How can we provide it?**
Tourism	marine access		
	intact cultures		
	pristine environments & wildlife		
Policy Makers & Regulators & Enforcement	manage resource efficiently for long term social value to multiple stakeholders		
Disaster Response	env hazards & risks data for planning	risk assessment & zoning	
	real-time information for response		
Broader Public Interests	climate change	rate of change of permafrost	outreach tools
	species diversity (charismatic megafauna)		
	romantic notions of wilderness		

Appendix A: Human Activities and Stakeholders Needs Matrix

Human-Ecosystem Interactions	Atmosphere (tropospheric-stratospheric coupling)		
Who are the stakeholders?	**Why do they care about [AON category]?**	**What do they need to know?**	**How can we provide it?**
Communities	subsistence - animal distribution		
	subsistence - hunters access		
	travel & safety	Weather forecasting	Contrib. to forecast fidelity through NWS & NASA
	cultural value		
	infrastructure		
Fishing Industry (small local vs big)	resource abundance and distribution		
	weather/safety/access	Weather forecasting	Contrib. to forecast fidelity through NWS & NASA
	planning for the future/ investments		
	regulations		
	operating costs		
	infrastructure		
Oil and Gas	infrastructure		
	access window		
	development and operating costs		
	env hazards, risks		
Shipping	env hazards & risks	Weather forecasting	Contrib. to forecast fidelity through NWS & NASA
	access window		
	infrastructure		
	operating costs		
Tourism	marine access		
	intact cultures		
	pristine environments & wildlife		

Human-Ecosystem Interactions	Atmosphere (tropospheric-stratospheric coupling)		
Who are the stakeholders?	**Why do they care about [AON category]?**	**What do they need to know?**	**How can we provide it?**
Policy Makers & Regulators & Enforcement	manage resource efficiently for long term social value to multiple stakeholders	need more real-time information and authroity to adjust regulations	
Disaster Response	env hazards & risks data for planning	Weather forecasting	Contrib. to forecast fidelity through NWS & NASA
	real-time information for response		
Broader Public Interests	climate change	Change in stratosphere (ozone layer) & climate change	Fingerprints & symptoms of climate change
	species diversity (charismatic megafauna)		
	romantic notions of wilderness		

Appendix A: Human Activities and Stakeholders Needs Matrix

Human-Ecosystem Interactions	Terrestrial Ecosystems		
Who are the stakeholders?	**Why do they care about [AON category]?**	**What do they need to know?**	**How can we provide it?**
Communities	subsistence - animal distribution	terrestrial plant availability & community change	
	subsistence - hunters access		
	travel & safety		
	cultural value		
	infrastructure		
Fishing Industry (small local vs big)	resource abundance and distribution	terrestrial plant communities affect runoff and DOC input	
	weather/safety/access		
	planning for the future/ investments		
	regulations		
	operating costs		
	infrastructure		
Oil and Gas	infrastructure		
	access window	terrestrial plant inter-action w/ snow cover, impact on tundra access	
	development and operating costs		
	env hazards, risks		
Shipping	env hazards & risks		
	access window		
	infrastructure		
	operating costs		
Tourism	marine access		
	intact cultures		
	pristine environments & wildlife	plant community changes & impact on wildlife use	

Human-Ecosystem Interactions	Terrestrial Ecosystems		
Who are the stakeholders?	**Why do they care about [AON category]?**	**What do they need to know?**	**How can we provide it?**
Policy Makers & Regulators & Enforcement	manage resource efficiently for long term social value to multiple stakeholders	changes in terrestrial plant communities impacting access & wildlife use	
Disaster Response	env hazards & risks data for planning		
	real-time information for response		
Broader Public Interests	climate change	plant community change impacts wildlife & land use	
	species diversity (charismatic megafauna)	plant community change impacts wildlife & land use	
	romantic notions of wilderness	plant community change impacts wildlife & land use	

