ARCUS

ARCTIC RESEARCH CONSORTIUM OF THE UNITED STATES

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Parallel Session Summaries

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Parallel Session Summary

Terrestrial Arctic - Sessions I & II

Session Chairs: Elizabeth Hoy, Cathy Wilson, Ted Schuur

Overview. There were two sessions devoted to the terrestrial arctic, with 15 presentations given total. These presentations ranged from the study of hydrological issues along the Beaufort Sea to the carbon balance at Imnavait Creek Alaska, and offered the opportunity for diverse discussion during the period following the presentations. Below are summaries of the two sessions combined, organized around the questions provided by the organizing committee.

<u>Question 1:</u> What scientific or operational advances have been facilitated by the network(s) of Arctic observations?

Many of the presentations described the use of Arctic observation networks to facilitate and advance research in the Arctic. It was noted that scientific advances have been made in measuring and monitoring gas exchange and carbon flux in the Arctic through such networks as AmeriFlux and FluxNet. However, it was also discussed that these towers and networks can be sporadic throughout the Arctic and additional towers could increase the scientific and operational effectiveness of these networks. Three networks mentioned during the sessions have a focus on measuring and monitoring changes in arctic permafrost including the Permafrost Carbon Network, Global Terrestrial Network-Permafrost (GTN-P), and the Circumpolar Active Layer Monitoring (CALM) networks. The long-term measurements provided by some of these networks have aided scientists and decision makers in better understanding thaw depth, permafrost temperature, and other aspects of permafrost research. Additionally, advances have been made in measuring other long-term phenomena in the Arctic. Without the long-term measurements and data availability provided by Arctic networks, it would be difficult to study many Arctic phenomena, which can take years to properly document. Two examples discussed in the sessions included a) subsidence of the soil surface (as slumping is measured using long-term methods) and b) understanding Arctic phenology changes over time (the ITEX Network is one example of how these changes are being investigated).

While the discussion participants noted that Arctic networks are being used to make scientific advances, many advances are occurring on a fine to intermediate scale, and large scale measurements and inferences are more difficult to attain for Arctic regions due to the vast areas of the Arctic where no measurements are currently being made (or being contributed to observing networks). One way discussed for closing this informational gap is the use of satellite remote sensing across the Arctic, which has enable more long-term, and pan-Arctic, observations for this community.

<u>Question 2:</u> What opportunities exist to address new science questions, operational challenges, or questions of Arctic communities through enhanced collaboration and a robust interagency observing system?

The participants in the two terrestrial Arctic sessions discussed many opportunities to address new questions and challenges. As mentioned in Question 1 above, utilizing new satellite imagery as it becomes available, including high resolution (sub-meter) imagery, is one opportunity that the group discussed. Additionally, the opportunity to use existing measurements, and satellite imagery, to "scale up" results both spatially and temporally was mentioned by the group. Spatially, researchers thought new opportunities existed to move from site-specific phenomena to addressing changes across the pan-Arctic region, through the collection of measurements across sites with differing characteristics (discontinuous/continuous permafrost for example). During the discussion, others mentioned using a geographic framework for research – as current research can be limited to the geographic mandates of different agencies/projects. If researchers were able to utilize a more robust network, including new satellite imagery, it could allow for greater geographic coverage for research. Temporally, participants in the discussion noted that developing datasets with continuous measurements year round (and even having some measurements reported in real time) could offer a new opportunities. Additionally, incorporating paleocommunity data into current research networks was brought forward as a way to aid in both spatial and temporal scaling (the Arctic2K network for example). A new opportunity could also exist in using models (such as the earth system model) to scale up measurements. Researchers questioned whether there are currently enough flux towers located throughout the Arctic region to sufficiently scale measurements and suggested that new opportunities for research would be gained if additional flux towers were added to current networks to extend/expand the network of observations and fill in geographic gaps.

Another new opportunity for this research community exists in addressing terrestrial connections with other parts of the earth system (land-ocean, -aquatic, -coastal, -nearshore marine, -river, and -atmosphere). One example discussed in detail during the session was addressing connections between the land and nearshore marine/costal systems. This connection contains many human dimensions (including food web and local economic issues). Participants in the discussion noted that more research is needed to understand groundwater (and nutrient) flow into lagoons. Others discussed the need for more research to better understand small/intermediate rivers, river deltas, and estuaries. There has been focused research on larger rivers and the oceans in the Arctic region (such as the Yukon River), but more research could be done to understand small/intermediate rivers and coastal areas in the region. It was pointed out that small/intermediate rivers and coastal areas can be greatly impacted by climate change and environmental issues (such as oil spills). While more research in these regions is needed, the research in these areas can be difficult, as multi-discipline teams are often needed. Due to agency requirements, there is often one agency responsible for monitoring land areas, and another responsible for monitoring ocean areas, leaving the nearshore environment unstudied (or sparsely studied).

The discussion focused on a number of new science questions/issues that could be addressed by Arctic networks. One issue that was mentioned frequently was the importance of addressing trophic level interaction questions through better understanding Arctic communities, which rely on local resources (such as subsistence lifestyle issues). Other issues discussed included ensuring that networks are ready to measure extreme events (such as the flooding on the Sag River in Alaska, 2015) as they become more common in the Arctic, and the importance of being able to use natural experiments to investigate positive feedbacks in the region (such as experiments with permafrost and vegetation). One investigator encouraged terrestrial networks to be prepared to study even more unique issues, which are now emerging with climate change, such as the study of former land areas (including permafrost areas) which are now under water due to rising sea levels. Researchers discussed the importance of engaging other agencies/countries to further extend networks (Russia, Canada, others). It was noted that the GTN-P and CALM networks have had successes engaging with other countries (including Russia), and other networks should strive for the same level of engagement across multiple agencies and countries. Engaging the public and a diverse community of stakeholders in an understanding of Arctic issues emerged in both terrestrial sessions as an issue which networks should be prepared to address.

Finally, two additional research metadata issues emerged throughout the discussion: 1) developing observational and metadata standards for observing networks, and 2) utilizing advances in technology to better share data among groups. These two issues are essential to observing networks as they allow for coordination across groups studying the Arctic. The discussion participants discussed the use of observational networks and communities of practice to set standards for measurements, and the use of tools such as ARMAP, Imiq, Arctic Observing Viewer, and the work by ADiWIG to develop a metadata crosswalk as just some of the examples of potential methods of standardizing aspects of Arctic research. Some "best practices" were suggested to encourage better data sharing, such as encouraging data sharing soon after a dataset is gathered, and it was noted that data embargos can slow this process. Faster authorship and data archiving can allow for faster dissemination of results to the community. An aspirational goal for some in the discussion was to have a single data portal or a single set of metadata standards that are consistent across data portals.

Question 3: How have observing activities contributed to the science needs of mission agencies or stakeholders?

Overall, it was noted that a better understanding of the Arctic, including ecosystem drivers and processes, has aided many agencies. The discussion participants noted that terrestrial Arctic observing networks have been particularly successful in providing information on gas exchanges and fluxes (AmeriFlux and FluxNet), as well as permafrost/thermokarst information (CALM, GTN-P, Permafrost Carbon Network). Observing networks have also aided in the development of web resources, such as the AON-CADIS web portal, which is providing the opportunity for researchers to view the locations where others are working. Others noted that terrestrial networks have been used to address local issues, such as the spread of invasive species. The Arctic Council is developing a strategy for managing and preventing invasive species, and additional efforts have been made to understand and manage invasive species along the Dalton Highway and at Toolik Field Station. Networks are also working to be responsive to the needs of local residents, and this has aided agency efforts to meet the needs of local groups. Examples addressed by the discussion participants included 1) incorporating indigenous knowledge into long-term monitoring (this can lengthen the temporal scale of networks), 2) including local residents in the collection of measurements (this is a way to extend measurement collections throughout the year, resulting in a more robust networks with more complete datasets), and 3) considering alternate funding sources for Arctic research which includes a local component (the Canadian NSERC program funds a scientist residency for the north, and NSF allows for this type of research as well). It was noted that many of the observing activities which contribute to the science needs of mission agencies and stakeholders require stable and consistent funding, which can be difficult with grant funding, where funding support can change from year to year. Observing networks must strive to maintain funding and continue to address new opportunities for funding as they develop.

