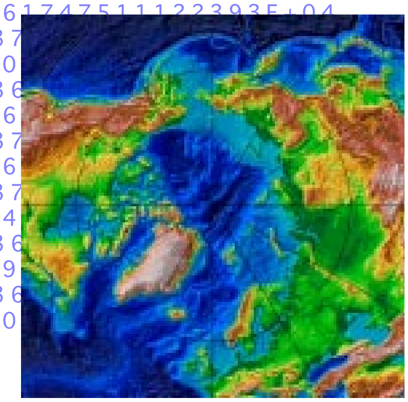

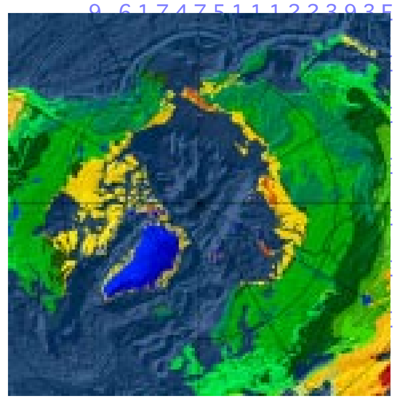

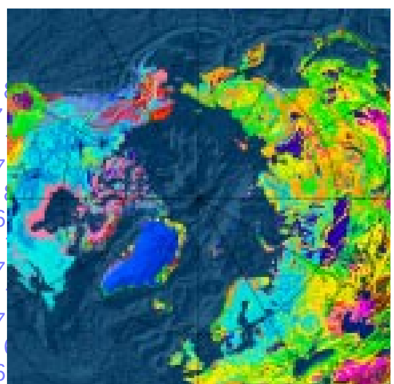

GIS

recommendations for a geographic information infrastructure to support arctic research: outcomes of the **arctic gis workshop**

phase 1 report • http://www.arcus.org/gis • april 24, 2001

GIS

Recommendations for a Geographic Information Infrastructure to Support Arctic Research: Outcomes of the Arctic GIS Workshop

Phase 1 Report

Bell Harbor International Conference Center
Seattle, Washington
January 22-24, 2001

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Prepared for
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Prepared by the
Workshop Organizing Committee and
Workshop Participants

with assistance from
Arctic Research Consortium
of the United States (ARCUS)

Cover illustrations prepared by William Manley and laid out by David Marusek

Foreword

The Arctic provides many opportunities for studying social, cultural, political, ecological, and economic processes over time and across political and cultural boundaries. Recent advances in information technology and geographic information systems (GIS) offer arctic researcher unique avenues for collaboration and investigation through an unprecedented ability to collect, examine, and share georeferenced data. In January 2001, the National Science Foundation sponsored the Arctic Geographic Information Systems Workshop to bring together academic and agency researchers and private industry experts to discuss and develop recommendations to improve the use of GIS in arctic research.

The number of participants, the diversity of fields represented, and the vigor of the discussions emphasized the importance of geographic information systems to arctic research and highlighted the many challenges to successful development and implementation. The questions raised do not have simple answers, nor can all of the recommendations be followed simply and quickly. A great deal must be done to continue this discussion and create a well-integrated infrastructure that promotes interagency and interdisciplinary collaboration and sharing of information. Recommendations in this report are a starting point to help guide the efforts of researchers, funding agencies, and technical experts.

We thank all who contributed their ideas and expertise to this endeavor. This report is due in large part to the commitment of the participants and to the efforts of the workshop organizing committee and working group leaders. Renée Crain of ARCUS coordinated the workshop organization and the report drafting and editing. David Marusek of Attention Graphics contributed technical expertise for graphics and report layout. Technical and logistical support provided by Diane Wallace, Zeb Polly, Josh Klauder, Sue Mitchell, Joed Polly, Danica Johnson and other ARCUS staff made the workshop go smoothly. Wendy Warnick of ARCUS guided the overall planning process.

On behalf of the arctic research community, we would like to thank the National Science Foundation for the opportunity to participate in this important planning process.

Mark Sorensen, co-chair
William Manley, co-chair
April 2001

Executive Summary

For over a century researchers have worked in the Arctic collecting data that are in most cases directly related to a geographic location. In the last two decades, technological advancements have made it possible for researchers to input spatial data, new and old, into desktop computers and analyze patterns of points, lines, and shapes using geographic information systems (GIS). This simple concept has revolutionized arctic research beyond basic mapping, to the layering of maps and points on maps, from geologic substrata, to vegetation, to precipitation, and at scales from entire continents, to landscapes, to meter-square grids. For the first time, researchers have been given the ability to place their own data in the context of spatial data collected by other researchers, which has opened up avenues for collaboration and investigation never before possible.

Opportunities for collaboration and novel investigations continue to grow. Tremendous assemblages of geospatial data are being developed by agency and academic researchers, often in consultation with technical experts in private industry. Typically, these data are only available for use by small groups of collaborators. Recent technological advances in GIS software, computer hardware, and the Internet are making it possible for researchers to electronically share datasets once thought to be impossibly large. To do this, however, data must be documented and maintained in a standard format that allows cross-platform, interdisciplinary, and international data sharing.

In January 2001, the National Science Foundation sponsored the Arctic Geographic Information Systems Workshop, through the Arctic Research Consortium of the U.S. (ARCUS), to bring together academic and agency researchers, and private industry experts to discuss and develop recommendations to improve the use of GIS in arctic research. Participants represented an international cross section of arctic science, with interests ranging broadly across anthropology, ecology, earth sciences, oceanography, resource management, information science, climate change, and other fields. The primary workshop objective was to develop ideas to promote the flow of georeferenced information within the arctic research community and to the broader public. The workshop began with keynote talks and other presentations to build a common understanding about

GIS technology and its relationship to arctic research. Participants then were asked to identify arctic science questions that would benefit from improved GIS capability, what paths could be taken to address those questions, and the anticipated impacts in terms of research and societal benefits.

Consensus emerged quickly that enhanced Internet-based GIS would benefit nearly all arctic scientific disciplines and problems, including societally relevant issues such as natural resource and land management, contaminants pathways, and the impacts of climate change on the Arctic. Improved spatial analysis and data sharing would add efficiency to a spectrum of research tasks, from logistical planning and data collection through statistical analysis, interpretation, publication, and public outreach. GIS enables completely new paths for intensive data analysis of variation, process, and feedbacks within the arctic system. In many cases, improvements in Internet-based GIS would minimize duplicated efforts, reduce costs of data dissemination, assist data-model comparisons, facilitate inter- and multidisciplinary integration, promote pan-arctic collaboration, and provide the tools to better communicate arctic science to policy makers and the public.

To meet these objectives, the arctic science community can take advantage of international efforts to develop data standards, organizational practices, and technology collectively known as spatial data infrastructure (SDI). Standards for geospatial datasets and associated metadata—evolving through the efforts of federal and international entities—readily permit sharing of geospatial information, in much the same way that HTML (hypertext markup language) and other standards enable the World Wide Web. The U.S. and other governments have further adopted guidelines and strategies for development of a distributed network of geospatial data producers, managers, and users linked electronically. Involving administrative, as well as technological solutions, SDI provides a basis to support integrated and multi-sector decision-making, research, and discovery at local to global scales.

To develop a spatial data infrastructure for the Arctic, workshop participants identified needs related to data, organization, tools, and culture. Framework layers of spatial information that are determined to be important across disciplinary boundaries are needed at various scales to establish a arctic geospatial library that can be shared easily and is widely useful. A comprehensive data clearinghouse is needed to catalog metadata that describe important characteristics about the spatial data in the framework layers. The generation, management, and dissemination of information can be efficiently conducted by distributed nodes within an organized arctic spatial data network, with some level of centralized coordination and facilitation. Tools for data access, online analysis, and visualization should be transparent and easy to use with the necessary ability to examine data in three dimensions and across time. An effort coordinated by researchers and funding agencies would promote incentives, skill development, and awareness building for long-term benefits to arctic research.

Finally, workshop participants identified specific recommendations for development of an arctic geospatial information infrastructure:

- Organize representation of the arctic research community;
- Align data producers with standards bodies;
- Develop an Arctic Spatial Data Catalog;
- Implement demonstration projects;
- Initiate data archiving and stewardship.

Spatial analysis is inherently cross-disciplinary, multinational, and rapidly evolving, as is arctic research. Coordinating the two will provide tangible benefits across a broad spectrum of the arctic science community.

This document, the preliminary report from the workshop, summarizes the workshop process and results as a first step toward synthesizing and documenting the recommendations from the workshop and engaging the broader community in the discussion. It is available as a PDF download from the ARCUS web site at http://www.arcus.org/gis/report.html. A more in-depth document will be published in print in 2001, with detailed recommendations to the National Science Foundation and other organizations for the improvement of geographic information systems to promote sharing and to improve capabilities for the use of geospatial data in arctic science.

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1.0 Introduction

1.1 Background

The vast majority of research in the arctic involves the collection of geographically referenced data. Geographic Information Systems (GIS) are a rapidly evolving tool that allow arctic researchers to manage, synthesize, analyze, and distribute geospatial information. To extend the use of GIS in arctic research, the National Science Foundation sponsored the Arctic GIS Workshop January 22-24, 2001 at the Bell Harbor International Conference Center in Seattle, Washington. This Phase I Report presents a synopsis of the Arctic GIS Workshop and resulting recommendations to improve the use of GIS for arctic science.

Workshop participants were asked to identify arctic science issues that would benefit from improved GIS capability, what path could be taken to address those issues, and the anticipated impacts in terms of research and societal benefits. Over 100 international researchers from a variety of scientific disciplines, representatives of state and federal agencies, and GIS professionals involved in scientific research and related activities in the arctic region participated in the workshop. The workshop was facilitated by the Arctic Research Consortium of the United States (ARCUS). A ten-person organizing committee worked with ARCUS and NSF in the development and conduct of the workshop.

Workshop Links

Outcomes of the Workshop are described on the ARCUS website:

Arctic GIS Workshop—*A starting point for these and other links and information*
http://www.arcus.org/gis

Poster and Presentation Abstracts—*Abstracts from posters and talks presented at the workshop*
http://www.arcus.org/gis/abstracts.html

Organizing Committee—*Ten representatives from academia, private industry, and government agencies*
http://www.arcus.org/gis/committee.html

Participant List—*Over 100 professionals from a broad spectrum of employment fields and scientific specialties*
http://www.arcus.org/gis/gis_participants.html

Links to Other Arctic GIS Websites—*Examples of Internet-based GIS, standards, data providers, etc.*
http://www.arcus.org/gis/links.html

1.2 Opportunities and Justification

Rapidly evolving capabilities of GIS provide broad new avenues of research in arctic science. GIS software are becoming more powerful and user friendly, while georeferenced datasets are more readily available. The Internet allows scientists and others to share information, files, images, and geodatasets. Moreover, emerging Internet-based GIS servers permit users to conduct analyses, make discoveries, and present new findings interactively over the World Wide Web.

As these technologies evolve and improve, the arctic region also is changing. Researchers modeling global climate change assert that the arctic environment is particularly sensitively to changes in climate. Scientific evidence indicates that this

Essentials of Understanding Geographic Information Systems (GIS)

Information that can be associated with a location is inherently geographic. **Geographic Information Systems (GIS)** provide a way to input, display, analyze, and interpret data identified with a location.

Most types of data have a spatial, or geographic association—a 'geographic footprint'—as a point, line, polygon, or continuous surface. The location of cities and roads in a country is geographic, as are the daytime temperature and population in each city. Data, such as temperature, are frequently collected in the same location at many points in time. These data are associated not only with their location in three-dimensional space, but also with the time they were collected (a fourth dimension or 4D).

Data collected at a specific location has information associated with it called **metadata**—data about the data. For example, a researcher may measure the soil moisture at a point in the Arctic. The location, date, time, technique used, and precision of the measurement are all metadata associated with that single measurement.

A specific location may have more than one **data layer**. Such "attributes" could include surface vegetation type, soil type, soil moisture and its pH. An arctic researcher might make many such measurements within a defined project area. Each attribute, accompanied by metadata, can be put into a map and layered among the other attributes, providing, for example, a picture of vegetation type layered with the associated soil type, soil moisture and pH. GIS allows users to record spatial data and associated metadata, examine data layers, conduct analyses, and make the results available for collaborative use.

