Summary and Recommendations

A successful Arctic Observing Network (AON) will allow us to address questions regarding environmental, ecological and socio-economic responses to a changing climate that are inherently interdisciplinary. While key scientific questions have been articulated in several documents (e.g., SEARCH, 20??), as stated they tend to be too broad to inform AON design. Questions must be laid out in actionable form. When an actionable question has focused on some part of the Arctic system, as was discussed in Section 5.2 for the changing freshwater budget for the Arctic, the general structure of interactions between the various components of the system are generally known. While detailed dynamics of the feedbacks between the components of the system may be uncertain, having an actionable question lays a path, via modeling, pilot studies or others approaches to design a measurement strategy that allows us to quantify them.

While some actionable questions have already been formulated, or can be developed with modest effort, developing them for problems of a highly interdisciplinary nature presents challenges. In other cases, the field may not be sufficiently mature to formulate actionable questions. . However, building on previous discussion, once actionable questions are formulated, one can begin to determine the quantities (e.g., fluxes, storages) that need to be measured, and define metrics to inform acceptable levels uncertainty (e.g., associated with network density). An analysis can then be carried out to design an optimal network to address the actionable scientific question.

A complication is that methodologies for network design and the degree to which they have been implemented to date vary widely between different disciplines. For example, OSSE and Adjoint modeling analyses are well established in many fields of the physical sciences, but these approaches are not appropriate for actionable social science questions. Furthermore, given limited resources, different actionable actionable questions will need to be prioritized. A further complication is that there are legacy components of the AON already in place. Table XXX provides a summary of the hierarchy that is required to design and optimize elements of the AON.

Due to the many science questions that an AON must address, the need for an extensive strategic analysis of their prioritization, the variety of the observational methodologies that must be implemented, and the different levels of readiness in each field, , it is impossible to construct a single blueprint or common, overarching design methodology as was the case with NEON (Section 3; Appendix 4, contributed by D. Schimel). Rather, the AON must be an agile network able to adapt to a rapidly changing Arctic, an evolving set of actionable scientific questions, to continued innovation in autonomous measurement platforms and new sensor packages. The AON should also take advantage of regional measurements that are mandated or taken by other national and international organizations. While AON is focused on the pan-Arctic scale, the need to address questions of societal relevance will often require information at local or regional scales that are often more relevant to stakeholders.

***Table XXX – Elements of AON design and optimization hierarchy***

|  |  |  |  |
| --- | --- | --- | --- |
| ***AON design elements\**** | ***Activity*** | ***Implementation*** | ***Discussion in report*** |
| **Problem definition** | Development of science goals and definition of actionable science questions | SEARCH program, agencies, stakeholders, AON Science Steering Committee | Section 2(AON science question alignment chapter) |
| **Strategy** | Feedback and uncertainty analysis, identification of metrics, model-based assessments, process studies | Working groups, funded projects, ad-hoc meetings (researchers, agencies, stakeholders) | Section 5.2.1 (Heuristic feedback and uncertainty analysis) |
| **Tactics** | Target quantity definition and measurement options, model-based assessments | Synthesis forums (e.g., Sea Ice Outlook, flagship site teams), funded projects and ad-hoc meetings (researchers, agencies, stakeholders) | Section 5.2.2 (Sea Ice outlook section) |
| **Deployment scale** | Sampling array design | AON projects, OSSE/OSE teams | Section 4.2.4 (OSSE chapter/case study) |

\* These elements expand and refine the organization of an AON envisaged in Table 1

Based on investigations by the ADI task force, including results from a comprehensive survey, specific recommendations for AON design and implementation follow below grouped into several major categories.

**Management Structure**

To implement and oversee an evolving AON (Table XXX) requires a Scientific Steering Committee (AON-SSC) to provide to a facile management structure that can respond to input from the SEARCH SSG (?), the scientific community, AON stakeholders, and federal agencies.

The *AON-SSC* should:

* Act as an advisory board with members chosen for their breadth, rather than representing a particular component of AON
* Include representatives from different agencies, international projects, academic researchers, and stakeholders
* Provide high-level vision, scientific oversight, and continuity
* Advise NSF on broad AON goals and provide input on how individual projects address these goals through proposal evaluation
* Translate broad science questions, such as those developed by SEARCH, into actionable scientific questions that can inform AON design
* Provide guidance for prioritizing different observations across disciplines and regions, using established optimization methods when appropriate, with the understanding that the AON will be built incrementally, and will be agile and adaptive
* Define AON data policies and advise on an the AON data management that is responsive to data providers, users and stakeholders
* Promote communications across AON scientists and stakeholders

To carry out these responsibilities the AON-SSC should establish Ad-Hoc Working Groups.

