Flagship Observatories for Arctic Environmental Research and Monitoring




Report of a workshop held November 18-20, 2004
at:
The Ecosystems Center, Marine Biological Laboratory, Woods Hole, Massachusetts, USA.

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This report is available at: http://www.ael.msu.edu/flagship

Cover Photographs (clockwise from upper-left):
Zackenberg, Abisko, Toolik, and Barrow Field Stations

FLAGSHIP OBSERVATORIES FOR ARCTIC ENVIRONMENTAL RESEARCH AND MONITORING

EXECUTIVE SUMMARY

Much of the knowledge of how Arctic terrestrial and aquatic ecosystems respond to global change has been generated at large, long-term research stations that facilitate multi- and interdisciplinary science. As the Arctic continues to undergo dramatic changes in climate and human land use, there is a paramount need to further understand how Arctic ecosystems will be impacted, and how these changes will influence the future state of the Arctic and Earth Systems. Integrated research efforts at and among "flagship" field stations will likely continue to underpin the most significant advances in the Arctic terrestrial and aquatic sciences.

To capitalize fully on opportunities provided by recent and forthcoming Arctic research programs that require integrated experimentation, data collection, monitoring, and modeling (e.g. SEARCH, ARCSS, CEON, ICARP II, IPY, ISAC, and AON), a purposeful vision of the research design and role of flagship Arctic research stations is required. Although integrated monitoring and research efforts are already in place at a few sites (such as Zackenberg in Greenland and the Arctic LTER research site at Toolik Lake in northern Alaska), and well-integrated research networks are established or under development throughout the Arctic (e.g. SCANNET, CEON, AON), improved integration and networking of these efforts are needed.

To help define the role of major observatories and field stations in future Arctic research, and to develop specific recommendations for development of both individual observatories and networks of observatories, the workshop on "Flagship Observatories in Arctic Research" was held at The Ecosystems Center in Woods Hole, Massachusetts, November 18-20, 2004. This workshop was intended as a follow-up to an earlier workshop held at the Abisko Scientific Research Station in Abisko, Sweden, in which the potential for international collaborations among major Arctic observatories was the main focus of discussion (Callaghan et al. workshop report).

The overall objective of the workshop on "Flagship Observatories in Arctic Research" was to stimulate researchers and funding agencies to move forward in developing and implementing flagship observatories, both in the US and internationally. To do this, four initial objectives were defined:

1.) Review the scientific and intellectual justification for integrated, long term, multi-variable, and multi-process research at flagship observatories and the role these observatories should play in Arctic terrestrial and aquatic research.
2.) Outline integrated research and monitoring needs that build upon and extend ongoing activities at flagship stations, and the potential problems of integrating a diverse range of ecological variables that are measured and that vary at multiple spatial and temporal scales.
3.) Describe how a network of flagship research stations might interact with smaller stations and regional/emerging networks like the Scandinavian /North European Network of Terrestrial Field Bases (SCANNET) and the Circum-Arctic Environmental Observatories Network (CEON).
4.) Define the research and logistic needs and challenges to implementing a network of integrated flagship observatories in the Arctic.

These objectives were met through a combination of plenary presentations and both plenary and small-group discussions. The plenary presentations included both invited and contributed talks, while the discussions were centered on a series of specific questions designed to focus discussion and to reduce overlap among groups. The main product of the discussions was a series of recommendations for moving forward with development of flagship observatories:

Recommendation #1: None of the existing major field stations fully meet all of the criteria for a fully-developed "Flagship Observatory". There are several stations that are very advanced with respect to one or more criteria, however, and others (particularly those with a long background of research such as former International Biological Program research sites) that could develop quickly with sufficient funding. There is no need for a comprehensive redesign, replacement, or relocation of these observatories.

Recommendation #2: Because many stations are well on the way to optimum development, there is no need to build a new network from the ground up. Rather, an incremental approach to bringing existing stations up to standards is likely to be both more efficient and more effective. These incremental improvements could begin immediately, in anticipation of already-established research needs and in concert with the continuing development of network standards and protocols.

Recommendation #3: Because integrated research at individual stations is valuable and well-justified by itself, it is not essential to develop all stations simultaneously as long as development of individual stations is consistent with international protocols.

Recommendation #4: Ultimately, only a limited number of stations need to be developed to "Flagship" status. Decisions about the location of new stations should be based on consideration of their representation of regional variation in Arctic landscapes, land/air/sea/ice interactions, human communities and development activities, and the educational and other needs of individual Arctic nations.

Overall recommendation: Large, permanent field stations clearly will continue to play a central and essential role in advancing understanding of Arctic ecosystems and of the whole Arctic region. To optimize the role that these "Flagship Observatories" will play, two general categories of needs must be met. The first need is to continue to define capabilities, standards and protocols for research at flagship observatories and in international Arctic research networks, and the second need is to begin immediately to implement these capabilities, standards and protocols on a country-by-country and an observatory-by-observatory basis. The general focus of these activities should be on increasing the incentives for and potential benefits from integrated, multi-investigator, multi-site research on effects of environmental variation on and responses to climate change by Arctic populations, communities, and ecosystems.