Systems of software and computers, administration, data standards, and other infrastructure for performing GIS are referred to as **Geographic Information Infrastructure (GII)**. The term **Spatial Data Infrastructure (SDI)** also is used to refer to the broad set of technical software, equipment, human resources, and organizational concepts required to effectively perform GIS, whether it is at the scale of a single user with a desktop computer, an entire organization that collects and manipulates spatial data for a variety of purposes, or a loosely connected global group of users that wish to share information, collaborate, or pursue related thematic problems and questions.

The field of **Geographic Information Science (GI Science)** examines the conceptual structures and quantitative relationships among spatial data. Combining statistics with a range of scientific disciplines, GI Science has led to a variety of approaches and technologies for collecting, organizing, manipulating, and exchanging spatial data.

GI Science is a dynamic field driven by technical experts, research scientists, land managers, city planners, and other users. Commercial off-the-shelf software (COTS), computer hardware, and the Internet are rapidly extending to meet the needs of users and to allow multiple users to exchange data and have access to public data sets. These users vary in their knowledge and ability to work with data and software. This report presents a discussion on the opportunities that now exist because of advances in technology and organizational concepts to develop an SDI to support arctic research.

change is currently underway, influencing arctic climate and ecosystems as well as having far reaching effects on the biosphere. The processes that drive climate change and link the arctic with the rest of the biosphere involve interactions between the ocean, ice, and land. To understand these complex interactions and predict their outcomes and impacts on humans and other biota requires intensive, focused studies of physical and biological processes across time and geography.

Arctic residents are confronted by environmental, social, and economic changes happening at a wide variety of scales, from local to regional to pan-arctic. This region is host to forests, wetlands, peatlands, tundra, permafrost soils, snow, ice, glaciers, rivers, continental shelves, and deep ocean basins. Seasonally the Arctic landscape, oceans, and rivers teem with wildlife as productivity increases with daylight and temperature. Arctic residents rely on the seasonal availability of subsistence resources from the land and waters. Contaminants transported by air and water are increasingly incorporated into the environment and subsistence foods and must be studied for impacts on human health. In some regions, arctic residents are gaining political power to govern northern lands, such as the establishment of Nunavut in northern Canada, a region now governed by indigenous people. At the same time, commercial enterprises have interests in extracting oil, coal, and natural gas deposits and developing shipping routes via the northern oceans. The arctic region, which encompasses eight nations, is a complex system important to global politics, economy, and climate.

While technological opportunities exist for the collection, manipulation, and sharing of spatial data, there also are certain limitations. Data files can be large and slow to transmit across the Internet. Often metadata—information describing aspects of the data—are not clearly and accurately defined, which jeopardizes the integrity of the data when shared with other users. The nature of academic and agency research allows for duplication in the collection of data because users may be unaware of existing data sets.

Arctic researchers can take advantage of an evolving information infrastructure—a set of standards and functionality that readily permits the sharing and analysis of GIS layers—to provide an appropriate and useful framework for geoinformation. The Spatial Data Infrastructure (SDI) concept has grown from international efforts over the past few decades. Arctic researchers can adopt the SDI concept to avoid redundant efforts, to reach a broader audience of scientists and the public, and to use the state of the art in Internet-based GIS.

Organized, accessible geospatial data are increasingly critical to scientists, land managers, and arctic residents. Advancing far beyond the creation of digital maps, Internet-based GIS opens up arctic research to public outreach, collaboration, and unique avenues of scientific investigation in ways that were not possible just a few years ago. GIS is contributing to advances in arctic research in such fields as anthropology, geology, geophysics, oceanography, ecology, biology, and resource management, as well as providing an avenue for integrated studies of climate change and ocean-atmosphere circulation, among others. The application of emerging GIS technologies is well suited to the diverse, environmentally sensitive expanses of the Arctic.

1.3 Purpose and Products

The purpose of the workshop was to provide NSF with community input and recommendations to enhance the use of Internet-based GIS for arctic research. Keynote speakers provided workshop participants with an overview concerning the current state of GIS development. Prepared with this background, participants addressed a variety of specific questions, initiating a dialogue and attempting to reach consensus regarding arctic research priorities and how GIS data, tools, methods, and, in particular, Internet-based capabilities, might be applied to support arctic science.

The phrase "Internet-based GIS" evolved to the broader concept of developing a geographic information infrastructure (GII), or spatial data infrastructure (SDI), for the long-term benefit of arctic research. While the Internet represents an unprecedented opportunity for managing, searching, and disseminating shared data, and utilizing web-based GIS application services, it is only one part of a larger information infrastructure needed to effectively support scientific research in the Arctic beyond the needs of specific projects or disciplines. The technology enabler represented by the Internet will only work if it has the foundation of other technical, administrative, legal, and financial frameworks that also support the development and sustainability of a regional coordination effort. The terms geographic information infrastructure (GII) and spatial data infrastructure (SDI) have been interjected where appropriate to more accurately reflect the requirements of providing for the needs of arctic researchers to input, man-

Workshop Objectives

- Which Arctic science questions would benefit from improved, Internet-based GIS capability?
- What strategies could be used to implement enhanced GIS capability for the Arctic?
- What are the anticipated impacts in terms of research and societal benefits?

age, exchange, manipulate, analyze, and display spatial data.

While the workshop focused on the needs of the arctic research community, it also was acknowledged that there is a broader community of GIS stakeholders in the arctic region and globally who have overlapping and potentially synergistic needs, activities, and resources. The workshop addressed the state of the art in GIS technology, the advancement of geographic information science, the growing movement towards the development of national, regional and global SDI, and the potential for broadly based regional and international collaboration in the arctic region with other related stakeholder communities.

This Phase I Report is the first of two products that have been derived from the workshop effort. This document summarizes the workshop process and results, and provides NSF and other involved entities with an initial synthesis documenting workshop recommendations and engaging the broad community of arctic researchers and users of GIS in the discussion. A subsequent final report will provide a more thorough and refined articulation of community input and recommendations to guide a development plan. The final report will undergo full public review before publication by ARCUS. It is anticipated that both reports will be used by the National Science Foundation and other agencies and organizations to guide the use of GIS in arctic research for years to come.

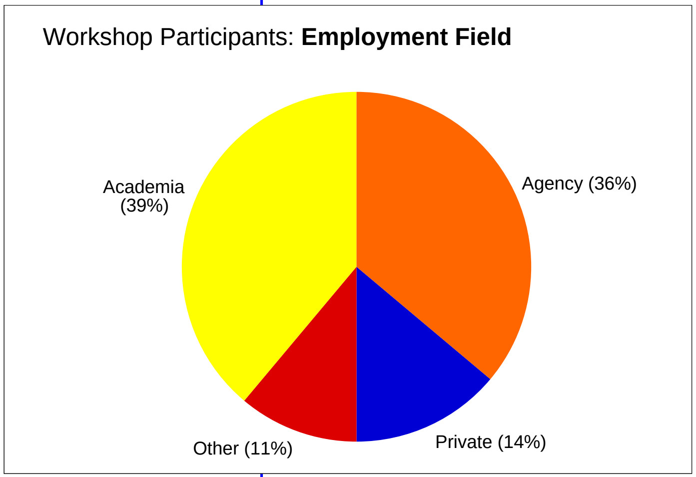


Figure 1. Workshop Participant Employment Fields. (Prepared by William Manley from information provided by the workshop participants.)

1.4 Workshop Participants

The workshop participants represented a diverse cross section of arctic scientists and researchers, agency representatives, academics and GIS professionals. As illustrated in Figure 1, nearly three-quarters of the participants were split almost evenly between agency staff and academia. GIS professionals and other interested parties accounted for the remaining 25%.

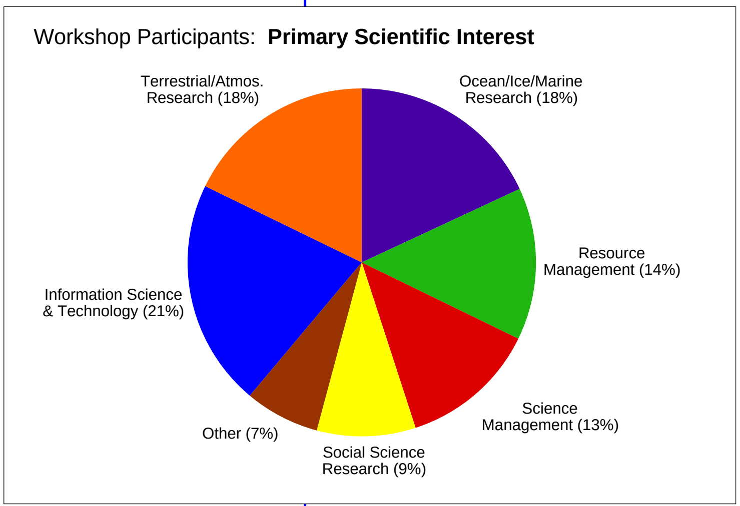


Figure 2. Workshop Participant Areas of Primary Scientific Interest. (Prepared by William Manley from information provided by the workshop participants.)

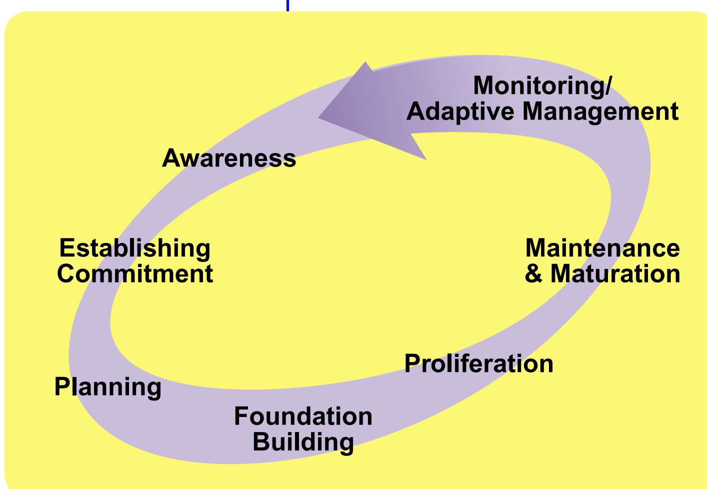
As shown in Figure 2, the participants also represented a broad variety of disciplinary interests. The top three categories were quite evenly spread among terrestrial and atmospheric science, ocean and marine research, and information science and technology. The other major constituencies were resource management, science management, and social sciences research.

1.5 The Workshop Process

Workshop organizers recognized that a diverse group of participants was needed to address a range of arctic research and GIS issues. Speakers, panelists, and working group leaders were invited to enhance this diversity. The workshop was open to all interested participants and areas of disciplinary expertise, however. Familiarity with GIS technology, GI Science, and related issues varied widely. Participants were invited to present posters to add to the scientific information accessible through the workshop process. This workshop was envisioned as the first step in a larger process to establish the arctic research community as a key stakeholder group within the larger community of GIS users.

Figure 3 indicates a series of developmental stages that have characterized regional GIS development coordination efforts elsewhere. The process shown here illustrates the need to attain certain levels of understanding and planning before proceeding with subsequent stages. Once established, an information infrastructure must be maintained, updated, and upgraded continually by repeating the steps. The workshop process began with awareness and commitment building, steps necessary to inform and provide a common foundation of understanding for working group discussions. Specific questions and issues were addressed in the working groups and working group ideas were synthesized in plenary. A broader effort engaging a larger segment of the arctic research community will need to begin the process of developing an arctic SDI from the first steps of awareness and commitment building for the successful development of arctic GIS.

Figure 3. Information Infrastructure Developmental Stages. (Diagram from Mark Sorensen, modified by David Marusek.)