Human-Ecosystem Interactions	Terrestrial Snowcover		
Who are the stakeholders?	**Why do they care about [AON category]?**	**What do they need to know?**	**How can we provide it?**
Communities	subsistence - animal distribution	snow impacts on grazing	SnowNet has expertise to provide maps etc., but not funded to do so
	subsistence - hunters access	over-snow travel conditions	SnowNet has expertise to provide maps etc., but not funded to do so
	travel & safety	over-snow travel conditions	SnowNet has expertise to provide maps etc., but not funded to do so
	cultural value	snow is central to travel and hence basic framework of society	
	infrastructure	snow control (snow fences, village design)	SnowNet has expertise to provide maps etc., but not funded to do so
Fishing Industry (small local vs big)	resource abundance and distribution		
	weather/safety/access		
	planning for the future/ investments		
	regulations		
	operating costs		
	infrastructure		
Oil and Gas	infrastructure	snow drifting & supply burial incurring snow removal costs	SnowNet has expertise to provide maps etc., but not funded to do so
	access window	oversnow travel for exploration	SnowNet has expertise to provide maps etc., but not funded to do so
	development and operating costs	reduced costs where snowroads feasible	SnowNet has expertise to provide maps etc., but not funded to do so
	env hazards, risks		

Human-Ecosystem Interactions	Terrestrial Snowcover		
Who are the stakeholders?	**Why do they care about [AON category]?**	**What do they need to know?**	**How can we provide it?**
Shipping	env hazards & risks		
	access window		
	infrastructure		
	operating costs		
Tourism	marine access		
	intact cultures	snow critical but somewhat intangible	
	pristine environments & wildlife	snowmobile trips for skiing etc.	
Policy Makers & Regulators & Enforcement	manage resource efficiently for long term social value to multiple stakeholders	critical component in considerations; current data base poor	
Disaster Response	env hazards & risks data for planning		
	real-time information for response	blowing snow	
Broader Public Interests	climate change		
	species diversity (charismatic megafauna)		
	romantic notions of wilderness		

Human-Ecosystem Interactions	Tidewater/Outlet Glaciers		
Who are the stakeholders?	**Why do they care about [AON category]?**	**What do they need to know?**	**How can we provide it?**
Communities	subsistence - animal distribution	Distribution & density of icebergs across (sub)Arctic	identify proc's controlling calving; develop predictive capability
	subsistence - hunters access	Distribution & density of icebergs across (sub)Arctic	identify proc's controlling calving; develop predictive capability
	travel & safety	Distribution & density of icebergs across (sub)Arctic	identify proc's controlling calving; develop predictive capability
	cultural value	Distribution & density of icebergs across (sub)Arctic	identify proc's controlling calving; develop predictive capability
	infrastructure		
Fishing Industry (small local vs big)	resource abundance and distribution	freshwater imports	identify proc's controlling calving; develop predictive capability
	weather/safety/access	iceberg density & distribution	identify proc's controlling calving; develop predictive capability
	planning for the future/ investments	new fjord area following retreat	identify proc's controlling calving; develop predictive capability
	regulations		
	operating costs		
	infrastructure		

Appendix A: Human Activities and Stakeholders Needs Matrix

Human-Ecosystem Interactions	Tidewater/Outlet Glaciers		
Who are the stakeholders?	**Why do they care about [AON category]?**	**What do they need to know?**	**How can we provide it?**
Oil and Gas	infrastructure	iceberg interference with shipping lanes	identify proc's controlling calving; develop predictive capability
	access window	periodic closure of shipping lanes (Prince William Sound)	identify proc's controlling calving; develop predictive capability
	development and operating costs	iceberg interference with shipping lanes	identify proc's controlling calving; develop predictive capability
	env hazards, risks		
Shipping	env hazards & risks	iceberg interference with shipping lanes	identify proc's controlling calving; develop predictive capability
	access window	periodic closure of shipping lanes (Prince William Sound)	identify proc's controlling calving; develop predictive capability
	infrastructure	iceberg interference with shipping lanes	identify proc's controlling calving; develop predictive capability
	operating costs		
Tourism	marine access		
	intact cultures		
	pristine environments & wildlife		
Policy Makers & Regulators & Enforcement	manage resource efficiently for long term social value to multiple stakeholders		
Disaster Response	env hazards & risks data for planning	iceberg interference with shipping lanes	identify proc's controlling calving; develop predictive capability
	real-time information for response	iceberg interference with shipping lanes	identify proc's controlling calving; develop predictive capability

Human-Ecosystem Interactions	Tidewater/Outlet Glaciers		
Who are the stakeholders?	**Why do they care about [AON category]?**	**What do they need to know?**	**How can we provide it?**
Broader Public Interests	climate change	Alaskan tidewater glaciers are major tourist draws	
	species diversity (charismatic megafauna)		
	romantic notions of wilderness	Alaskan tidewater glaciers are major tourist draws	

