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# Development Of A Web-Based Geographic Information System For Arctic Science

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DEVELOPMENT OF A WEB-BASED GEOGRAPHIC INFORMATION SYSTEM FOR ARCTIC SCIENCE: THE ARCTIC RESEARCH MAPPING APPLICATION (ARMAP)

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## Dedication

This thesis is dedicated to my parents Jerry and Kathy Johnson, Raquel, and all of my closest friends for their guidance, moral support, love, and encouragement throughout my life and educational experiences.

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by

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THESIS

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## Abstract

Environmental science is a large field of study that requires the acquisition of data for decision making in solving environmental issues. Leveraging desktop geographic information systems (GIS) and web-based GIS (WebGIS) systems for assisting in the problem solving processes can benefit both the research community and policy makers for decision making activities. Ensuring interoperability between desktop, web, and server GIS is essential for maximizing access, sharing and manipulation of data. Interoperability is maximized through the adoption of best practices, use of open standards, and utilization of Spatial Data Infrastructures (SDI). While many of the interoperability challenges such as infrastructure, data exchange, and file formats are common between applications, some regions like the Arctic present specific challenges including the need for presenting data in one or more polar projections.

This thesis describes the development and use of the Arctic Research Mapping Application (ARMAP) suite of online interactive maps, web services, and desktop virtual globes (http://armap.org/) and several of the interoperability challenges and solutions encountered in development to date. The Arctic Research Logistics Support Service (ARLSS) database is the informational underpinning of ARMAP and has been incorporated in the ARMAP suite. Three case studies are described and demonstrate how the ARMAP suite can be used to improve access to ARLSS data and information for the purpose of facilitating Arctic science and logistic support. The cases presented include the use of: 1) A Keyhole Markup Language (KML) networked link file for Google Earth (GE) which eases the use of Arctic research information in a virtual globe for non-

technical GIS users to develop quick maps; 2) A customized Internet Map Server client (ArcIMS), which provides access to many Arctic data sets in a powerful online GIS application with data exploration capabilities in a free web viewer to develop logistic plans for future research; and 3) A customized ArcGIS Explorer (AGX) application that provides users access to Arctic research information in a virtual globe similar to GE while providing GIS query capabilities developed to mimic the ArcIMS application.

ARMAP has become a unique science and logistic tool supporting U.S. and international Arctic science by providing users with the ability to access, query, and browse information and data. Avoiding duplication of effort has been a key priority in the development of the ARMAP applications. The ARMAP suite incorporates best practices that facilitate interoperability such as Federal Geographic Data Committee (FGDC) metadata standards, web services for embedding external data and serving framework layers, and open standards such as Open Geospatial Consortium (OGC) compliant web services. Outcomes of this project include the development and promotion of free desktop and web GIS tools that improve access to and exploration of pertinent information about U.S. Arctic research effort while using best practices for data storage and use developed from a task based analysis. Many of the features and capabilities of ARMAP are expected to greatly enhance the development of an Arctic Spatial Data Infrastructure (SDI). This project has provided functionality to the research community, logistic providers, public outreach, and program managers for Arctic research and decision making activities.

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**Table 1 Primary acronyms used in this thesis.**

| Acronym | Definition |
|---|---|
| A2DI | ARMAP 2D Internet Map Server |
| ARMAP | Arctic Research Mapping APplication |
| ACCER | Alaska Climate Change Executive Roundtable |
| ADIwg | Alaska Data Integration Working Group |
| AGX | ArcGIS Explorer |
| API | Application Programming Interface |
| COTS | Computer of the Shelf |
| EPSG | European Petroleum Survey Group |
| ESRI | Environmental Research Systems Institute |
| HTML | Hyper Text Markup Language |
| IMS | Internet Map Server |
| IPY | International Polar Year |
| GE | Google Earth |
| GIS | Geographic Information System |
| NSF | National Science Foundation |
| NSIDC | National Snow and Ice Data Center |
| OGC | Open Geospatial Consortium, Inc. |
| OPP | Office of Polar Programs |
| OSS | Open Source Software |
| WCS | Web Coverage Service |
| WFS | Web Feature Service |
| WMS | Web Map Service |
| WWW | World Wide Web |
| XML | Extensible Markup Language |

# 1. Introduction

Environmental science (ES) is an interdisciplinary field of study focused on improving knowledge about interactions between physical, biological and social systems for the purpose of environmental problem solving and prevention of environmental degradation. Over the past few decades, there have been dramatic advances in the environmental sciences, which have largely been motivated by concerns that anthropogenic disturbances are altering the Earth System to an extent that will affect provision of ecosystem goods and services (IPCC 2007; MEA 2005). These advances have resulted in the collection of large amounts of data (Overpeck et al. 2011) and new fields such as *Ecoinformatics* have developed to improve capacities for analysis and synthesis of this data by leveraging Information Technology (IT) and the computational sciences (Jones et al. 2006). Increasingly, the combined use of advanced sensors and sensor networks, computer hardware and software that store and interact with sensor and other data, and the human capacity to manage and develop these (collectively known as cyberinfrastructure (CI) *sensu* [Atkinson et al. 2007]), are being viewed as critical for the advancement of the environmental sciences (Reichman et al. 2011; Wooley 2006).

There are many CI challenges facing ES including data collection, storage, documentation, visualization, and dissemination (Christian et al. 2009; Morton et al. 2009; Peters 2010). First, ES data are difficult to work with (Lindenmayer and Likens 2010; NEON 2010) because the spatio-temporal scales of observational data, data parameters, and the duration of study can vary widely between studies (e.g., [Gordo and Sanz 2009; Madin et al. 2007; Ohlemuller et al. 2006; Steyaert et al. 1997; Wirtz

and Wiltshire 2005]). In particular, geospatial ES data typically used in Geographic Information Systems (GIS) are becoming large in size and diverse in format, are formatted in multiple projections and resolutions, and are documented with a range of metadata standards (Di and McDonald 1999). Combined, these challenge the development of data discovery tools due to the large size of many datasets creating the possibility of long downloading time.

Efforts to link database networks and formulate standards for developing infrastructure to store, distribute, and visualize data have been embedded as an integral component of several ES research efforts over the past few years (e.g., National Ecological Observation Network [NEON; http://www.neoninc.org/] and the Global Earth Observation System of Systems [GEOSS; http://www.earthobservations.org/geoss.shtml]). These efforts will facilitate improved discovery and access to many ecological datasets that will benefit studies examining complex ecosystem interactions. Despite these advances, more is needed - especially an infrastructure that links important data attributes from a range of disciplines within the ESs (Govindaraju et al. 2009; Wooley 2006).