The workshop agenda was arranged to:

- build awareness regarding the state of the art in GIS technology, GI Science, and Spatial Data Infrastructure;

- showcase working examples of regional geographic information infrastructure and research programs currently using Internet-based GIS to give the workshop participants a sense of what is possible and practical at present;
- task working groups to explore specific questions related to arctic research priorities, and the potential role of Internet-based GIS in addressing those topics;
- compare working group results in plenary session and discuss commonalities and differences;
- present a series of short scientific talks to increase participant awareness of existing efforts applying GIS to specific arctic research issues;
- increase awareness of operational realities associated with the development and management of regional data sharing arrangements, through the real-life experiences and perspectives of several panelists participating in a "Reality Roundtable";
- assign working groups the task of defining strategies for the implementation of an arctic research information infrastructure;
- establish a basic consensus and framework for the development of recommendations to enhance the use of Internet-based GIS for arctic research;
- define an action plan and timeline for the preparation of a preliminary report and final workshop report.

The activities listed above were carried out over the course of a very intense, three-day agenda. Details regarding the agenda, participants, and other workshop materials can be accessed through the ARCUS website at (http://www.arcus.org).

2.0 The State of the Art in Geographic Information Technology, Science, and Infrastructure

Keynote presentations, technology demonstrations, and a poster session all provided workshop participants with a background in the present state of GIS technology, leading-edge conceptual foundations being explored by the GI Science community, and the growing movement towards the development of regional, national, and global spatial data infrastructures. Presentations and demonstration information, including web site addresses, can be accessed through the ARCUS website (http://www.arcus.org).

Invited Presentations

Keynotes

- Current and Potential Uses for GIS in Academic Arctic Research, Michael Goodchild (NCGIA, University of California, Santa Barbara)
- Current and Potential Uses for Geospatial Information and Technologies in Government, Mark Reichardt (Open GIS Consortium, Inc.)
- Digital Earth, Jeff de la Beaujardière (Digital Earth, NASA)
- Advances in GI Science Towards Web-Based Arctic GIS, Max Egenhofer (NCGIA, University of Maine)

Science Shorts

- Wired, Vision and Wisdom, Lars Kullerud (UNEP, GRID-Arendal)
- Proposed Spatial and Temporal Reconstruction of the Environment for the Iqaluktuuq Project, Victoria Island, Nunavut Canada, Julie Ross (University of Toronto)
- GIS Tools for Collecting and Accessing Arctic Bathymetry: International Bathymetric Chart of the Arctic Ocean (IBCAO), Martin Jakobsson (University of New Hampshire)
- GIS and the Northern Sea Route: Applications during INSROP, Lawson Brigham (Scott Polar Research Institute)

Live GIS Demonstrations

- Building and Deploying Enterprise Geographic Information Systems, the Creation and the Delivery of Content, Christopher Kroot *et al.* (TREESystems)
- The University of Alaska Fairbanks: A member of an Arctic GIS community, Skip Walker *et al.* (University of Alaska Fairbanks)
- The Alaska Geographic Data Clearinghouse, Mark Shasby and Emily Binnian (EROS, USGS)
- On-line Resources, Strategy, and Environmental Data Tools, Hugo Ahlenius and Lorant Czaran (UNEP, GRID-Arendal)

Special Presentation

- Arctic Science on the Move: Much New Information—Many Old Problems, Norbert Untersteiner (University of Washington and University of Alaska Fairbanks)

2.1 GIS Concepts and Practices—A Dynamically Evolving Field

GIS is not just about information technology anymore. In the past, GIS has been commonly described as a *"computerized system for the compilation, access, retrieval, analysis and display of geographic and geographic-related data"*. Modern GIS is much more than computerized mapping—it now provides the basis for a societal *information infrastructure* for bringing what we know about the planet together geographically to support integrated and multi-sector decision-making, exploration, and research at many levels. GIS has grown from a relatively obscure and esoteric field just two decades ago, to a globally recognized and fundamental part of our modern world. It is becoming a more routinely used tool in scientific research, as evidenced by Figure 4.

Thirty years ago the foundations of modern GIS were being developed among a variety of disparate, disciplinary application areas such as digital cartography, natural resource mapping and assessment, regional land use planning, forestry, remote sensing, computer science and information technology (IT). In parallel with other information system developments over the past two decades, GIS progressed from a tool used to conduct special projects, to a departmental tool, to an organization-wide tool (enterprise GIS) used across departmental boundaries, and in most recent years towards a regional, national and international infrastructure supporting whole countries and collaborators across the world.

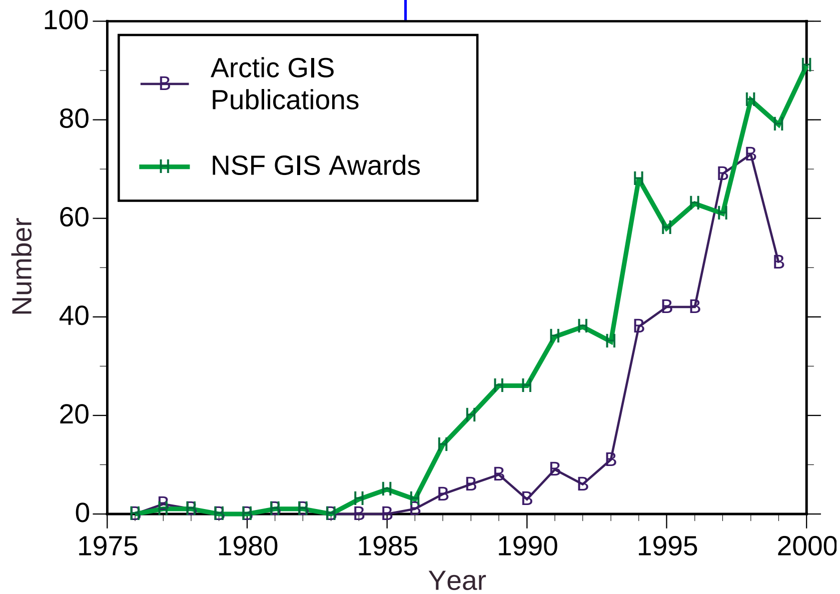


Figure 4. Rapid growth of GIS in scientific research. A search of NSF grant awards—across all Foundation funding programs—reveals a strong increase during the 1990s for projects that utilize spatial analysis with GIS. Past or current grants were identified from the NSF Award Database (https://www.fastlane.nsf.gov/a6/A6AwardSearch.htm) using keywords "GIS" or "Geographic Information System", and are shown by start date. Similarly, a search of scientific publications—specifically for the Arctic, and across a range of geologic, biologic, and other journals—depicts exponential growth in the application of GIS. Publications were identified using these same keywords combined with regional Arctic identifiers, using three biobliographic databases (GeoRef, GEOBASE, and Biological Abstracts). Though not exhaustive, the bibliographic searches reveal clear trends (information prepared by William Manley).

This development has not been linear. GIS is still being used to carry out projects and other levels of integrated use within organizations, but the concept of spatial information as a component of societal infrastructure, fueled in part by the global Internet and the unprecedented access it provides, may yield the most profound developments and benefits in the GIS field yet.

Today, GIS has matured significantly. A field of GI Science has emerged within the academic community that is exploring new ways of thinking about, structuring, cataloging, accessing and using geographic-based information. An entire industry has grown around the development and provision of GIS software and services. Whole governments are adopting the concept of spatial information as an important infrastructure for better decision-making, management of public resources, and governance. Industry is implementing GIS to increase operational efficiencies, better understand markets, and maintain competitive advantage.

International development organizations are incorporating GIS as a component of regional and national economic and social development efforts and the assessment, management, and conservation of transnational environmental resources. International collectives are tackling the development of standards for describing and cataloging GIS data, and domain experts are collaborating in the development of content and format standards for certain framework data topics. A Global Spatial Data Infrastructure (GSDI) initiative is underway that has attracted the participation of dozens of countries around the world (http://www.gsdi.org/).

Despite significant progress, most GIS practitioners will readily admit that there is still much work to do to achieve maximal societal benefits of GIS. Establishing and maintaining a regional initiative for data sharing takes time and resources, and there is a broad range of both technical and administrative challenges that must be addressed. Technical challenges must be solved, but these tend to be secondary to the human factors and organizational culture issues that must be resolved before effective collaborations can develop among experts and users throughout the Arctic.

2.2 Data Representation and Standards

Data Representation. GIS data represents features of the real world in an abstract form that can be manipulated on a computer using GIS software. The ontology, or methods of thinking about the world and how to model or describe it in a structured digital form that most effectively and flexibly supports problem solving, decision-making and scientific research, is evolving. Because different disciplines have different perspectives and analysis needs, the evolution of GIS is enriched by the growing breadth and diversity of the user community. The growing academic field of GI Science is actively exploring new and better ways of dealing with data representation issues, among other research agendas.

Traditionally, real world features have been represented in GIS as topical data layers, in either a raster (grid cell) or vector (polygon, point, line) form. Characteristics of these features are maintained in tabular files that can be linked to the spatial objects and each other by relational database management systems (RDBMS) for analysis and display. Object-oriented data modeling and other techniques are being developed to provide more flexibility in representing spatial information.

While the most widespread forms of data representation (data models, in the GI Science vernacular) have been adequate for most two-dimensional (2D) representations, they have generally lacked the ability to efficiently accommodate 3D (surface, volumetric, fluid), 4D (time) and other issues that are necessary for many scientific applications (Figure 5). Individual researchers and some organizations have developed methods for addressing these factors, but the mechanisms by which these structures can be reviewed, refined, adopted as standard by the community, and integrated to operate in the more common GIS software environments have been lacking.

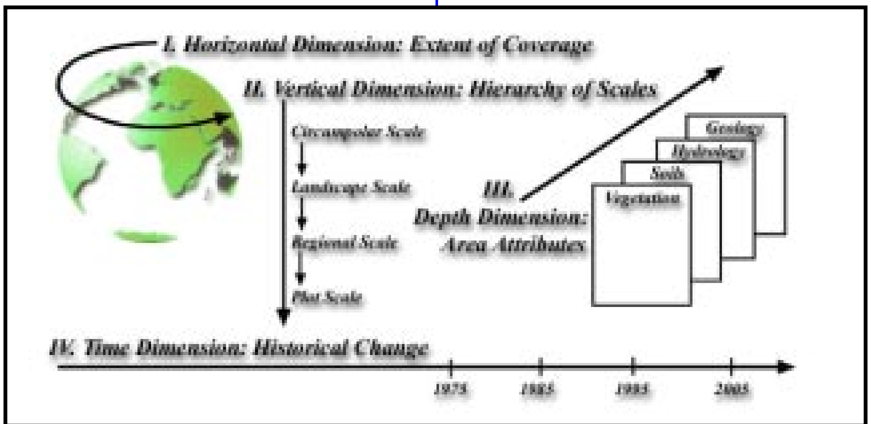


Figure 5. An example of the four-dimensions (4D) that can be represented using GIS. Spatial data may have a horizontal, vertical, depth, and/or time component. Terms often referred to are "scale,"defined in the vertical component, and "layer," defined in the depth component. (Diagram courtesy of Skip Walker, University of Alaska Fairbanks, Northern Ecosystems Analysis and Mapping Laboratory http://www.neaml.uaf.edu/*).*

***Metadata Standards*.** Metadata are data about data. As data sharing has increased, so has the necessity for describing the information in a manner that can be readily understood by users who may not have been involved in the data collection. In the past, some organizations cataloged their data holdings in one form or another, but there was no standard framework for this information, thus users had difficulty searching for information.

Several national and international efforts have been undertaken to develop and adopt spatial metadata standards. Metadata standards from several national and regional initiatives, including the Federal Geographic Data Committee (FGDC) in the United States and the Open GIS Consortium (OGC), are contributing to the development of an international standard to be adopted by the International Standards Organisation (ISO).

Also important for the scientific community to consider is the concept of geography as a metadata descriptor for any sort of information that has a geographic footprint. Thus, any report, publication, geographic dataset, organization, monitoring effort, field activity, photograph or other information resource that has a reference to a location can be cataloged as geographic. This sort of geographic reference can provide a powerful tool for linking information by place in a way that is often missed in traditional cataloging methods. The geographic footprint is an integral part of the existing spatial metadata standards, but its use in bibliographic and other information resource types is only now being explored. These and other cutting-edge concepts for cross-media data cataloging and searching are being advanced by a variety of organizations, including the FGDC, OGC, Dublin Core, the Geography Network, the distributed geolibrary research community, and others.