Appendix A: Human Activities and Stakeholders Needs Matrix

Human-Ecosystem Interactions	Sea Ice		
Who are the stakeholders?	**Why do they care about [AON category]?**	**What do they need to know?**	**How can we provide it?**
Communities	subsistence - animal distribution		
	subsistence - hunters access	***Persistence of ice during transition period for access to game animals***	***Remote sensing & local obs, trend analysis & model***
	travel & safety	***Shorefast ice stability and persistence***	***Remote sensing, mass-balance & tide gauge data***
	cultural value		
	infrastructure	***Sea-ice buffer during freeze-up; ice as geologic agent***	***Local obs; hi-res remote sensing; coastal radar***
Fishing Industry (small local vs big)	resource abundance and distribution weather/safety/access planning for the future/ investments regulations operating costs infrastructure	Persistence of ice during transition period & open water season	Remote sensing & coastal obs, trend analysis & model
Oil and Gas	infrastructure	***Shorefast ice stability and persistence***	***Remote sensing, mass-balance & tide gauge data***
	access window	Persistence of ice during transition period & open water season	Remote sensing & coastal obs, trend analysis & model
	development and operating costs		
	env hazards, risks	***multiyear & deep-draft ice presence***	***remote sensing; thickness surveys; buoy drift***

Human-Ecosystem Interactions	Sea Ice		
Who are the stakeholders?	**Why do they care about [AON category]?**	**What do they need to know?**	**How can we provide it?**
Shipping	env hazards & risks	multiyear & deep-draft ice presence	remote sensing; thickness surveys; buoy drift
	access window	Persistence of ice during transition period & open water season	Remote sensing & coastal obs, trend analysis & model
	infrastructure		
	operating costs		
Tourism	marine access	Persistence of ice during transition period & open water season	Remote sensing & coastal obs, trend analysis & model
	intact cultures		
	pristine environments & wildlife		
Policy Makers & Regulators & Enforcement	manage resource efficiently for long term social value to multiple stakeholders	***Ice regimes from perspective of access and hazards***	***Remote sensing & coastal obs, trend analysis & model***
Disaster Response	env hazards & risks data for planning	Climatology of ice conditions	Remote sensing, surveys
	real-time information for response	***Ice stability, motion, thickness***	***Remote sensing, coastal radar, realtime surveys***
Broader Public Interests	climate change		
	species diversity (charismatic megafauna)		
	romantic notions of wilderness		

"2008 Arctic Sea Ice Outlook" Overview
A Recommendation from the Arctic Observation Integration Workshops
17–20 March 2008, Palisades, NY
DRAFT

Background

The "Arctic Observation Integration Workshops," held 17–20 March in Palisades, NY, examined the series of events that led to the extraordinary arctic summer sea ice minimum in 2007 (see the workshop website at: http://www.arcus.org/search/Meetings/2008/aow/index.php). While a full understanding of this event requires further analysis of data from an international observing network and synthesis and modeling activities, workshop participants identified key aspects and components for understanding this event, as well as the response of other components of the arctic bio-geophysical and human systems.

One major workshop recommendation is to track and—to the extent possible—provide an integrated outlook and summary on the evolving 2008 summer season over the Arctic Ocean's ice pack. Heightened interest from the public, as well as within the arctic research community, suggests that an integrated monthly outlook based on coordinated tracking of the atmosphere, ice, ocean and other components of the arctic sea ice system will advance scientific integration and synthesis. Such an effort also would perform an important service by informing and engaging interested sectors of the public and the arctic stakeholder communities.

Description of the "2008 Arctic Sea Ice Outlook"

The "2008 Arctic Sea Ice Outlook" will provide a means for the international arctic research community to track, evaluate, and anticipate the evolution of the atmosphere–ice–ocean system from May through September 2008. This effort would create an instrument for synthesis of data from arctic observing systems and modeling efforts and provide insight into characteristics of the atmosphere–ice–ocean system. A final evaluation of the monthly outlooks after the summer melt-season will help guide future observations, modeling, and integration efforts. This effort is not a forecast or model-based prediction, but rather a coordinated, collaborative process to help the scientific community understand and anticipate complex phenomena in a method that can also serve the public and stakeholders.

