Arctic Spatial Data Infrastructure (SDI) for Scientific Research

White paper

Discussion Draft

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Revision History

Name	Date	Reason For Changes	Version
Mark Sorensen, GPC Stuart Rich, SGCI Sabine Hoover, AMERICEC Dick Lawrence, ESRI	02/14/2004	Develop Draft Whitepaper	1.0
Allison Graves, Nuna Technologies Andrew Balser, University of Fairbanks Craig Tweedie, Michigan State University	06/01/2004	Comment and revise Draft Whitepaper	1.1
Mark Sorensen, GPC Sabine Hoover, AMERICEC	06/11/2004	Incorporate comments into Final Whitepaper	2.0

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Executive Summary

Geographic Information Systems (GIS) have become an indispensable tool for managing and using spatial information at the local, regional, national and global levels. Many organizations need the same information, but in most countries and regions — including the Arctic — there is no effective structure for the effective coordination and sharing of these data. The concept of a Spatial Data Infrastructure (SDI) has been implemented in many parts of the world, and provides a framework of standards, policies, data, procedures, and technology to support the effective coordination and dissemination of spatial information across many sectors and levels of government and society. This sort of SDI framework is under consideration for the multinational Arctic community, towards the development of an Circumarctic SDI based on international SDI standards and thus linked to the growing global network, but extended in a manner that is required to address the special needs of the Arctic scientific research community.

At present, Arctic GIS and related information are distributed and uncoordinated throughout many organizations, although several consolidation nodes have been developed by specific institutions. The community has worked together during the past couple of years to consider the potential for a more coordinated vision for capturing and managing geospatial and other research related information in a more synchronized and mutually beneficial manner.

This paper presents the framework for an Internet-based Portal to serve as a foundation component in an Arctic Spatial Data Infrastructure (ASDI) to support scientific research in the multinational Arctic region. This kind of ASDI Portal infrastructure could help improve access to available spatial data, promote its reuse, and ensure that additional investment in spatial information collection and management results in an ever-growing, readily available and useable network of information. While such an information infrastructure can built on mainstream geospatial portal concepts and tools, this paper also explores other special needs specific to the Arctic research community, including the development of metadata standards and potential applications such as the research logistics support application or educational outreach applications, to name but a few.

There is a clear need — particularly in light of today's climate change scenarios — to be able to access, integrate and use spatial data from disparate sources in guiding decision making. Our ability then, to make sound decisions collectively at the local, regional, and global levels, is dependent on the implementation of a sound infrastructure that provides compatibility across jurisdictions and promotes data access and use.

Only through common conventions and technical agreements will it be feasible for local communities, nations and regional decision-makers to discover, acquire, explore and share geographic information vital to the decision-making process. The use of common conventions and technical agreements also makes sound economic sense by limiting the cost involved in the integration of information from various sources, as well as

eliminating the need for parallel and costly development of tools for discovering, exchanging and exploiting spatial data.

An initial Draft Whitepaper was circulated among the Arctic research community for review, and comments were subsequently incorporated into a Final Whitepaper. The current document is intended to serve as a basic framework and catalyst for moving forward with the ASDI Portal Initiative.

1.0 Conceptual ASDI Portal Architecture

This document presents a framework for a Arctic Spatial Data Infrastructure (ASDI) Portal architecture. The ASDI concept describes requirements for computer technologies, policies, and people necessary to promote the sharing of scientifically-relevant geospatial and other information throughout all levels of research institutions, government researchers and resource managers, individual researchers, non-governmental organizations, and the academic community. The Portal is intended to interconnect information sharing nodes across the Internet — and in many cases over secure networks — to share information with one another openly (i.e., based on the best available set of working, widely adopted practices and methods). These and other types of Geographic Information System (GIS) portals are being built at national, state, and local levels for geographic information access and sharing. It is expected that many of these portals will be central sites that users can readily access and search in the future. The ASDI can build on those efforts, but must be extended and refined to meet the special requirements of the Circumarctic scientific research communities.

Building this kind of research support information infrastructure for the Circumarctic region will be a long-term process that will require coordination and collaboration between the many data producing scientists, institutions and land management agencies that comprise the potential stakeholder community.

A list of Fundament Geographic Data Set (FGDS) layers has been prioritized for the Arctic region (shown in Figure 1.) Existing researchers and several agency geospatial data producers have considerable GIS and mapping experience and expect to manage and maintain geospatial data specific to their mission in the future. It follows that data custodianship for specific FGDS layers should remain with lead organizations that currently collect and maintain this type of information.

In the future, it is expected that additional institutions and agencies may contribute shareable geospatial information assets, including data and services that go beyond those required as basic infrastructure items for research support, environmental and cultural resource management.
To meet the primary goals of easily accessible and shareable geospatial and related research information in this environment implies an overall SDI architecture as a distributed network of nodes that are connected through the Internet. Shareable data sets are provided through data nodes

What is a Geospatial (Catalog) Portal?

A GIS metadata catalog plays the same role as a card catalog in a library. The card catalog in a library has a record for each holding. All catalog records are compiled into one comprehensive catalog and indexed by author, subject, and title (and other keywords) so that the catalog can be searched. In a GIS, each dataset has a metadata document. The concept behind a GIS catalog portal— or *Geospatial Portal* — is that these metadata documents are collected into a comprehensive metadata catalog that can be indexed by various means, such as by geographic location. The catalog portal can then be searched to find candidate datasets for use. Just as in a library search, each metadata record in a Geospatial portal can be viewed. Optionally, users can connect to and explore the actual dataset to make a decision about its potential use. This is a critical function necessary for advanced GIS applications.

that are hosted by the individual FGDS data custodians. The goal of easy access to geospatial information resources is met by providing a central, high-availability portal with a current metadata catalog and associated search and discovery services. This concept is illustrated in Figure 2.

Figure 2 shows a selection of existing nodes that could be part of the ASDI, with one node for each proposed FGDS data custodian agency (shown as red squares). Also included are additional nodes that may have data assets available for publication (shown as blue boxes). A single, central portal site consists of a metadata repository to which all nodes would publish their data holdings. This concept is based on the internationally established National Spatial Data Infrastructure, NSDI (note: from this point onwards, we are referring to the Circumarctic SDI as the ASDI, for lack of a better term).