FLAGSHIP OBSERVATORIES FOR ARCTIC ENVIRONMENTAL RESEARCH AND MONITORING

INTRODUCTION

Large, permanent field stations play a special role in developing our understanding of Arctic ecosystems and their interactions with regional and global environmental systems. These field stations, or observatories, attract scientists from a wide range of disciplines to work, often closely together, and often over long periods of time. Although the main attraction drawing the scientists together may simply be the existence of a logistics base in a sparsely-settled part of the world, the important result is a rich, diverse, and detailed understanding of the ecology, climatology, biogeochemistry, geomorphology, and human interactions with the landscapes surrounding the observatories.

The understanding that comes from research at major field stations or observatories is particularly valuable because new research results can be interpreted in the context of an existing base of knowledge and data, leading to insights that would not be possible with more isolated studies. If long-term records exist, results from a particular study in a particular year can be interpreted in terms of the history of temporal variation in climate, populations and communities, or driving processes. Development of community and ecosystem models is greatly facilitated by the existence of integrated data sets that do not require many of the transformations or assumptions that would be necessary if the data came from diverse studies done at widely-varying places and times.

Observatory-based research is especially valuable and efficient when a multifaceted program is designed from the start as an integrated effort. One of the best examples of integrated environmental research in the Arctic remains the International Biological Program’s Tundra Biome study, completed during the late 1960’s and early to mid-1970’s. The Tundra Biome studies, based at observatories in all of the Arctic countries and also linked to observatories in several temperate alpine and Antarctic sites, carried out comprehensive investigations of plants, animals, climate, and biogeochemistry, all measured in essentially the same ways and at the same times and places. These studies made possible the development of biogeochemical budgets and comparisons of processes and patterns within and among research sites that are still used today, largely because integrated research of this kind is still rare. Although the Tundra Biome projects ended more than 30 years ago, the pan-Arctic network of Tundra Biome research sites still serves as the best-developed model for integrated and network-level ecological research in the Arctic.

As both the Arctic and the global climate continue to change, it is imperative that we develop a clear and broadly-based understanding of interactions and feedbacks among all parts of the Arctic system including land, air, water, and ice. Major observatories or field stations must play a significant role in the development of such understanding and indeed all of the current plans for national and international Arctic research acknowledge this need. To help define the role of major observatories and field stations in future Arctic research, and to develop specific recommendations for creating both individual observatories and networks of observatories, the workshop on “Flagship Observatories in Arctic Research” was held at The Ecosystems Center in Woods Hole, Massachusetts, November 18-20, 2004. This workshop was intended as a follow-up to an earlier trilateral workshop held at the Abisko Scientific Research Station in Abisko, Sweden, and funded mainly by the Swedish Research Council, in which the potential for international collaborations among major Arctic observatories was the main focus of discussion.

OBJECTIVES OF THE WOODS HOLE WORKSHOP

The overall objective of the workshop on “Flagship Observatories in Arctic Research” was to stimulate US researchers and funding agencies to move forward in developing and implementing observatories, both in the US and with international collaborators. To do this, four initial objectives were defined:

1. Review the scientific and intellectual justification for integrated, long term, multi-variable, multi-process research at major field stations or observatories and the role these observatories should play in Arctic terrestrial and aquatic research.
2. Outline integrated research and monitoring needs that build upon and extend ongoing activities at major observatories, and the potential problems of integrating a diverse range of ecological variables that are measured and that vary at multiple spatial and temporal scales.
3. Describe how a network of major research stations might interact with smaller stations and regional/emerging networks like the Scandinavian /North European Network of Terrestrial Field Bases (SCANNET) and the Circum-Arctic Environmental Observatories Network (CEON).
4. Define the research and logistic needs and challenges to implementing a network of -integrated observatories.

These objectives were met through a combination of plenary presentations and both plenary and small-group discussions, leading to the development of a series of recommendations for future development of “Flagship Observatories”.

The plenary presentations included both invited and contributed talks, focused on past successes and new opportunities in integrated and network-level Arctic environmental research. The discussions were centered on a series of specific questions designed to focus discussion and to reduce overlap among groups. The following sections summarize the results of these discussions, organized on a question-by-question basis.

RESULTS OF PLENARY AND GROUP DISCUSSIONS

Question #1: What is a flagship observatory?