Each monthly outlook would include a statement with a detailed explanation of observed and expected changes of the state of arctic sea ice. Regional information would be derived and/or compiled, as available, to provide perspectives at scales potentially relevant to stakeholders. The outlook would be distributed monthly and made available through a website through a number of international outlet centers. Workshop participants also proposed a meeting of all contributors for a retrospective analysis after the end of the summer season (perhaps defined by the seasonal ice-extent minimum); through this process we hope to improve understanding of variability and change in the arctic atmosphere–ice–ocean system on seasonal-to-decadal timescales. A draft template that would be used to solicit scientific input for the monthly outlook products can be found at the end of this section.

Organizational Structure and Process

The proposed organizational and governance structure would include a Core Integration Group (CIG, approximately six members) to integrate community input and produce draft outlook products as well as an end-of-season summary; an Advisory Group (AG, approximately 20 members) to ensure broad international input and review of products; and a Central Outlet (CO) to facilitate the distribution of final products through U.S. and international outlet centers.

Convening the Core Integration Group and Advisory Group

An open nomination process will solicit recommendations for the Core Integration Group (CIG) and the Advisory Group (AG) from the broad international arctic science community. Final appointments will be made in the form of a task force adopted by the SEARCH Science Steering Committee, in consultation with the Arctic Observation Integration Workshop Organizing Committee, ARCSS Committee, SEARCH for DAMOCLES (S4D) Steering Committee, and other relevant programs and agencies (e.g., the Pacific Arctic Group (PAG), Canadian ArcticNet program, etc.). The CIG and AG will be appointed to ensure diverse disciplinary, geographical, programmatic, and institutional participation. Support for activities will be explored through U.S. and international funding agencies as well as in-kind support from participating institutions. The Arctic Observation Integration Workshop co-chairs and SEARCH SSC chair have requested that the Central Outlet be housed at the current SEARCH Project Office, currently at the Arctic Research Consortium of the U.S. (ARCUS).

Soliciting Scientific Input for the "2008 Arctic Sea Ice Outlook"

Contributions to the "2008 Arctic Sea Ice Outlook" will be solicited from the broad scientific community and integrated on a monthly basis by the CIG, with review by the AG. Principal attention will be paid to ice extent, thickness, and other key characteristics relevant to stakeholder communities. Monthly release dates of the outlook products will be determined by the CIG and AG; the final product(s) will be disseminated by the Central Outlet in collaboration with relevant outlet centers.

"2008 Arctic Sea Ice Outlook" Product(s)

As this is an initial exploratory effort, the details of the type and scope of product(s) to be released will be determined by the CIG, AG, and CO as community scientific input is collected and synthesized. At a minimum, however, it is expected that a short document synthesizing the outlook of the seasonal evolution of the arctic sea ice cover will be produced monthly, with an online forum for community discussion. Additional components, tools, and products related to the "2008 Arctic Sea Ice Outlook" may be contributed by collaborating organizations and institutions, as appropriate. In addition, a final seasonal review will identify outcomes of the process and make recommendations to guide future arctic sea ice observations, modeling, and integration efforts.

Action Items and Next Steps

CIG = Core Integration Group

AG = Advisory Group

CO = Central Outlet

1. Arctic Observation Integration Workshop Organizing Committee invite nominations for the CIG and AG.
2. CIG and AG appointed and adopted as a task force by SEARCH Science Steering Committee, in consultation with Workshop Organizing Committee, ARCSS Committee, SEARCH for DAMOCLES (S4D) Steering Committee, and other relevant programs and agencies.
3. CIG and AG finalize the implementation plan for producing "2008 Arctic Sea Ice Outlook" products and associated tools, in consultation with international Outlet Centers.
4. CIG, AG, and CO, in consultation with Outlet Centers, prepare and distribute first call for scientific input to Outlook (see Appendix A for draft template form), and develop related tools for producing and distributing Outlook product(s), including a web-based interface to provide a forum for discussion as the season progresses.
5. First outlook summary prepared and released for late May 2008 through integration and review of broader input. Subsequent summary outlooks prepared and released on monthly basis.
6. After end of season, review and assess "2008 Arctic Sea Ice Outlook."

Draft Template for Soliciting Scientific Input to the "2008 Arctic Sea Ice Outlook"

Please keep submission to a maximum of 5 pages, including figures.