Developing a CI to link disciplines within the ESs will be challenging if new tools for accessing data are not developed. The most promising advances appear to stem from a combination of ecoinformatics and Web 2.0 technologies (De Longueville 2010). This new culture of key technical abilities and community efforts is likely to create new capacities for accessing site or network specific data, even if key data are not readily available or in a correct format to be easily used (Atkins 2006; Atkins et al. 2003; Atkinson et al. 2007). It is, however, important that duplication of effort be limited in such

efforts as this could limit expandability of application tools and the efficient advancement of ES (Atkins et al. 2003). Instead, broader adoption and re-use of tools and standards will greatly enhance CI development in the ESs (Govindaraju et al. 2009; Wang and Zhu 2008).

In building a CI for ES, technology can pose many challenges. Costs and maintenance of hardware and software can be high (Boehm and Abts 1999). There are also inherent technical disparities between users and developers of such CI, which affects choices between commercial off-the-shelf (COTS) and open source software (OSS) packages (Atkins et al. 2003). Nonetheless, by building on the advances and learning from previous mistakes in data integration, warehousing and distribution, community needs will likely be better addressed and scientific knowledge will be advanced (Atkins et al. 2003). Software that are built with a focus on ES data such as Geographical Information Systems (GIS) and integrate GIS with the World Wide Web (WWW) to allow users to search, explore, and visualize data are likely to be revolutionary (Díaz et al. 2011; Wang and Zhu 2008; Yang et al. 2010). Such tools have a potentially broad utility ranging from the scientific community to policy makers and educators.

The power of integrating the World Wide Web (WWW) and Geographic Information Systems (GIS) is well recognized in disciplines as disparate as city planning to dentistry and scientific research (Doyle et al. 1998; Falkman et al. 2008; Longley and Clarke 1995; NRC 2010; Sorensen et al. 2001). WebGIS, the marriage of the WWW and GIS, establishes a foundation that provides users with the ability to dynamically interact with geospatial and other data in both 2D and 3D platforms. WebGIS has

generally developed rapidly, giving a diverse online user community free access to previously unavailable GIS tools and data (Alesheikh et al. 2002; Dangermond 2009; Plewe 1997). As such, WebGIS has catalyzed a paradigm shift for web based data discovery, integration, analysis and visualization. Currently, the frontiers of WebGIS development are focused on the interoperability of distributed services with a wider array of geospatial CI to enhance analytical capacities and access to data (Wei et al. 2009; Yang et al. 2010; Yin 2009; Zhang and Tsou 2009).

Within information technology fields, interoperability commonly refers to the ability of hardware or software to work together seamlessly, which is generally made possible due to standardized hardware or software specifications and standards (Simpson and Sellers 2009; Tamayo et al. 2009; Yin 2009). Advances of Web 2.0, interoperability through standards and technology has largely been made possible because systems can utilize data and information interchangeably from many different sources through web services (De Longueville 2010; Lu 2005). For both desktop and WebGIS systems, the Open Geospatial Consortium (OGC) has established the primary set of standards for geospatial data sharing and discovery (Huang et al. 2009; Wei et al. 2009). Ongoing improvements to interoperability are largely focused on enhancing end user experience through high performance computing (Chandra et al. 1997; Coddington et al. 1999; Coveney et al. 2005), systems integration (Cha et al. 2008; Lu 2009; Tian et al. 2006), software reusability (Granell et al. 2010; Standish 1984; Zongyao and Yichun 2009), data fusion (Gupta et al. 2008; Kiehle et al. 2007; Wald 1999), and cloud computing (Huang et al. 2010; Painho et al. 2010).

Improved access to data and information has been recognized as a priority for the advancement of arctic science (IPYDIS 2008; Li et al. *In Press*-a; Li et al. *In Press*-b; Parent et al. *In Press*; Sorensen et al. 2001; Zhou et al. *In Press*). By its very nature, arctic science requires extensive international collaboration and is interdisciplinary (Aksnes and Hessen 2009; Pearce et al. 2009; Stamnes et al. 1999). The Arctic also appears to be responding to climate change faster than any other region on Earth (IPCC 2007; Hinzman et al. 2005; Overpeck et al. 1997) and it is likely that arctic change will manifest to impact the rest of the globe (McGuire et al. 2006; Sommerkorn and Hassol 2009). Over the past decade, improved access to data and information benefiting arctic science has been provided by a range of efforts using interoperable tools. These efforts include: i) initiatives of federal funding agencies to require open access to data such as the National Science Foundation's (NSF) general grant conditions (NSF 2010), which requires all funded research to share and archive data; ii) international collaboratory efforts such as the 2007-09 International Polar Year (IPY) Data and Information Services (IPYDIS 2008; http://ipydis.org/) coordinated by the National Snow and Ice Data Center (NSIDC), which provide free IPY (Arctic and Antarctic) data access, metadata, and data preservation assistance; and iii) efforts such as the Alaska Data Integration Working Group (ADIwg; http://www.aoos.org/akdiwg/index.html) that was formed by the Alaska Climate Change Executive Roundtable (ACCER) to address the technical challenges that constrain data integration and sharing among the federal and state agencies in Alaska focused on climate science.

During 2006, and before the 2007-09 International Polar Year, the U.S. National Science Foundation's Office of Polar Programs (OPP) initiated the Arctic Research Mapping Application (ARMAP). ARMAP was designed to improve free and open access to data and information on US Federally funded research in the Arctic to enhance international collaboration, science logistics planning, and knowledge of what research has and will take place where, when, and by whom. A WebGIS was an obvious choice to meet the development needs of ARMAP. Over time, however, ARMAP has grown to include a suite of online maps, 2D mapping applications, 3D globes, and web services. By documenting more than 20 years of research history and showing details on more than 2000 research projects (2018 unique projects as of 31 December 2010), and information on more than 11,000 research activities, ARMAP now provides the most comprehensive access internationally to information on both historic, extant, and future research effort in the Arctic. Interagency collaboration and improvements to data and software interoperability have underpinned development of the ARMAP suite for the promotion of information sharing and discovery through a variety of web services.