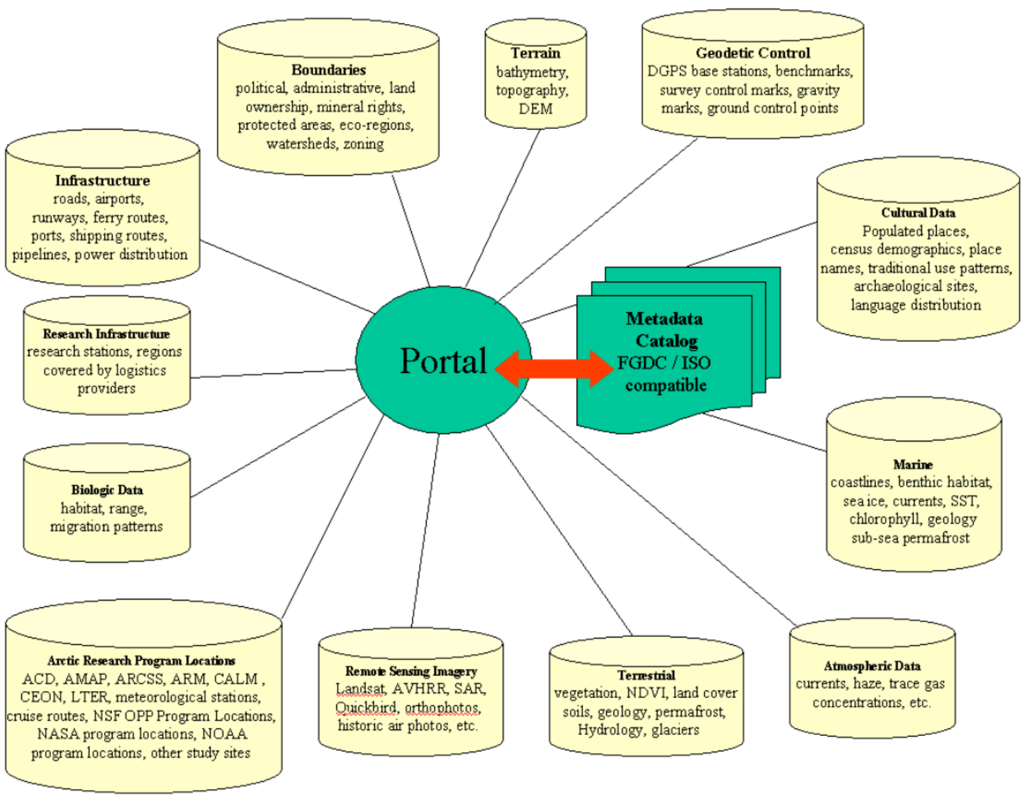

Figure 1. Fundamental Geographic Data Set (FGDS) Layers

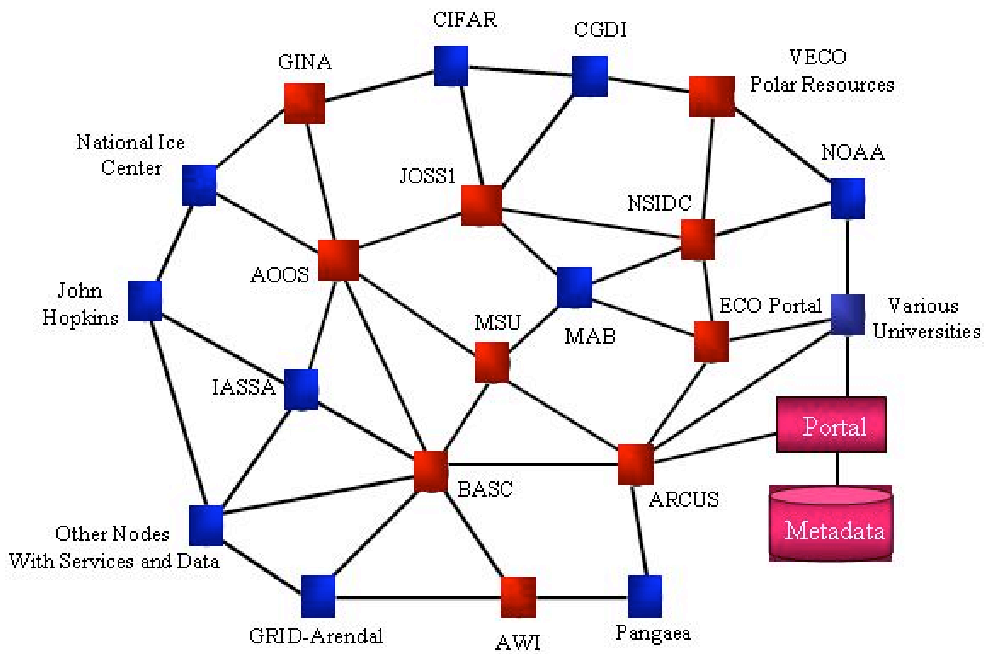

Figure 2. Circumarctic SDI Conceptual Architecture[1]

Essentially, by becoming an ASDI node, an institution of agencies would opt to publish its data as a node on the central metadata portal. At the same time, the agency would also subscribe to data on other nodes through the portal. This will provide initial capabilities for data sharing and will foster partnerships. For example, FGDS data that is published on the portal could be fused dynamically to create standard map products or to create custom map products and services.

The conceptual structure suggested above is fundamental to SDI and is currently in place or being implemented in a number of countries and regions around the world, including the U.S., India, European Union, Thailand, and others.

While the concept presented here envisions a separate physical node for each custodian agency with its own hardware and software infrastructure, sharing of facilities between nodes, especially in circumstances where data holdings are limited, could be an effective way to realize savings in terms of hardware/software infrastructure costs. Other methods

[1] This infrastructure is conceptual only and the links between the various organizations and agencies are fictional. Definitions of acronyms are presented in Appendix A.

to achieve this would be to establish infrastructure standards and consolidate purchases as part of strategic planning and budgeting that could occur under the auspices of various organizations such as the US National Science Foundation, Global Ocean Observing System (GOOS) and the Global Terrestrial Observing System (GTOS at www.fao.org/gtos) or the National Office for Integrated and Sustained Ocean Observations of the US (IOOS at www.ocean.us), for example.

Building Blocks of an SDI:

The three key activities of an SDI include:

1. GIS data publishers document and register their datasets in a metadata Catalog.

2. Users search for data at Metadata Catalog Servers to find potential datasets for use. This is similar in concept to a library catalog search.

3. Users directly connect to a GIS data service or download datasets for use in their application. Intensive data investigation (via live GIS data services) if often a crucial step before advanced GIS use.

An SDI requires:

- Catalogs of GIS data holdings (the building and hosting of a series of GIS catalog search portals).

- Content standards (adoption by user communities of common, multipurpose GIS data models).

- A commitment by data publishers to ensure a persistent trusted source of GIS information and services

While Figure 2 illustrates an overall architecture, it should be noted that during the early phases of ASDI implementation, the online availability of agency nodes might be limited to certain key agencies that have existing geospatial data holdings suitable for publication. Examples include:

University of Colorado Arctic Climate Project
http://www.colorado.edu/Research/HARC/gisdatab.html

National Snow and Ice Data Center
http://nsidc.org/index.html

EOS Data Services
http://eospso.gsfc.nasa.gov/eos_homepage/data_services.php

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

Further, to overcome existing limitations in network infrastructure, replicating certain data required for mission critical applications (e.g., support of research logistics) to the portal or other central high-availability site should be a consideration. This conceptual approach is being implemented on a smaller scale with the Alaska Ocean Observation System (AOOS) where the Geographic Information Network of Alaska (GINA) at the University of Alaska will serve as a portal for regional AOOS nodes in Alaska that may be based in remote locations. Pilot studies are an excellent framework to test capacity (number of hits a server can handle) and fault tolerance.

In a recent 2003 project, the application performance of the Barrow Area Information Database – Internet Map Server (BAID-IMS) was tested between two mirrored sites. A server located at the United States' northernmost research hub at Barrow, Alaska, experienced timeout issues due to satellite based Internet communication and seasonal sun spot activity. BAID-IMS performed seven times faster on a server running at Michigan State University (MSU) when compared with the mirrored site in Barrow, Alaska.

> ***Note:*** The guidelines for a pilot project for the Prince William Sound Observation System were discussed at the AOOS data management meeting and will be implemented in 2004-2005 between Cordova and the University of Alaska Fairbanks (UAF). This will be an interesting project to follow.

To realize the vision of shareable and easily accessible resources through a distributed network of ASDI nodes and a central portal, ASDI components including data, applications, and services will have to be developed and deployed according to a common framework of standards:

- FGDS and/or ISO metadata content should be standardized based on recognized standards frameworks. Specialized metadata for issues that are specific to research and not addressed by current standards (e.g. research project descriptions, logistics requirements, etc.) will need to be developed.
- Hardware and software infrastructure should be based on common IT standards.
- Applications and services should adhere to common specifications, protocols, and interfaces.

Finally, some of the key benefits of an ASDI can be summarized as follows:

- One-stop shop search system for geospatial and related Arctic data
- Data is described through metadata (ISO 19115/FGDC) and made searchable through many local catalogs known as Clearinghouse Nodes
  - Improves search precision and relevance
  - Improves appropriate use and sharing of data

- Ability to search and discover information from any node
- Ability to access data through a variety of mechanisms – for example, via connections to data streaming services, access to map services, and data downloads in numerous desired formats
- Includes free and for-fee data
- Provides an open network for the Arctic research community
- Intuitive web-based operation for low-tech users to visualize information
- Enhances international connections to share data and information
- Can be extended to include Arctic logistics and resource coordination and other research project information for common reference.

The following sections further describe the critical components of the NSDI architecture, including the portal and agency nodes.

2.0 Conceptual Architecture of the Portal

The primary function of the portal is to provide a metadata catalog of geospatial information holdings and services. As such, the ASDI portal would fulfill the same role as a library catalog. In a library, holdings are typically compiled into one comprehensive catalog and indexed by author, subject, title, and other keywords. Similarly, the concept behind the ASDI portal is a central catalog of metadata documents indexed by various means, including geographic components. ASDI data producers will have mechanisms to publish their holdings to the portal. Data users in turn will be able to access this centralized catalog to find candidate data sets or services for use. Similar to a library catalog, users will be able to view the metadata record of a specific data set, or may be able to connect directly to a specific source to further explore its suitability for their specific purposes. Figure 3 presents a conceptual overview of an example central metadata portal as a connecting point between ASDI data publishers and user communities, illustrated by the example of Thailand.