Parallel Session Summary

Arctic Atmosphere – Sessions I & II

Session Chairs: Matthew Shupe and Gijs de Boer
Rapporteurs: Lisa Sheffield Guy and Brit Myers

Overview. The two-part Arctic Atmosphere session had 15 presentations on a variety of topics. Part one consisted of presentations on clouds, radiation, and surface energy budget. Part two consisted of presentations on large-scale interactions, aerosols, gases, and isotopes. After each part of the session there was engaging discussion that aimed to cut across much of the presented material and place it in a broader context. Discussions were broadly organized around the three questions listed below. Narrative summaries of those discussions are provided below each question.

<u>Question 1:</u> What scientific or operational advances have been facilitated by the network(s) of Arctic observations?

The Arctic atmospheric observing network has been successful in covering a relatively wide range of locations that are, in principle, representative of much of the Arctic. These include inland terrestrial sites, mountainous sites, coastal sites, sites over ice-sheets, and some drifting measurements over the ocean/sea-ice. Year-round observations at Summit, Greenland were noted as a specific success due to their difficulty and expense, yet great value scientifically (away from coastlines, representative of ice sheet processes, high altitude, etc.). It was noted that not all sites are equally instrumented, such that the observing networks for different parameters are distinct. Moreover, many gaps exist for specific measurements (such as radiative fluxes over the Arctic Ocean) and it is not always clear how broadly representative individual measurements/sites are of regional or pan-Arctic processes.

Specific advantages to a network were identified. First, some network measurements, such as radiosondes, are assimilated into operational models and reanalysis products, providing a limited but crucial constraint on model performance in a data sparse region. Additionally, networks help to provide a generalization of knowledge for specific processes as they manifest in different locations, conditions, and/or times of year. This generalization is critical for development of understanding and model parameterizations (particularly for global models) and to provide a representative data set for model and reanalysis evaluation.

The discussion identified a number of specific thematic areas of success, or partial success:

- Trace gases. Using network measurements the community has developed a solid understanding of the sources, sinks, and seasonality of some trace gases (e.g., CO_2), which provides critical insight into the Arctic response and contributions to global change.
- Aerosol optical properties. The community has worked towards developing operational standards and techniques for analysis. There is still important work to be done in this regard, but past work has laid the groundwork for future progress in this direction.
- Clouds. Measurements from the modest network of cloud instrumentation, and periodic campaigns, has revealed important properties and processes of clouds. Specifically, it has been found there are some properties that are consistent across sites and various different moisture/energy/aerosol conditions. This suggests that some processes are inherent to the clouds themselves, facilitating their consistent representation in models. Yet the network approach also reveals that there is variability among sites related to large-scale influences. While there is still much work needed to understand the interplay of local-scale versus large-scale processes for clouds, and to represent these in models, the network provides a unique possibility to distinguish these effects.
- Cloud radiative effects. The network has allowed us to develop a generalized understanding of cloud radiative forcing and how it varies as a function of space, surface type, sun angle, etc. The network has also enabled an understanding of how cloud radiative effects are important, particularly in the spring, for pre-conditioning the sea-ice for seasonal melt cycles. Multi-site synthesis work is currently underway.
- Surface radiation and energy budgets. While this work has not yet come to fruition, much has been done to develop consistent data sets for surface energy budgets, and the numerous terms that comprise these, at a network of Arctic sites. In the near term, the community is poised to make significant progress in this direction. To do so will require addressing some important questions about the representativeness of individual sites, the impact of local and pan-Arctic heterogeneity, and how these are captured by the available measurements.

<u>Question 2:</u> What opportunities exist to address new science questions, operational challenges, or questions of Arctic communities through enhanced collaboration and a robust interagency observing system?

Numerous opportunities exist across the Arctic atmospheric observing community to clarify guiding science drivers, expand the impact of current observations, optimize the observing network for various scientific objectives, and set priorities.

The Arctic atmosphere community needs stronger guiding science questions

It was noted that successful networks are typically structured around captivating science questions. The general belief is that the atmospheric community could do a better job of formulating questions that have broad appeal and that can help to organize and coordinate the field. For example, the ice sheet community can simply point to "sea-level rise", or the permafrost community points to the potential rapid release of greenhouse gases. The atmosphere is potentially more challenging because the atmosphere interacts with most other sub-systems within the coupled climate system, its influence is wide-reaching and important for many broad science questions (i.e., the atmosphere is strongly influential on sea-level rise, but generally that question is not viewed as an atmospheric one). The opportunity exists for the atmospheric community to develop unifying, provocative, and broadly appealing science questions around which to organize observing networks. Proposed themes for such questions include: "Closing the Arctic energy budget," as this is broadly connected with Arctic change, large-scale linkages, and the global climate system; "Water" as all US agencies and many stakeholders care about water in its various forms; "Role of Arctic change on global weather"; etc.

Enhanced synthesis and knowledge dissemination are cost effective ways to increase impact

There are also great opportunities, at relatively modest expense, to better harness existing network measurements through more cross-cutting analysis, synthesis, and distribution. Again, it is important to keep science questions in mind as a framework for synthesis. Some specific focus areas in need of further synthesis included: CO_2 time series and analysis, Arctic surface energy budgets, water balance, the pan-Arctic radiation budget, constraints on large-scale Arctic circulation, etc. Synthetic efforts around these themes will likely produce results that will be of more use to the broader community. Additionally, it is important to communicate these results to stakeholders through public access, outreach, and data publishing (e.g., www.datacite.org).

To guide this synthesis it is important to consider various stakeholders. For example, the modeling community has specific needs in terms of data assimilation, process information, and model/reanalysis evaluation. The network approach, with its diversity of observations across the Arctic, is effective for serving all three of these primary needs. Reanalyses are a good case in point: they serve as an important backbone for Arctic research, often considered as truth for users of atmospheric information, but have key limitations and deficiencies that are crucial to understand and address using observations. Evaluation of reanalyses to ensure their robustness with representing the basic meteorological state is important. The model community needs clearer information and guidance on the use of network observations with regard to their consistency, uncertainties, and best estimates. Additionally, the model community requires some balance of long-term monitoring measurements with shorter-term, detailed process-level measurements. Facilitating better communication and cooperative research across the modeling and observing communities will help define observational and synthesis requirements and promote an enhanced exchange of knowledge via targeted synthesis products.

It is also important to consider how coordination across disciplines can facilitate synthesis that will be more effective for stakeholders. From an environmental systems perspective, the atmosphere interacts with many other sub-systems through a variety of "interfaces" and via coupled processes. Promoting collaboration across these interfaces (i.e., atmosphere-ice-ocean, atmosphere-land, etc.) will lead to enhanced knowledge with compounding impact. Similarly, there are important opportunities for cross-platform synthesis. Satellite measurements offer the unique potential for extensive, and sometimes pan-Arctic, coverage, but the information from these platforms must be guided by solid, well-defined measurements from the Arctic atmospheric observation network. The UV radiation community offers a nice example for synthesis of observations across ground and satellite systems.

One last point from the synthesis perspective: The community should embrace organizations that help to facilitate network science and synthesis. This embrace should occur both at the agency level, through explicit funding for such activities, and at the individual level, through engagement and collaboration. Numerous opportunities are presenting themselves through the IARPC collaboration teams, SEARCH focus teams, and IASOA working groups, among others.

Understanding and innovation can support a robust network to address evolving requirements

A final topic area that garnered much discussion is the concept of optimal network design, specifically evaluating the existing network and considering a robust network for the future. From the retrospective side, it is important to understand the current network and what it represents. For example, many atmospheric observatories are along coastlines and it is not clear what domain is represented by their measurements. Barrow is a major research hub, but can be influenced by terrestrial or marine environments depending on large-scale conditions and season. Moreover, it is uncertain if the existing network captures the true variability and diversity of conditions in the system. Short-term campaigns and large-scale model studies are two tools to help address this issue.