Metadata standards under development catalog a wide variety of general purpose information about each dataset. However, these standards do not always address some of the discipline-specific descriptors that may be needed by scientific researchers (for example, identification of what water quality constituents may be associated with a monitoring plan). This may require the development of domain-specific metadata standards and descriptive semantics to adequately meet the needs of the scientific research community.

Framework Data Standards. Most of the major national and regional spatial data initiatives establish and develop content and structure standards for data topics that are fundamental to the work of a majority of stakeholders. This framework data development often serves as the focus for initial collaborative work that can establish relationships and become the foundation for other aspects needed to develop and maintain any regional initiative. Framework data provide a geographic foundation upon which additional geospatial information can be built.

Framework data topics and content standards often only address those elements that are needed in common by the broadest number of stakeholders. The National Spatial Data Infrastructure (NSDI) has identified seven framework layers that tend to be commonly useful in GIS: geodetic control, orthoimagery, elevation, transportation, hydrography, governmental units, and cadastral information. Scientific research often will require or generate specific content that may not be supported by the broad content standards. Determining what framework data topics and content standards are most needed to support arctic research will require more exploration.

Open Data Format Standards. The GIS user community has been encouraging software and data providers to support open data standards that will increase interoperability from system to system. The Open GIS Consortium (OGC) has taken an active role in facilitating the development of open standards, and in encouraging the marketplace to adopt them.

On-line GIS Data Facilitators

STANDARDS SOURCES:
Digital Earth (DE)
http://www.digitalearth.gov/

Dublin Core
http://dublincore.org/

Federal Geographic Data Committee (FGDC)
http://www.fgdc.gov/

Internatioinal Standards Organisation (ISO)
http://www.iso.ch/

Open GIS Consortium (OGC)
http://www.opengis.org/

GRID-Arendal
http://www.grida.no/

DATA SOURCES:
Alexandria Digital Library (ADL)
http://www.alexandria.ucsb.edu/adl.html

Arctic Monitoring and Assessment Programme (AMAP)
http://www.amap.no/

Geography Network
http://www.geographynetwork.com/

National Geospatial Data Clearinghouse (NSDC)
http://nsdi.usgs.gov/

Northern Information Network (NIN)
http://esd.inac.gc.ca/nin/

2.3 GIS Software Functionality

GIS software provides tools for data capture, management, retrieval, measurement, query, analysis, visualization, transformation and many other purposes. Most people applying GIS in their work today are using commercial software packages that have been produced by companies that specialize in this area. Because these are commercial products, the software functionality provided has been developed around the needs of the primary market consumers. Custom functions such as some of the specialized modeling and analysis needs of the scientific research community may not be well supported by commercial off-the-shelf (COTS) products. However, there is an increasing trend toward the development of specialized functionality in the form of extensions, application programs, linked models, and other add-ons that are being built on top of the foundation provided by COTS software. This trend will likely increase as the commercial software vendors—such as ESRI, the makers of ARCInfo, ARCView and other programs—move toward component architecture for modular software development and distribution that will provide very flexible software building blocks that can be used to develop highly specialized application software to meet particular needs.

Also of significance to researchers is the increasing integration between data collection sensors, increasingly rugged field computing, GIS and Global Positioning System (GPS) technology. Real time and near real time data collection and visualization is becoming more common. Handheld computers are now being built to withstand extreme field conditions and can be equipped with GPS and GIS capabilities to support more efficient field data capture. The cost of these components has plummeted over the last few years, and there are now companies that specialize in the development and integration of such systems.

2.4 Data Access and Dissemination

The growing recognition of the importance of standardized data cataloging and metadata is making it easier to retrieve information, once you know where to look for it. The National Spatial Data Initiative (NDSI) in the U.S. has supported the development of a distributed network of Data Clearinghouse nodes across the country, each acting as a metadata repository for contributing stakeholders in their geographic area. Other countries and regions are adopting similar approaches.

The Internet is revolutionizing spatial data access and dissemination. Users search metadata catalogs to locate the information they need and many web sites now provide easy to use tools to download the actual data directly. Some sites are providing Internet-based interactive mapping that allows users to access GIS analysis and visualization capabilities that they may not possess on their own desktop. There is a growing trend towards providing users with simultaneous, interactive linkage to two or more geographic data servers over the network, backed up by specialized services to reduce client-side data handling complexities. This development is significant to the research community because it will help to provide users who are not GIS specialists with transparent access to data. Under this scenario, technical issues like distributed sources, area of interest extractions, data format conversion, geographic projections, graphic symbology and other technical issues are handled through the web-based service, thus relieving the user from having to confront these at the desktop. Efforts like NASA's Digital Earth project (http://www.digitalearth.gov) and ESRI's Geography Network (http://www.geographynetwork.com/) are making strides in this direction.

While data are becoming more accessible, there are still many hurdles to overcome. Data that are downloaded or otherwise acquired may not be in a usable format or may not be integrated with datasets from other sources. Some data are proprietary or sensitive and are therefore subject to limited or controlled distribution. Some organizations will not share data, some sell their data or restrict access, others provide it freely. Technical constraints to the wide sharing of data over the Internet are mostly solvable, with some effort. Many of the obstacles could be overcome through wide acceptance of standards for data and metadata formats. The political, legal, and financial frameworks needed to support the development of a regional spatial information infrastructure are often much more difficult to resolve, however.

2.5 Spatial Data Infrastructure

As mentioned previously, there is a world-wide movement towards the development of the spatial data infrastructure (SDI) concept at the regional, national and global levels. This movement has been evolving over the past decade or so. In the early stages of development, the SDI concept was largely the concern of government and was based on the premise that just as it has been the legitimate role of government to provide a common and consistent infrastructure to support a wide variety of government, private sector, and community activities in areas such as telecommunications, regional highways and healthcare, the same principle should be applied to spatial information. In an SDI, data are part of the infrastructure, with the same importance and administrative responsibilities of any other part of infrastructure. A nation or region's SDI is necessary to support economic growth and its social and environmental objectives, backed by the standards, guidelines, and policies needed to maintain the integrity of the infrastructure and safeguard access.

Several governments and consortia around the world have initiated the development of national and regional geographic information infrastructure frameworks. In the U.S., a National Spatial Data Initiative was called for by the Clinton administration under Executive Order 12906 published in April,1994. The Order stated *"Geographic information is critical to promote economic development, improve our stewardship of natural resources, and protect the environment. Modern technology now permits improved acquisition, distribution, and utilization of geographic (or geospatial) data and mapping. The National Performance Review recommended that the executive branch develop, in cooperation with State, local, and tribal governments, and the private sector, a coordinated National Spatial Data Infrastructure (NSDI) to support public and private sector applications of geospatial data in such areas as transportation, community development, agriculture, emergency response, environmental management, and information technology"* (United States Executive Order, 17671). The Order further called for establishing a National Geospatial Data Clearinghouse for the development of a *"distributed network of geospatial data producers, managers, and users linked electronically"*. A Federal Geographic Data Committee (FGDC) was created to coordinate the U.S. federal government's development of the NGDC.

At present, there are a variety of regional SDI efforts underway on nearly every continent. Global Spatial Data Infrastructure (GSDI) lists 239 data clearinghouse nodes in 26 countries (146 in the U.S.). This trend is accelerating as more countries realize the significance of spatial data infrastructure for both national and regional development, understanding and responding to transnational environmental issues, and participation in the global society. The arctic research community now has the opportunity to link with initiatives currently underway to improve sharing and management of geospatial data.

3.0 Arctic Research and the Potential Role of GIS

Workshop participants met in small working groups to respond to three key questions regarding arctic scientific research and the potential role of GIS:

- Which arctic science questions would benefit from improved, Internet-based GIS capability?
- What are the anticipated impacts in terms of research and societal benefits?
- What strategies could be used to implement enhanced GIS capability for the Arctic?

These questions were intended to initiate discussion rather than direct it. Working group members were free to expand on the basic themes represented in these questions and to suggest other questions for consideration by the scientific working community in the Arctic.

3.1 Potential Benefits to Arctic Science

The discussion regarding the benefits to arctic research of an improved GIS capability focused initially on two major research themes, described below. The more detailed description of key benefits to arctic research beginning on page 25 arose from these points.

Much arctic research is inherently geographic and could benefit from an improved GIS capability. Many areas of arctic research involve the characterization of points, lines, polygons, or surfaces on the earth, from data collection through analysis to public outreach. A list of specific areas of arctic research identified at the workshop as beneficiaries of improved GIS capability covered a broad spectrum of current research and included:

- global warming and arctic climate impact assessment;
- sea ice dynamics and change;
- terrestrial and atmospheric dynamics and trends;
- permafrost change;
- geotechnical dynamics;
- social systems and interactions;
- marine and terrestrial environments and interactions;
- ocean and terrestrial habitat assessment;

Potential Benefits to Arctic Science

Major Themes:

- Much arctic research is inherently geographic and could benefit from an improved GIS capability.
- Some of the most complex, pressing, and societally relevant arctic scientific questions can be addressed using GIS.

Key Benefits:

- Improved GIS enables a more holistic, cross-disciplinary, and multinational look at the environment.
- Improved coordination and communication among data producers and data users would have numerous benefits.
- Better data management and dissemination would yield immediate benefits.
- GIS will provide new information and tools to support science education and academic research.

- identification and characterization of environmental hazards;
- pollution and contaminant assessment;
- coastal erosion;
- disaster or emergency management and response;
- resource management;
- urban and regional planning and sustainable development;
- economic development;
- epidemiology;
- wildlife health and disease;
- fisheries assessment;
- policy analysis.

Some of the most complex, pressing, and societally relevant arctic scientific questions can be addressed using GIS. Spatial analysis and data sharing within and across disciplines can advance research on such issues as:

- natural environmental variability;
- human impacts on the environment;
- the impact of global warming on the environment (i.e., the Arctic as both a sensitive indicator of climate change, as well as the source of internal feedbacks that exacerbate global change); or
- the impact of environmental change on resources and society.

Benefits could be realized by enabling interdisciplinary research among such themes as the biosphere, terrestrial environments, the lithosphere, hydrosphere, cryosphere, atmosphere, oceans, and social sciences. Improved Internet-based GIS would add value to existing research programs through:

1) logistical support for field data or sample collection;
2) infrastructure for data management;
3) expanded tools for data analysis;
4) vertical integration between disciplines;
5) horizontal integration across disciplines; and
6) effective communication for outreach, education, and policy making.

Furthermore, GIS is enabling entirely new avenues of research, with analysis of large empirically based, multiparameter datasets that bear on environmental process and change. Internet-based GIS provides the means of crossing disciplinary divides. Contributions include the ability to facilitate multi- and inter-disciplinary collaboration, horizontal integration of datasets, data-model comparisons, and the ability to stimulate new avenues of research, as well as making existing avenues more effective.

Key benefits of an improved GIS capability to support arctic research are described below in the the form of a summary statement, followed by specific supporting points.

Improved GIS enables a more holistic, cross-disciplinary, and multinational look at the environment. Beyond the recognizable operational efficiencies and opportunities for applying new tools within a discipline, the potential to extend arctic science in general could be greatly improved through the use of more coordinated information and integrative analysis tools. Specific benefits include:

> PROMOTE INTEGRATION ACROSS DISCIPLINES. A spatial data infrastructure for the Arctic would allow for the integration of information and provide better tools to understand the horizontal and vertical linkages among physical and biological systems, and their interactions with human activities;
>
> SERENDIPITY—NOVEL DISCOVERIES USING UNIQUE TOOL AND DATA COMBINATIONS. With greater data access and more powerful analytical tools, scientists may discern issues, dynamics, relationships and trends that have not been recognized in the past;
>
> IMPROVE INTERNATIONAL COORDINATION. The arctic system is interconnected with other systems in the biosphere, thus, arctic issues have implications beyond the Arctic and require communication and coordination among the eight arctic nations, as well as with other nations. Data standards, new methods to communicate scientific research and share findings, and arctic-wide framework data can help improve scientific advancement across international boundaries;
>
> RELATE REGIONAL AND LOCALIZED PHENOMENA. Comprehensive, regional information can help scientists to better relate local issues with regional factors and trends, and to understand contextual influences.