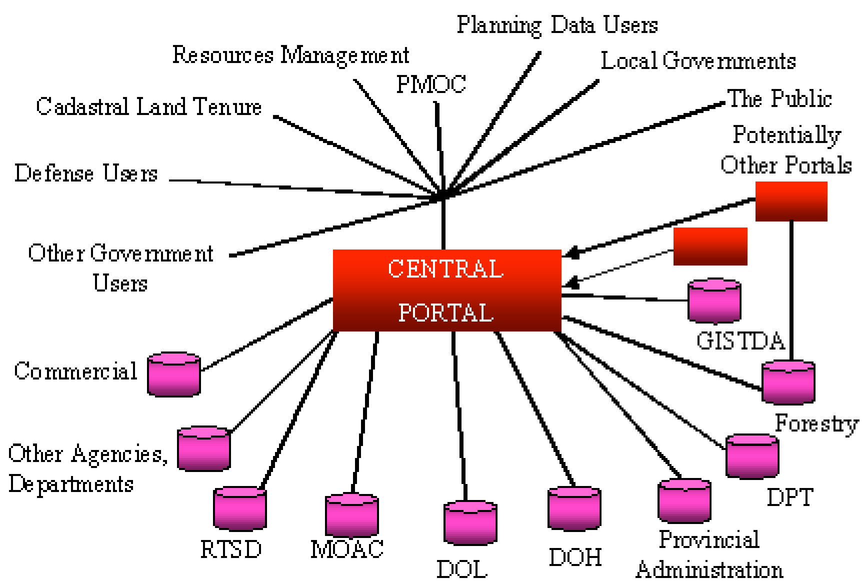

Figure 3. NSDI Portal Business Viewpoint[2]

[2] This figure was developed in the context of a Thailand National Spatial Data Infrastructure (NSDI) Feasibility Study, funded by the U.S. Trade and Development Agency (USTDA). The feasibility study was conducted during November 2003 through April 2004. Definitions of acronyms are presented in Appendix A. The Thailand portal has not yet been implemented, but the underlying technology and basic concepts can be explored at the U.S. Bureau of Land Management sponsored site at http://www.geodata.gov.

The portal provides a high-availability online access point. Data producing agencies such as the University of Alaska, UNH EOS, UNEP GRID Arendal and others will publish their data sets to the portal via standardized metadata records. User communities (which in turn may also be data producers) will access the portal to examine data holdings and connect to potential data providers. The portal as well as geospatial information services providers will utilize standardized protocols for information access and exchange. Therefore, users of the portal will not need any specialized knowledge about how data is stored and maintained by an organization. They will simply connect to the portal location via an Internet browser and execute data access and discovery functions provided by the browser client.

As the ASDI grows, other portals may become available that may support more specialized data or functions. For example, there may be topical portals (atmosphere and climate, oceanography/hydrology, environmental, research logistics, etc.), or regional portals (e.g., specialized resources in different regions in the Arctic). Data authoring organizations would continue to maintain their own information and associated metadata. To maintain the concept of providing a central access point to geographic information, the central catalog would periodically harvest pre-approved metadata and data from these portals to remain synchronized.

While the central portal interacts with data provider and user communities through standardized protocols, the components of the portal broadly speaking consists of a multi-tier architecture with data components, server side software components, and end user applications. Figure 4 illustrates the system components of the central portal.

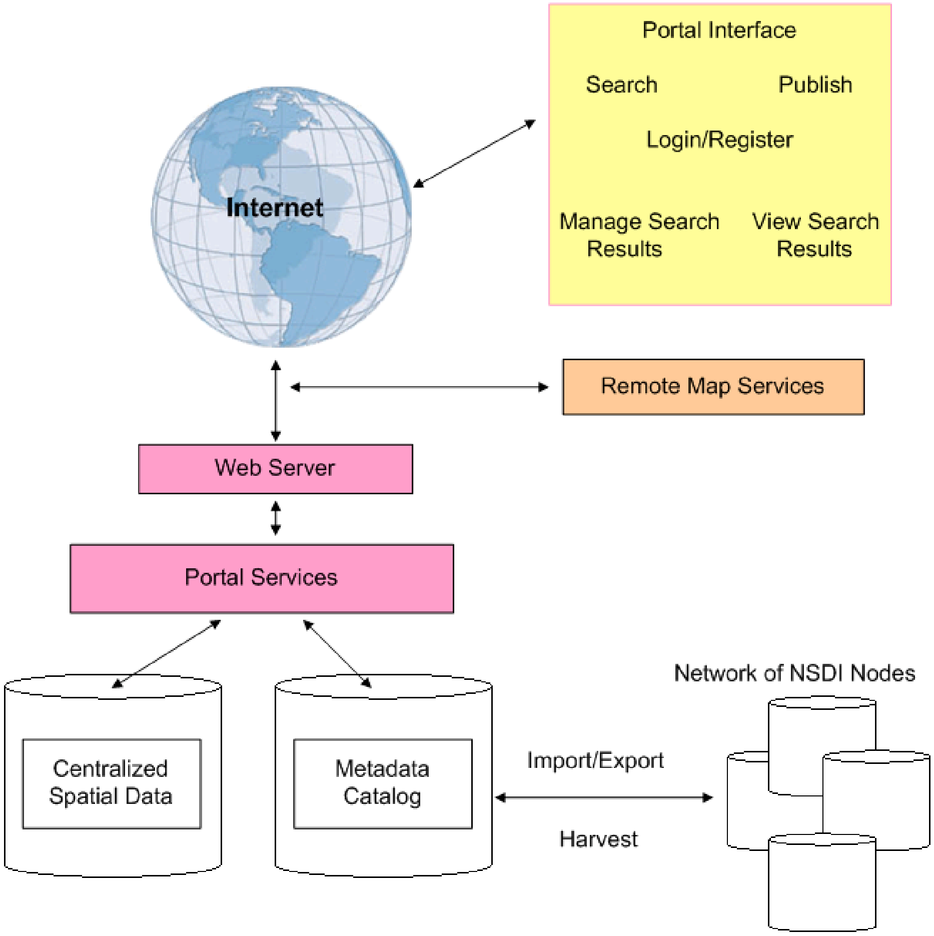

Figure 4. System Components of the Central ASDI Portal

The following sections describe each of the basic portal components.

2.1 Metadata Catalog

This is the central, coordinated metadata catalog of data holdings. To support standardized searches against this catalog, the repository should be based on Relational Database Management System (RDBMS) technology and should hold metadata records that are published according to established metadata standards. For the ASDI, this will likely involve a metadata profile based on the ISO 19115 standard. Scripts should be made available to convert metadata records in the Federal Geographic Data Committee (FGDC) format to the ISO 19115 standard. The role of metadata for the ASDI is to support the fundamental goal of data sharing. Additional standards will need to be developed to address data and issues that represent evolving requirements of the Circumarctic scientific research community. Therefore, the content of metadata should be aimed at supporting the following:

- Catalog searches;
- Simple, high level descriptions of data sets;
- Providing details to determine appropriate uses of a data set, especially in circumstances where a user cannot connect and directly browse the data set to infer those details.

In the context of the ISO 19115 standards, these functions can be supported by deploying metadata records with a limited set of core attributes that are populated.

A complete and current metadata catalog of geospatial information holdings is critical to the success of a metadata portal. To provide this capability two complementary strategies are typically considered:

- **Perform distributed searches from a centralized Web site.** In this approach, users access a central Web site, but rather than providing a centralized metadata repository, a distributed search against many separate catalogs is performed. This approach ensures that users will always have the most up-to-date view of a provider's (shared) metadata, assuming the distributed node is online. However, such a search will incur a performance hit for each individual node that is searched and will require high availability of all nodes in the network to ensure consistent search results.

Why is Metadata important?

Documentation and metadata serve as the fundamental foundation of any trustworthy information system, enabling proper data creation, storage, retrieval, use, modification, retention, and destruction.
Metadata can be simply defined as "data about data." More specifically, metadata consists of a standardized structured format and controlled vocabulary that allow for the precise description of record content, location, and value. Metadata often includes (but is not limited to) attributes like file type, file name, creator name, date of creation, and use restrictions. Metadata capture, whether automatic or manual, is a process built into the actual information.
Furthermore, metadata is important because it:

- Assigns relative quality
- Defines relative limitations
- Improves appropriate use of data
- Improves data sharing
- Improves search precision and relevance

- **Harvest catalogs into one central database for focused search and access.** In this approach, metadata content from other providers is periodically harvested into a central database. Assuming a portal that is implemented with high availability, this ensures a high performance search with a consistent result set. However, depending on the frequency of catalog synchronization, users may not always have the most up-to-date view of current data holdings.

For implementation of the central portal in the Arctic, it is recommended to employ the harvesting approach. This approach can provide a single, consolidated point for metadata query from which users can discover and in some cases directly link to and acquire data from a network of distributed nodes.

The central catalog with harvesting will require periodic synchronization of the catalog but will realize the following important advantages:

- ***Improved search performance.*** Since searches will go only against a single catalog there is less performance impact. Also, individual data provider nodes will not have to build infrastructure to support metadata searches against their nodes.