In looking forward there were a number of key questions related to network design that were discussed. It was noted that network design depends on many factors such as the driving science questions, the discipline of interest, the cross-cutting interactions in a system, and stakeholder needs. Specific to the atmosphere community represented here, there were some specific questions for which we did not have sufficient answers, yet need to be addressed in a concerted manner:

- How much information is enough at a given site and/or for a given parameter? This will depend on the nature of the measurement and its use by stakeholders. In some cases limited observation periods are sufficient for understanding a given process, while in others (especially in a changing system) longer term observations are required.
- How do we balance the need for longer time series at specific locations with the need for more observations at additional locations? How do we balance intensive/sophisticated/cutting-edge/expensive measurements (often for process understanding) against simpler distributed measurements over longer periods

(monitoring for change, model assimilation)? Moreover, which parameters are best suited for these different approaches? For example, downwelling longwave radiation is a data set the community felt was absolutely critical for long term understanding of the system as it is an integrator of many different processes.

- How are science questions/objectives prioritized against each other for use in optimal network design?

Building on these more conceptual questions, there were some clear discussions that outlined important gaps in the current network and potential opportunities for addressing them. From a constituent perspective there are critical gaps in: aerosol physical and chemical properties, aerosol spatial and vertical distributions, water isotope measurements, and cloud microphysics. For atmospheric measurements, a major spatial gap was identified over the Arctic Ocean where there are limited observations, and no existing network coverage, for surface radiation, turbulent heat fluxes, clouds, aerosols, and boundary layer structure. Lastly, a generic gap was identified for coupled system observations; supersites are typically defined along disciplinary lines and are not usually coordinated in location and/or design.

Regarding future network expansion, some key concepts were discussed. Networks should consider the model grid box perspective and attempt to represent spatial variability that must be represented by models. Additionally, standardization is needed to ensure the interoperability and intercomparability of network data.
It is important to consider cost-effective means for expanding the network and for obtaining the unique new measurements needed to address guiding science questions. Robust autonomous instruments must be better integrated into the Arctic atmospheric observing network. Due to a number of factors, the atmosphere community is generally lagging behind other communities with this type of development. The "O-buoy" network is an example of autonomous measurements for some gases from buoys. Beyond this, there are few success stories. Surface radiation measurements were identified as a major priority area in need of development, specifically with robust and efficient means for defrosting sensors to maintain high quality observations. While funding resources for the requisite engineering development are sparse, there remains a major opportunity for innovations that will support a potentially vastly expanded network with robust, efficient, autonomous atmospheric observations. The NOAA observatory in Barrow is considering development of an instrument testbed; this may facilitate future instrument development.

Unmanned aircraft systems (UAS) should also play an important and growing role in the Arctic atmospheric observing network. These systems offer the potential to address key gaps related to spatial heterogeneity, surface mapping, surface turbulent heat fluxes over unstable surfaces, aerosol profiles, and others. There exists a great opportunity to harness and coordinate the broad interest in UAS across many agencies and institutions. Additionally, UAS share the ability of satellites to provide measurements across several different components of the coupled Earth system, providing simultaneous observations of surface and overlying atmosphere, for example. Collaborative development and implementation in this realm will promote robustness, leverage resources, and open opportunities for innovation and access.

Lastly, the atmosphere community sees an opportunity to increase network coverage by instrumenting vessels and aircraft with semi-autonomous, robust measurements. For example, the US Coast Guard supports a variety of science missions in the Arctic, many of which are not focused on atmospheric systems. With relatively little impact, enhanced atmospheric measurements could be operationally obtained during these activities. Similarly, commercial aircraft conduct regular flights in and around the Arctic. Alaska Airlines was specifically mentioned as an example, due to the frequent tropospheric profiling that is completed by their aircraft as part of their routing flight operations along the North Slope of Alaska. There are likely additional opportunities in the private sector through cruise boat operators, other airlines, and more.

<u>Question 3:</u> How have observing activities contributed to the science needs of mission agencies or stakeholders?

The discussion on this topic started by acknowledging a basic, yet complicating, principle: Different agencies and observing activities have different stakeholders. There is no single stakeholder. Moreover, the diversity of stakeholder needs and agency priorities sometimes leads to a disjointed network with little standardization, coordination, or synthesis across the network. Stakeholders are more easily identified for mission agencies, while NSF's stakeholder is "the nation," which is broad and vague.

From the atmospheric community (and likely others), we can improve the effectiveness of the network for meeting stakeholder needs through enhanced efforts to package data, produce synthesis / best estimated products, and to communicate with user communities (as outlined above). Discussion highlighted a few areas that have worked or are working, including CO_2 long-term records, attempts to develop consistent radiation and/or energy budget products at multiple sites, etc. Often stakeholders are not present at science meetings, resulting in a disconnect between what is possible and what is needed. Acknowledging and addressing this disconnect will facilitate more effective transfer of knowledge. SEARCH was identified as an important synthesis effort in its ability to bring people together and represent a broad community. It has largely contributed to synthesis through "higher-level thinking," but has not necessarily resulted in making more effective network products for the atmosphere community. Nonetheless, SEARCH is a nice link to the stakeholder community that can support the needed dialog.

One primary point was raised that the important step of facilitating stakeholder use of scientific data and understanding through teaching and outreach is often de-emphasized or neglected. Individual scientists are not always well equipped with the skills or connections for effective outreach. SNAP, at the University of Alaska –

Fairbanks, was put forward as a good example of how this should work: It downscales data and provides simple explanations to the community on how to use it. As the atmospheric community, we need to increase our efforts to identify and reach out to stakeholders in both the public and private sector (i.e, insurance companies, etc.). Identification of stakeholders and development of communication strategies should be better built into the structure of science. Individual scientists should take it on themselves to better identify the users of their information and to reach out to them for better guidance. Additional investments in this area would be a cost effective way to enhance the impact of the observing network.

Parallel Session Summary

Community Based Monitoring

Session Chairs: Lillian Alessa and Sandy Starkweather
Rapporteur: Matthew Druckenmiller

Presentations included the following:

1. "An Interoperable System for Sharing the Results of Community Based Monitoring" by Peter Pulsifer (University of Colorado Boulder)
2. "Best Practices for Community-based Observing Networks and Systems (CBONS) – standards, quality assurance, protections and data interoperability" by Andrew" Kliskey (University of Idaho)
3. "Historical Ecology for Risk Management: Youth Sustainability for Coastal Observers of Barrow" by Anne Garland (Applied Research in Environmental Sciences Nonprofit, Inc.)
4. "Tracking the state and use of coastal ice in Alaska communities through collaborative observations" by Hajo Eicken (University of Alaska Fairbanks)
5. "Citizen Science at the North Pole: Tourists as a Data Resource" by Alex Cowan and Lauren Farmer (Poseidon Expeditions)

Question 1: What scientific or operational advances have been facilitated by the network(s) of Arctic observations?

Broadly, it was acknowledged that community-based systems are critical to the detection and observation of change in the Arctic and have the potential to play an important role in helping agencies to meet their missions. This includes defining indicators, understanding their relation with other factors (interoperability), devising responses to changing environments and critical events, and informing adaptation decision-making. A few examples that emerged from the session illustrated how community networks are extremely dynamic and can detect changes in anything from fish and animal populations to physical systems like sea ice and shoreline erosion.

A key scientific and operational advance that was identified is *context*. Community-based systems are critical to establishing the context of observations in a way that autonomous observational networks cannot, because of the ability to observe "co-identified" indicators within a coupled human-environment system (Kliskey et al.). The role of tools to support context was one subject of the talk from the Pulsifer et al. on ELOKA[1] where "interactive maps allow users to visualize geographic data while at the same time linking to associated multimedia that provides an extended view and understanding of space and place." While Eicken et al. illustrated a success of SIZONET[2] was using hybrid (geophysical & traditional) methods to track diverse changes to the sea ice. The traditional knowledge insights and subsequent indicators were developed over centuries of observing these systems in context.