This thesis outlines the ARMAP development environment and application suite, and highlights several specific interoperability challenges and solutions developed to date. Particular attention has been paid to how ARMAP development has utilized interoperable tools, standards and practices to address the changing needs of the user community, adapted to changing technologies, and improved access to data and information through open and free access to data services and interactive visualization tools with GIS functionality (Li et al. *In Press*-a). Many of the challenges for improving interoperability experienced in the development of ARMAP are important considerations

for the development of an Arctic Spatial Data Infrastructure (ASDI; Li et al. *In Press*-b; Parent et al. *In Press*; Yang et al. *In Press*).

## 2. Development of the ARMAP suite of online interactive maps and services

ARMAP was initiated with the development of an Internet Map Server (ArcIMS, version 9.2) that was followed by a range of tools that utilize newer technologies and data services to meet the growth of user needs and expectations (described below). These tools have become collectively known as the ARMAP suite of online interactive maps and services (Figure 1). The ARMAP suite utilizes the same underlying SDI and uses data from external sources such as ArcOnline's World imagery web service, which includes Landsat 15m imagery for the Arctic.

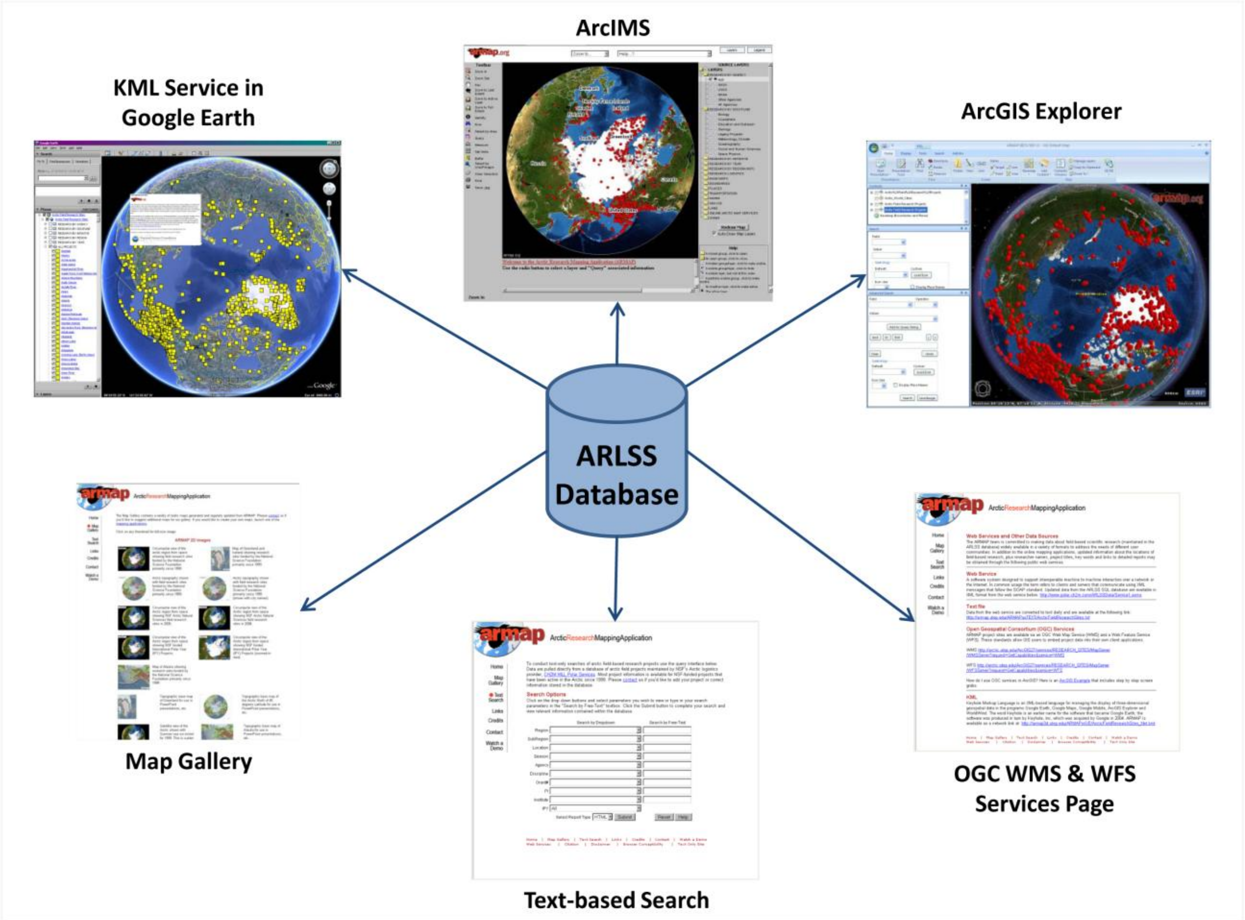


**Figure 1 Overview of the suite of ARMAP interactive maps and services. All mapping applications and services draw information on research projects from the Arctic Research Logistics Support Service (ARLSS) database maintained by CH2M HILL Polar Services (CPS).**

ARMAP's online interactive maps and services interface with the Arctic Research Logistics Support Service (ARLSS) database service that can be found online as a web service (http://armap.org/armap_services.aspx) hosted by CH2M HILL in Englewood, Colorado and allows for the generation of detailed project reports (Figure 1). ARLSS houses information on U.S. federally funded field-based research projects. These reports include high-level project information and links to project websites, investigator contact information, and where scientific data will be archived or made available for a

made available for the respective research project. Most projects documented in ARLSS are sponsored by NSF, but recent efforts have focused on including projects funded by other U.S. federal agencies such as the National Oceanic and Atmospheric Administration (NOAA), National Aeronautics and Space Administration (NASA), and the U.S. Geological Survey. Available tools at the ARMAP website include a text-based search page (section 2.3.2), an ArcIMS application (hereafter referred to as A2DI) and Map Gallery (section 2.3.3), and 3D Globe applications in Google Earth (GE) and ArcGIS Explorer (AGX) (section 2.3.4) (Figure 1). ARMAP also provides links to OGC Web Map Services (WMS; OGC 2006), Extensible Markup Language (XML, http://www.w3.org/TR/xml/) web services, and KML (formerly Keyhole Markup Language; OGC 2008a) services (section 2.3.1). Users can also access FGDC standard metadata in the ArcIMS application by clicking any data layer name which provides links for accessing the associated datasets. These metadata offer links to where data can be accessed through the web or downloaded.