1. What will the sea ice extent be at the September 2008 minimum?

   a. What will the sea ice situation be in September for:

      i. Arctic as a whole
      ii. North Pole
      iii. Chukchi/Beaufort Sea
      iv. Barents Sea
      v. Northern Sea Route
      vi. Northwest Passage

   b. How will the sea ice situation evolve over the course of the summer (May–September) for:

      i. Bering/Chukchi/Beaufort Sea
      ii. Barents Sea
      iii. Northern Sea Route
      iv. Northwest Passage

2. On what information and data is your outlook based?

3. What information do you lack that might improve your outlook?

Arctic Observation Integration Workshops
17–20 March 2008
IBM Palisades Conference Center
Palisades, New York
Final Agenda

Monday, 17 March 2008

Continental breakfast available starting at 7:30 a.m. (Coffee Pavilion A390). Full breakfast available 6:30–8:30 a.m. (Hearth Dining Room) for participants staying at the IBM Center.

8:15 a.m. Introduction and Workshop Goals — *Hajo Eicken, University of Alaska Fairbanks*
Peter Schlosser, Lamont-Doherty Earth Observatory

8:30 a.m. AON Progress and Development, Brief SAON Update
Martin Jeffries, NSF AON Program Director

AON Project Presentations

10-minute talks, with time for questions and discussion after each group of projects (PIs with two projects are given additional time). Presenters are asked to limit the presentation to four (4) slides:

1) Title and Project Team Members
2) Project Status and Progress
3) Coordination and Integration Plans
4) Future Directions and Planning for the 2008 Season

Human Dimensions Project:

8:45 a.m. Is the Arctic Human Environment Moving to a New State?
Larry Hamilton, University of New Hampshire
Sharman Haley, University of Alaska Anchorage

8:55 a.m. Brief Discussion: Developing AON Human Dimensions research and coordinating networked observations

Atmosphere Projects:

9:05 a.m. Core Atmospheric Measurements at Summit, Greenland Environmental Observatory — *Joe McConnell, Desert Research Institute*

9:15 a.m. Pan-Arctic Studies of the Coupled Tropospheric, Stratospheric, and Mesospheric Circulation — *Richard Collins, University of Alaska Fairbanks*

9:25 a.m. Development of Data Products for the University of Wisconsin High Spectral Resolution Lidar — *Ed Eloranta, University of Wisconsin-Madison*

9:35 a.m. Cloud Properties Across the Arctic Basin from Surface and Satellite Measurements – An Existing Arctic Observing Network
Matthew Shupe, University of Colorado

9:45 a.m. Brief Discussion: Coordinating & Integrating Atmosphere Observations

Ocean and Sea Ice Projects:

10:00 a.m. The State of the Arctic Sea Ice Cover: An Integrated Seasonal Ice Zone Observing Network (SIZONET) *Hajo Eicken, University of Alaska Fairbanks*

10:10 a.m. Ice Mass Balance Buoy Network: Coordination with DAMOCLES
Don Perovich, CRREL

10:20 a.m. Design and Initialization of an Ice-Tethered Array Contributing to the Arctic Observing Network [and] Towards an Arctic Observing Network: An Array of Ice-Tethered Profilers to Sample the Upper Ocean Water Properties During the International Polar Year
John Toole, Woods Hole Oceanographic Institution

10:35 a.m. BREAK

10:50 a.m. Ocean-Ice Interaction Measurements Using Autonomous Ocean Flux Buoys in the Arctic Observing System [and] Toward Developing an Arctic Observing Network: An Array of Surface Buoys to Sample Turbulent Ocean Heat and Salt Fluxes During the IPY *Bill Shaw, Naval Postgraduate School*

11:05 a.m. The Collaborative O-Buoy Project: Deployment of a Network of Arctic Ocean Chemical Sensors for the IPY and Beyond *Don Perovich, CRREL*

11:15 a.m. Coordination, Data Management, and Enhancement of the International Arctic Buoy Programme (IABP) *Ignatius Rigor, University of Washington*

11:25 a.m. A Modular Approach to Building an Arctic Observing system for the IPY and Beyond in the Switchyard Region of the Arctic Ocean
Peter Schlosser, Lamont-Doherty Earth Observatory

11:35 a.m. The Beaufort Gyre System: The Flywheel of the Arctic
Andrey Proshutinsky, Woods Hole Oceanographic Institution

11:45 a.m. Observing the Dynamics of the Deepest Waters in the Arctic Ocean
Mary-Louise Timmermans, Woods Hole Oceanographic Institution

11:55 a.m. North Pole Station: A Distributed Long-Term Environmental Observatory (and) Aerial Hydrographic Surveys for IPY and Beyond: Tracking Change and Understanding Seasonal Variability
Jamie Morison, University of Washington