- ***Consistent results sets.*** Only the central catalog is searched; therefore, search results are not dependent on the availability of other online services as is the case for distributed searchers.

- ***Search results are more easily interpreted.*** A single set of results is returned rather than multiple result sets that are difficult to reconcile and sort.

2.2 Centralized Spatial Data Repository

To support searches based on spatial criteria as well as visualization of search results, the portal will include basic spatial data holdings in various data themes, such as boundaries, geographic names, and topographic information. Given that network infrastructure may be limited particularly early in the NSDI implementation, providing a centralized data repository for mission critical applications should also be considered. This repository would be available to special user groups (e.g. researchers, policy makers, educators, public) and would contain critical data that is replicated from data producing agencies at regular intervals.

2.3 Portal Services

The middle tier of the portal architecture will contain standards-based software for the services the portal will provide to its clients. Although there are many possibilities for implementing portal services, portal services should be based on industry standards and specifications, for example, with respect to APIs and software protocols. Distributed nodes adopting the same standards for metadata could allow the ASDI to use and benefit the existing infrastructure of data archives throughout the Arctic – essentially they provide the data sequestration interface and the Arctic SDI etc provides the networking of these infrastructures.

Portal services can be categorized as follows:

- **Access Services.** These services provide the ability to explore, query, and use data and services. Services will have to be able to control access levels to the catalog to ensure sensitive information remains secure.

- **Metadata Catalog Services.** These are database utilities that store metadata documents in an RDBMS that are accessible through the portal. Utilities include:

    - Ability to store metadata documents in XML format.
    - Capabilities to Add/Delete/Modify metadata documents.
    - Search for documents that satisfy a spatial or keyword query.
    - Support document indexing.

- **Metadata Search Services.** These services provide the middleware components that allow searches for metadata contained in the central metadata repository. The services will have to support spatial, thematic, temporal, or keyword search criteria. Services will also have to provide capabilities for intelligent sorting, full metadata viewing, and spatial footprint viewing. Based on search results the user will be able to access the referenced services, data sets, or applications.

- **Map and Spatial Data Viewing Services.** These services will allow users of the portal to browse, explore, and query map data; view multiple spatial data viewing services; and save map views.

- **Content Management Services.** These services are directed at data providers and will allow them to publish their data holdings in a variety of ways. The most common types of services include:

    - **Metadata file (XML) submission.** Allows providers to submit individual metadata files.

    - **Online metadata entry service.** Allows providers to submit metadata through an online form.

- **Metadata harvesting service.** Allows providers to register their metadata repository to be automatically harvested. Metadata harvesting promotes the rapid development, maintenance, and use of diverse metadata repositories within a distributed network. Harvesting services can include the following:

- Exposing some or all of a repository contents to other ASDI portals or applications.
- Populate the central metadata catalog by gathering documents from other repositories.
- Harvest distributed repositories using the Open Archive Initiative Protocol for Metadata Harvesting (OAI-PMH) or Web Accessible Folders with XML files containing the metadata.

- **Administration Services.** These services allow backend administrators to manage the portal. Services required include:
  - **User Account Management.** User account management consists of the functions necessary to support user registration, authorize metadata publishing, associate published metadata with users, and save maps and searches.
  - **SDI Portal Administration.** The Administration component will allow portal administrators to review, manage, approve, and reject published metadata and users.

2.4 Web Server

The function of the Web server component is to support communication between portal services of the middle tier and Web client applications. Web servers typically translate Web HTTP traffic generated by user requests into communications that are understood by portal services.

2.5 Client Applications

Since the central portal will function as an Internet application, many of the basic client applications will essentially be Web browser applications (thin clients). Client applications will be provided via a portal Web site with the functional capabilities needed to publish and search metadata, and to visualize and directly connect to spatial data and services over a distributed network (i.e., the World Wide Web).

It should be noted that most essential portal functions described above could be supported by thin clients such as HTML viewers for example. The use of thin clients is advantageous, because it minimizes network traffic, which will be an important consideration for ASDI implementation, especially in the near-term. However, portal clients may ultimately also support thick clients that provide more sophisticated application capabilities.

3.0 Participating Agency Nodes

The primary function of the individual nodes in the ASDI is to provide shareable geospatial information resources to end-users. As previously discussed, the conceptual design for the ASDI envisions a distributed network of ASDI nodes, with each FGDS data custodian contributing a separate node to the ASDI. At the same time, the individual ASDI data custodians will publish their shareable geospatial data information holdings to the central ASDI portal.

Being a node in the ASDI network will mean that the participating custodian agency (and others in the future) will publish the specific data content that is deemed to be of common interest to others. Therefore, shareable resources will in most circumstances be a subset of geospatial information a specific FGDS custodian node produces and maintains. At the same time, a contributing ASDI node will still separately maintain specialized data, including that specific to its mission.

To achieve the benefits envisioned by the ASDI, these shareable resources will depend on the definition and implementation of common data structures, data models, and services interfaces. This implies development of agency node components that are based on existing industry IT, data, and process standards. However, these standards do not address some of the special needs of the Arctic research community, thus it is fully expected that it will be important to initiate parallel efforts among the research community to address and integrate those needs over time.

The conceptual design of an agency node is illustrated in Figure 5.

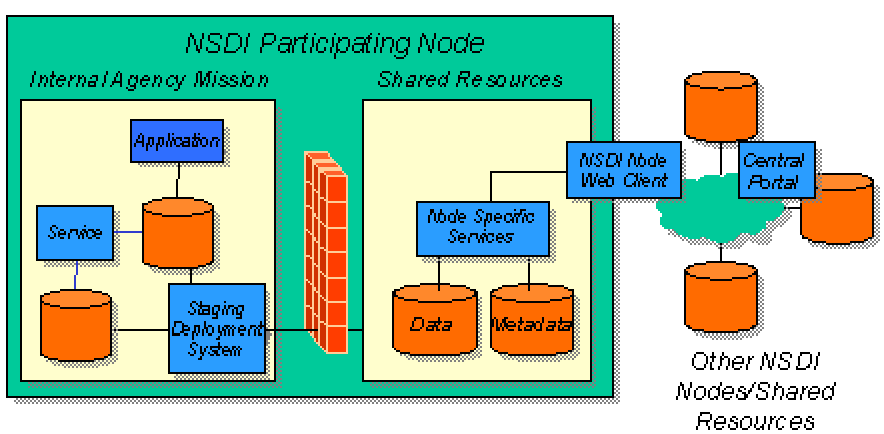

Figure 5. ASDI Participating Node Conceptual Design

As Figure 5 illustrates, an ASDI participating node will consist of the following basic components:

- **Backend agency systems.** These systems will consist of agency specific databases, services, and applications, including those required to produce specific shareable geospatial information resources such as FGDS. These systems will typically exist inside an organization's firewall. Basic architecture components will vary based on an agency's mission but, in support of ASDI, will most critically have to support functions such as FGDS layers as well as associated metadata creation.

- **Staging and deployment environment for shared resources.** This environment will consist of systems and processes required to stage and deploy shareable resources. As shareable resources are deployed on the ASDI participating nodes, these systems serve to initially separate shareable resources from others, process and format them according to the standards required for sharing, perform quality assurance, and move shareable resources to an environment that is accessible by others.

- **System and data repositories with shared resources (data, applications).** These resources will consist of shareable data and services and will typically exist outside an agency's firewall. Metadata regarding these resources will be published to the portal. Users discovering these data resources on the central portal will then access them by connecting to services provided by the node, typically via a Web browser. As illustrated in Figure 5, the basic architecture of system components that support shared resources is conceptually similar to that of the central portal.

The following summarizes ASDI related tools and functions that will have to be provided by those nodes that will participate in the ASDI for the Circumarctic Region:

- **Tools for metadata creation and publication.** In order to publish shared resources, participating agencies will have to create metadata that adheres to the standards established by the ASDI. Institutions and agencies will have a number of mechanisms available for accomplishing this (e.g., those tools and services that are provided by the portal) utilizing one of the many standards-based applications that are available to support the chosen ASDI metadata standard.