A flagship observatory (FO) is a major, permanent field station supporting research that spans organism to landscape to regional processes including human interactions at all of these scales (and with coastal and marine systems where possible). Research at FOs is designed to meet high priority research needs in climate, energy balance, biogeochemistry, watersheds, landscape interactions, plant and animal communities, trophic interactions, and both indigenous and non-indigenous human communities. A flagship observatory is where:

- Researchers place a priority on doing integrated measurements (i.e., researchers attempt to facilitate intercomparison, interpretation, and synthesis of results by working together at the same locations and on the same experiments where possible, at the same times and under the same environmental conditions)
- Spatial scaling and extrapolation of results in both space and time is a priority and is incorporated into research design (e.g., applications of remote sensing)
- Sustained, uninterrupted observational time series measurements are made and long-term records are kept

- Long-term, large-scale ecosystem manipulations are maintained with multidisciplinary measurements of responses
- A synoptic approach to environmental research is adopted (i.e., there is an attempt to document and understand all components of local and regional ecosystems and landscapes)
- Detailed, discipline-based measurements requiring advanced infrastructure (e.g. electrical power, on-site chemical analyses, automated telemetry) can be performed
- Measurements are linked/networked to regional/circum-Arctic/global initiatives
- Data are made available readily to the Arctic and non-Arctic science community
- A geographic information system is maintained covering the local and regional landscapes and long-term, large scale changes (e.g., remote sensing archive). All new data and manipulations are georeferenced.
- There is a legacy of both short- and long-term research and monitoring and the scope for improved interpretation of old research as new data become available
- Significant logistic resources are available to visiting researchers (e.g., trucks, boats, helicopters, standard equipment)
- Research practices are recorded (location, methods, investigators etc) for archiving and future re-sampling potential.
- There is enhanced site security for research infrastructure and for long-term observations and experiments.
- Research efforts are a hub for local to regional networks
- New techniques and technologies can be tested against human-resource demanding measurements (e.g. NDVI and biomass etc.)
- Year round measurements can be performed (automated and non-automated), and year-round research support facilities are available.
- A sample archive (e.g., tissues, soils, seeds) and basic plant and animal collections are maintained
- Capacity for rapid response to document major disturbances and extreme events is maintained
- Long-term interactions and an attitude of mutual trust and support between researchers and local residents are maintained
- Enhanced education and community outreach activities are performed, including formal courses and workshops

There are currently NO sites that fully meet all these criteria. Although established, large field stations exist that have the potential to develop into flagship observatories (e.g., Zackenberg, Abisko, Toolik, Barrow, Ny Ålesund, and Longyearbyen), these field stations are currently deficient in one or more of the criteria outlined above. Other sites, such as old IBP sites and others in Canada, Greenland, Finland, and Russia might be developed or redeveloped to meet many of these criteria

Question #2: "What major issues in Arctic terrestrial and aquatic research are most appropriately studied at integrated, flagship observatories?"

The issues that are most appropriately studied at FOs are those that require an extensive suite of measurements over a prolonged time, to provide a mechanistic and process-based understanding of the Arctic system at multiple scales of space and time. FOs have added benefits because they will attract research and educational programs that can take advantage of existing and previous studies to increase their intrinsic value. FOs are particularly relevant to projects that require significant logistical resources and capabilities, and that address a wide range of fundamental scientific questions. FOs will provide opportunities to study systems and answer questions that require an extensive suite of integrated measurements at a site over a prolonged time to provide a mechanistic process-based understanding of the Arctic at multiple scales (interactions of major system components provide synergistic analyses and conclusions). Examples of key areas for research to be supported include:

- Response to global change at all levels of ecological organization
- Changes in permafrost, slope processes, glacier mass balance, and hydrology
- Interactions and feedbacks between the Arctic and Global Environmental Systems
- Arctic ecosystem resilience and sustainability
- Cumulative impacts of near- and far-field anthropogenic stressors
- Land and sea use change
- Long-term changes and patterns in biodiversity and their effects on ecosystem processes
- Global change effects on subsistence, recreation, and commercial uses of the Arctic
- Land/Sea/Air interactions
- Interactions among multiple drivers for environmental change (disturbance, climate change, etc.)
- Environmental and ecological interactions with human health and welfare
- Ecosystem dynamics and regulation of biogeochemistry in both disturbed and undisturbed conditions
- Climate change and its effect on biotic and physical environments
- Present population states, dynamics, and species interactions
- Effects of invasive species

Question #3: "How can we best integrate data collection and monitoring across a wide range of disciplines and spatial and temporal scales?"

Research at FOs benefits greatly from the proximity of multiple individual projects, the opportunities for frequent and direct communication among students and investigators, and the availability of long-term data sets. This research can be even more powerful and useful, however, if the FO establishes policies designed to optimize the integration, synthesis, and application of research results. Broadly, these policies include *a priori* consideration of issues of spatial and temporal scaling, standardization of methods, the sharing of core data sets, and the promotion of coordinated sampling and measurement on the same sites (including major experiments). Integration, synthesis, and application will be especially strengthened if the FO itself maintains the capacity for maintenance of long-term data bases and archives, as well as for support of some modeling and synthesis efforts. Planning for site security and long-term maintenance of data bases and sample archives is also important. Ideally, an FO should have the capacity to initiate research designed to fill gaps in its knowledge base and to promote its application through workshops and interactions with local communities.