12:10 p.m. An Innovative Observational Network for Critical Arctic Gateways: Understanding Exchanges through Davis and Fram Straits
Craig Lee, University of Washington

12:20 p.m. Comparison of Water Properties and Flows in the U.S. and Russian Channels of the Bering Strait - 2005 to 2006 [and] The Pacific Gateway to the Arctic- Quantifying and Understanding Bering Strait Oceanic Fluxes
Rebecca Woodgate, University of Washington

12:35 p.m. Bering Sea Sub-Network: International Community-Based Observation Alliance for Arctic Observing Network (BSSN)
Victoria Gofman, Aleut International Association

12:45 p.m. Brief Discussion: Coordinating Ocean and Sea Ice Observations

1:00 p.m. LUNCH (Hearth Dining Room)

Hydrology/Cryosphere Projects:

2:00 p.m. Thermal State of Permafrost (TSP): The U.S. Contribution to the International Permafrost Observation Network [and] Development of a Network of Permafrost Observatories in North America and Russia: The US Contribution to the International Polar Year *Jerry Brown, International Permafrost Association*

2:15 p.m. A Prototype Network for Measuring Arctic Winter Precipitation and Snow Cover (Snow-Net) [and] Long-term Measurements and Observations for the International Arctic Research Community on the Kuparuk River Basin, Alaska
Matthew Sturm, CRREL

2:35 p.m. Arctic Great Rivers Observatory *Peter Raymond, Yale University*

2:45 p.m. Columbia Glacier Project *Tad Pfeffer, University of Colorado Boulder*

2:55 p.m. Brief Discussion: Coordinating Hydrology/Cryosphere Observations

Terrestrial Ecosystem Projects:

3:10 p.m. Study of Arctic Ecosystem Changes in the IPY using the International Tundra Experiment *Steve Oberbauer, Florida International University*

3:20 p.m. Carbon, Water, and Energy Balance of the Arctic Landscape at Flagship Observatories and in a PanArctic Network
Gus Shaver, Marine Biological Laboratory
Donie Bret-Harte, University of Alaska Fairbanks

3:30 p.m. Brief Discussion: Coordinating Terrestrial Ecosystem Observations

3:45 p.m. BREAK

Data Management and Coordination:

4:05 p.m. Exchange for Local Observations and Knowledge in the Arctic (ELOKA)
Mark Parsons, National Snow and Ice Data Center

4:15 p.m. Cooperative Arctic Data and Information Service (CADIS)

- Update on CADIS activities and portal development
- Issues on data sharing, collaboration, and integration

James Moore, NCAR Earth Observing Laboratory, and CADIS Team

5:15 p.m.	Review of discussions, plan for any evening working groups, goal for Tuesday
6:00 p.m.	DINNER (Hearth Dining Room)
7:00 p.m.	Working group(s) addressed topics identified during the day. Working group topics included: 1. Data management and integration 2. Observing system/network design, and coordination and integration through observations and modeling 3. Interactions between human activities and sea, land, ice, and atmosphere

Tuesday, 18 March 2008

8:30 a.m. Welcome, review of Monday's discussions, and goal for the day
Martin Jeffries, Hajo Eicken, Peter Schlosser

International Observing Programs and Efforts

8:35 a.m. International Study of Arctic Change (ISAC)
Maribeth Murray, University of Alaska Fairbanks

8:50 a.m. Developing Arctic Modeling and Observing Capabilities for Long-term Environmental Studies (DAMOCLES)
Jean-Claude Gascard, Université Pierre et Marie Curie

9:05 a.m. Nansen and Amundsen Basins Observational System (NABOS)
Igor Polyakov, International Arctic Research Center (IARC)

9:20 a.m. ArcticNet and Canadian Arctic Research Efforts
Martin Fortier, Université Laval

9:35 a.m. Japanese Arctic Research Efforts
Koji Shimada, Japan Agency for Marine-Earth Science and Technology

9:50 a.m. U.S. Agency Activities:
John Calder, Arctic Research Office, NOAA
Peter Murdoch, U.S. Geological Survey
Lee Koss, BLM-Alaska State Office
John Farrell, U.S. Arctic Research Commission
Dan Lubin, NSF Office of Polar Programs, Cyberinfrastructure Program Manager

10:20 a.m. BREAK

Integrating Multidisciplinary Observations in a Changing Arctic

10:40 a.m. Reports from Monday evening break-out groups (10-minute presentations):