PLACE-BASED EXPLORATION AND INTERACTION. A more integrated information infrastructure enables scientists to cross-reference and analyze information about specific geographic places, like watersheds, biomes, or community boundaries.

IMPROVE LINK BETWEEN SCIENCE AND POLICY. More holistic and cross-disciplinary assessment will better inform policy making at local, regional, national, and international levels.

PROVIDE A MORE ANALYTICAL BASIS FOR POLICY ANALYSIS AND ADOPTION, RESOURCE MANAGEMENT, AND BASIC AND APPLIED SCIENTIFIC RESEARCH. Better information and analytical tools can yield better informed decision-making at all levels, and help to facilitate more consistency and synergy among policy making, resource planning and management, and scientific research activities.

PROVIDE IMPROVED OUTREACH AND COMMUNICATION TOOLS. GIS provides powerful tools that can help researchers and research institutions to present scientific data and findings to policy makers and the public in a graphic and compelling manner. Numeric and otherwise abstract data can be transformed in a variety of formats more easily understood by persons who are not scientists, but who nevertheless have a great deal of influence on how the science is used and supported.

Improved coordination and communication among data producers and data users would have numerous benefits. Workshop participants described many ways in which an arctic SDI could yield improved coordination and communication among arctic researchers. This included improved coordination of field activities, better communication with local communities, and more efficient data collection. These are only a few of the ways GIS can be used to unite people with information, and people with people, to improve data sharing, communications, and advance arctic science.

MORE EFFECTIVE DISSEMINATION OF RESULTS AND DATA. Access to timely, accurate information about research findings and the associated data is important. By establishing an accessible and easy-to-use information infrastructure, researchers will be more likely to deposit their information to this framework, as well as extract information from it.

More effective logistics and coordination. Researchers would be able to access information about what research is being conducted in which locations. This could lead to better coordination of field logistics, thus reducing conflicts and promoting resource sharing.

More widespread notification of research. Both the scientific community and local communities can benefit by knowing what research is going on within their area of interest or community. This would help researchers to better coordinate their field activities with native communities, landowners, facility operators, land managers and others.

Establish more effective links between data producers and users. Agencies often develop datasets based on known user requirements. At present, the needs of the academic research community are not well communicated to the agencies that generate a majority of the geographic data. A coordinated effort is needed to define missing data and communicate the special needs of the arctic research community to data producers.

Integrate new datasets. Using common framework data and other related information, new datasets can be developed in a more integrated manner, thus increasing their utility for addressing multi-disciplinary and regional issues.

Improve data and modeling. The collection and compilation of empirical data for use in, or testing of, numerical simulations can help improve the accuracy of analysis and the identification of data gaps.

Integration of different types of information. Examples of information that has not been typically included in GIS that could benefit researchers are:

- traditional environmental knowledge (TEK),
- geo-bibliographic links between scientific research reports and other publications and the geographic places they reference,
- references to organizational, jurisdictional, and area-of-interest boundaries, and
- links to experts based on geographic or topical areas-of-interest.

Improvements in data quality through increased review and communication. As data accessibility increases, so will the number of people reviewing and evaluating that data for application to their own purpose. This level of scrutiny can help to reveal data errors or inconsistencies but, more importantly, can lead to dialogue towards the development of more robust data content and format standards. If properly channeled, this dialogue also can be used by the community at large to better identify data gaps and areas requiring further investigation that can be included in future research proposals.

Better data management and dissemination would yield immediate benefits. Many researchers reported that a significant amount of their time is consumed looking for, acquiring, qualifying, and processing data from other sources. In many cases, researchers are reluctant to make the investment because of the time and resources that might be required and the uncertainty that the information will actually be useful for their particular application.

More efficient data acquisition. The development of metadata standards and data clearinghouse functions to help researchers search for, qualify, and acquire needed data in a useful form can save a great deal of time that might better be spent on fundamental science. This was one of the points cited most often by the working groups in support of a more coordinated, regional information infrastructure. Participants noted, however, that it is important for researchers to be able to acquire information in a usable form to avoid wasting time in data format conversion, projections, and other related issues.

Decrease data dissemination costs and constraints. Internet-based distribution of common-interest data can increase access and decrease data reproduction and distribution costs.

Minimize duplication of effort. With increased coordination, researchers can more easily find data they need to support their work, thus reducing redundancy of data collection. Also, coordinated efforts can result in the development of datasets that can support multiple purposes.

GIS will provide new information and tools to support science education and academic research. GIS and related tools for the gathering, management, analysis and visualization of scientific research in the Arctic will continue to expand as the technology is advanced and as more researchers discover new ways to apply it in their work. Integration of these data and tools to the educational process will help equip new generations of scientists with the knowledge to apply these resources more effectively toward the advancement of research and education.

One working group took the approach of ranking the more obvious GIS benefits according to type and likely beneficiaries, ranging from individual investigators to the general public, as shown in the following table (Figure 6).

Figure 6. This table from the workshop ranks possible benefits and beneficiaries of improved GIS infrastructure. Using a scale of 1–5, 1 representing the least benefit, participants quantified benefits in the Total column, where 55 is the maximum score. (Table prepared by the working group lead by Stéphane Pesant, modified by David Marusek.)

Ranked Benefits of Improved Geographic Information Infrastructure

Rank	Benefits	Total	Individual PI	Science Project	Science Community	Public
1	Data Sharing	51	X	X	X	X
2	Interdisciplinary Results	48	X	X	X	X
3	Synthesis	47	X	X	X	X
4	Improved Productivity	45	X	X		
5	Collaboration (Science)	44	X	X	X	
6	New Analyses	42	X	X	X	
7	Communication and Networking	41	X	X	X	X
8	Collaboration (Institutional and International)	40			X	X
9	Natural Resource Management	39				X
10	Data Model Comparisons	37		X	X	
11	Education	36				X
12	Reduced Redundancy	36		X	X	
13	Temporal Baselines	35		X	X	
14	Serendipity	33	X		X	
15	Cost Savings	32		X		
16	Policy Guidance	32			X	X
17	Logistical Planning	32	X	X		
18	Local Involvement	30	X			X
19	Outreach	30			X	X
20	Guidance for PIs	28	X			

3.2 Needs, Opportunities, and Constraints

Working groups identified critical needs, opportunities and constraints with respect to the improvement of GIS capabilities to support scientific research in the Arctic. The following sections are organized around four key issues that must be considered in developing a regional spatial data infrastructure, including:

Data. The informational resources that are the foundation of a spatial data infrastructure;
Organization. The principles and methods by which people, institutions, agencies, and several nations in the pan-arctic region can cooperate;
Tools. Hardware, software, and other basic technical infrastructure components that are needed to acquire, manage and use spatial data.
Culture. The collective attitudes and motivations of the arctic research community that will either foster or constrain a regional, science-focused data infrastructure.

3.2.1 Data

Data are the foundation resource of any spatial data infrastructure. The data available, and how they are compiled, structured and documented will determine the value of an SDI to the community of arctic researchers.

Framework data should be established at various scales. Certain data are of common interest to a wide variety of research projects and these need to be available at specific levels of detail. Some of these can be accomplished in partnership with the broader community of GIS users and the agency producers. Others will require original work, or the compilation and integration of existing sources.

POTENTIAL FRAMEWORK DATA TOPICS. Data topics cited most often by the working groups included:

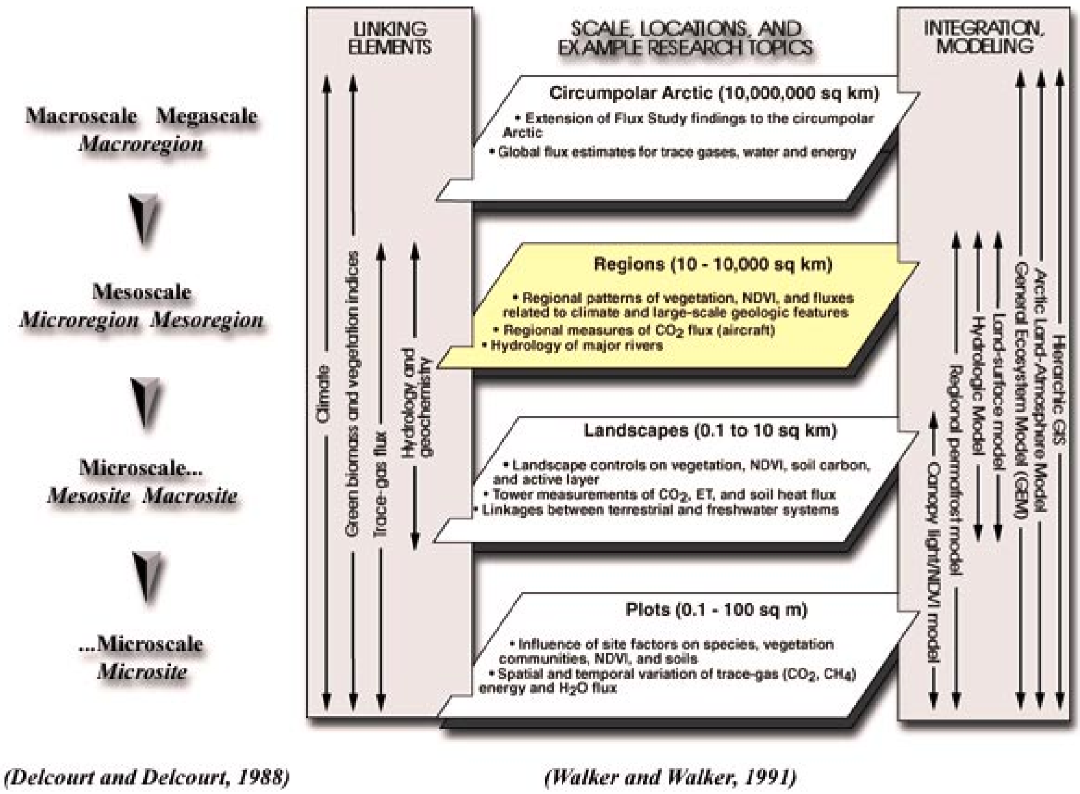
- bathymetry and topography (includes both terrestrial and ocean-bottom digital elevation models (DEMs), and contours);
- geodetic control and/or global positioning systems (GPS);
- sea ice coverage;
- sea surface temperature;
- ocean currents;
- atmospheric currents;
- permafrost;
- social (census, traditional use patterns, etc.);
- place names;
- populated places;
- human infrastructure (roads, pipelines, sea routes, power distribution lines, landing strips, etc.)
- land use and land cover (including vegetation);

- marine and terrestrial habitats;
- satellite remote sensing data;
- coastline;
- cadastral (land ownership and rights, including mineral rights);
- geology (surficial and subsurface);
- soils;
- benthic types;
- meteorological (station locations and data);
- hydrology and glacial;
- contaminant distributions;
- protected areas;
- political and administrative boundaries;
- physiographic boundaries and eco-regions;
- study locations.

Some of these data topics are common to the National Spatial Data Initiative (NSDI) definitions of framework data layers in the U.S., and those of other regional and international initiatives. It is likely that agency data producers will do their best to comply with those standards over time, thus the arctic research community will benefit from those efforts. Participation in the development and implementation of the standards by the research community will help to ensure that the resulting information is responsive to researchers' needs.

Science-specific framework data. It is evident that some of the standard framework layer definitions will need extension or refinement to meet the needs of arctic researchers. Data layers that are not recognized as framework data by the broader community of GIS users will need to be addressed directly by the scientific community. There may be a need to convene committees of domain experts to develop content and format standards for such things as glaciers, sea ice, and permafrost, for example (Figure 7 on page 32).