All of these efforts are also key to successful implementation of larger networks of observatories and to interactions with satellite sites. Ideally, the FO will establish and maintain agreements with other FOs and with satellite stations for the exchange of data and for other forms of collaboration among investigators.

Integration of research can be improved in the following specific ways:

- Encourage researchers to make measurements at the same time and place (where appropriate) to enhance integrative potential of data over space and time; publish sampling schedule to maximize integration.
- Develop large-area, long-term manipulations where researchers can make diverse measurements at a common site
- Develop a basic monitoring program to enable researchers who do not do monitoring to use and enhance data derived from monitoring, using models as an integrative framework
- Develop a geographic information system including accurate locations of all observations and data collection points
- Use an ecosystem framework for interpretation and comparison of individual project results
- Promote use of integration tools including expert systems and models;
- Improve communication between modelers/remote sensing and field researchers
- Reevaluate frequently scaling strategies and critical gaps
- Strive for transparency, proper documentation, and publication of model related outputs and metadata.
- Characterize relative uncertainty among system components as part of research priority-setting
- Tap into the local, traditional ecological knowledge base by soliciting community input on local concerns and observations

Particular attention must be paid to issues of "scaling up" in space and time, including:

- Define a clear hierarchy of measurements and their integration (e.g., molecule/cell/organ/individual, population/community/ecosystem, or ecosystem/landscape/Arctic region/globe).
- Include both local and remote human populations and their interactions with the land as part of the hierarchy.
- Design a sampling scheme that incorporates the measurement hierarchy and that includes spatial linkages among ecosystem and landscape components
- Link satellite observations to field data collection by sampling at appropriate scales
- Promote timely delivery of information to local communities (e.g., snow/ice status/breakup, flood warning, location of game, etc…)
- Use FOs as a "hub" for more extensive networks in support of larger studies, with other sites serving as the "spokes" away from the hub.

Examples of issues related to standardization include:

- Individual observatories (FOs) must adopt data standardization practices that are consistent with practices at the regional and circumpolar scale. (examples include ITEX, LTER, Fluxnet, WMO, CMDL)
- The major components of standardization include:
    - Standardized metadata (data descriptions in standard formats, terms and units)
    - Standardized sampling procedures in space/time; i.e., clearly developed and stated sampling strategies
    - Standardized hierarchy of spatial organization
    - Standardized field protocols (methods, units, etc.) and instruments

- Standardized informatics (data delivery, formats, units, documentation, projection coordinates, etc.)
    - Standardized practices for timely delivery of data and information to research communities and stakeholders
    - Standardized training and skills via workshops, manuals, etc.
    - Standardized indices of ecosystem and environmental states ("indicators")
- All standards, including the types, frequency, and spatial distribution of measurements must be reevaluated at regular intervals over time to refine and improve the monitoring program

<u>Finally, collection and maintenance of core data sets and major instrumentation, logistics, and communication and facilities must be carefully planned and supported , including:</u>

- One-time installation of major equipment/infrastructure e.g. boreholes for measurement of permafrost temperature, access roads and walkways, remote shelters, power lines, and power generation.
- Linkage of core monitoring to the most stable funding entity, ideally the source of support for the FO itself or for a related network of observatories.
- Availability of real-time data and remote access to field based instrumentation.
- Enhanced, web based visualization, GIS, archiving, searching, metadata tools and portal technologies at the FO.
- Capability for lateral information transfer (both among FOs and with the rest of the world) that is standardized, transparent, and accessible via high speed data transfer
- Capability for frequent and effective communication and exchange of knowledge with local and regional human communities

Question #4: What role should flagship observatories play in pan-Arctic research programs and networks?

Flagship observatories should play a central, well-defined role in Arctic research networks. A number of Arctic networks already exist or are in the planning stages (e.g., SCANNET, CEON, AON), with more planned for the future. These networks typically consist of a mix of major observatories and smaller, widely distributed field stations. The aims of these networks include understanding of the large-scale patterns and variability in the Arctic physical environment as well as understanding of controls over the distribution and function of Arctic populations, communities, and ecosystems. Networks are ideal for monitoring and prediction of panArctic changes and responses to climate variability, separating local variation from large, regional changes. As part of such networks, FOs may serve as central nodes for sharing of data, logistical resources, and major instrumentation and equipment. FOs can serve another central function as centers of education and outreach to both local communities and students and communities outside the Arctic. FOs may also serve as the sites where network-level observations of broadly-distributed organisms, processes, and environmental variables can be interpreted in the context of detailed knowledge of interactions among multiple ecosystem components. Long-term observations at FOs may be particularly useful for interpretation of shorter-term records at remote sites. Detailed models of ecosystem responses or remotely-sensed variables developed at FOs can be used to make large-area predictions for testing at remote sites.

