Parallel Session Summary

Arctic Atmosphere – Sessions I & II

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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.

Question 1: 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.