Data integration. The adoption by the research community of common framework data layers at various scales can help ensure that new information developed in reference to those layers will be more spatially integrated than would otherwise be possible. Consistent and accurate use of GPS technology also can assist in achieving spatial integration. The definition of domain content and format standards for layers that are specific to arctic science will



help in the data integration process by establishing a common data quality framework, and also will help to ensure interoperability among data topics to support integrative modeling and simulation.

Figure 7. Possible data framework layers, scales, and potential applications in the Arctic (Figure courtesy of Skip Walker, University of Alaska Fairbanks, Northern Ecosystems Analysis and Mapping Laboratory http://www.neaml.uaf.edu/).

DATA QUALITY. Metadata should describe scientific datasets at a level sufficient for other researchers to decide whether it is appropriate for their application or not. Data quality is a relative term; what might serve well for one purpose will not be of sufficient spatial or temporal detail to support another, or the definition or structure of the data may render them unusable for those other purposes. All framework datasets made available to the research community must be subjected to an appropriate level of quality control, and must be described in enough detail to inform others before they commit to using it in their work. Increasingly, electronic journals and other computer-based distribution allow rigorous review and rapid availability of geodatasets.

COMPILATION OF FRAMEWORK DATA FROM EXISTING SOURCE MATERIAL. Much of the data that have been collected for the Arctic exist in a variety of media, formats, scales and spatial resolutions. Others may never have been produced in a usable, digital form, and they may be hidden away in paper form in filing cabinets, undocumented archives and personal libraries. Some may have been cataloged but are now lost. Development of some framework data layers may require the careful consolidation and integration of various collateral data sources. One example of this is the new arctic digital bathymetric grid model developed under the auspices of the International Bathymetric Chart of the Arctic Ocean (IBCAO) and presented at the workshop by Martin Jakobsson (Figure 8).

Compilation, integration and automation of information from several collateral sources can be a significant and resource-intensive undertaking that should be approached through a structured and well-designed process. Such a process requires careful consideration of the needs of the stakeholders, the nature and quality of the existing sources, the availability of resources to carry out the effort, and definition as to how the information will be maintained in the future, among other issues.

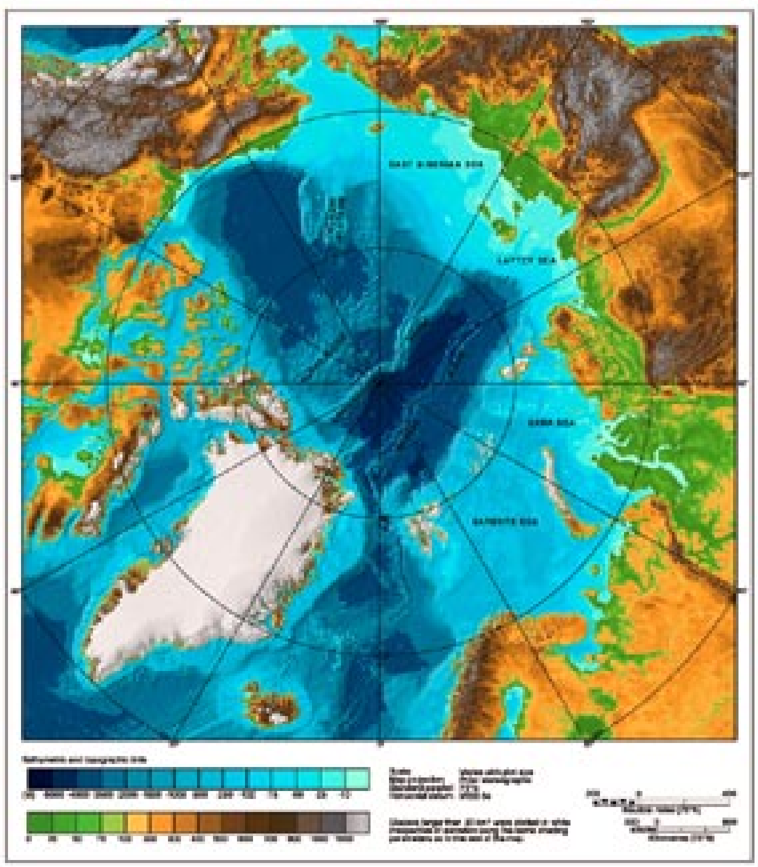


Figure 8. International Bathymetric Chart of the Arctic Ocean (IBCAO, http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html). Development of this chart engaged the volunteer efforts of investigators who are affiliated with eleven institutions in Canada, Denmark, Germany, Iceland, Norway, Russia, Sweden, and the U.S. The activity has also been endorsed and/or supported financially by the Intergovernmental Oceanographic Commission (IOC), the International Arctic Science Committee (IASC), the International Hydrographic Organization (IHO), the U.S. Office of Naval Research (ONR), and the U.S. National Geophysical Data Center (NGDC).

STANDARD DATA COMPILATION SCALES. In principle, arctic researchers need information that is applicable to the broadest range of spatial scales, from microtopography to landscape to global scales. Within that range of scales, there was a general consensus that several intermediate scales would support the primary needs of most researchers.

TREATMENT OF NON-FRAMEWORK DATA. Data specific to a particular project or research agenda and not included in the definition of framework data need to be cataloged according to the standard metadata conventions for future reference, but there may be no need for them to be forced to conform to specific content and structure standards. It may be useful for the community to monitor these projects over time, to identify repeating data topic clusters that may point towards subjects for potential future standards development. Data innovations add value to the geographic information for the arctic, particularly insofar as they can be built upon or utilized by others.

OTHER DATA MODEL INNOVATIONS. Some workshop participants indicated that commercial off-the-shelf software does not effectively address some data modeling needs of the arctic research community such as continuous surface, volumetric modeling, fluid, finite element, time series and other such constructs. Members of the community should be encouraged to develop or collaborate with GIS professionals or software vendors in the development and integration of data constructs that more effectively meet their needs.

A comprehensive* Data Catalog for the Arctic, *based on standard metadata, should be established. There is a large amount of data available for the arctic region, and a significant number of sources have been cataloged at one level or another in different repositories.

CONSOLIDATION OF EXISTING DATA CATALOGS. At present there are several data catalogs in existence that reference a significant number and variety of data sources for the Arctic. These do not conform to common metadata standards or format, however, and many are not being updated regularly or at all, some are not easy to search, or the search results are not reliable.

PROJECT METADATA. The arctic science community would benefit from a catalog describing past, on-going, and planned research projects tied to a location or region. The Arctic Monitoring and Assessment Programme (AMAP) has initiated a database of arctic research projects, now available at http://www.amap.no/pd2000.htm. Reseachers can add their projects to the database and search for studies currently being conducted. When used, this information can greatly assist logistical efforts and would foster interdisciplinary collaboration. Information from studies in or near communities or sensitive ecosystems is readily available. Catalogs of project metadata need to be kept up-to-date with information on the objectives and the spatial and thematic scope of the research.

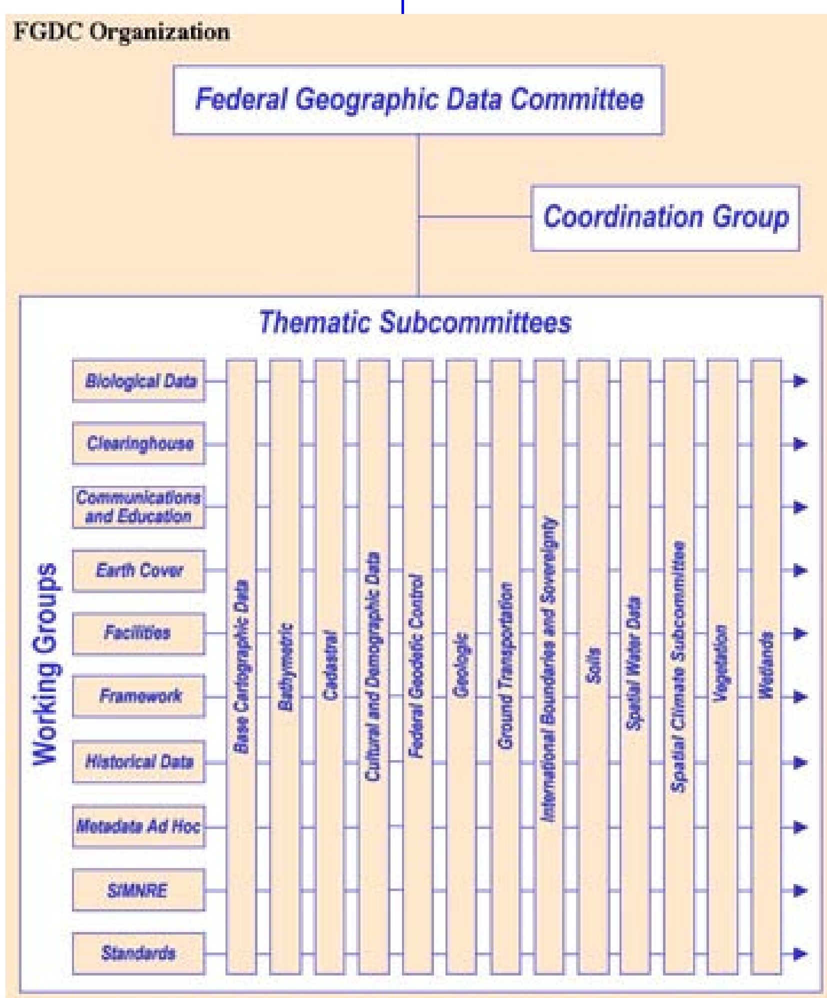
ARCTIC METADATA STANDARD REFINEMENT. The spatial metadata standards being developed by the international GIS community may provide a useful starting point, but the special needs of arctic research will likely require extension and refinement of metadata content and descriptive semantics. It will require a significant effort to convert existing legacy catalogs to a new standard and many organizations will not have the resources needed to carry this out immediately.

3.2.2 Organizational and Administrative Framework

A comprehensive Data Clearinghouse and coordination function is needed. There exist several organizations that perform some level of data clearinghouse function within the Arctic, but most of these are not coordinated with the other clearinghouses, or with the research community at-large. The USGS NSDI Clearinghouse node represents the broadest range of U.S. based arctic stakeholders at present. Figure 9 shows the working groups and subcommittees organized by a coordination group within the FGDC, which coordinates the development of the NSDI. GRID-Arendal in Norway has possibly the largest international constituency. Other repositories are housed within various academic and research institutions. Clearinghouse issues that will need to be addressed include, but are not limited to the following:

DECENTRALIZED DATA MANAGEMENT WITH SOME LEVEL OF CENTRALIZED COORDINATION AND FACILITATION. The volume of spatial data for the arctic prohibits a single entity from managing all aspects of GIS data cataloging and sharing. To maintain researcher control over data and data integrity, data authors and their organizations should be responsible

Figure 9. Organizational tree of the Federal Geographic Data Committee (FGDC), which coordinates the development of the National Spatial Data Infrastructure (NSDI). (Figure from the FGDC web site http://www.fgdc.gov/fgdc/fgdcmap.html)



for management and upkeep of data. Entities with the necessary facilities can act as nodes, distributed throught the world, but connected by the Internet and with mutual data standards and protocols. Coordination and facilitation could ensure that metadata are being collected and that common purpose data are being compiled according to content and format standards established by the community. A centralized function could accept data from authors who do not have the infrastructure to support data management and dissemination. This coordination and facilitation entity would ensure long-term accessibility and quality of data stored within the distributed node network.

POLICY FRAMEWORK FOR DATA ACCESS AND DISSEMINATION. A commonly accepted policy framework that establishes the basis for data sharing among the research community needs to be developed. This policy framework should address data access and distribution protocol, data security for private or sensitive information, follow-up on NSF and other data publishing policies, funding to cover costs for data management and dissemination, and related issues.

COMMON DATA DELIVERY SYSTEM. Spatial data in the Arctic are distributed among many archives and with various data dissemination policies and technical infrastructure. A mechanism that will facilitate and guarantee consistent and reliable access to information by all stakeholders in an efficient manner is necessary.

COMMON FORMAT CONVERSION CAPABILITY. Researchers will primarily want to acquire the information they need in a format that is immediately usable without much additional processing. Creating a transparent user interface means the development of search, download, and format conversion routines or Internet-based mapping services that are specifically tailored to the needs of this research community.