Additional roles of FOs in larger networks include:

- Serving as sites for testing of instrumentation and methods for application at extensive sites to enhance scalability
- Serving as sites for major, multi-investigator manipulations
- Addressing the needs of the policy and management community
- Making measurements that can validate remotely sensed products and model output.
- Testing models and theories using multiple, related data sets
- Communicating with local stake holders and incorporation of Traditional Ecological Knowledge (TEK) into research
- Providing logistic support to locally distributed stations/observation platforms that capture local-regional scale variability in landscape heterogeneity

Question #5: How many flagship observatories are needed?
Although it is tempting to recommend that all current and future Arctic research stations should have the goal of eventually achieving "Flagship Observatory" (FO) status, this would be an inefficient use of funding resources. Clearly, only a relatively small number of fully-developed "flagship" stations will ever be needed, perhaps less than a dozen across the Arctic. Appropriate scientific criteria for selection include representation of major regional Arctic landscape types and their local variations, environmental and human history, and kinds of land/water/ocean/atmosphere/human interactions. The final number of FOs needed thus depends largely on their location and distribution across the Arctic region. Inevitably, however, the location of these FOs will require compromises because of the need for the availability of logistics and communications, the varying priorities of individual Arctic nations and local governments, and past investments in existing research stations.

Perhaps the most important point to consider in developing future FOs is that each FO is also valuable as a stand-alone entity in addition to its value as part of a panArctic network. Future development of FOs may proceed one station at a time, particularly if the development of each FO is planned in anticipation of a future role in larger networks. Such an incremental approach would also have the benefit of allowing subsequent additions to the FO network to avoid or at least minimize logistical pitfalls encountered by established FOs.

Criteria for selection as an FO include:

- Representativeness of panArctic variation in ecosystems and landscapes
- Proximity to terrestrial, aquatic, and/or marine biological and geophysical diversity, and proximity to a broad spectrum of local variability
- Representativeness within the panArctic spectrum of climatic change and of natural climates and climatic variability
- Representativeness of natural and anthropogenic disturbance regimes and of change in disturbance regimes
- Representativeness of the spectrum of human relationships with Arctic ecosystems and landscapes
- Potential for use of large and small watersheds(US)/catchments(European) as integrated systems for study of ecosystem and landscape change
- Potential for linkage of terrestrial, marine, aquatic, earth, and atmospheric sciences in a regional environmental system context
- Potential for filling of gaps in coverage of existing FOs

- Potential to serve as major nodes or hubs with smaller distributed stations and autonomous instruments filling in the gaps.
- Ability to operate year-round
- Should obtain and maintain fundamental monitoring datasets (climate/cryosphere/hydrology/phenology/vegetation/population dynamics) as well as local and regional GIS layers, species lists, herbaria.
- Should be permanent repositories for metadata/data; the data policy goal would be to maintain metadata from all projects, archive copies of all publications, and with ability to request specific raw data of potentially broad value.
- Ownership of land and facilities must be compatible with long-term site stability and security.
- Capacity to support a diverse, critical mass of researchers and diverse individual research projects, to promote creativity, interaction and science integration
- Availability of existing logistics and communications capabilities and infrastructure, including the capacity to serve as a clearinghouse for research coordination, permitting, and management.
- Ability to meet individual national and local research needs as perceived by communities and governments

Question #6: What is the current state of flagship observatories in the US and internationally?
There are currently NO sites or stations in the Arctic that fully meet all criteria, although several (e.g., Toolik, Barrow, Abisko, Zackenberg, Ny Ålesund) support large and diverse research and monitoring programs and could relatively quickly develop additional programs and logistical support to fill gaps. Inevitably, some otherwise well-developed sites will be missing some elements of the "ideal" FO, such as involvement with indigenous peoples, research on marine systems, or very large-area remote sensing studies. The principal need is to increase the integration of current research by developing incentives for researchers to work together in a way that enhances their ability to compare results and to interpret their results in the context of a background of existing knowledge. Some existing stations, such as Zackenberg, have extensively developed protocols and commitment to long-term, standard data collection; others, such as Abisko, maintain extensive and diverse research and monitoring programs but are focused mainly on provision of logistical and other support with relatively little formal communication or integration among individual projects and investigators. Education is unevenly developed at existing stations, as well; at Longyearbyen on Svalbard a full program of formal university courses is maintained in concert with research and monitoring. Integration and standardization is better-developed in the various Arctic research networks, although the focus of the networks is often more narrow than of the broadly-conceived program of research that might be hosted at FOs. Links to global and multi-biome networks of researchers (e.g., GTOS, ILTER, LTER, IGPB, etc.) are inconsistently developed, with little uniformity in participation among major Arctic research stations. Finally, there is considerable variation among existing stations in the stability of their long-term funding and the protection of their research sites from future development.