During the discussions the idea of capacity building emerged as an important advance as well. The Bering Sea SubNet Program kept detailed metrics on their observers and where they go in terms of employment and degrees.

All talks to some degree discussed the issue of interoperability. Pulsifer et al. provided a few definitions some examples of advancements made on this front.

- Property of a product or system, whose interfaces are completely understood, to work with other products or systems, present or future, without any restricted access or implementation.
- Task of building coherent services for users when the individual components are technically different and managed by different organizations (Wikipedia)
- Semantic interoperability: the ability to effectively exchange meaning between information systems

While it was also acknowledged that advancement has been made in the interoperability of diverse community observing systems, there remain significant challenges. These are discussed further in the section question.

<u>Question 2:</u> What opportunities exist to address new science questions, operational challenges, or questions of Arctic communities through enhanced collaboration and a robust interagency observing system?

The concept of interoperability emerged as a key area for methodological progress in community observing. In this context, the idea of ***interfaces*** came up. Like context, interfaces speak to the ability to not just exchange numbers but to exchange meaning. While ontologies are often identified as an important part of this mapping, it was also acknowledged that they are time consuming to develop and maintain. A number of examples were provided where an interface might be machine to machine and based on well-defined standards, there is often a need for institutional or human interfaces as well. The extent to which social sciences (e.g. human ecology) can inform this work was an important point.

The human interface also brought the discussion towards issues of relationship building and trust. The use of traditional knowledge, in particular, but more

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[1] Exchange for Local Observations and Knowledge of the Arctic
[2] Seasonal Ice Zone Observing Network

generally any human shared observation requires high trust environments, fair compensation for knowledge (paying observers) and time. One contributing factor to trust that was discussed was the extent to which communities are legitimately involved in the problem framing to begin with.

One opportunity identified for moving community observing forward was through APECS and their desire to reach out to more indigenous youth in scientific partnerships. It was noted that APECS is moving into the domain of data management as well and these are very complementary domains.
Some tangible examples of agencies that are seeking greater involvement from community observers include the Park Service. There they are developing projects to train people in local response and response plan creation, which they are hoping this feeds into Arctic ERMA. Traditional knowledge is a big part of this. Further NOAA's Distributed Biological Observatory (DBO) is looking for ways to link with CBM activities, specifically at Point Hope and Barrow. They are interested in working with communities to find out what questions they have. For example, marine mammal or sea bird diet and body condition could be a topic for exchange with local communities. They can also work with local people to identify what washes up after storms and whether that matches what we're observing offshore through instrument based observing.

<u>Question 3:</u> How have observing activities contributed to the science needs of mission agencies or stakeholders?

A common thread among the presentations and the discussion concerned the power of community-based observing for early warning, hazard identification, ecosystem management, adaptation and resilience efforts. Many agencies (DHS, DOC, DOD, etc.) share a stake in these efforts.

For example, SIZONET worked "jointly with the Alaska Native Tribal Health Consortium and informed the development of a freeze-up observation protocol."

The work presented by Garland also underscored the importance of these systems for risk management. Further, it was noted the NOAA, with its mission for fisheries management can benefit extensively from these networks, but must consider how complex caveats about observations can be captured.

Representatives from NOAA National Weather Service wanted to better understand at an operational level how efforts like SIZONET might translate into improved forecasts. It was noted that in some cases, community members are already tracking their own information in databases like ELOKA. But it was emphasized that integration is still hampered by lack of communication between agencies and communities. There needs to be improved interfacing to integrate.

Parallel Session Summary

Marine Ecosystems

Session Chairs: Craig Lee and Jackie Grebmeier
Rapporteur: Lisa Sheffield Guy

Question 1: What scientific or operational advances have been facilitated by networks of Arctic observations?

The scientific community has made significant advances in Arctic marine ecosystem observations during the past decade. New platform and sensor technologies have given the community the ability to collect a limited suite of biological and biogeochemical measurements at similar spatial/temporal scope and resolution as the basic physical observations (e.g. temperature, salinity, velocity). This provides critical building blocks for the design and implementation of broad networks for sustained studies of marine ecosystems and facilitates multidisciplinary investigations of the mechanisms that govern ecosystem response to changes in the surrounding physical environment. Studies can thus more readily address linkages between physical, biological and human systems. Introduction of autonomous platforms and sensors has also highlighted the need to continued in situ observing. Although such efforts are more resource-intensive, they provide complementary data that are critical for the quantitative interpretation of autonomous measurements. Examples of research facilitated by Arctic observing efforts include investigations focused on how changes in sea ice and snow cover, and in upper ocean stratification, impact timing and magnitude or productivity in the Arctic Ocean, and on the Arctic's role in ocean acidification.

Adoption of network-oriented approaches to Arctic observing have been at least as important as the introduction of new technologies. The implementation of international distributed networks (e.g. the Distributed Biological Observatory) have facilitated broad, sustained data collection through thoughtful identification of science and observational priorities, community coordination and protocols that specify open data access. The Distributed Biological Observatory (DBO; http://www.arctic.noaa.gov/dbo/), specifies eight sites that serve as a change detection array and coordinates annual sampling through a variety of national and international efforts. This provides a successful model of international cooperation to sustain extensive, climate-scale observing. The networked nature of recent, sustained Arctic observing activities has also afforded opportunities to collect simultaneous biological and biogeochemical measurements across multiple regions within the Arctic, yielding insights that could not have been achieved by a collection of smaller, regional projects operating asynchronously.

Broad, open data access, supported by dedicated curation and dissemination/discovery efforts, represents a central pillar to network observing in the Arctic. Timely delivery and open access facilitates operational use of Arctic observing network data, such as incorporation into nowcast/forecast models. Open access also promotes broad use of Arctic observations that can lead to analyses and findings well beyond those originally anticipated. Open data access also forms a basis for broad coordination and collaboration, highlighting the benefits of contributing to the larger system.

<u>Question 2:</u> What opportunities exist to address new science questions, operational challenges, or questions of Arctic communities through enhanced collaboration and a robust interagency observing system?

The breakout group discussed new areas of research that might be able to leverage ongoing efforts to implement an Arctic observing system and the underlying technological advances. Identified topics included:

- Colony-based studies of seabirds
- Studies that intentionally exploit the capabilities of autonomous platforms and animal-borne sensors (e.g. tagged marine mammals) to study ecosystem response to a changing Arctic
- Implementation of a sustained, distributed network of autonomous profiling floats instrumented with physical, biological and biogeochemical sensors.
- Enhanced collaboration to improve predictions of subsistence animal phenology
- Cabled observatories
    - Pro – provides real-time time-series data
    - Con – ability to address high-priority science objectives, high cost and lack of flexibility

Several key suggestions were identified to improve the network of Arctic observing efforts in the future:

- Facilitate improved knowledge sharing between communities, scientists, managers, and decision makers
- Accelerate communication of observations and findings to better match the speed with which ecosystem and societal changes are occurring
- Improve engagement with modelers to improve pan-arctic analyses. United States-led Arctic observing efforts concentrate on the shelves, while European efforts tend toward basic ecosystem assessment in the basins. Numerical studies could help integrate these investigations.
- An opportunity to create space following AOOSM to allow more detailed discussions is important.
    - IARPC and meeting space at the Alaska Marine Science Symposium are both good options

Coordination of Arctic observing activities across US agencies was identified as a significant need. The Interagency Arctic Research Policy Committee (IARPC) has established a web-based platform for collaboration, with several teams formed around topics related to Arctic observing (http://www.iarpccollaborations.org). The teams provide a vehicle to promote coordination and collaboration between Arctic scientists of various backgrounds. (http://www.iarpccollaborations.org).

Shifts in industry needs, such as the cessation of Shell Oil's exploration efforts, can impact the underlying motivation for observing efforts. Although Shell's decision diminishes the immediate need for observations to support exploration and resource extraction, other compelling drivers for broad-scale ecosystem observations remain, including risk assessment for local communities that rely on subsistence hunting and the need to understand how the Arctic's role in the global carbon cycle might respond to climate change.

Question 3: How have observing activities contributed to the science needs of mission agencies or stakeholders?