- *Working Group 1:* AON as a "Collaboratory"; Use of cyberinfrastructure; Data Management; Communications and information dissemination
  Rapporteur: Jim Moore
- *Working Group 2:* Observing system/network design; Coordination/integration through observations and modeling
  Rapporteur: David Holland

- *Working Group 3:* Interactions between human activities and ice, ocean, atmosphere, and land *Rapporteur: Sharman Haley*

11:10 a.m. Discussions on next steps for developing an integrated multidisciplinary network out of individual projects and efforts:

- Gaps in meeting the scientific objectives for observing, understanding, and responding to change, and how they can be addressed
- Plans for integration and coordination among AON projects
- Plans and next steps for integration and coordination between AON and other national and international efforts
- Data coordination issues
- Specific needs given the rapid and unexpected changes in 2007
- Specific needs for the 2008 observing season and for the longer-term

12:00 p.m. LUNCH (Hearth Dining Room) (Chairs and Rapporteurs Meet for Lunch)

1:00 p.m. Conclusions, Recommendations, and Next Steps:
Martin Jeffries, Hajo Eicken, Peter Schlosser

- What are the priorities and next steps for meeting the observing, understanding, and responding to change scientific objectives?
- What are the priorities for integration and coordination among AON projects?
- What are the priorities for international integration and coordination?
- What are the achievable action items that can be accomplished in the next 12 months?
- What can AON produce as a lasting legacy of IPY?
- Workshop product/publication, timeline, and assignments

2:00 p.m. AON Meeting Adjourns

Concurrent Afternoon Sessions:

2:00 p.m. Lagrangian Platform Workshop begins (Room A350)

2:00 p.m. CADIS portal training for AON PIs (Room A230 on 2nd floor)

2:00 p.m. AON working groups, as needed (Rooms A360, B340, C370)

2:00 p.m. Introduction *Craig Lee, University of Washington*

- Welcome, agenda overview and workshop charge. Emphasize objectives, tasks and products.

2:10 p.m. Science Drivers and Fit within AON
Jean-Claude Gascard, Université Pierre et Marie Curie

(1) Autonomous and Lagrangian platforms in the context of AON. What science questions might these platforms contribute to, what critical measurements might they allow? How can they help measure change, and where do they fit within the existing suite of platforms and approaches (e.g. hydrography, moorings)?
(2) Science drivers/key measurements:
  (a) Surface albedo
  (b) Ice thickness distribution
  (c) Persistent (year-round, multi year), full-depth, extensive measurements of watermass variability. Quantify broad changes in heat and freshwater storage, vertical stratification.
  (d) Long-term characterization of watermass and velocity structure across key frontal regions, slope-shelf interfaces.

2:25 p.m. Current state of the technology (introduced and moderated by Lee)

(1) What's working today, and how is it used? What are the major technological and development hurdles?
(2) 5-minute summaries of state of play in:
  (a) Arctic buoy program - Rigor
  (b) ITPs (WHOI ITP and POPS) - Gascard/Toole
  (c) Floats (PPF and DAMOCLES) - Gascard/Toole
  (d) Gliders and AUVs - Lee
  (e) Navigation and communications - Lee

3:00 p.m. BREAK

3:15 p.m. Discussion (moderated by Lee and Gascard)
Try to touch on the following broad topics:

(1) How could these platforms be exploited to track, understand, and ultimately forecast arctic change? Are they appropriate tools for this task? How might they be employed? How will these platforms complement conventional approaches and technologies?
(2) How should these technologies be adapted in response to the changing Arctic? Specifically, how might these platforms and approaches be changed to compensate for and exploit changes in arctic ice cover?
(3) Identify technological challenges and development goals for enhancing the utility of autonomous Lagrangian platforms in the Arctic. Identify political and international coordination issues that will need to be addressed. How would the resulting systems fit within the larger scheme of arctic observing?

5:00 p.m.	Recommendations and Next Steps (moderated by Lee and Gascard) (1) What are immediate, mid- and long-term strategies to improve observational system design? (2) What specific efforts should be directed toward developing autonomous and Lagrangian systems and/or supporting technologies to provide long-term operation in the changing Arctic? (3) Discussion of workshop product(s), next steps, and writing assignments.
6:00 p.m.	Dinner (Hearth Dining Room) Organizing Committee meet for dinner together in the Hearth Dining Room
7:00 p.m.	Working group(s) as needed

Wednesday, 19 March

Continental breakfast available starting at 7:30 a.m each morning (Coffee Pavilion A390). Full breakfast available 6:30–8:30 a.m for participants staying at the venue (Hearth Dining Room).