Current candidate FOs and networks include:

- Important stations: Barrow, Toolik, Abisko, Zackenberg, Ny Ålesund, Alert, Resolute, Kevo, Tiksi, Cherskii,, Bonanza Creek, Abisko/Tarfala, Lena Delta, Churchill, Salekhard, Disko Island, Whapmagoostui-Kuujjuarapik. Many others could be mentioned, including northern universities such as those at Longyearbyen, Tromsø, and Umeå. Arctic Networks: CEON, AON, CALM, ACD, SCANNET, CAFF, AMAP, LTER, HLEON, GTN-P, ITEX, ArcticNet, ARCN

RECOMMENDATIONS

Overall recommendation: Research at flagship observatories is essential to future progress in understanding Arctic ecosystems and Arctic land/air/sea/ice interactions. Although considerable progress is possible with existing observatories and smaller research stations, much could be done to improve the integration and application of research results at both individual FOs and within research networks. To optimize the role that FOs will play, two general categories of needs must be met: the first is to continue to define capabilities, standards and protocols for research at FOs and in networks, and the second is to begin implementing these capabilities, standards and protocols on a country-by-country and an observatory-by-observatory basis. The general focus of these activities should be on increasing the incentives for and potential benefits from integrated, multi-investigator, multi-site research on effects of environmental variation on and responses to climate change by Arctic populations, communities, ecosystems, and landscapes. Because we already have a useful and productive suite of Arctic observatories in place that are actively doing research, there is no need for a comprehensive redesign and replacement of these observatories. Instead, an incremental and opportunistic approach is called for, in which improvements to existing observatories and establishment of new observatories occur as opportunities arise and as demand increases. These incremental improvements could begin immediately, in anticipation of well-established research needs and in concert with the development of standards and protocols. Specific steps to be taken include the following.

Recommendation #1: None of the existing major field stations fully meet all of the criteria for a fully-developed "Flagship Observatory". There are several stations that are very advanced with respect to one or more criteria, however, and others (particularly those with a long background of research such as former International Biological Program research sites) that could develop quickly with sufficient funding. There is no need for a comprehensive redesign, replacement, or relocation of these observatories.

Recommendation #2: Because many stations are well on the way to optimum development, there is no need to build a new network from the ground up. Rather, an incremental approach to bringing existing stations up to standards is likely to be both more efficient and more effective. These incremental improvements could begin immediately, in anticipation of already-established research needs and in concert with the continuing development of network standards and protocols. Examples of incremental improvements include:

- Improve core station instrumentation and logistical/technical support, consistent with individual observatory needs
- Support collection of core, long-term climatic and other monitoring data as an observatory activity rather than by individual projects
- Establish or improve GIS, core data base, and informatics services at observatories

- Develop or increase core support for long-term ecosystem or catchment-scale experiments as a focus for multi-investigator research
- Develop policies and procedures for encouraging new research projects that fill gaps in knowledge of local ecosystems and of local and regional variation in ecosystem structure and function
- Develop procedures that facilitate interactions with extensive sites (e.g., data sharing, synthesis, testing of predictions)
- Promote communications with local communities and develop procedures for incorporation of indigenous knowledge and concerns into research programs
- Integrate education programs at all levels into research at observatories
- Promote integration of diverse research at observatories through regular workshops and modeling and synthesis activities

Recommendation #3: Because integrated research at individual stations is valuable and well-justified by itself, it is not essential to develop all stations simultaneously as long as development of individual stations is consistent with international protocols. Key steps in this process include:

- Develop memoranda of understanding/cooperation among existing observatories and with extensive sites
- Develop a core suite of descriptive data and long-term monitoring activities for panArctic comparison and synthesis. A hierarchical approach may be useful to allow different levels of participation among sites with different capabilities and levels of funding
- Develop standard manipulations (experiments) of key ecosystem variables, and standard protocols for monitoring responses at multiple locations (e.g., ITEX experiments)
- Establish standing committees for integration and synthesis, and for standardization of protocols and monitoring
- Promote opportunities for travel and comparisons among Arctic research sites including major observatories, and promote integration of network-level research through regular workshops and modeling and synthesis activities
- Develop a "network of networks" (e.g. CEON, AON, COMAAR) to promote communication among networks with different specific research objectives
- Foster and enhance understanding of the Arctic system by increased linkages among international, interagency, private, NGO, public, and intergovernmental groups.

Recommendation #4: Ultimately, only a limited number of stations need to be developed to "Flagship" status. Decisions about the location of new stations should be based on consideration of their representation of regional variation in Arctic landscapes and land/air/sea interactions, the history of research at the sites, human communities and development activities, and the educational and other needs of individual Arctic nations.