In addition to providing users with access to data and metadata, development of ARMAP has followed guidelines promoting best practices for sharing geospatial data described by Sorenson et al. (2001) and IPYDIS. This includes publication of FGDC metadata through a Web Accessible Folder (WAF) registered with GeoData.gov and the GEOSS Clearinghouse and Portal. This has allowed for improvements in search capacity for data and web services. Also, publishing OGC web services for serving data and consuming similar distributed data archives has helped to avoid duplication of publishing effort.

## 2.1. Collaboration

Primary development of the ARMAP suite has been a collaborative effort between the Systems Ecology Laboratory (SEL) at the University of Texas at El Paso (UTEP), Nuna Technologies, the INSTAAR Quaternary GIS (QGIS) Laboratory, and CH2M HILL Polar Services (CPS). A relatively high number of undergraduate and graduate student developers from a range of different departments and programs have participated to enhance cross-disciplinary training and educational application development activities. Application development has benefited from leveraging support through UTEP's Cyber-ShARE Center of Excellence (www.cybershare.utep.edu) and information technology group, and from ESRI's technical assistance program. These teams have attempted to embrace best practices in testing new technologies (e.g., Adobe Flex framework) to improve user experience (e.g., speed, usability, usefulness) and enhance interoperability. Beyond the application development team described above, the ARMAP project team has collaborated with NSIDC, the Cooperative Arctic Data and Information Service (CADIS), the U.S. Arctic Observing Network (AON), the State of Alaska, the University of Alaska Fairbanks (UAF) Geographic Information Network of Alaska (GINA), and ADIwg. The prime focus of these collaborations is to improve data and application interoperability, discuss standards for adoption and implementation, and share experiences with development challenges and solutions. Although difficult to quantify, it was noticed that the cross disciplinary human interactions and institutional collaborations implemented in the development ARMAP have been just as important as any technological innovation for the enhancement of interoperability. The experiences in development of ARMAP support Simao et al.'s

(2009) findings that the importance of human interactions is often underappreciated in the development of interoperable WebGIS applications.

## 2.2. Hardware and Software

Hardware acquisition benefited from bulk purchasing agreements offered by the Dell Computer Corporation (http://www.dell.com). Blade servers running Windows Server 2003 (Dell PE 1855 Dual 3.2 GHz processors 8 GB RAM, 146 GB mirrored hard drives/1955 Dual 2.33 GHz processors 8 GB RAM, 73 GB mirrored hard drives) were used for application development, prototyping, and hosting. Microsoft SQL 2005 running on a Dell PE 1955 (2.33 GHz processors 16 GB RAM, 73 GB mirrored hard drives) connected to Dell EMC SAN (Cx-500) device providing 2.23TB of storage space was used as the project database server.

The decision to utilize commercial off-the-shelf software (COTS) or Open Source solutions (such as MapServer; http://mapserver.org) in the development of ARMAP hindered on the challenges inherent with Open Source solutions and the need for experienced programmers and leveraging of 10 or more Open Source software packages compared to five COTS packages that are typically utilized for the same application development (Anderson and Moreno-Sanchez 2003). Ultimately, the benefits of educational licensing (ESRI and Microsoft) in combination with access to extensive online training and discussion forums for the relatively inexperienced student developers, and the focus on educating students with industry recognized GIS software and standards, underpinned the decision to use primarily a COTS solution. ARMAP development to date has been executed using primarily ESRI GIS architecture

(ArcInfo/Server/SDE/IMS 9.2/3), Microsoft Server 2003 and Microsoft SQL Server 2005 (http://www.microsoft.com/).

## 2.3. Primary Component of the ARMAP Suite

The ARMAP project was designed to improve free and open access to data and information on US Federally funded research in the Arctic. To enhance international collaboration, science logistics planning, and knowledge of what research has and will take place where, when and by whom, both a front and back end GIS infrastructure was an obvious choice to provide various services to meet the needs of the Arctic community. Although many of the interoperability challenges such as infrastructure, data exchange, and standardized file formats are common to all WebGIS application developments, some regions such as the Arctic present specific challenges including the need for presenting data in one or more polar projections. The primary components of the ARMAP suite are described immediately below (2.3.1 – 2.3.4); followed by the challenges and solutions experienced throughout out the development of the applications (Section 3).

### 2.3.1. Provision of Data and Services with a Polar Projection

Currently the ARMAP suite provides free access to one of the largest and diverse archives (125 layers of data) of integrated arctic geospatial data offered through the ArcIMS application in up to six different polar projections clipped to 35 degrees north. Layers include sea ice cover, various boundaries and place names, transportation routes, landcover and other terrestrial map layers, a range of basemaps, and research sites. In addition, five data layers are made available through web data services in a variety of formats including OCG compliant WMS, Web Coverage Service (WCS; OGC

2008b), Web Feature Service (WFS; OGC 2005) and KML services (Table 2). These services are published with ESRI's ArcGIS Server technology. Users of these services include the North Slope Science Initiative, ADIwg, the NOAA National Geophysical Data Center, Geodata (Denmark), and NunaGIS (Greenland).

**Table 2 ARMAP data layers in available formats through web services found at http://armap.org.**

| | *For ArcGIS* | *For Google Earth* | *OGC Compliant* | | | |
|---|---|---|---|---|---|---|
| **Data Services** | **Layer Files** | **KML** | **WMS** | **WFS** | **REST** | **TXT** |
| **Field Research Projects** | X | X | X | X | X | X |
| **Site Place Names** | X | | X | X | X | |
| **Arctic Base Map** | X | | X | | X | |
| **Arctic Countries** | X | | X | | X | |
| **Arctic World Cities** | X | | X | X | X | |

### 2.3.2. Text-based Search

The gateway website includes an online text-based search interface enabling users to query field research sites in ARLSS by researcher name, year, program and discipline. The ARLSS database is maintained in Microsoft SQL Server 2005 and is made available in an XML format via a public web service (http://www.polar.ch2m.com/ARLSSData/Service1.asmx). The text search has been utilized for generating persistent Simple Object Access Protocol (SOAP, http://www.w3.org/TR/soap/) XML URLs for other entities to harvest project tracking information (e.g., the North Slope Science Initiative in Alaska).