*AON Working Groups* should:

* Carry out the necessary steps to produce actionable questions and evaluate network design studies, and report these findings back to the SSC.
* Work with agencies to develop efficient funding support mechanisms to carry out these responsibilities

To aid in the implementation of this design an AON Project Office should also be created, modeled after other successful projects offices (e.g., LTER, FWI)

*The AON Project Office should:*:

* Provide day to day support for AON activities
* Inventory both AON measurements as well as those of other regional observations and AON international partners
* Provide advice to other programs on collaboration to extend AON measurements
* Coordinate with AON data management to assure optimal services to data providers, users and stakeholders, including dissemination of model analyses such as sensitivity studies

**Actionable Science Questions**

* Broad science questions, such as those developed by SEARCH, need to be broken down into series of actionable questions
* Actionable questions regarding energy and freshwater budgets should be a first priority since as they are relevant to many disciplines
* For aspect of the system for which understanding is relatively immature (e.g. social sciences), network design must draw from regional pilot studies that can help determine scales of variability. This includes both improved understanding of the dynamics and development of improved sampling methods.

**Space and Time Scales**

* The AON focuses on the pan-Arctic space scale and seasonal scale, laying a foundation for complementary national ir international measurement programs that may focus on regional to local scales. regional downscaling.
* For parameters that are determined by well-known dynamics and have well established sampling methodologies, space and time scales of variability should be determined and used for array optimization studies.

**Metrics**

* Network design to address specific science questions requires quantitative metrics (targets) of allowable uncertainty in the quantities being measured (e.g., how accurately must we be able to measure sea ice thickness?) metrics should be relevant to the present and possible future states of the Arctic as opposed to the Arctic of the past:
  + Allowable uncertainties will depend on the science question being asked; different science questions will require their own analysis of allowable uncertainties
  + There must be consensus within the community on allowable uncertainties
  + For science questions at a relatively low understanding, development of more specific science objectives may help to identify key variables, but not necessarily metrics; an approach similar to that suggested for the Arctic freshwater cycle (see main body of text) can help identify uncertainties
  + For science questions at a higher level of understanding, analysis may adopt rigorous mathematical metrics that depend on precise formulation of the problem in terms of derived variables and processing steps

**Prioritization and Optimization**

* The AON should strive for a balance of addressing physical, biological and human components of the system
* Observations should be prioritized based on breadth of application for different actionable science questions; those that can help address multiple questions should be given higher priority
* Some variables have well-established sampling methodologies and well-defined space and time scales of variability; this information will be central in network design
* While the network can be initially designed based on past experience in sampling strategy, more rigorous evaluations should be carried out for comparison using OSSE’s and other methodologies, such as data denial
* Trade-offs between different sampling methods need to be examined, particularly for a rapidly changing ice cover regime.
* Retrospective studies based on the existing network should be used to evaluate adequacy of components in address scientific questions
* Pilot studies should be implemented to explore effective approaches for system design where the background science has not yet developed sophisticated design algorithms.

**Implementation**

* Based on existing infrastructure, past work, other constraints as well as experiences gained by other networks (e.g. LTER, EarthScope/ Earth Cube, TAO) an agile iterative, adaptive, incremental approach towards observing system design appears to be the most appropriate path for AON development AON
* A mechanism must be developed for the AON SSC to evaluate the effectiveness of the evolving network, technology, science questions and fits with synergistic international activities
* Recent research and experiences with other observing networks and systems / software design indicate that such incremental approaches with repeated reviews by stakeholders and information users along the way support this strategy
* AON should make effective use of resources and build partnerships focusing on consensus areas (survey results appropriate here)
* A cooperative data center with agency involvement and a cooperative governance structure are required to make these approaches successful
  + Review lessons learned from LTER, TAO, ARGO, NEON

**Next Steps**

Based on the conclusions and recommendations above, the ADI task force suggests the following next steps:

*Data services*

* Create an inventory of harmonized data from different agencies to improve data interoperability, access to data, knowledge of data holdings and provide greater support for models

*Coordination*

* Identify the structure and membership of the AON SSC that includes representatives from the international community, different agencies and AON researchers that can act in the capacity outlined in the recommendations

*Prioritization*

* Identify overlaps
* Develop a hierarchy of current observing activities which can help inform the priorities for detailed observing activities
* Begin to formulate actionable questions
* Formulate metrics to evaluate the existing AON components for already developed actionable science questions
* Initiate optimization studies for existing components where array design methodology is well established