Due to lack of time, the breakout group did not address this question.

Parallel Session Summary

The Fate of Sea Ice

Session Chairs: Ron Kwok and Axel Schweiger
Rapporteur: Alice Bradley

Overview. Arctic sea ice extent and thickness are declining, and the expectation that current trends will continue portends a future with larger expanses of open-ocean, longer durations of ice-free conditions, and a more accessible Arctic. However, our limited understanding of the coupled interactions among the sea ice, ocean, atmosphere, and land hinders our ability to predict the rate and magnitude of future change and its impact on physical, biological, and human systems. The need to understand, adapt to and take advantage of a changing sea ice cover places new demands on the research community and observational systems. Discussions were broadly organized around the three questions listed below. The answers point to the crucial need for long-term coordinated observation networks to address the needs of scientific understanding, short-term predictions, climate projections, planning and operations.

Question 1: What scientific or operational advances have been facilitated by the network(s) of Arctic observations?

While the observational systems of sea ice were not initially conceived as a coordinated network, these systems (supported by different agencies) have produced observations that have benefited the broader understanding of coupled Arctic ice/ocean/atmosphere interactions. The plenary talk and discussions highlighted a number of specific thematic areas/programs of success based on observations from instruments deployed on satellite, airborne, submarine and in situ platforms (this is not an all-inclusive list). Also, the sea-ice observation programs (examples below) would benefit from increased 'networking' even though a broad range of science investigations already benefit from their results.

- Satellite ice concentration and extent (since 1978). The multidecadal record of satellite observations has been the driver to better understand arctic climate and global change.
- International Arctic Buoy Programme (since 1978). The program maintained a network of drifting buoys to provide meteorological and oceanographic data for real-time operational requirements and research purposes (Sea level pressure; Surface air temperature; ice drift.). It has contributed to understanding of air temperature, changes in large-scale sea level pressure, and the spatial and temporal variability of ice drift.

- Maps of ice age (since 1985). The estimates from ice drift and ice concentration highlighted the large increase in the coverage of younger seasonal ice in the Arctic, and decrease in overall ice age within the basin.
- NSF AON: Sea ice deformation array provided time-varying strain rates at sub-daily time scales sufficient to resolve tidal and inertial effects.
- Ice Mass balance (IMBs) from buoys. IMBs are the only instruments capable of providing a time-series of surface and bottom melt – not available elsewhere. The contributions of the IMB observations in advancing the state of knowledge, as part of AON, have been clearly demonstrated over the last decade.
- Seasonal Ice Zone Observing Network (SIZONet): Coordinated airborne, field, under-ice surveys of the seasonal ice zone.
- NASA IceBridge Mission. The seasonal campaigns have documented seasonal and interannual changes in spring ice thickness and snow depth.
- ICESat /CryoSat-2 Satellite Missions. Basin-scale ice thickness and ice volume estimates are now available from satellite measurements on a monthly time scale.
- Submarine ice draft and thickness. The combined submarine ice draft and satellite data have documented the decrease in Arctic ice thickness since the 1950s.
- New satellite observations of dynamic topography that allow the estimation of time-variable geostrophic circulation in the Arctic Ocean.

<u>Question 2:</u> What opportunities exist to address new science questions, operational challenges, or questions of Arctic communities through enhanced collaboration and a robust interagency observing system?

Addressing the questions of Arctic sea ice changes and predictability depend on a robust program of well-planned and coordinated observations. Improving short- and long-term forecasts will require better models, with fully coupled ice-ocean-atmosphere processes that assimilate advanced observations and generate time-varying sea-ice concentration, thickness, and ice-edge location at high temporal and spatial resolution. Continuous or frequently repeated data collection will be needed, including broad surveys of ice conditions over the annual cycle to initialize forecasts. Furthermore, data – especially satellite data - should be returned in near real-time to support forecasting at shorter time scales and to verify sensor performance.

Significant key points for a robust interagency observing system: 1. Complementary platforms and field activities at different time and length scales (field programs, airborne and satellite remote sensing) are key to producing relevant basin-scale scientific results; 2. Development of programs for comprehensive process studies driven by well-posed scientific questions (e.g. ONR MIZ and Sea State DRIs). 3. Joint support of modeling efforts that address improvement in process understanding and impact on predictability. 4. Sharing of new observational capabilities for measurement of ice parameters.

Another broad opportunity, in addition to interagency activities, is the leveraging of international collaborations to advance our knowledge of the polar-regions. For example, organizations in the European Union, Canada, Japan, S. Korea and China are interested in the Arctic and collaborative programs that facilitate the exchanges of data and sharing of resources would benefit the international Arctic community.

Question 3: How have observing activities contributed to the science needs of mission agencies or stakeholders?

There is a distinction between mission driven agencies (e.g., NASA, NOAA, ONR, etc.) and NSF, which has a broader mandate to promote the progress of science. Thus the contributions to NSF needs are not as well defined even though observational networks implemented for understanding of changes in the Arctic require dedicated programs and long-term commitment of resources, and perhaps more difficult for NSF. But, long-term observations with well-defined objectives are required to document and understand the changes, and to improve operational planning on seasonal-to-decadal time scales.

An example of long-term observations is the record of ice extent acquired by the series of space-based radiometers that started with NASA's Nimbus-7 SMMR in 1979. The observations have been maintained by successive SSM/Is launched by the Defense Meteorological Satellite Program (DMSP). Without these assets, the time series for monitoring of the Arctic sea ice cover, used in a broad range of applications (from operational to scientific research), would not have been available - this includes the multi-decadal record of ice extent that has served to document the dramatic decline in the Arctic Ocean sea ice coverage.

Long-term coordinated observational networks are crucial for advancing our knowledge in the coming decades.

Parallel Session Summary

Ocean Circulation and Mixing

Session Chairs: An Nguyen and Laurie Padman

Question 1: What scientific or operational advances have been facilitated by the network(s) of Arctic observations?

The session was highly engaging for all scientists involved, including several who just arrived back from their latest expeditions and reported on the data just collected for current/last-year/accumulation of years. The presentations cover a wide range of observations and scientific goals aiming to address the processes governing the Arctic Ocean including circulation/budgets. By design, these observations are part of the Arctic-wide observing network. The advantage of this, and to address question (1), is that scientists can see how observations from upstream/downstream (spatial), earlier/later (temporal) time fit into what they observed/trying to study at their particular sites. Discussions on scientific connections naturally arisen as a result. These discussions led to questions as to why meetings such as these, pure discussion on science based on their collective results, to enhance collaboration, have not happened more frequently. A few examples of advancement that has been facilitated by the network include: understanding the time-scale and pathway of the general circulation of the Atlantic Water from upstream at the NSF-funded NABOS sites (A.Pnyushkov, UAF) and down-stream in the Canada Basin (R.Pickart, WHOI), connection between the inflow of Pacific Water upstream (R.Woodgate, UW) and downstream (R.Pickart WHOI, P.Stabeno), connection between wind-driven upwellings upstream (P.Stabeno) and downstream (R.Pickart, WHOI) and how that affect ocean mixing and circulation of Pacific-origin water in the Western Arctic. System-wide questions such as budgets / pathways / mixings were still unclear due to lack of (a) data and (b) time to discuss amongst scientists.

On this last point, questions raised by the group include the lack of transparency of what has been achieved so far using the network of observations including those presented in the session, e.g., have the achieved work been publicized well enough? Have we made any progress to constrain budgets in the Arctic using the available data? The consensus is “no”, and thus the relevant question is what other type/locations of observations are needed to answer these questions. Given the long time-series of observations at various Arctic gateways, have we improved our understanding on mean/variability or are the spatial and temporal coverages still inadequate? A special note was made that significant advancement has been made with new technology (e.g., ITP) in the Western

Arctic but sites such as along the Russian shelves we have not made a lot of progress due to lack of access / data.

<u>Question 3:</u> How have observing activities contributed to the science needs of mission agencies or stakeholders?