### 2.3.3. Interactive 2D Mapping Applications and Maps

2D mapping applications provide an intuitive interactive and visualization environment for users (Khan and Adnan 2010; Kleppin et al. 2010). A2DI was designed using ESRI's ArcIMS (version 9.2) software and includes a series of six regional ArcMap Services to address NSF's requirement to be able to change the polar orientation of the map view. Each ArcMap service's (section 2.3.1) allows users to switch the map view to Canada, Greenland, Northern Europe, Russia and Alaska. The user can access these views through a "Zoom to…" drop-down list located on the top frame to re-orientate the map viewer allowing for the ease of making maps for presentations in a non-North America-centric map orientation. This functionality was achieved through customized HTML and JavaScript code that controls the ArcIMS interface. These map services have also allowed for streamlined updating of predefined map images for the gateway website "Map Gallery". The map gallery is updated monthly and has a set of predefined maps (JPEG) that users can download for use in presentations, grant proposals, reports, and other applications.

### 2.3.4. Virtual 3D Globes

The scientific community has rapidly embraced the use of 3D virtual globes for visualizing scientific data, and for education and outreach activities (Sheppard and Cizek 2009; Wu et al. 2010). ARMAP's 3D services promote interoperability through a customized KML Network Link file that can be downloaded and saved to a local file system (http://armap3d.utep.edu/armapinGE/ArcticFieldResearchSites_Net.kml), which can be directly (AGX; NASA WorldWind) or programmatically (Microsoft VirtualEarth)

consumed by other 3D clients. AGX (Build 1500) used by ARMAP provides a useful virtual globe with fly-through capabilities and options for symbolizing high concentrations of research sites as extruded features combined with powerful GIS query tools. It can also switch between 2D and 3D views, use local geospatial data, connect to WMS, KML, GeoRSS, ArcIMS server, ArcGIS Online services, and connect to remote geospatial servers, thereby providing a robust and free interoperable platform for utilization by the science community.

# 3. Interoperability Challenges and Solutions

The following sections address five specific challenges that were encountered during the development of the ARMAP suite. Solutions to these challenges are included and are described with a focus on how the interoperability of the ARMAP suite was improved through ongoing development as user's needs and expectations changed and hardware and software capabilities were adapted to meet industry standards (DiBiase et al. 2010; Nittel et al. 2008; Sonnen and Morris 2005).

## 3.1. Data Availability and Access

There is a gamut of data sources (including metadata) and web services for base maps, imagery and vector files in the contiguous United States and Europe, but not for the Arctic (NRC 2006). Initially, data layers, such as Arctic sea ice extents and averages, permafrost, place names, hydrology, topography, bathymetry, and shaded relief, were not readily available from data centers and needed to be acquired from specialists in the field and/or reprojected to an Arctic projection (section 2.3.1). Although time consuming, development of ARMAP required the fundamental development and documentation of a range of baseline Arctic data sets. For all data layers in the ArcIMS, FGDC compliant metadata was created. Metadata for information that is unique to ARMAP is published via a WAF. The challenge of improving the availability and access to Arctic data is far from being solved, but through the development experience, has shown that reprocessing and modernizing access to arctic data through the ArcIMS and web services registered with clearinghouses benefits the broader community and improves the interoperability with other applications.

The development and maintenance of the ARMAP IMS requires a weekly update of the harvested ARLSS data set. Since the ARLSS database is hosted offsite and the only access to it is through a non-geospatial XML service, a method of harvesting the tabular data with spatial attributes, converting it to a spatial dataset, and updating the geospatial data and map services was developed and refined over time. Initially updating was performed manually for all steps, but newer versions of the ArcGIS software allowed for us to incrementally automate the process. First, the harvesting and parsing of the ARLSS XML data service was automated with custom Java and .NET scripts (executable files that were scheduled to run every night) to generate a text file (accessible at http://armap.utep.edu/ARMAPasTEXT/ArcticFieldResearchSites.txt), which was then converted into shapefiles for use in map services. The ability to publish ArcIMS services based on ArcMap MXD documents was made possible with the release of ArcGIS 9.2 and utilized ArcSDE (Spatial Database Engine) to store geographic data. This allowed for rapid development, modification, and updating of map services through the publication of data stored in the SDE database. However, problems with database versioning and file locks were encountered but were resolved with the release of ArcGIS 9.3 in June 2008. Processing of harvested ARLSS data and updating of map services is now completely automated following the development of a potentially reusable Python (http://www.python.org/) geoprocessing script. Figure 2 depicts the abstract workflow of geospatial data integration, storage, use, and dissemination of ARLSS data within the ARMAP suite.