PROVIDE SOME LEVEL OF SUPPORT INFRASTRUCTURE FOR THOSE WHO NEED IT. Some level of facility and technical support may be needed by researchers and organizations that do not have their own infrastructure. This may include everything from access to Internet map servers for publishing their data, to on-call technical support for data and software issues. While the cost of entry to the use of GIS has lowered significantly in recent years, it is still prohibitive for some would-be participants. Access to com-

Organizational and Administrative Framework Tasks

- Create a comprehensive Data Clearinghouse and coordination function
- Archive existing data
- Facilitate cross-pollination of arctic research and GIS expertise
- Build a closer collaborative relationship between arctic research and GIS communities for mutual benefit

mon infrastructure and low or no-cost technical support could help lessen this burden.

COMMUNICATIONS INFRASTRUCTURE. Many parts of the Arctic do not have access to reasonable communications infrastructure or sufficient data communications bandwidth, and are therefore constrained from some Internet-based functions. These constraints will need to be considered as the clearinghouse and coordination functions are evolved.

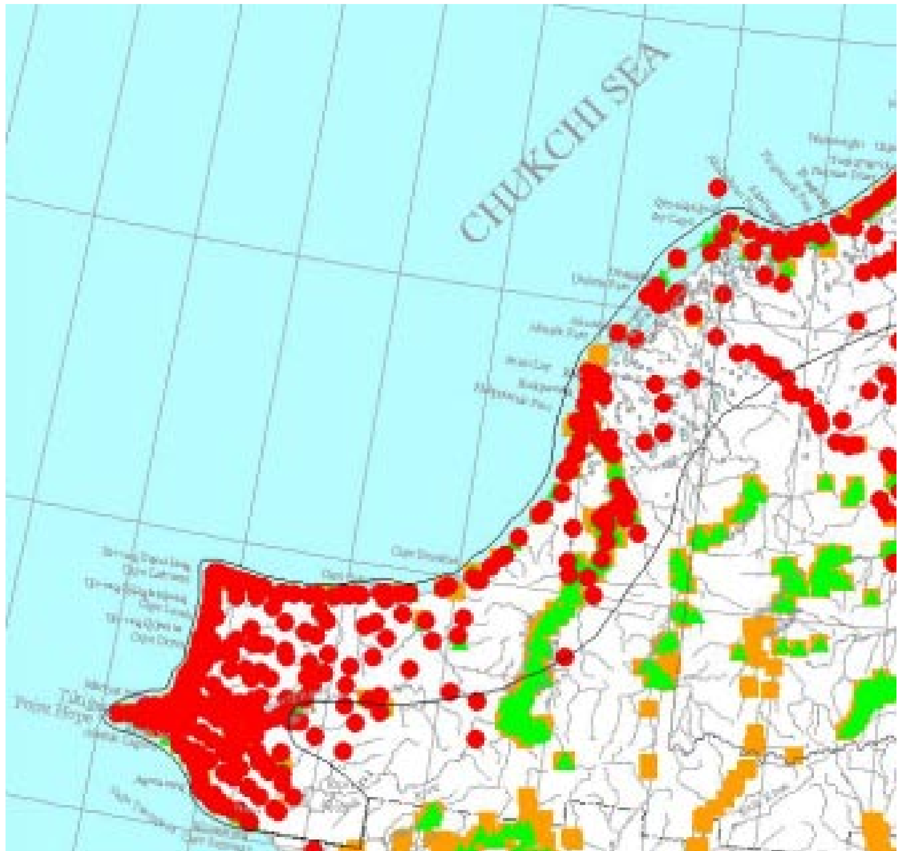


Figure 10. An example of an historical database in peril. The figure shows cultural database information automated by the Alaska North Slope Borough (NSB) Planning Department GIS Division from hard copy records compiled in the 1970s and early 1980s. The North Slope Cultural Site Inventory consist of 2,377 sites documented by archeologist Edwin S. Hall. The North Slope Borough Traditional Land Use Inventory (TLUI) consists of location information, place names and descriptive text for hundreds of sites which document and continue to describe the living culture of the Iñupiaq Eskimo. Funding shortfalls may result in the loss of the NSB GIS Division, leaving no steward for these and other GIS data from the North Slope Borough. (Figure courtesy of Allison Graves.)

Existing data must be archived. There exists a large body of arctic data that have been created over the years and the rate of collection is accelerating. Some data sets are threatened by becoming misplaced or destroyed due to lack of funding or proper management (Figure 10). Some data were never properly documented or archived and need intensive reconstruction. Most research organizations are not set up to manage large data collections and do not have the infrastructure, resources, or technical expertise to do so, particularly if there is no obvious way in which the data are being used. With some infrastructure, these organizations can have access to the technical assistance needed to manage their data, data can be transported to safer locations, and other users can have access to existing data.

Cross-pollination of arctic research and GIS expertise yields better results. Although some research institutions in the Arctic are making great progress in the application of GIS to their fields of endeavor, there still exists a large gap between disciplinary science and GI Science/Information Technology (IT). There are many technological and ontological contributions that the latter can provide the former, and the GIS field will be further enriched by the special needs, insights, and ideas of the research community.

Awareness building. A majority of the scientific research community has little comprehensive exposure to what GIS technology and the concept of spatial data infrastructure have to offer. The development of various media, primers, demonstrations, pilot projects, conference presentations, and published articles may help to increase awareness and support.

Skill development. Not all scientists will want or need to develop comprehensive GIS skills. Some may wish to use GIS in their work, but rely on GIS specialists to support them. Others may wish to become fully proficient with the technology, and still others may not want to become involved at all. Broad community acceptance and use of the technology may not occur until there is a critical mass of "early adopters" demonstrating the utility of the tools through exemplary scientific work.

Increase opportunities for researchers to learn more about GIS. Researchers should have access to training programs that are tailored to their needs for the application of GIS to scientific research problems. The blending of GI Science with disciplinary science will need to address a variety of areas, including analysis of requirements, data structure and database design, application design, application programming, spatial analysis, cartographic design, and data visualization, among others.

GIS technical support specialists should be trained from within the community. There are not many GIS professionals who can understand and effectively support the scientific community. This combination of skills is not yet a discipline that is taught in many schools. It is clear that some tiered levels of technical support will be needed to assist institutions and individual researchers in adopting the technology as an integral part of their work. Producing such individuals may require teaching scientists to be GIS specialists, or training GIS professionals to understand the real needs of the scientific community.

Arctic research and GIS communities benefit from a closer collaborative relationship. The arctic GIS community has been particularly active in the development and application of GIS technology; some of the agency applications go back twenty years or more. GIS community members like the USGS and several other Federal and State agencies are intimately involved in the National Spatial Data Initiative (NSDI) and the implementation of metadata standards, framework data standards, and clearinghouse functions discussed previously.

ALIGN THE RESEARCH COMMUNITY WITH EXISTING NATIONAL AND INTERNATIONAL INITIATIVES. Direct or indirect participation in the national (NSDI) and global (GSDI) initiatives and the Open GIS Consortium (OGC) can help the research community become familiar with the strategic directions of those efforts. Such participation also could give the community a role in shaping technical and policy issues responsive to the needs of the scientific community. This participation could consist of direct membership in the various technical committees and policy-setting bodies. It could also be indirect, by working with the USGS or other agencies and institutions in the Arctic that are already active in those arenas.

ESTABLISH A MORE DIRECT RELATIONSHIP WITH DATA PRODUCERS. The research community can become more involved with the primary data producers in the arctic region. This would help the producers to better understand researchers' needs and to develop base information that is more responsive to those needs.

CONTRIBUTE TO THE DEVELOPMENT OF FRAMEWORK DATA STANDARDS THAT ARE RESPONSIVE TO THE NEEDS OF SCIENCE. Participation in existing spatial data infrastructure initiatives and closer collaboration with primary data producers could help in the formulation of framework data standards that are more responsive to the needs of arctic scientists.

APPLY PROVEN METHODS TO SCIENCE-SPECIFIC ISSUES. Considerable investment has been made over the past decade at the national and global levels to define methods and standards for supporting the development of spatial data infrastructures. The scientific community in the Arctic can benefit from examining what has worked and what has not, as it moves forward with its own efforts.

3.2.3 Tools

Tools are the hardware, software, network and other technical components that comprise a spatial data infrastructure for the Arctic.

Arctic researchers want easy-to-use access to information. Implementing a comprehensive regional infrastructure will be a significant undertaking. But like any infrastructure, such as telephones or roads, most end users do not need to understand the underlying complexity and, if possible, should be shielded from wasting time getting to know it. The sidebar on this page illustrates the straight-forward access and interaction with the system that would be most useful to typical researchers, agency staff, or students working with geospatial data in arctic research.

Arctic science requires special analytical modeling and simulation software functionality. Many of the same constraints listed previously for data model constructs apply as well to the analysis functionality of the available commercial off-the-shelf (COTS) software. Arctic science has particular needs, some of which are unique to the polar environment. Specific examples cited by workshop participants of software functionality not well supported by mainstream COTS software include:

- 3D and 4D dynamic modeling;
- finite element modeling;
- volumetric analysis;
- time series modeling;
- fluid dynamics.

Considerations regarding special needs of arctic science include the following:

THE RESEARCH COMMUNITY LACKS A COMMON VOICE FOR PROMOTING THE DEVELOPMENT OF NEW SOFTWARE TOOLS BY COMMERCIAL VENDORS OR INSTITUTIONS. Other industries have been able to make their needs known to vendors and developers and have been successful in having those needs incorporated in new software. Existing efforts by researchers and academic institutions to develop specialized tools for the scientific community are not well coordinated. Many of these efforts are not accessible to the larger community or are not broadly advertised or supported. The development of a common forum for identifying, defining, and communicating the needs of the scientific community to the software vendors and institutions clearly needs more exploration.

INNOVATIONS IN SOFTWARE ARCHITECTURE MAY HELP SCIENTISTS TO BETTER INTEGRATE THEIR MODELS WITH GIS. The move towards component architecture in software development

Transparent User Interface for Arctic Geographic Information Infrastructure (GII)

A Researcher, Agency-user, or Student need to:

- **Find** a clearinghouse website easily
- **Browse** or search for GIS layers of interest
- **View** the layer, or a combination of layers
- **Examine** the metadata for the layer(s), to determine project relevance
- **Manipulate** the layer(s) through online spatial analysis
- **Download** the layer(s) in commonly accepted image or data formats
- **Access** related websites easily
- **Upload** new data layers and metadata for public access
- **Communicate** and **collaborate** with other Arctic GIS users, within and across disciplines

will help to open the door for specialized modeling that is better integrated with the GIS environment. Using GIS components, modelers can develop specialized functions on top of COTS base functionality, thus taking advantage of existing software functionality while incorporating special analysis techniques.

3.2.4 Culture

The most significant building block for any regional spatial data initiative also is the most difficult to define. Past experience suggests that the culture of any group of stakeholders will more quickly drive a regional data sharing initiative to success or failure than all the other technical issues combined. Understanding the motives, aspirations, methods, practices, biases, and values of the scientific research community is critical to designing the form and function of a useful and sustainable information infrastructure and defining the path necessary to achieve it.

Arctic research is the focus, GIS is one set of tools that can support it. Basic and applied research is the central focus of disciplinary scientists. This focus should not be lost on information technology, which is, after all, only a tool. At the same time, modern science cannot be accomplished without modern tools and GIS technology and information infrastructure are emerging issues increasingly fundamental to science.

Spatial data information as a fundamental component of science infrastructure. Data is the backbone of research. While facilities like research stations and ice-breaker ships are commonly recognized as necessary infrastructure for arctic research, data systems generally are not.

PUBLISH OR PERISH. The peer-reviewed and published scientific findings of the research community represent its knowledge base. These contributions are well recognized and rewarded as valid professional accomplishments. There is no equivalent recognition for data publishing in the current research culture. Nevertheless, data publishing can extend the ability of researchers to collaborate and develop their knowledge base.