Note: At the recent AOOS Data Management workshop in Anchorage, the Ecological Metadata Language (EML) standard was presented as a possible standard for IOOS/AOOS. EML formatted metadata is being developed for NSF's Long Term Ecological Research (LTER network.) The participants of AOOS felt that the EML based web tools for compiling metadata were very useful (for those without GIS software) but that FGDC should be retained as the metadata standard for AOOS with translation scripts to convert from EML to FGDC. These will be made available on the web sites below in the near future:

http://gce-lter.marsci.uga.edu/lter/data/eml_metadata.htm
http://knb.ecoinformatics.org/software/eml/

- **Database construction tools, specifically for the creation and maintenance of FGDS.** In order to have shareable resources, the various custodian nodes must be able to create and maintain FGDS data. Establishing this environment will initially depend on the definition of the content and database structures for FGDS (through the auspices of a Circumarctic GIS Committee, for example) and devising implementation roadmaps and specifications for FGDS layers. Implementing FGDS based on these specifications will then involve conversion of existing digital sources to the required format or automating geospatial data through the use of GIS editing tools. A wide variety of GIS products are available to meet these needs. Specific functions include:

    - Initial database construction tools, including comprehensive editing, data conversion, and data automation;

    - Geoprocessing tools that support format conversions, topology construction, coordinate management, tabular and attribute manipulation, generalization, and data validation;

    - Database management tools to allow transactions and updates against all information sets;

    - Work flow management tools to manage data production processes.

- **Services for accessing, viewing, using/obtaining data.** Once users have discovered an appropriate data source through the central portal, they will need the capability to connect to the participating ASDI node for access to data services. These can include live data services (e.g., a Web map or data downloading service). In circumstances where no such services are yet available, users should at least have the capability to read descriptions about a data set and contact the appropriate provider. This situation might be desirable for proprietary and/or sensitive data where the data custodian would prefer to be consulted before releasing the information (in the case of certain types of satellite imagery, archaeological sites, subsistence harvest data, etc.) Early in the deployment of the ASDI in the Circumarctic Region, live data services may be limited by network and other infrastructure limitations. In terms of architecture, the structure of these services will be similar to those deployed as part of the central portal. Specific services that should be considered as high priority include:

    - **Web map services.** These allow spatial data visualization and can effectively demonstrate the benefits of data sharing. For example, many standards-based, open access tools exist to deploy such services in a short time frame and they can be used effectively to integrate data sources from multiple providers even in environments where infrastructure is limited.

- **Downloading services.** These types of services place heavier demands on network infrastructure but are the most direct mechanism for users to obtain data. A number of methods should be considered, including "clip-zip-ship" methodologies or FTP nodes. A clip-zip-and ship methodology, for example, will let the user specify a subset of data. The downloading service will then extract it, compress it, and send it (via email or a posting mechanisms) to the user.

- **Services that allow direct use of geospatial data in GIS applications.** This may be a longer-term goal. However, experience has shown that as data sharing concepts take hold, and network infrastructures grow, users expect to realize the convenience of using specific data sources directly in their GIS applications.

- **Tools for management of shared data resources, including staging and deployment.** These types of tools are oriented toward batch processing operations and include system level tools for database management operations such as importing and exporting data sets, as well as application deployment.

Logistics Catalog Services. Doing research in the Arctic often requires significant logistical support to reach the research area. An online catalog of logistical support suppliers and past, present and planned field activities can be developed to allow researchers to better understand the support capabilities that are available to them.

4.0 NSDI Database Architecture

The proposed ASDI data architecture can be closely aligned with the ASDI system architecture. ASDI data components would consist of FGDS layers as defined by the Circumarctic GIS community. The FGDS layers would be stored in standardized database or exchange formats at data custodian nodes. A centralized metadata repository can hold a catalog of data holdings that is structured in a manner allowing library-like catalog searches. Individual data custodians would be responsible for publishing their geospatial information holdings to the central catalog via standardized metadata records. At the same time, the FGDS data custodian nodes can subscribe to services through the central portal.

As such, the ASDI data architecture can be distributed with each FGDS data custodian serving as the data node for the FGDS data layers that are its responsibility. The concept is illustrated in Figure 6.

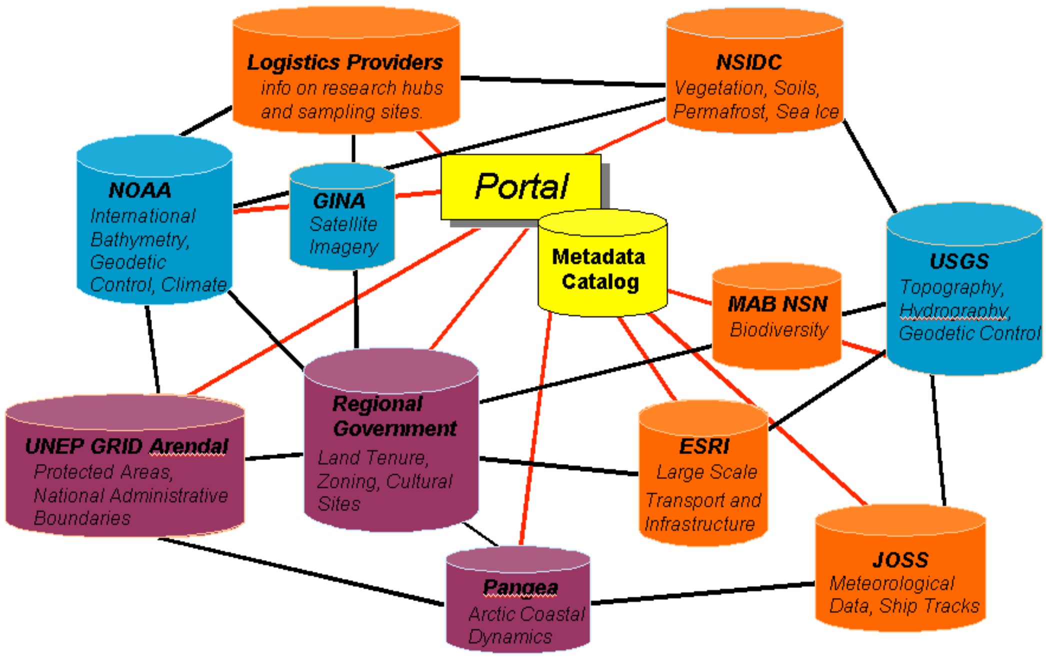

Figure 6. Distributed Network of ASDI Data Custodians

As is evident from Figure 6, the distribution of data nodes reveals several important sub groupings and structural/topical components that are relevant for ASDI deployment:

- There is considerable separation of data custodianship based on scale. For example, regional government entities such as Alaska's North Slope Borough would be responsible for maintaining relatively large scale cadastral data for its jurisdiction. While UNEP would provide coarser data on administrative boundaries for the entire Arctic region. This will require interagency coordination to derive consistent data content specifications.

- Ownership of large-scale FGDS data layers is more distributed than that of medium and small-scale sources. This is sensible, because large-scale data tends to be more specialized thereby requiring a greater compilation effort and expertise that might be quite concentrated in a specific agency.

- While distributing data custodianship, building a complete set of FGDS layers, particularly at the large scale, will involve considerable coordination between multiple data custodians that are designated to own these layers. The Circumarctic GIS Commission and its potential subcommittees and working groups could provide the framework for this coordination.

The current availability of data resources suggests that the initial deployment of FGDS could provide considerable data assets by focusing on a small number of nodes:

- The central portal with a metadata catalog of existing data holdings (whether or not currently deployable in digital form). A central portal is critical to initiate the one-stop data access that is needed not only to promote data sharing, but also to facilitate accessibility to resources that are described in a standardized way. While the final location of the central portal will have to be determined in the future, it will likely include an agency with credentials in administering data for a large stakeholder community. Suggested possibilities are to host the portal at a coordinating institution, or to perhaps utilize other centralized locations with resources.

- National Snow and Ice Data Center for temporal ice analysis

- NASA EOS for satellite imagery

- UNEP for various environmental data sets

As the ASDI expands other data providers will likely contribute data resources as separate nodes. However, for ASDI implementation data custodians of FGDS data should be given the highest priority.

The following subsections provide further information on the data and database architecture of the portal and contributing agency nodes.

4.1 Metadata Catalog

The metadata catalog for the ASDI in the Circumarctic Region would be a central data repository that allows users to search and discover geospatial information assets in a standardized manner that resembles library catalog searches. While metadata describing the individual data holdings would be the most critical for this repository, the central catalog database would also have to contain the data sets that users need to initially formulate specific searches and visualize search results. At the same time, the central catalog will require data structures that support the maintenance and management of

How to use a Geospatial Portal:

Users need to find GIS data for use in their applications. They need to explore datasets and often perform further geoprocessing on the data to make it usable (and often simply just to certify that the dataset is appropriate for use in their applications).

Users typically perform the following tasks to discover available information at GIS catalog portals:

- Connect to and search specific portals.
- Discover and investigate candidate data to find appropriate datasets for specific purposes. This may be as simple as reviewing the metadata record for a datasets or as involved as further geoprocessing on the data for validation.
- Connect to live data services (e.g., a GIS Web service), download data (e.g., from an FTP node), or contact the provider for the data.
- Integrate and use the selected data in the application.

metadata, for example, through harvesting. As the critical part needed by users as well as data producers for data publication, discovery, and sharing, it is recommended to deploy the central catalog repository as a high availability environment with redundant databases. The concept of the metadata catalog is illustrated in Figure 7.