To this, the scientists were quite unclear. Most of the PIs are funded by NSF to address specific science questions in their particular studied area, with "promises" in their proposals to connect what they observed to the "implications" on the larger-scale Arctic-wide changes. We did not get far with this question (3) primarily because for the central Arctic with ice cover it is not of high priorities to many stakeholders.

<u>Question 2:</u> What opportunities exist to address new science questions, operational challenges, or questions of Arctic communities through enhanced collaboration and a robust interagency observing system?

In addition to private and federal funding agencies, potentially new opportunities include those by IARPC and the new NPRB program in the Chukchi Sea. The details for IARPC and NPRB are included at the end of this summary.

Related to the challenges involving "availability" of the network of data and what opportunities or lack thereof are available for addressing scientific questions and enhancing collaborations, some PIs noted that they are spending a significant amount of their time collecting and distributing the data and not having enough funding opportunity to analyze and understand the system-wide science questions. In addition, data from different projects can be scattered on both the projects' sites and/or the PIs' own sites as well as some scattered on repository (e.g., ICES). From the PIs' perspective, they know exactly where the data are and are puzzled by the "difficulty" the users were pointing out. From the users' point-of-views, the data are too scattered and efforts to gather and clean up are repeated by every user. In addition, the users do not know when a certain data set become available, and thus cannot take full advantage of the network. A suggestion is perhaps a repository (AON) with a "mailing-list" such as NSIDC where for example if a new dataset for sea-ice becomes available there is an announcement either on the site itself or via the mailing lists. The team analyzing CRYOSAT data for example has made announcement to the CRYOLISTS mailing list advertising and calling for users to evaluate and use data for scientific research. Perhaps this can also be done with AON data sets to facilitate usage.

The group questioned whether an available observing network where any person can come and download the data without intimate knowledge of the details of data quality will be the best way forward. Perhaps it should be that the PIs who collected the data should also benefit. A related question is whether AON is not taking advantage of the vast knowledge of the PIs by not allowing room for "scientific research" questions to be addressed as part of the proposal. Given the funding involved in the field works, a fraction dedicated to scientific investigation is miniscule but can have much higher potential return than a completely separate and time-consuming proposal written by the PIs / anyone to a separate program. Perhaps one possible way forward, and to include young / early career scientists, is to hold meetings such as this to allow one-on-one exchange of ideas / knowledge / strategy and facilitate collaborations and joint-writing proposals. It should be noted however that young scientists have limited resources to attend such meetings (and thus web based resources are preferred.)

Lastly, the community questioned whether they are doing themselves a dis-service via the proposal reviewing system. The once per year opportunity is too limited and collaborative efforts, especially those involving system-wide synthesis of data and/or models, can be difficult to get through the reviewing process. This essentially short-change our own community's advancement in exploring new ideas / approaches because they can be deemed too "risky".

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1. IARPC Collaboration Teams
    - 12 Teams total, IARPC will meet in December to refine structure. Consider participating in monthly IARPC calls
    - Agencies participate in these calls and are looking for opportunities – encourage presentations by scientists to share work
    - Maybe IARPC needs to seek out participants more actively – or maybe not
    - Encourage all to visit the IARPC website, join relevant CTs
2. New NPRB program in Chukchi Sea
    - All PIs will meet and share science during 5 year study to get ecosystem picture. Interested in outside participants (if you can support your travel). Contact Danielle Dickson for more information.

Parallel Session Summary

Robust Autonomous Arctic Observations – Successes and Challenges

Session Chairs: Craig Lee and Ron Kwok

Overview. The technological focus of this topic led the breakout group to an alternative to the original three-question structure.

Successes

- Many of the autonomous technologies that revolutionized observing at lower latitude have been adapted for Arctic observing. Development of the underlying technologies typically required years to more that a decade of support, often from multiple agencies. Adaptation for Arctic use required shared risk-taking by researchers and agencies, and additional years of development and testing. Examples of successful transitions include Ice Tethered Profilers (ITPs), a variety of ice-tethered instruments; novel moored instruments for sampling near the ice-ocean interface and acoustically navigated Seagliders. These developments have been employed to augment many components of the Arctic observing network.
- The Arctic science community has worked to share knowledge and technological developments. ITPs have been deployed for a wide range of programs, mooring technologies are widely shared and sea ice researchers share expertise in the development of a ice mass balance buoys.
- Coordinated deployment of clusters of ice-tethered platforms has become common. Multiple instruments with complementary capabilities are deployed together to provide a more comprehensive picture of atmosphere, ice and ocean.
- The dramatic increase in autonomous platform deployments has yielded large gains in both temporal and spatial data density, as well as improved coverage across the Arctic. These data have been exploited to seek new understanding, such as investigations of seasonality and freshwater storage and release.
- Rapid data release with open access has enabled the use of Arctic observations and data products by a wide range of stakeholders, including climate researchers, policy makers and Arctic residents. Provision of real time data also allows ingest into models to generate nowcasts and forecasts.
- International collaboration is an essential component of an Arctic observing system. Programs such as the Nansen and Amundsen Basin and Canadian Basin Observational Systems demonstrate the benefits of such collaboration.

Challenges

- Develop more efficient approaches for deploying clusters of ice-based instruments.
- Accelerate adaptation and adoption of unmanned aerial vehicles for ship-based sampling and for long-term measurements of surface fluxes.
- Autonomous sensors, especially those for biological and biogeochemical properties, can provide only a fraction of the desired variables. In situ sampling using ships and aircraft thus remain a critical component of the observing system. These capabilities must be maintained.
- Sensors for atmospheric variables that are capable of long-term, untended operation in the Arctic.
- Measurement of trace gas fluxes.
- Upscaling (temporal and spatial) of sparse observations.
- Access to vessels capable of working in sea ice.
- Scientific cooperation to provide access within national EEZ boundaries.

Parallel Session Summary

Human Dimensions of the Arctic

Session Chairs: Mia Bennett and David Payer

Overview. The Human Dimensions in the Arctic session had seven presentations on a wide range of topics, including demographics and climate, management of Arctic data, social indicators, Russian Arctic communities in transition, paleo-archaeology, and maps. Each presentation was followed by a brief Q&A and discussion, while a more overarching discussion occurred after all seven presenters had spoken. The session chairs attempted to structure the discussions around the three questions provided by AOOSM organizers, but the questions were not always conducive to discussing advances in the social sciences and human-related issues in the Arctic. Still, in keeping with the organizers' intent, a summary of our wide-ranging conversation is divided accordingly.

Question 1: What scientific or operational advances have been facilitated by the network(s) of Arctic observations?

Participants questioned whether a functional observation network currently exists in the Arctic social sciences, and further wondered whether such a network was even possible. The Marine Science Network was given as an example of a scientific research network, but nobody could identify an equivalent network for social scientists – only specific projects such as the Arctic Social Indicators Project (discussed further below). One researcher commented that networked social science data are complex, and stressed the concept that "Knowledge Lives in Places". Since so much of these data are place-specific, creating networks may be good for comparing and contrasting metadata, but networks of observations are not necessarily as insightful as they might be in the biophysical sciences. Participants cautioned that generalizing inferences derived from location-specific data may lead to fallacious conclusions.

Another participant emphasized that membership in networks is not the ultimate goal; rather, the network itself has to have an end purpose. That purpose can be better refined and targeted by involving indigenous peoples in research networks. Discussants noted that many research efforts are overly academic and detached from the communities they are studying. This underscores the need to examine existing research interfaces and do a better job of bringing indigenous peoples into the conversation in a systematic, universal way. Through these more integrated research networks, researchers can work directly with members of indigenous communities to select monitoring targets.

Direct involvement of indigenous peoples in observing networks should not be limited to the communities in which they reside. As an example, one presenter discussed a meeting at the National Snow and Ice Data Center in Boulder, Colorado where attendees included 15 indigenous people. This was an important achievement because even though indigenous peoples often desire to get involved and assist with monitoring in Northern communities, they typically have limited capacity to participate in meetings held outside their communities. The researcher stated, "We need the people who define the North to be defining the networks and have research be generated by the people living up there. We're still largely looking at the region from the outside." Cooperation with indigenous peoples and local residents in the North can help foster Arctic observing networks in the social sciences that are less top-down, and that examine the region from within rather than from outside.