APPENDIX I: GLOSSARY OF ACRONYMS AND ABBREVIATIONS

ACD: Arctic Coastal Dynamics

AMAP: Arctic Monitoring and Assessment Programme

AON: Arctic Observatories Network

ARCN: Arctic Network – National Park Services (United States)

ARCSS: Arctic System Science (NSF-OPP)

ArcticNet: A Canadian based network of Arctic scientists and managers

CAFF: Conservation of Arctic Flora and Fauna

CALM: Circumpolar Active Layer Monitoring Porgram

CEON: Circum-Arctic Environmental Observatories Network

CMDL: Climate Monitoring and Diagnostics Laboratory of NOAA (National Oceanogrpahic and Atmospheric Administration)

COMARR: Co-ordination of Observation and Monitoring of the Arctic for Assessment and Research

FARO: Forum of Arctic Research Operators

FO: Flagship Observatory

GTOS: Global Terrestrial Observing System

GIS: Geographic Information System

GTN-P: Global Terrestrial Network for Permafrost

HLEON: High-Latitude Environmental Observatories Network

ILTER: International Long-Term Ecological Research Network

IGBP: International Geosphere-Biosphere Programme

IASC: International Arctic Science Committee

IBP: International Biological Programme

ICARP ii: Second International Conference on Arctic Research Planning

IPY: International Polar Year

ITEX: International Tundra Experiment

ISAC: International Study of Arctic Change

LTER: Long Term Ecological Network (NSF)

NSF-OPP: National Science Foundation – Office of Polar Programs (United States)

NDVI: Normalized Difference Vegetation Index

NGO: Non-Governmental Organization

US-PRB: untied States – Polar Research Board

SEARCH: Study of Environmental Arctic Change (United States)

SCANNET: Scandinavian/North European Network of Terrestrial Field Base

TEK: Traditional Ecological Knowledge

WMO: World Meteorological Organization

APPENDIX II: MEETING INVITATION AND AGENDA

'Flagship' Observatories in Arctic Research:
Their design and role in ecosystem research and the need for networking.

November 18-20, 2004,
The Ecosystems Center, Marine Biological Laboratory,
Woods Hole, Massachusetts, USA.

Conveners: ***Patrick Webber***, Michigan State University, USA.
Gus Shaver, The Ecosystems Center, Marine Biological Laboratory, USA.
Terry Callaghan, Abisko Scientific Research Station, Sweden.
Craig Tweedie, Michigan State University, USA.

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Sponsors: US **National Science Foundation**, Office of Polar Programs (NSF-OPP) and
The **International Arctic Science Committee** (IASC).

Background: Much of the knowledge of how Arctic terrestrial and aquatic ecosystems have/will respond to global change has been generated at large, long-term research stations that facilitate multi and interdisciplinary science. As the Arctic continues to undergo dramatic changes in climate and human land use, there is a paramount need to further understand how Arctic ecosystems will be impacted, and how these changes will influence the future state of the Arctic and Earth system. It is likely that integrated research efforts at and among '*flagship*' field stations will continue to underpin the most significant advances in the Arctic terrestrial and aquatic sciences.

To capitalize fully on opportunities provided by recent and forthcoming Arctic research programs that require integrated experimentation, data collection, monitoring, and modeling (e.g. SEARCH, ARCSS, CEON, ICARP II, IPY, ISAC, and AON), a purposeful vision of the research design and role of flagship Arctic research stations is required. Although integrated research and monitoring efforts are already in place at a few sites (such as Zackenberg in Greenland and the Arctic LTER research site at Toolik Lake in northern Alaska), and well-integrated research networks are established or under development throughout the Arctic (e.g. SCANNET, CEON), improved integration and networking of these efforts is needed.

You have been invited to attend an international workshop that will initiate an outline, for funding agencies and the international science community, a rationale, justification and implementation plan for terrestrial and aquatic research at flagship Arctic research stations and the role that such stations should play in pan-Arctic research programs and networks. At this relatively small workshop, 25-30 internationally recognized Arctic research specialists will spend two and a half days addressing four *key* objectives:

1.) Review the scientific and intellectual justification for integrated, long term, multi-variable, and multi-process research at flagship observatories and the role these observatories should play in Arctic terrestrial and aquatic research.
2.) Outline integrated research and monitoring needs that build upon and extend ongoing activities at flagship stations, and the potential problems of integrating a diverse range of ecological variables that are measured and that vary at multiple spatial and temporal scales
3.) Describe how a network of flagship research stations might interact with smaller stations and regional/emerging networks like the Scandinavian /North European Network of Terrestrial Field Bases (SCANNET) and the Circum-Arctic Environmental Observatories Network (CEON).
4.) Define the research and logistic needs and challenges to implementing a network of integrated flagship observatories in the Arctic.