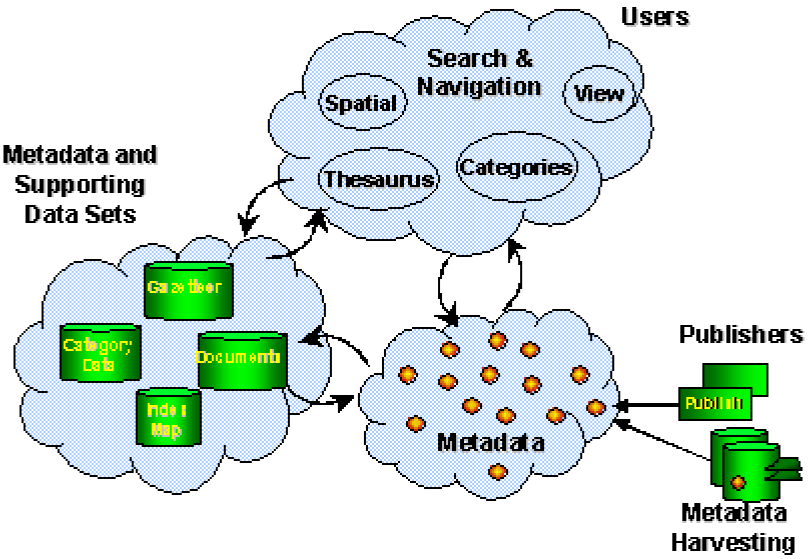

Figure 7. Metadata Catalog Data Concept and Interactions

To successfully support the basic functions of the metadata catalog, the central repository will have to contain the following data components:

- Documents (typically in XML format), with descriptive information about data sets. These may be stored separately or within an RDBMS.
- Tabular information stored in an appropriate relational model that identifies information needed for searching such as subjects and keywords.
- Individual records for data sets with linkages to documents as well as tables with subjects and keywords.
- Spatial information to discover searches and visualization of searches. Examples are a gazetteer (place name index), reference maps, map indexes.
- Database tables needed for metadata administration, including metadata submittal, review, and quality assurance.

From a conceptual perspective, the portal itself will not hold significant spatial data holdings, other than those that are needed to support the search and visualization functions of the portal. However, to realize good data access of some data holdings that may need to be available with high reliability in an environment with limited network infrastructure, physical architecture of the portal could be designed to support the deployment of some critical FGDS data holdings.

Based on previous work, the metadata content that will be stored in the central catalog will likely be based on the ISO 19115 Standard or perhaps related harmonized metadata standards such as FGDC. These standards have a large number of properties that can be used to document a GIS data set. When selecting from these properties to document GIS data sets for the NSDI, it is important to focus on those properties that support the fundamental goal of data sharing.

- **Support catalog searches.** Data should be categorized at a minimum in terms of keywords and subjects. Therefore, attributes should be collected that allow consistent searches against the catalog.

- **Provide simple, high-level descriptions.** To provide an overview of a data set, data set owners should provide at least a data abstract. To provide access to a data set, an end user must know the origin and ownership of a data set. Therefore, contact information should be part of the metadata.

- **Provide details to determine appropriate uses of a data set.** To ensure the goal of data sharing is realized, users must have access to important information about the content, accuracy, and quality of a data set. Therefore, data providers should provide metadata to these properties of a GIS data set.

For the ISO 19115 Standard, a core set of approximately 20 attributes can provide all the critical information needed to support these goals. Their content and how they support specific goals of metadata are summarized in Table 1. Additional metadata will be required to address some issues that are specific to the Circumarctic research community.

Table 1. Core ISO 19115 Metadata Components and Their Function for the Central Portal

Metadata Attribute	Function
Data set title	High level description, subject search
Abstract describing the data set	High level description
Metadata point of contact	Accessibility, sharing
Data set responsible party	Accessibility, sharing
Online resource	Accessibility, sharing
Data set topic category	Category, subject, keyword search
Geographic location (bounding rectangle) of the data	Spatial search

Metadata Attribute	Function
Additional extent information for the data set (vertical and temporal)	Spatial search
Data set reference date	Temporal search
Spatial resolution of the data set	Usability
Distribution format	Usability
Spatial representation type	Usability
Reference system	Usability
Lineage	Usability
Data set language	Search, usability
Data set character set	Search, usability
Metadata language	Search, usability
Metadata character set	Search, usability
Metadata date stamp	Metadata maintenance
Metadata file identifier	Metadata maintenance
Metadata standard name	Metadata maintenance
Metadata standard version	Metadata maintenance

If necessary, this set of core attributes could be further reduced. A minimal set of attributes and the metadata functions each will support are summarized in Table 2.

Table 2. Minimal ISO 19115 Metadata Components

Metadata Attribute	Function
Title	High level description, subject, title search
Data set abstract	High level description
Responsible party with contact information	Data access, data sharing, data usability
Data set theme	Keyword, category search
Data set extent	Spatial search
Reference date	Temporal search
Metadata date	Metadata maintenance management
Resolution, reference scale or accuracy	Usability
Reference system (map projection)	Usability

This approach minimizes the amount of metadata to be collected initially, but users will depend critically on contacting the data provider directly for much of the information needed regarding data usability. While metadata collection on usability, for example, will involve an initial investment in time and coordination; making that investment will ultimately prove more efficient than individual data providers having to supply the same information repeatedly for potential data users. Also, limiting the amount of metadata that is collected will ultimately limit the types of search functions that can be performed against it.

> ***Note:*** The EML metadata standard has been developed for NSF's LTER program. The standard accommodates more extensive metadata descriptions pertaining to attributes and relational databases pertinent to the ecological community. This standard is XML based and interoperable with FGDC and ISO. Conversion scripts have already been created in addition to online metadata entry tools. It is conceivable that the Circumarctic GIS Commission appoint a "metadata working group" to focus on the accommodation of international, federal and ecological standards and the associated metadata entry tools. The portal web site should contain information about the standards. Regional portals could provide metadata templates and online data entry tools for those without specialized metadata software. The metadata should be quality control checked by the regional node prior to submission to the portal web site. Metadata training and technical services could be provided periodically by the regional nodes until the "culture" of compiling metadata among the scientific community becomes a mainstream activity. In recent workshops, it was identified that the scientific community is focused on publications. There is a lack of incentive to publish data and associated metadata unless required by the funding entity. Changing this culture among the scientific community, should be addressed by the Circumarctic GIS Commission.

4.2 FGDS Data Nodes

As indicated previously, the proposed data architecture envisions a separate NSDI data node for each FGDS data custodian. This list of custodians would need to be developed through a cooperative dialog with participating institutions and agencies involved in scientific research in the Circumarctic region.

While each FGDS data node may support a specific range of thematic components, the conceptual structure and database architecture of the individual data nodes would need to be somewhat similar in terms of ASDI components. The data environment of a conceptual ASDI data node is illustrated in Figure 8.

The following further describes the conceptual data architecture of FGDS data nodes.

- **Data Environments.** As illustrated in Figure 8, each FGDS data node would need to support three primary environments:

  - **Data components specific to an agency's mission.** These will include geospatial data the agency produces for its own use. It will include highly specialized data, data that is part of the FGDS themes, but whose detail goes beyond that required for common usage, and data deemed non-shareable, because of confidentiality or security restrictions.

- **Data environments that store shareable resources.** These will include the geospatial information resources that will be accessible to others. These will typically be a subset of the data that is specific to the agency's mission. In order to address the ASDI goals of data accessibility and data sharing, the data sets in these environments will have to be developed to a common set of standards and compatibility.

- **Staging and deployment environments.** These can be independent or semi-independent holding areas that provide the necessary infrastructure to initially separate non-shareable from shareable components, perform quality and consistency checks, and deploy shareable resources to an accessible environment.