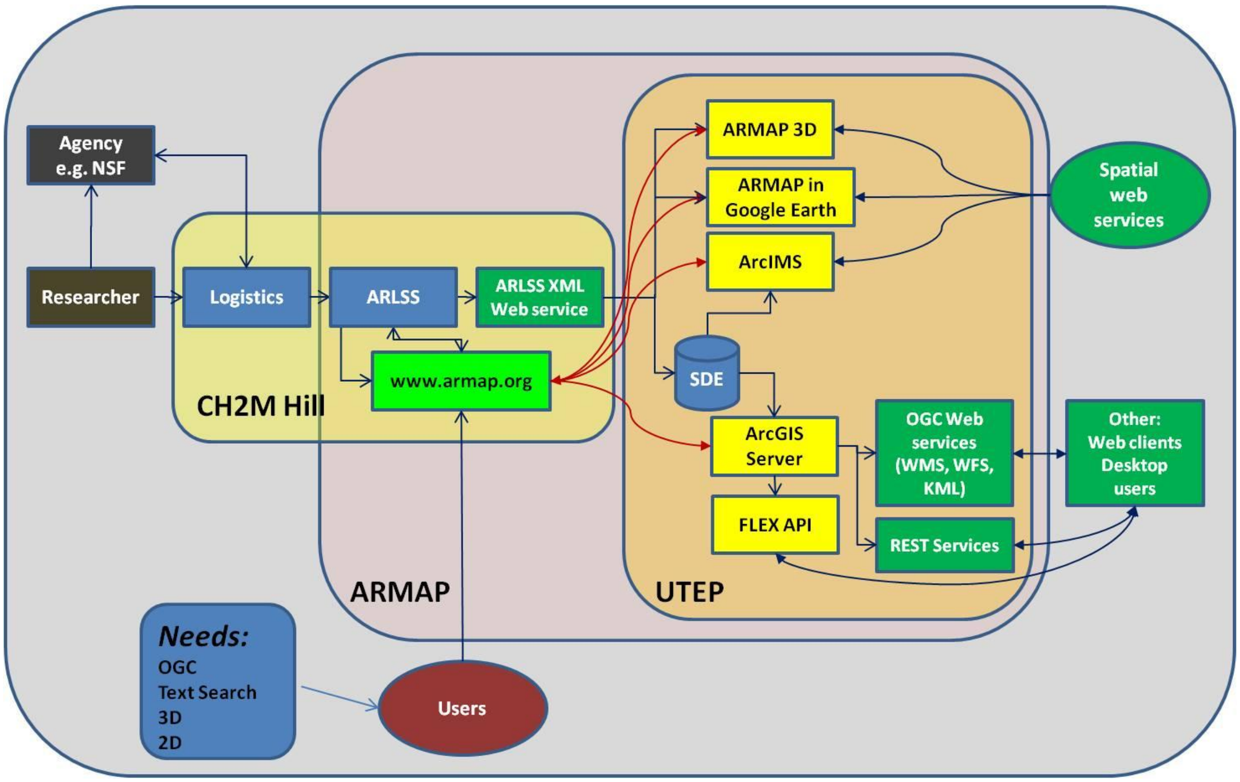


**Figure 2 Workflow of UTEP data integration of the ARLSS web service and data services used in applications and services provided to the Arctic science community.**

## 3.2. Polar Map Projections

The challenge with developing a WebGIS application for the Arctic is that most global map services (e.g., OGC and ArcOnline) are available in projections that do not visualize data well for the polar regions (e.g., a hole in the North Pole [Bentsen et al. 1999]). Some data services also have text annotation embedded as graphics in the service image, which can be distorted when reprojected. Due to the lack of availability of data services in a Circumarctic projection, most map layers were reprojected to a Circumarctic view before services were created. In order to avoid maintaining six versions of the 125 layers of data, layers were reprojected for the additional regional polar projections "on-the-fly" in A2DI. Reprojection initially seemed to cause an

unacceptable decrease in application performance, which was mitigated through the implementation of ArcSDE (Spatial Database Engine) and tested using a tasked based performance analysis (section 3.2.1). ArcSDE provides the capability for supporting high-performance management of large spatial data in multiuser GIS systems and supports reprojecting data on-the-fly with minimal loss of performance from a relational database server. To test WebGIS performance (*sensu* Yang et al. 2005) using SDE, speed tests were conducted in applications with and without data served from SDE.

### 3.2.1. Tasked Based Performance Analysis - Methods

Two tests were developed to evaluate load times from a task-based performance test that assessed the time A2DI took to load the same data stored in two different sources (SDE and a local file system as shape and raster files) and also included using two of the ARMAP projected services - Canada and Alaska. Using two map services during the test allowed for analysis of the time it took to load large data sets and reproject these data into a different map view, which is one of the key functional components of A2DI. The assessment of this analysis helped developed the best practice of data usage in ArcIMS for the A2DI.

20 tasks were executed (Table 3) to demonstrate a workflow of tools and processes a user would develop in the ArcIMS application to derive a final product (e.g., map, image, information table). Testing was accomplished through tasks that were set up and repeated 10 times using three different connection types (10 on a local server using remote desktop, 10 from a computer on the UTEP campus network, and 10 from computer off the UTEP network) for a total of 30 replicates per task. Execution times where averaged to remove bias for connection speeds and network performance for

application load times. An F-test and two-sample t-test were used for statistical comparison between the tasks to determine the best practices for hosting data, either stored locally or in a SDE database.

**Table 3 Tasks developed for task-based performance testing for load times in ArcIMS application to assess time A2DI took to load the same data from different sources (SDE and a local file system).**

| Task | Task description |
|---|---|
| 1 | Load IMS from ARMAP homepage |
| 2 | Changed map service to Canada |
| 3 | Zoom into Alaska |
| 4 | Selected research sites by area in Alaska |
| 5 | Cleared the previous selection |
| 6 | Turn on the Biology layer |
| 7 | Turn off the NSF layer |
| 8 | Turn on Permafrost layer |
| 9 | Turn on Vegetation layer |
| 10 | Turn off Permafrost and Vegetation layers |
| 11 | Turn on Permafrost and Vegetation layer together |
| 12 | Changed map service to Alaska |
| 13 | Look at map legend |
| 14 | Printed the created map (Alaska Biology with Vegetation and Permafrost) |
| 15 | Turn legend off |
| 16 | Refresh the ARMAP ArcIMS application to reset the map view and clear previous tasks |
| 17 | Simple query (Last_Name = "Tweedie") |
| 18 | Advanced query (Year_ = 2008 AND IPY = "Yes") |
| 19 | Selected four Canada research sites to create buffer along with displaying attributes in table |
| 20 | Create buffer to select airports within 500 km from Canada RS |

### 3.2.2. Tasked Based Performance Analysis - Results

Task 15 was the only task left out of overall graphical representation of the analysis due to lack of significant time it took for loading ($p > 0.05$; .26 seconds for data in SDE and .24 seconds for data not in SDE). Thirteen out of the 20 tasks showed a significant difference ($p < .005$), where there were greater load times of the application using local data supporting the use of SDE to host data (Figure 3). Six out of the 20 tasks showed a significant difference ($p < .005$) with greater load times of the application when using data stored in SDE. This result does not support the use of SDE to host data (Figure 3). These results in supporting the use of local data versus SDE suggest that querying data could cause processing times to increase more so than utilizing map selection tools. This, however, needs to be assessed in more detail in combination with other performance testing.