In recent years, headway has been made in building networks that include Arctic indigenous people, which in turn has facilitated science and operations in the region. Additionally, research protocols are now coming from various indigenous groups. For instance, the Inuit Circumpolar Council (ICC) has been providing more input, helping to define science objectives that better meet the needs of local residents in the Arctic. One example was raised concerning the ICC's forthcoming publication on food security, which was only written after ICC members visited Inuit communities. Scientists working alone could not have accomplished this work; the involvement of the ICC with their local knowledge and community connections was crucial to the project's success.

Question 2: What opportunities exist to address new science questions, operational challenges, or questions of Arctic communities through enhanced collaboration and a robust interagency observing system?

Our discussion focused on enhancing collaboration in Arctic observing systems between scientists and local communities rather than between agencies and/or scientists. Several experienced researchers emphasized that longstanding engagement and collaboration with Arctic communities is important so that research questions can be appropriately framed. Relationships need to be established and maintained over time to successfully perform research in Arctic communities. As one researcher emphasized, "The key is to shape questions together with Arctic people so that they understand why it's important and why we're doing the research we're doing." This is particularly relevant to research that focuses on sensitive topics such as substance abuse, suicide and loss of cultural identity. Shaping questions together, building mutual trust, and identifying gaps and needs allows the foundation of community-driven, participatory research. Although the task is difficult, it is not impossible, and it was repeatedly emphasized that it is necessary. Researchers can take advantage of existing regional networks, such as within the Northwest Arctic Borough, to help them in this endeavor.

In addition to formulating the research topic to be locally meaningful, researchers should be aware of local perceptions of them as scientists. They should also be attuned to the problem of "burnout" among the Arctic peoples and communities they are studying. Several participants mentioned that researchers put sizeable demands on Arctic people's time. There is consequently a real need for scientists to become economical in the contacts they make with indigenous peoples for data-collection purposes. This can be achieved partly through networking, which allows researchers to become more efficient in the demands they are making of people.

The flip side of the problem of researchers placing high demands on their subjects' time is that investigators often spend only limited time in their communities. This can create feelings of resentment among local people. To avoid this situation, reiterating the notion that Arctic researchers need to strengthen ties with Arctic peoples, researchers need to become trusted members of the community rather than fly-in, fly-out scientists who exacerbate the problems associated with studying the Arctic from the outside. Moreover, it was emphasized that if financially feasible, living in the Arctic as a researcher allows you to do things that you couldn't do otherwise and gain a deeper sense of understanding of social issues in the region that only come with time. Of course, the current funding structure for social sciences is not always amenable to long-term stays in communities of interest, a problem that must be remedied at the level of the funding agency. Scientists can possibly work around this by including long-term stays in their grant proposals.

Greater efforts should also be made to report results of studies back to communities, in a manner that is respectful and accessible. "Closing the loop" in this manner is essential for conducting long-term observing in the social sciences.

One researcher mentioned that funding for social-sciences research may be easier to obtain in Europe, suggesting that North American scientists could benefit from enhanced collaboration with European institutes, thereby inserting themselves into European research networks to access more resources to study Arctic communities and social-science issues.

<u>Question 3:</u> How have observing activities contributed to the science needs of mission agencies or stakeholders?

Participants discussed the Arctic Social Indicators Project (ASIP), which is part of the Arctic Human Development Project. ASIP attempted to identify measurable indicators of human well being and determined that economic well-being, health, and population were relatively easy to measure. In contrast, levels of self-determination (for indigenous peoples), language, and ties to nature were more difficult.

Several recent projects have examined archaeological records and cultural heritage together. During this session, two of the seven presentations focused on this topic. The presenters demonstrated that it is possible to involve communities and stakeholders so that both scientists and locals are engaged in, and enthusiastic about, the preservation taking place. In the North Slope Borough, for instance, this type of research helped create positive change by getting an oil and gas company's risk assessment to include the recognition that the culture was at risk due to eroding shorelines and the potential loss of archaeological heritage embedded within. Communities are not always enthusiastic about observing and/or research projects occurring in their area, however; for instance, carrying out genetic studies on archaeological finds can be very controversial. In contrast, many Arctic residents are more accepting of modern genetic work.

More work is needed on methodologies underpinning social science observing activities in the Arctic so that they can better meet the science needs of both mission agencies and stakeholders. Data collection in the Arctic is often difficult because of obvious factors such as the harsh climate and high costs. Less obvious problems also create challenges, however. For instance, much social sciences work relies on telephone surveys, but residents in the North are more likely to be difficult to reach by land-line telephone, and the area codes for the more commonly used cellular phones are not necessarily tied to geographical location. This exemplifies how the Arctic is "kind of a blank map" with regards to social science methods commonly used elsewhere.

Parallel Session Summary

Application of High Latitude Observations and Experiments in Regional to Global Climate Modeling

Session Chairs: An Nguyen and Cathy Wilson

Overview. The presentations in this session covered a wide range of efforts including terrestrial, atmospheric, and oceanic and sea ice modeling. A few of modeling efforts were still in early stages of development and do not yet have available measurements for validation. A couple of presentations demonstrated how independent efforts using complimentary data sets and validations have helped improving the quality of models (e.g., modeling effort to validate atmospheric data sets help constraining inputs to ocean and sea ice models). Below is a summary of the discussion within the group to address the following three key questions.

<u>Question 1:</u> What scientific or operational advances have been facilitated by networks of Arctic observations?

As highlighted by one of the talks, the network has enabled the modeling community to use data both in real-time (e.g., satellite-derived sea ice observations) and post-processing to validate the models. Data alone are too sparse both in time and space to build a coherent dynamically evolving state in the Arctic and thus models are needed. However models are not useful if they cannot be validated. On this point, the group noted that improved data accessibility and distribution is still needed for the community. One possible way to do so is to have a centralized repository with announcement of when the data have been submitted / become available. This could be via subscription (e.g., to the CRYOLIST or AON mailing list, or via NSIDC).

<u>Question 2:</u> What opportunities exist to address new science questions, operational challenges, or questions of Arctic communities through enhanced collaboration and a robust interagency observing system?

Currently there exists opportunity through private and public funding agencies to incorporate observations to improve/understand model strengths and weaknesses. Depending on the agencies' targets the opportunities vary ranging from real time prediction applications to understanding climate dynamics. Challenges identified by the participants include mistrusts between the modeling and observing communities, lack of communication, lack of platform/meetings to bring the two communities together. The idea of improving the development for a “network of people” in addition to developing the network(s) of data was brought up.

On the point of enhancing “a robust interagency observing system”, the group thought there is a need to bring in agency representatives and other science community members to discuss innovative ways we can use existing data.

A significant challenge to the community is the quantification of the uncertainties associated with both the observations and model representations. Without a concerted effort to understand how certain we are regarding what we observe / model, the arguments / mistrusts can widen the gaps both in communication between the communities and lack of understanding of the dynamical processes governing the Arctic system. Related to this point, any set of observations can be useful as long as we understand its limitation, thus limiting the perceived potential issue of having “too much data”. Lastly, it was noted that many of the “products” such as satellite-derived quantities or atmospheric reanalyses should be treated with care and understanding of their uncertainties.

While formal quantification of uncertainties can potentially be beyond our current capability due to lack of data coverage and understanding of the processes governing the noise/signals, the group suggested that a development of a user forum to discuss product uncertainty may be useful to the science community. Some modeling groups are also currently actively pursuing both formal and other methods to quantify uncertainties, e.g., CCSM has paid support staff to provide answers to questions from data users, ECCO has extensive experience quantifying satellite and in-situ observations in their data/model inversion efforts.

Regarding the challenges accessing the data sets by general users, suggestions include the development of data services that would allow user to identify and select possible sets (some of these do exists but are quite scattered, e.g., WOCE, ICES, PANGEA, NSIDC, AON). In addition, with the development of Google applications, there might be an opportunity for the Arctic science community to work with Google to develop an integrated Arctic database and repository and/or taking advantage of EarthCube.