8:30 a.m. Introduction, Background and Workshop Goals
Martin Miles, Environmental Systems Analysis Research Center (ESARC)
Jean-Claude Gascard, Université Pierre et Marie Curie

I. 2007 CHANGES IN COMPONENTS OF THE ARCTIC SYSTEM

Sea Ice Changes:

8:45 a.m. Sea-Ice Changes Observed in 2007/8 and Leading-up
Ignatius Rigor, University of Washington
Jean-Claude Gascard, Université Pierre et Marie Curie
Martin Miles, ESARC
Hajo Eicken, University of Alaska Fairbanks

Discussion

Atmospheric Changes:

9:30 a.m. Arctic Temperature and Modes-of-Variability *Jim Overland, NOAA PMEL*
Jean-Claude Gascard, Université Pierre et Marie Curie

Radiation and its Role in Sea-Ice Melt *Don Perovich, CRREL*

Discussion

10:30 a.m. BREAK

Ocean Changes:

11:00 a.m. Ocean Changes Observed in 2007 and Leading-up
Rebecca Woodgate, University of Washington
Jean-Claude Gascard, Université Pierre et Marie Curie
Igor Polyakov, International Arctic Research Center (IARC)
Koji Shimada, Japan Agency for Marine-Earth Science and Technology (JAMSTEC)

Discussion

12:00 p.m. LUNCH (Hearth Dining Room)

Terrestrial Ecosystem Changes:

1:00 p.m. Recent Changes in Circum-Arctic Vegetation: Greening of the Arctic
Skip Walker, University of Alaska Fairbanks

Marine and Terrestrial Changes – Other:

1:15 p.m. Recent Changes in the Greenland Ice Sheet
Mark Fahnestock, University of New Hampshire

Human System Changes:

1:30 p.m. Human Response to the Recent Sea-Ice and Climate-System Changes
Maribeth Murray, University of Alaska Fairbanks

Brief Discussion

II. SYNTHESIS OF 2007 ARCTIC-SYSTEM CHANGES:

1:45 p.m. Synthesis Overview
Martin Miles (ESARC)
Hajo Eicken, University of Alaska Fairbanks

2:00 p.m. Presentations and Discussion (Plenum, with break-out groups)
Cecilia Bitz, University of Washington
Frank Kauker, Ocean Atmosphere System
Ralf Döscher, Swedish Meterological and Hydrological Institute
Jinlun Zhang, University of Washington

Discussion

3:00 p.m. BREAK

3:30 p.m. Working Groups:

1. Through modeling and data analysis activities – including retrospective analyses of the long-term observational record – how well do we understand 2007? What are the gaps in observing and understanding sea-ice loss and related changes?
2. What do modeling and data analysis tell us about overall system behavior that is relevant for predicting sea ice – on seasonal to decadal time scales – and related arctic changes? How does the "tipping point" concept factor in?
3. What are the science / policy / human implications of the unexpected, faster- than-forecast changes? What does this mean for responding to change?

6:00 p.m. Dinner (Hearth Dining Room)

7:00 p.m. Working Groups Continue

Thursday, 20 March

III. LESSONS FROM 2007: GAPS & NEEDS FOR UNDERSTANDING ARCTIC CHANGE

8:30 a.m. Welcome, review of Wednesday discussions, and today's goal
Martin Miles (ESARC)
Jean-Claude Gascard, Université Pierre et Marie Curie

9:00 a.m. Working Group Reports

10:30 a.m. Conclusions, recommendations, and next steps:

- Given the unexpected changes witnessed in 2007, what are the priorities for observing, understanding, and responding to change activities?
- How should these priorities be addressed? What are the next steps?
- Discussion of workshop products (synthesis papers and other products), next steps, and writing assignments.

12:00 p.m. Workshop Series Conclusions and Recommendations: Summary of the week's discussions, achievements, and next steps

12:30 p.m. Workshop Series Adjourns

12:30 p.m. LUNCH (Hearth Dining Room) (Possible Organizing Committee Meeting)

1:30 p.m.–4:00 p.m. Meeting rooms available for continued working groups and other discussions

Appendix D: Workshop Series Participant List

* Organizing Committee Member
⊙ AON Investigator
✧ ARCSS / SASS Investigator
‡ DAMOCLES Investigator
✷ S4D Steering Group

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