Products: This workshop extends tri-lateral discussions between Swedish, Norwegian and American scientists concerned with international cooperation in the arena of climate change and its impact on Arctic terrestrial ecosystems (Callaghan *et al.* 2004[1]). A white paper from this meeting will be drafted and circulated to the US and international Arctic science community for comment. Circulation will include the International Polar Year (IPY) planning committee, a '*blue ribbon panel'* of international Arctic research specialists recently chosen by the US Polar Research Board (US-PRB) to *Design an Arctic Observing Network* (AON), the International Arctic Science Committee (IASC), the Forum of Arctic Research Operators (FARO) and the steering group of the second International Conference on Arctic Research Planning (ICARP II). Presentations and other products of the meeting will be made publicly available on the CEON website (http://ceoninfo.org/).

Proposed Agenda:

Wednesday 17th Nov *Attendees arrive in Woods Hole and book in to accommodation at SWOPE (information with travel instructions will be forthcoming)*

Thursday 18th Nov

0730 – 0845 *Breakfast at SWOPE Center*

Session 1.1: ***Introduction, background and charge for this meeting (Pat Webber Presiding)***

0845-0900 Welcome (John Hobbie);

0900-0930 Charge for this meeting and preliminary outline of White Paper (Gus Shaver)

0930-1000 *Climate change and its impacts on terrestrial ecosystems and landscapes of the Arctic: insights, challenges and ways forward: Conclusions and recommendations from a workshop to explore trilateral collaboration among Sweden, Norway and the USA* and a summary of relevant findings from the *Arctic Climate Impact Assessment* (Terry Callaghan)

1000-1030 Opportunities for Arctic Environmental Observatories (Pat Webber)

1030-1100 *Coffee and pastries*

Session 1.2: ***Studies demonstrating the use of multi-variable and integrated time series data collected at flagship Arctic observatories (Craig Tweedie Presiding)***

1100-1130 The International Biological Program and the Tundra Biome Project (Jerry Brown and John Hobbie)

1130-1150 Analysis of multi-variable integrated time series data from a single observatory (Eric Post)

1150-1210 Use of multi-variable integrated time series data from a circum-Arctic network for remote sensing (John Kimball)

1210-1230 Integrating multi-variable time-series data from high-latitude observatories with terrestrial ecosystem model simulations (Eugenie Euskirchen)

1230-1330 *Lunch at SWOPE Center*

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[1] Callaghan *et al.* (2004). Climate change and its impacts on terrestrial ecosystems and landscapes of the Arctic: insights, challenges and ways forward. Conclusions and recommendations from a workshop to explore trilateral collaboration among Sweden, Norway and the USA. Royal Swedish Academy of Sciences' Abisko Scientific Research Station, September 15-16, 2003. 24pp.

Session 1.3:	***Plenary Discussion of major issues (Gus Shaver Presiding)***
1330 – 1415	Plenary Discussion #1: “What major issues in Arctic terrestrial and aquatic research are most appropriately studied at integrated, flagship observatories?”
1415-1500	Plenary Discussion #2: “How can we best integrate data collection and monitoring across a wide range of disciplines and spatial and temporal scales?”
1500 – 1530	*Coffee and cookies*
Session 1.4:	***Plenary Discussion of major issues cont’d (Terry Callaghan Presiding)***
1530-1615	Plenary Discussion #3: “How many flagship observatories are needed and what should be their role in pan-Arctic research programs and networks?”
1615– 1700	Plenary Discussion #4: Implementation: what is the current state of flagship observatories in the US and internationally and what are the next steps?
1730 – 1830	*Cocktail hour*
1830 – 2100	*Dinner at SWOPE*

Friday 19th Nov

0730-0830	*Breakfast at SWOPE Center*
Session 2.1:	***Plenary Discussion and break-out groups (John Hobbie Presiding)***
0830-0915	Review and modify outline of White Paper, assign to writing groups
0915-1200	Writing groups meet separately *(Coffee and pastries available, 1030-1100)*
1200-1330	*Lunch at SWOPE Center*
Session 2.2:	***Plenary Discussion and break-out groups (Walt Oechel Presiding)***
1330 – 1400	Plenary discussion of progress by each writing group
1400-1700	Writing groups continue work *(Coffee and cookies available 1500-1530)*
1800 – 2200	*Catered Workshop Dinner at the home of Jerry and Celia Brown (transport will be provided)*

Saturday 20th Nov:

0730-0830	*Breakfast at SWOPE Center*
Session 3.1:	***Plenary Discussion (Terry Callaghan Presiding)***
0830-0900	Plenary: merge sections of White Paper, identify gaps
0900-1030	Plenary: Develop and prioritize recommendations
1030-1100	*Coffee and pastries*

Session 3.2: ***Plenary Discussion and workshop wrap-up (Gus Shaver Presiding)***
1100-1200 General discussion, assign remaining tasks, concluding remarks, closure of the meeting

1230 – 1330 *Lunch at SWOPE Center*

1330-1700 *Attendees begin departing*

NOTE: Afternoon available for additional writing as needed. For attendees wishing to depart on Sunday 21st November, dinner will be catered for in a local restaurant that is yet to be confirmed.

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