On the modeling side, challenges facing the modeling community include misrepresentation of processes due to lack of understanding of physics, lack of observations, and scaling issues. Examples of misrepresentations include atmospheric lower boundaries, ocean sediment diffusion, oceanic diffusion, sea ice physics. Examples of scaling issues (both temporal and spatial) include bridging the gaps of exchange between coarse-resolution global and fine-resolution regional models to cover the range across the complex Arctic systems. These challenges limit the model’s current capability in “predicting” both in real-time and hind-/fore-casts.

On the last note, the group suggested the need to develop a “wants & needs” list by the Arctic modeling community to identify and target data gaps and to identify new problems and questions that we can tackle collectively as a community.

Question 3: How have observing activities contributed to the science needs of mission agencies or stakeholders?

The group identified the need for real-time or short-term model forecasting and to provide predictions to stakeholders. However for scientific research questions, the group was uncertain as to what stakeholders need from the science/model community.

Parallel Session Summary

Ice Sheets and Glaciers

Session Chairs: Leigh Stearns and Mark Fahnestock

Overview. Arctic glaciers and ice sheets have undergone large changes in the past decades, doubling their contribution to sea level rise. However, high-resolution and long-term observation networks are needed in order to understand the physical processes driving these changes. In particular, large questions remain concerning the interaction between atmosphere-ice sheet, and ocean-ice sheet processes. Observing platforms that can measure ice dynamics and the evolution of subglacial discharge or fjord circulation will help address these uncertainties. The glaciology community has very few long-term observing networks, yet there is a great need for ground-based measurements that operate in concert with remote sensing and airborne campaigns.

Because the glaciology community does not have a strong presence in the current AON framework, we found it hard to address the specific questions outlined for each session.

1) *What scientific or operational advances have been facilitated by the network(s) of Arctic observations?*
2) *What opportunities exist to address new science questions, operational challenges, or questions of Arctic communities through enhanced collaboration and a robust interagency observing system?*
3) *How have observing activities contributed to the science needs of mission agencies or stakeholders?*

Instead, our discussion revolved around these alternate questions.

Question 1: What are the advantages of having a network as opposed to smaller projects?

Since ground-based monitoring of ice sheet and glacier dynamics is fairly scarce, collaboration and data sharing tend to be strong. However, it is difficult to compare observations from different glaciers/time periods/scales of measurements because each glacier is unique, even over short time periods. A network of observations allows for a direct comparison between different processes occurring coincidentally. Networks allow for interdisciplinary observations that are often not feasible in single PI grants.

One additional limiting factor in modeling and understanding glacier change that can benefit from shared measurement campaigns is improved knowledge of outlet glacier bed geometry and fjord bathymetry. For many glacier systems in Greenland, Arctic Canada, and Alaska, the bed is poorly known, fundamentally limiting efforts to model evolving flow.

Question 2: What opportunities exist to address new science questions?
Our group was most excited about developing observational networks to address two main science questions: "What is the freshwater budget of ice sheets (Can we close the freshwater budget?)" and "How does water move from the ice sheet to the open ocean"? These are two fundamental glaciology questions that are difficult to address without an interdisciplinary network of observations. These questions give us specific targets to address processes related to surface mass balance, plume dynamics, characterization of subglacial discharge, and freshwater budgets.

In addition, a network focused on understanding the processes of how meltwater gets to the ocean would complement several currently funded projects aimed at understanding ice-ocean interactions. If co-located, these complimentary networks could yield great insight into the full trajectory of a water molecule – as it falls on the ice sheet as snow, melts, is transported to the base of the ice sheet, travels subglacially through cavities or tunnels, emerges as a subglacial plume, and circulates through the fjord. An observational network is the only way to feasibly connect all this interdisciplinary work.

Parallel Session Summary

Meeting the Needs of Managers and Decision Makers

Session Chairs: David Payer and Sandy Starkweather

Overview. The "Meeting the Needs of Managers and Decision Makers" session focused on how scientific output from existing networks is or is not meeting societal needs for natural resource management. The seven presentations in this session provided examples of how observing systems are designed to meet management and stakeholder needs, how data and other products are (or are not) made available to mission agencies and others, and how Arctic observing activities can assist with emergency preparedness. Presenters called for greater stakeholder participation in research planning, identified logistical, social, and other challenges inherent in Arctic observing, and contrasted the state of Arctic vs. Antarctic observing. The ensuing discussion focused primarily on challenges and potential solutions to creating Arctic observing systems that are inclusive of all stakeholders, are responsive to management needs, and are sustainable.

Question 1: What scientific or operational advances have been facilitated by the network(s) of Arctic observations?

- Practices that increase discoverability and interoperability of information enhance usefulness of observations to decision makers.
- The Alaska Ocean Observing System (AOOS) provides an example of such practices. AOOS increases data access and makes data available in formats useful to stakeholders.

Question 2: What opportunities exist to address new science questions, operational challenges, or questions of Arctic communities through enhanced collaboration and a robust interagency observing system?

- Researchers should consider stakeholder needs for data format and accessibility, and work with portals such as those hosted by AOOS to meet those needs.
- When using research to support decision making, researchers must consider decision-making time frames and design/report accordingly to maintain relevancy. Temporal scale varies from immediate (emergency response) to long-range planning.
- Collaboration Teams organized under IARPC include both Federal and non-Federal partners, and provide valuable opportunities to increase collaboration.

- Discussants noted that high costs of technology and logistics create challenges. E.g., this was discussed in the context of tide gages.
- Community observations (i.e., citizen science in remote communities) will help control costs and builds a sense of stewardship.
- Local observers require sustained support; in the past there have been problems with sustainability of local observer networks.
- Technology must be rigorously tested under Arctic conditions prior to deployment.
- Often, lower-cost and lower-tech solutions may be preferable for sustainability and to encourage local involvement.
- Discussants felt that much data that have been collected haven't been fully documented or analyzed; emphasize data rescue in an integrative framework.
- Some participants felt that there should be more emphasis on efficiencies and engaging more broadly, while others urged that scientific rigor should be the primary emphasis in Arctic observing. Ideally of course, study designs should strive for all of these factors.
- Interoperability between observing systems is key. We discussed the example of AOOS working with NOAA'a Environmental Response Management Application (ERMA) at multiple organizational levels.
- There have been significant recent increases in multidisciplinary, multi-agency and cross-institutional efforts such as the Landscape Conservation Cooperatives (LCCs), North Slope Science Initiative (NSSI) and the Alaska Center for Climate Assessment and Policy (ACCAP, a NOAA Regional Integrated Science and Assessments program), which serve at the interface of observing activities and mission-agency management needs. Increased engagement in these efforts will increase relevancy and sustainability of observing efforts.
- There is also greater awareness among the American public that the US is an Arctic country. This has been enhanced by news coverage of Arctic climate change and its sequelae (e.g., endangerment of ice-dependent species), Arctic resource development (including environmental controversies and politicization), and US chairmanship of the Arctic Council. The Arctic Observing community can take advantage of this awareness to increase momentum through outreach and by adapting to stakeholder needs.

<u>Question 3:</u> How have observing activities contributed to the science needs of mission agencies or stakeholders?

- Traditionally, researchers and managers tended to be stove-piped by institution and specialty. Observing activities will be most relevant to mission agencies and stakeholders if those barriers are breached in the initial planning stages. Identifying management-relevant observing targets will enhance sustainability of observing systems.

- Managers in remote regions appreciate map-based data such as that provided by Spatial Tools for Arctic Mapping and Planning (STAMP), which provides managers of commercial fisheries with data integration and visualization tools for decision making. STAMP is available at the AOOS Arctic Portal.
- Observing activities provide vital information for resource protection in the event of environmental disasters such as contaminant spills. Some data are sensitive, e.g., spatially explicit information about archeological resources and endangered species distribution, but must be readily available for response.
- Observing activities are most useful to mission agencies when they are firmly grounded in meeting needs for decision making. Meetings such as the AOOSM that bring together managers and scientists are vital to maintaining relevancy of Arctic Observing Systems.