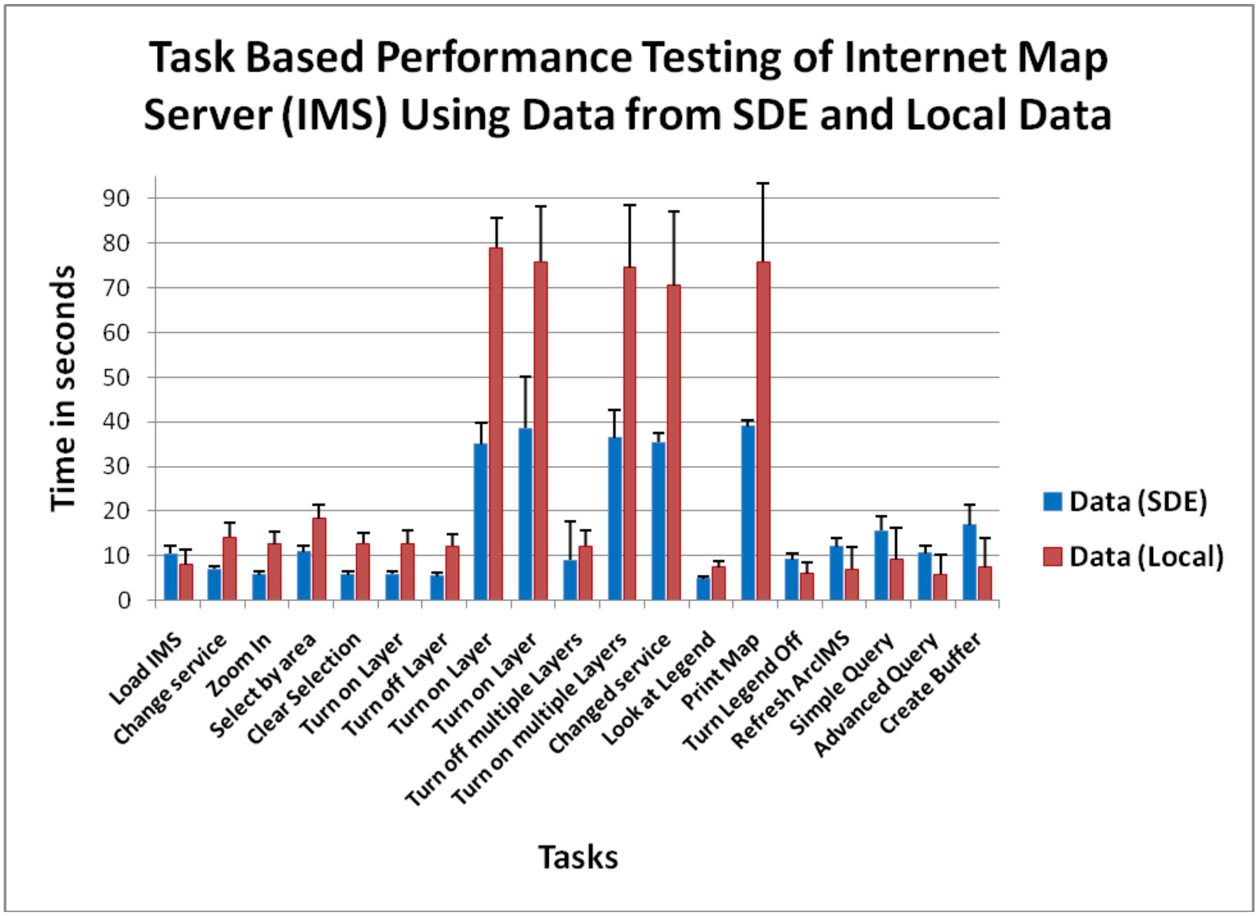


**Figure 3 Results from task-based performance testing, which assessed the time A2DI took to load the same data from different sources (data in SDE and data in a local file system).**

An F-test for the equality of variance indicates that the variance for the loading and reprojecting of data in the Canada test (F=0.059, p< 0.001) were significantly different and the same functional tasks in the Alaska test (F = 0.013, p = 0) were not significantly different (Figure 4). In the test results reported, the Alaska view took longer to load because three additional large data layers were included for the Alaska test. A two-sample t-test not assuming equal variances performed for the Canada test indicated a significant difference in load time (SDE: =6.976 SD= 0.803, N= 30; non-SDE: =14.178, SD=3.292, N= 30; t(32) = -11.64, p < 0.001). A two-sample t-test assuming equal variances performed for the Alaska test indicated a significant

difference in load time (SDE: =35.465 SD= 1.88, N= 30; non-SDE: =70.487, SD=16.71, N= 30; t(58) = -11.404, $p < 0.001$).

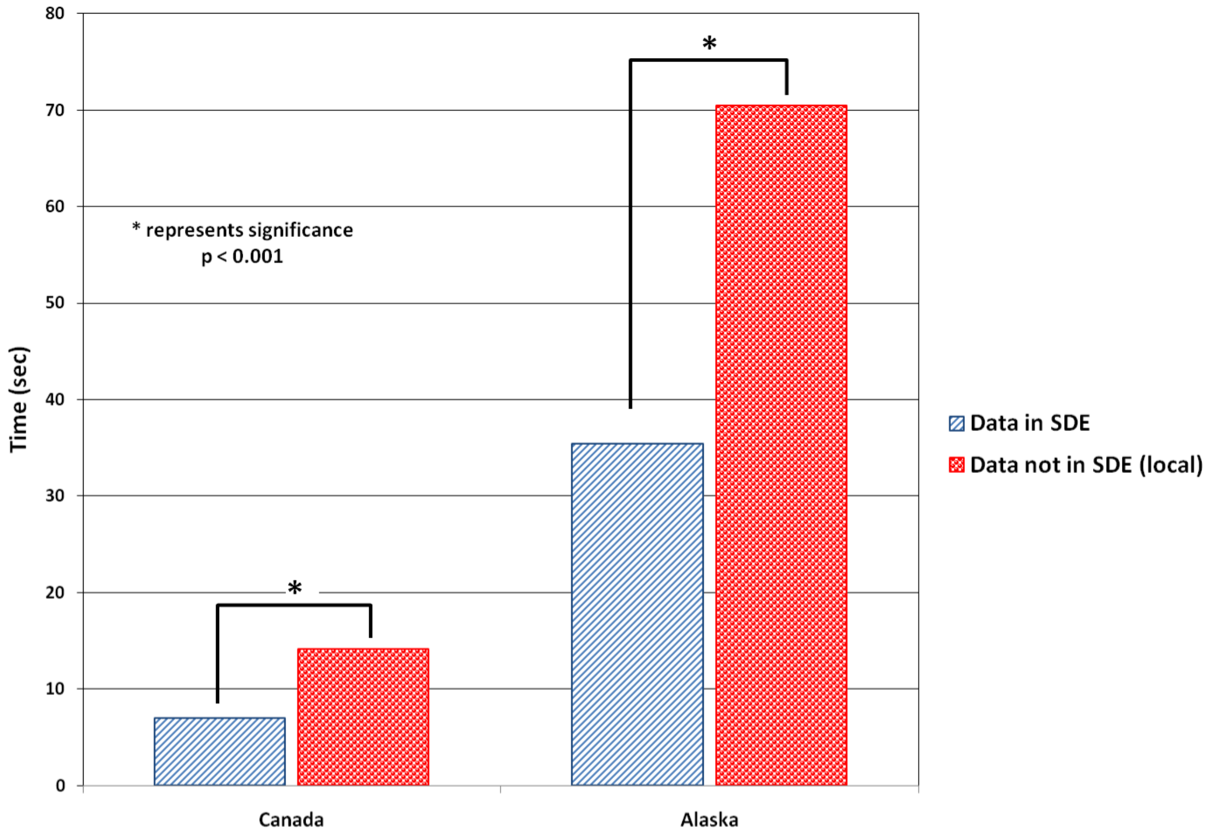


**Figure 4 Results from task-based performance testing, which assessed the time A2DI took to load the same data from different sources (SDE and a local file system), for the same projection (tested for Canada and Alaska services).**