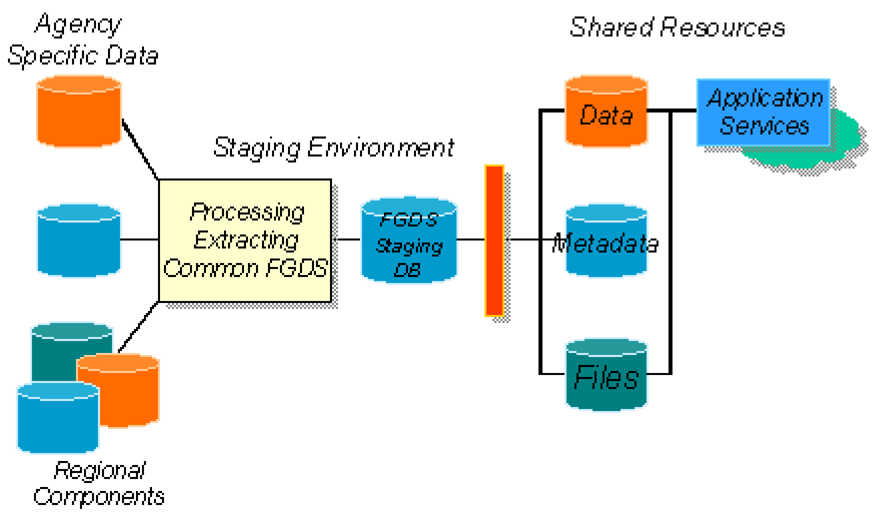

Figure 8. Conceptual Data Architecture of an FGDS Data Node

- **FGDS Standardized Data Content.** The contents of the shareable FGDS data will need to be based on common standards. To accomplish this, stakeholder organizations will initially have to develop framework data models that specify data entities and their relationships, and then establish data specifications to implement data according to these models. The following are important considerations:

  - A framework data model should focus on establishing thematic groupings of topically related data. For example, the grouping of terrestrial landscape related data will have to include thematic groupings of land cover, vegetation, soils, geology, hydrology and other topics. This implies multi-agency cooperation to develop framework models.

- A data specification will follow the establishment of framework models and, to be developed according to best practices, will have to consider the common research applications the data will have to support.

- Common data models and specifications will facilitate data exchange mechanisms and will allow a potentially diverse user community to develop applications and services utilizing these data sets according to open standards and protocols. Development of framework data models will have to be the role of topical working groups that comprise data producers and data users and should occur under the direction of the Circumarctic GIS Commission.

Include non-standard models that will be produced through research innovations that cannot be accommodated within existing standards.

- **Data Location.** While agency specific data may be distributed at headquarters, regional, and international offices, the shareable FGDS data sets should be stored at a single location in a seamless environment. This will facilitate the management of maintenance and dissemination operations and will help realize efficiencies in terms of physical infrastructure.

- **Metadata.** Each FGDS data node will have to maintain metadata about its data holdings and will have to publish this data to the central metadata portal.

- **Storage and Dissemination Environment.** Primary data storage will be based on open standards-based RDBMS technology, since this type of environment will provide the necessary mechanisms to maintain a consistent, reliable, and high performance data environment. At the same time, to facilitate data dissemination, FGDS data providers should be able to disseminate data according to common data exchange mechanisms including, for example, XML, comma delimited text files, database exchange files, shapefiles, etc.

- **Data Dissemination Mechanisms.** Data structures will likely vary based on specific services and applications an FGDS node will provide as part of its shareable resources. However, data structures should support dissemination according to logical groupings inherent in the data, for example, in terms of thematic components, spatial organization (i.e., by province, city, nationwide) or scale (i.e., common layers at various scales, or various layers at common scales).

The physical infrastructure of FGDS data will primarily be a function of data volume and reliability and performance requirements. Assuming the central portal with metadata holdings will be available with high reliability, a high reliability configuration for data nodes (i.e., in the form of fail-over and data server redundancy) will in most cases not be necessary. Exceptions may be nodes that hold data of importance to mission critical operations including, for example, data related to critical research missions or emergency management.

FGDS data will typically be a combination of raster and vector components that will be available at various scales and resolutions. Apart from the obvious differences in data volume, typically, large-scale data tends to support different applications than small scale, and raster data, which dwarfs all other sources in terms of volume, will depend on different storage, query, and access mechanisms than vector data. Considerations in terms of physical data structures are as follows:

- A number of industry standard RDBMS are available that are capable of supporting very large database environments, including those required for FGDS deployment. Most involve many different GIS as well as Web mapping environments. Some of the most well known ones include Oracle and SQL Server. Oracle is generally considered the more high-end and high-availability environment and offers more tuning capabilities when compared to SQL Server. SQL Server on the other hand is a simpler environment to work with and tends to be more cost effective.

- Various FGDS nodes may have to deploy large volumes of raster data that will form the foundation for most large scale base mapping operations in the Arctic. To utilize this data efficiently, at a minimum, such FGDS nodes will have to make a regionwide photo index of its data available from which others can order requisite digital orthophotos. However, the fact that this data will have to support many users implies that it should become available online in a relatively short time frame. This will most likely entail building a raster data repository extensive enough to accommodate such large data volumes.

- Image compression techniques can be applied to realize efficiencies in file sizes.

- When storing image and vector data, there are advantages in locating the image data in disk volumes that are separate from the vector data, particularly in supporting backup and recovery operations.

- For raster data, data input/output is larger; therefore, disk block sizes should be configured differently from vector data.

- Proper database tuning, including spatial and tabular indexing, should be utilized. Indexes should be placed separately from tables.

- To maximize performance and take advantage of indexing structures, queries resulting in full table scans (e.g., allowing free form text strings) should be minimized.

4.3 ASDI Operating Environment

This section more specifically outlines how the ASDI in the Circumarctic Region will work operationally in an environment with a central portal or metadata catalog and distributed agency nodes with shareable geospatial information.

An example ASDI operating environment is illustrated in Figure 9, and shows how the various components of the architecture can interoperate with one another. At the most basic level, the ASDI can be realized through catalog holdings that document geospatial data holdings and services.

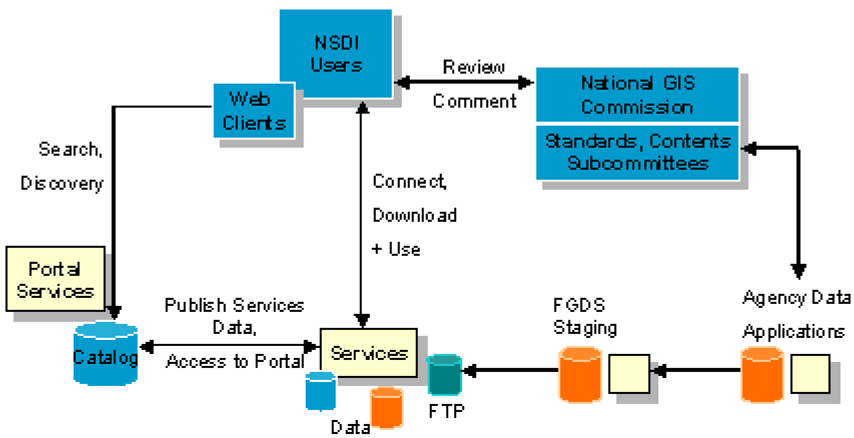

Figure 9. Operational Interactions of ASDI Components

Figure 9 illustrates the four primary ASDI activities that will interact with one another. Since the conceptual system and data architecture are distributed, the Internet will be an important base for each of the components to interact with one another.

- **FGDS Data and Services Development.** At the backend of ASDI implementation are system and applications that develop FGDS data and associated services and deploy them into a shareable environment. The shared environment is a distributed network of nodes, which for the Circumarctic Region will consist of those agencies that will be designated data custodians. The design of the content for shared data and resources, as well as the best practices methods to develop them, is the result of a collaborative effort between end user and data producing agencies that could be directed by the Circumarctic GIS Commission.

- **Metadata Development and Publication.** FGDS data publishers as well as publishers of other geospatial information resources publish their data sets to a central catalog portal. Data publishers will publish metadata based on established standards, but may utilize any number of standards-based tools and methodologies to submit metadata. Possible approaches include direct publication on the portal via on line forms, file exchange, and use of established GIS tools that provide metadata capture capabilities, or exposing their metadata holdings to periodic harvesting by the central portal.

- **Search and Discovery of Resources.** While data providers access the portal for metadata publication, end users (which may also include data provider agencies) access the portal and use functions provided by a Web browser application to find potential data sets and geospatial information resources for use. These searches will be similar in concept to those conducted at a library catalog. Therefore, search tools focus on capabilities that guarantee consistent search results. Users will visualize search results directly on the portal, or connect directly to the participating node that is hosting the desired data or services component.

- **Connection to Participating NSDI Nodes.** Once users have identified potential data sources through their searches on the portal, they may utilize a Web link to directly connect to a participating node and obtain the data through the ordering mechanisms provided by the node.

Today's technology allows implementing this kind of ASDI operating environment based on commercial off-the-shelf (COTS) software which will accomplish two main objectives:

1. Reduce cost as much of the core software has already been created.

2. Provide a platform that will be supported by the vendor as technology changes and advances.

The international spatial data infrastructure community has laid important technical groundwork that can be leveraged in many ways by the Circumarctic research community. However, existing standards have been built around the needs of data and resource managers and policy makers. The nature of scientific research has some fundamental and unique requirements that suggest that while the existing standards provide an important foundation, there is still significant work to be done to extend and refine those ideas and tools to effectively support the needs of Circumarctic research.