INVESTING MONEY IN ARCTIC GIS. Researchers tend to work in grant-to-grant funding cycles of only a few years. To be an effective tool for arctic research in the long term, infra-

Projects or Programs Providing Arctic GIS Data

- Arctic Environmental Atlas
  http://www.grida.no/
- Arctic Mapping and Assessment Programme
  http://www.amap.no/
- Circumpolar Arctic Geobotanical Atlas
  http://www.neaml.uaf.edu/
- International Bathymentry Chart of the Arctic Ocean
  http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html
- Master Environmental Library (MEL)
  http://mel.dmso.mil/
- National Snow and Ice Data Center
  http://nsidc.org/index.html

structure improvements such as an arctic SDI must have sustained funding for maintenance and development. Infrastructure improvements, such as facilities remodeling or the construction of an ocean-going research vessel, are often construed as competition for research funding, despite their obvious value to large groups of researchers. Arctic SDI is an investment that should occur only if it will increase the efficiency and value of science.

Developing a data infrastructure to facilitate sharing of spatial data reduces duplication of data collection, provides framework data layers for the Arctic, and enables logistics coordination and collaboration among colleagues. A handful of institutions have endeavored to develop their own internal information infrastructure. Some of these exist primarily to support their own research activities, but others make information publicly available, thereby providing a significant benefit to researchers. Figure 8 on page 33, the International Bathymetric Map of the Arctic Ocean, provides an example of spatial data sharing in the arctic that resulted from an international collaborative effort to produce a data set useable to all marine scientists in the arctic.

Incentives and disincentives. Sponsors of information infrastructure typically must wield both the carrot and the stick to encourage researchers to participate in a regionally coordinated effort to share arctic spatial data.

COMPLIANCE WITH DATA DOCUMENTATION AND CONTENT STANDARDS. Requirements for metadata documentation and the imposition of content standards for framework data maybe considered intrusive by some researchers. Without strong incentives or consequences (e.g., no metadata, no funding), researchers may resist spending time on standardized data preparation or documentation activities. An infrastructure that provides data support to researchers can work with researchers to minimize the burden. When individual researchers begin to benefit directly from the results of data documentation and content standards, voluntary compliance will likely increase.

RELUCTANCE TO RELEASE DATA TOO EARLY OR AT ALL. Research careers are built largely on reputation, and that reputation is, in part, based on publishing findings supported by original data. Researchers often need time to interpret data, detect patterns, or reconcile anomalies, and thus, may be resistant to releasing information prior to peer review and publication of their findings. Many researchers prefer not to share data because it reduces their control of the information and increases the likelihood that others may gain a competitive advantage. Sharing data after they are published is valuble to future research, as GIS layers are built up over time. Information infrastructure managers should clearly define incentives for and consequences of not sharing data and provide researchers with the time necessary to collect and analyze their data.

FUNDING AGENCY REQUIREMENTS MUST BE SPECIFIC AND DILIGENTLY ENFORCED. Funding agencies have the power of the purse-string and the ability to impose and enforce standards and regional collaboration. Similarly, funding agencies have the resources and connection to researchers to facilitate compliance with data standards. Participants felt that agency requirements should be clearly specified and diligently enforced to ensure compliance. Currently, NSF requirements for submitting data impose no content or format standards or metadata documentation and are not peer reviewed, nor does the NSF Office of Polar Programs have the resources to follow up or enforce standards. Within some specific NSF funded research programs or groups of researchers, common data management infrastructures have been set-up and supported.

PUBLIC OUTREACH IS NOT A COMMON CHARACTERISTIC OF THE RESEARCH CULTURE. The taxpaying public and most policy makers generally are not aware of arctic research and the significance of research results unless it makes the evening news. GIS tools may be useful in helping researchers convey the significance of their work in graphically compelling easily understood by non-scientists. For the most part, researchers and their institutions are expected to organize and make the effort to participate in education and outreach and to provide information to the public, although more recently funding agencies are stipulating that outreach activities are necessary to secure research funding.

To address the challenges described in section 3.0, a range of implementation considerations and recommendations to increase awareness, communication, and incentives are presented in section 4.0.

4.0 Implementation Considerations

The development of an arctic spatial data infrastructure requires a plan that will carry the process through implementation, maintenance, proliferation, and adaptive management. The planning process should include short-term steps for building a comprehensive arctic spatial data infrastructure (SDI) and it should establish methods that ensure long-term utility of the SDI. Five steps emerged from the workshop as the necessary first steps to developing a sustainable, complete SDI to support arctic research. These steps are discussed in detail in this section.

Organize Representation of the Arctic Research Community

(1) Some form of organization is needed to represent and coordinate the spatial data infrastructure interests of the arctic research community. A sustainable organization is necessary to represent and advance the needs of the research community as a whole. This organization would, preferably, be international in scope, with participation from research institutions, academia, and agencies from the eight arctic nations.

> SMALL ON BUREAUCRACY AND LARGE ON MEASURABLE RESULTS. Participants indicated that a coordinating committee or other small group of representatives should be mobilized to facilitate and coordinate the common initiatives of the research community. Other members could be drafted to participate in focused working groups to address specific issues. Funding would be needed to cover expenses, along with a core permanent staff to support and follow up on the directions set by the coordinating committee. Institutions and agencies acting as nodes would contribute some staff time, and possibly a small membership fee to support operational costs. The Committee would focus on identification of immediately useful and actionable initiatives that could be carried out in concert with others, or through funded research projects. Such an organization also could host web-based issue forums and periodic meetings of data managers and researchers to address issues of mutual interest.
>
> ARCTIC SCIENCE INFORMATION INFRASTRUCTURE PORTAL SITE. Participants suggested the establishment of a centralized clearinghouse portal that would facilitate access to distributed information sources.

Five Initial Steps to Implementation of an Arctic Spatial Data Infrastructure (SDI)

- Organize Representation of the Arctic Research Community
- Align Data Producers with Standards Bodies
- Develop an Arctic Spatial Data Catalog
- Implement Demonstration Projects
- Initiate Data Archiving and Stewardship.

Domain working groups. Working groups could be set up on an as-needed basis to address specific issues, such as framework data specifications and framework modeling application development.

Progress monitoring and adaptive planning. The fields of GIS and SDI are evolving rapidly. The arctic research community has special needs that should be developed and strategically integrated or aligned with broader efforts already underway. This integration will occur in an environment of nearly constant, dynamic change. The coordinating committee function can help to monitor these dynamics, evaluate the effectiveness of existing programs, and suggest course changes and new developments and innovations for consideration by the larger research community.

Outreach and public access. The coordinating committee also could assist the arctic research community in making science more accessible to local communities and the general public. Outreach through common media such as television and easy access to information in forms that are understandable to the lay public would help the public and decision-makers to understand the role, significance, and impacts of science in their everyday lives.

Librarian support function. Some organizations do not have the infrastructure, resources, or expertise to deal directly with metadata cataloging and related activities. Some participants suggested establishing a spatial librarian function that could support this need, among other duties.

Align Data Producers and Standards Bodies

(2) Primary data producers and standards bodies align and develop domain working groups to address issues unique to the arctic research community. The international GIS community has committed a significant amount of time and resources over the past decade toward the development of national and global spatial data initiatives. Many primary data producers in the Arctic are already participating in those efforts. The research community can take advantage of those investments by aligning and collaborating with the existing community.

Organize and fund research projects to address special domain issues. The arctic research community has specific data and analysis needs that are not being addressed by the broader GIS community. These will require focused attention that can be accomplished by domain-specific research projects. These projects should first address the identification of community priorities and needs that can be articulated as general specifications for future projects. Actual development work for priority components could then be carried out through those projects:

- Framework data. Identification of framework data topics needed most commonly by the community, assessment of existing data sources, estimate of time and resources needed for development, and definition of a strategic plan defining specific projects for future implementation.

- Framework modeling applications. Identification of framework modeling applications needed most commonly by the community, assessment of existing models, estimate of time and resources needed for development of priority components, and definition of a strategic plan defining specific projects for future implementation.

- Transparent data searching, acquisition and/or web-based mapping services tailored to the needs of researchers.

Develop an Arctic Spatial Data Catalog

(3) Develop a comprehensive Arctic Spatial Data Catalog. A specific initiative is needed to develop a comprehensive spatial data catalog for the Arctic, including high priority, common interest data topics and based on a common metadata standard. For the most part, this effort would consist of consolidating and integrating information from several existing catalogs.

First phase minimal metadata set. The first incarnation of the catalog would focus on common interest data that are presently available in digital form, and might be based on a minimal set of metadata fields that can be developed quickly.

Online metadata tools. In parallel, an easy to use, web-based metadata form could allow current researchers and archivists to start documenting their data, and consolidating that information to a common clearinghouse.

Implement Demonstration Projects

(4) Implement strategic projects to demonstrate the value of the SDI concept to arctic research. The usefulness of an integrated GIS capability for the Arctic can be shown clearly with the initiation of select efforts. Such projects can take advantage of the efficiency and organizational resources of small groups of investigators. Various approaches to defining strategic projects were suggested, including:

MAJOR RESEARCH ISSUE. Under this scenario, a single major research topic like global climate change could be used as the defining framework for the development of a pilot program. The pilot would need to identify the research components to be addressed, data needs, modeling needs, and demonstrate the process and results through some focused investigation. The Arctic Climate Impact Assessment (ACIA) was suggested as an example of an effort in which collaborative, international, interdisciplinary efforts resulted in a synthesis of information about a focal question in the Arctic (http://www.acia.uaf.edu/).

SPECIFIC COMMUNITY OR GEOGRAPHIC AREA. A specific geographic area or community could be chosen as the basis for a pilot program. The area or community chosen should represent the broadest set of natural and human environmental questions that could be effectively addressed.

SPECIFIC EXISTING INSTITUTE AND ITS PROJECTS. Several institutes have already developed significant spatial data infrastructure to support their own projects and research agendas. One or more of these could be used to demonstrate the refinement of such programs to meet metadata and data content standards, data integration, integrated modeling and other issues.

IMPLEMENT AWARENESS BUILDING AND PROFESSIONAL DEVELOPMENT PROGRAMS. An effective spatial data infrastructure to support arctic scientific research will require significant effort and the support of the majority of the research community. Building support and commitment will require building awareness of the technology and its potential significance to the advancement of basic and applied science in the Arctic. It also will need to include opportunities for new and established researchers to learn new skills and concepts as a part of their ongoing professional development.

Initiate Data Archiving and Stewardship

(5) Initiate a Science Data Archiving and Stewardship function. There is a significant amount of legacy scientific data for the Arctic that is threatened with extinction if active steps are not taken to protect it. Other resources remain inaccessible to the community because the sponsoring organizations have neither the resources nor expertise to manage, exploit and promote these resources. A function needs to be developed that will:

- Identify, acquire and preserve significant Arctic datasets that are at risk of being lost;
- Establish an international outreach program to locate important historical arctic data, and facilitate a program to retrieve, document and archive them;
- Assist other organizations to improve data stewardship where such assistance is needed.

5.0 Summary of Arctic Spatial Data Infrastructure (SDI) Implementation Strategies

The establishment of an arctic spatial data infrastructure (SDI) requires an organized approach to assimilating the existing GIS data and metadata for the arctic, recruiting and archiving new data, and disseminating GIS data. An advisory group of arctic researchers and experts in GIS standards and administration could guide and coordinate the process, including archiving existing data, developing an arctic data catalog, designing a plan for the incorporation of new GIS data, and providing for the long-term maintenence of a SDI to support arctic research. Combining future efforts to improve arctic GIS with existing U.S. and international spatial data sharing programs would increase useability of a spatial data infrastructure for the Arctic.

Strategic projects involving small groups of arctic researchers demonstrate the value of an arctic SDI. Such focused projects might rely on existing data to design an approach that builds on the arctic spatial data inventory and contributes new data, collected and archived according to international standards and made publicly available. A geographic information infrastructure built strategically upon such efforts would do much to benefit arctic research, while allowing for flexible and diverse implementation. In addition to supporting and enhancing arctic research, a growing arctic geographic information infrastructure will provide long-term benefits for education and outreach, land management decision-making, and environmental problem solving.

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