5.0 Application Development

The development of a Circumarctic Geospatial Data Infrastructure would spur the development of applications focused on regional planning, modeling, logistics and outreach. The availability of FGDS layers with standard metadata would supply national leaders, decision makers, researchers and educators with information that could be integrated and analyzed across national boundaries. Web services for several key applications have been suggested in discussion among the international community. These include:

Regional Planning: The Arctic presents special challenges for resource development and utilization due to the challenging environmental conditions and remoteness of the region. The implementation of infrastructure (roads, pipelines, power distribution, ports) and resource extraction is costly and at times can be better managed through international cooperation.

Modeling: The Arctic region is experiencing some of the greatest impacts of climate change as well as high concentrations of contamination. FGDS data sets are needed to more accurately model and predict trends associated with coastal erosion, sea ice, atmospheric radiation, biodiversity, etc. Current efforts to develop key FGDS data sets such as onshore and offshore elevation models, vegetation, soils, permafrost, sea ice and shoreline inventories will promote the development of new models to analyze regional change.

Logistics: The international research community would benefit from enhanced utilities as an aid to logistic support of field operations. This includes information on research hubs, cruise tracks, current and historic sampling sites, land tenure, cultural information, and local infrastructure (landing strips, ports, power distribution, roads, housing, DGPS base stations, etc.).

Outreach: Educational outreach about the Arctic environment, its people and special challenges are needed. Experiencing the region through visualization tools is often the only opportunity to promote understanding of this region. Web services provide an opportunity to foster both formal and informal education. Existing organizations such as the University of the Arctic (*http://www.uarctic.org/*), for example, could help promote this kind of educational outreach to the public.

5.1 Examples of Arctic Web Based Applications

The following lists various examples of web based applications resulting from the 2001 report "Recommendations for a Geographic Information Infrastructure to Support Arctic Research: Outcomes of the Arctic GIS Workshop". These examples demonstrate the standards and technology discussed in the report.

United Nations Environment Network (UNEP) - Arctic Environmental Atlas
This Internet Map Server allows for the display of several FGDS covering the Arctic region. In addition, UNEP has data and associated metadata available for download.
http://maps.grida.no/arctic/

Veco Polar Resources Maps of NSF-Funded Field Research in the Arctic
A series of GIS based maps are periodically updated to show the locations of research supported by the U.S. National Science Foundation (NSF).
http://www.vecopolar.com

Circumarctic Environmental Observatories Network – Internet Map Server (CEON-IMS)
This application has been developed to enable visualization and search ability of a geo-database comprised of observational platforms congruent with CEON's mission. CEON-IMS includes a range of remote sensing products, topographic maps as well as historical and current research and logistic information.
http://www.ceonims.org/

Barrow Area Information Database – Internet Map Server (BAID-IMS)
This tool is designed to enhance logistics and research planning efforts supported by the Barrow Arctic Science Consortium (BASC). The application incorporates information to track the locations of current and historic research sites dating back to the 1940's for the Barrow area. In addition, the application provides access to remote sensing products, topographic maps, land ownership and local infrastructure to help facilitate science.
http://ims.arcticscience.org/

Geographic Information Network of Alaska - Institute of the North Swath Viewer
This satellite image viewer includes swaths of MODIS and Landsat imagery.
http://ion.gina.alaska.edu/sv/

Geographic Information Network of Alaska –Metadata Catalog
This is an example of a web based NSDI metadata server.
http://map.gina.alaska.edu/metadataexplorer/explorer.jsp

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The Global Ocean Observing System Data and Information Management Strategy and Plan. UNESCO. June 2001.
http://ioc.unesco.org/goos/GOOSdm_final.pdf

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http://www.fgdc.gov/publications/documents/metadata/metafact.pdf

http://geology.usgs.gov/tools/metadata/tools/doc/faq.html

http://www.getty.edu/research/conducting_research/standards/intrometadata/

Appendix A - Acronyms and Agency Abbreviations

Acronym	Definition
ACD	Arctic Coastal Dynamics
AGDI	Arctic Geospatial Data Infrastructure
AMAP	Arctic Monitoring and Assessment Program
AOOS	Alaska Ocean Observation System
API	Application Program Interface
ARCSS	Arctic System Science (ARCSS) Data Coordination Center
ARCUS	Arctic Research Consortium of the United States
ARM	Atmospheric Radiation Measurement
ASCII	American Standard Code for Information Interchange
AVHRR	Advanced Very High Resolution Radiometer
AWI	Alfred-Wegener Institute
BAID-IMS	Barrow Area Information Database - Internet Map Server
BASC	Barrow Arctic Science Consortium
CALM	Circumpolar Active Layer Monitoring
CEON	Circumarctic Environmental Observatories Network
CEON-IMS	Circumarctic Environmental Observatories Network - Internet Map Server
CGDI	Canadian Geospatial Data Infrastructure
CIFAR	Cooperative Institute for Arctic Research
COM	Component Object Model
COTS	Commercial Off-the-Shelf
CSSM	Content Standards for Spatial Metadata
DBMS	Database Management System
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
EML	Ecological Metadata Language
EOS	Earth Observation Satellite
ESRI	Environmental Systems Research Institute
FGDC	Federal Geographic Data Committee
FGDS	Fundament Geographic Data Set
FTP	File Transfer Protocol
GII	Geographic Information Infrastructure
GINA	Geographic Information Network of Alaska
GIS	Geographic Information System
GOOS	Global Ocean Observation System
GPS	Global Positioning System

GUI	Graphical User Interface
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
I/O	Input/Output
IASSA	International Arctic Social Sciences Association
IOOS	National Office for Integrated and Sustained Ocean Observations of the US
ISO	International Standards Organization
IT	Information Technology
JOSS	Joint Office for Science Support
LTER	Long Term Ecological Research
MAB	Man and the Biosphere (UNESCO)
MSU	Michigan State University
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NIC	National Ice Center
NOAA	National Oceanic and Atmospheric Administration
NSDI	National Spatial Data Infrastructure
NSF	National Science Foundation
NSN	Northern Studies Network
OAI-PMH	Open Archive Initiative Protocol for Metadata Harvesting
OGC	Open GIS Consortium
OGIS	Open GeoData Interoperability Specification
OPP	Office of Polar Programs
RDBMS	Relational Database Management System
SAR	Synthetic Aperture Radar
SST	Sea Surface Temperature
UAF	University of Alaska Fairbanks
UNEP	United Nations Environment Program
UNH	University of New Hampshire
USGS	United States Geological Survey
VPR	Veco Polar Resources
WAN	Wide Area Network
WWW	World Wide Web
XML	Extensible Markup Language

Figure 3

PMOC	Prime Minister Operation Center
RTSD	Royal Thai Survey Department
MOAC	Ministry of Agriculture and Cooperatives

DOL	Department of Lands
DOH	Department of Housing
DPT	Department of Public Works and Town & Country Planning
GISTDA	Geo-Informatics and Space Technology Development Agency (Public Organization)

Appendix B - Various GIS and Arctic GIS Resources

Arctic Ecology Lab
http://www.cevl.msu.edu/ael/index.html

Arctic Environmental Data Directory
http://www.arctic-council.org/f2000-add.html

Arctic Mapping and Assessment Programme
http://www.amap.no/

Athropolis Links
http://www.athropolis.com/links/maps.htm

Barrow Arctic Science Consortium
http://ims.arcticscience.org/DWG/Text/geospatial_links.htm

Circumpolar Arctic Geobotanical Atlas
http://www.geobotany.uaf.edu/arcticgeobot/index.html

CRREL
http://www.crrel.usace.army.mil/research/arctic/

Geocommunicator – GIS catalog portal for the U.S. Bureau of Land Management and the U.S. Forest Service
www.geocommunicator.gov

Geography Network
www.geographynetwork.com

Global Terrestrial Observing System
http://www.fao.org/gtos/

International Bathymetry Chart of the Arctic Ocean http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html

Master Environmental Library (MEL)
http://mel.dmso.mil/

National Ice Center
http://www.natice.noaa.gov/

National Snow and Ice Data Center
http://arcss.colorado.edu/data/

National Snow and Ice Data Center
http://nsidc.org/index.html

Northern View – Earth Observation for Northern Monitoring
http://www.northernview.org/index.htm

Open GIS Consortium
http://www.opengis.org/

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

University of the Arctic (UArctic)
http://www.uarctic.org/

University of Colorado Arctic Climate Project
http://www.colorado.edu/Research/HARC/gisdatab.html