Provision of OGC services allows a diverse user group improved access to multiple data layers embedded in GIS systems (Kenyon 2010; Teng et al. 2001). To benefit the capacities for interoperability with ARMAP circumarctic data layers, a proposal was written and accepted by the Oil and Gas Producers Surveying and Positioning Committee (formerly the European Petroleum Survey Group [EPSG]), for the six regional polar projections used in the ARMAP suite. Each Polar Lambert projection has been customized by shifting the central meridian of the map view to focus

on Canada, Greenland, Northern Europe, Russia, Alaska, and the Bering Sea respectively (Table 4). The acceptance of these projections permits the publication of OGC web services for data layers used in A2DIMS (section 2.3.3). ARMAP provided these new EPSG codes for the Arctic to ESRI and other Arctic data service providers including the NSIDC (Atlas of the Cryosphere, http://nsidc.org/data/atlas/) and GINA (Alaska Mapped, http://www.alaskamapped.org/) to include in their OGC capabilities files. Other interoperable tools, such as AGX, handle all accepted EPSG map projections and OGC web services (WMS, WFS, and KML), thereby increasing the capacity to overlay and integrate data from a variety of sources. Data providers can implement Arctic projections in GIS data services by including a projection code in the data service capability file (non-ESRI service) or through reprojecting and serving the data in a predefined polar projection using ESRI software.

**Table 4 List of accepted polar projection EPSG codes from the Oil and Gas Producers Surveying and Positioning Committee (formerly the European Petroleum Survey Group [EPSG]) used in ARMAP applications and hosted web services.**

| Name | EPSG Code | ARMAP Map Name | Online Link |
|---|---|---|---|
| WGS 84 / North Pole LAEA Bering Sea | 3571 | Circumpolar | http://spatialreference.org/ref/epsg/3571/ |
| WGS 84 / North Pole LAEA Alaska | 3572 | Alaska | http://spatialreference.org/ref/epsg/3572/ |
| WGS 84 / North Pole LAEA Canada | 3573 | Canada | http://spatialreference.org/ref/epsg/3573/ |
| WGS 84 / North Pole LAEA Atlantic | 3574 | Greenland | http://spatialreference.org/ref/epsg/3574/ |
| WGS 84 / North Pole LAEA Europe | 3575 | Northern Europe | http://spatialreference.org/ref/epsg/3575/ |
| WGS 84 / North Pole LAEA Russia | 3576 | Russia | http://spatialreference.org/ref/epsg/3576/ |

## 3.3. Virtual Globe Development

Google Earth (GE) has clearly dominated the field of 3D Geobrowsers (Butler 2006; Goodchild 2008). GE is an excellent platform for visualization with outstanding performance and imagery (Goodchild 2008; Sheppard and Cizek 2009), but lacks the

GIS functionality required by the ARMAP user community, specifically the ability to dynamically filter and query data. As well as having enhanced GIS functionality, ESRI's ArcGIS Explorer (AGX) has superior capacities for interoperability compared to GE because it can support a multitude of local and remote raster and vector data formats, OGC services, XML, GeoRSS, map services, and text files. ARMAP data layers were developed for both GE – to meet performance needs of users, and AGX - to meet the GIS functionality needs of users. In addition, GIS functionality in AGX was provided through the development of customized tasks (query tools). These tasks load a KML layer and enable querying of the ARLSS XML web service (Figure 2).

## 3.4. Evolving Web Service Data Standards

Implementing geospatial data standards increases data portability (Albrecht 1999; Bernard and Ostländer 2008) and encourages data providers to adapt standards that increase interoperability, and therefore the likely popularity and usability of their data (Bernard and Ostländer 2008; Díaz et al. 2011). Software developers are also benefited by the adoption of data standards to improve access to data, and data manipulation, fusion, and visualization, thereby improving the functionality, scalability, and usefulness of their software (Poulin 1995; The Joint Data Standards Study 2005). Ensuring ready access to Arctic data and metadata has been one of the most time consuming elements during the development of ARMAP. Because of this and the very interdisciplinary and international nature of Arctic research, development of ARMAP has strived to improve data discovery, access, and reusability through the adoption of data standards and best practices. Over the past three years the development and implementation of new software has made the integration of rapidly evolving OGC

standards for web service development significantly easier. For example, in ArcGIS version 9.2, ArcIMS image-based (*.axl) services only supported the importation of WMS and publication of WMS/WFS vector services. In this same version, ArcMap (*.mxd) services supported importation of WMS services but did not support publication of OGC services. ArcGIS Server 9.3 featured the ability to provide enhanced support for OGC services including the publication of WMS, WFS, WCS, and KML specifications, along with a new geospatial Representational State Transfer (REST) service. The development of an ASDI (Li et al. *In Press*-b; Parent et al. *In Press*; Yang et al. *In Press*) incorporating and adhering to the use of OGC, REST, and EPSG codes for polar projections is likely to greatly enhance access to data and information benefiting Arctic science.

# 4. ARMAP Use-case Scenario

In software development, use-case scenarios appeal to user needs and offer pragmatic insight for users to gage the usefulness of unfamiliar applications (Bai et al. 2002) by identifying steps they can take to operate, answer questions and/or fulfill using software systems (Coughlan and Macredie 2002; Sutcliffe et al. 1998). These techniques have been used in software development in academic and industry sectors since the early 1990s (Bai et al. 2002; Jacobson et al. 1999; Sertic and Fijar 2004). A scenario based approach for software development also gives developers insight as to how a system is envisioned or utilized from a user point of view (Bai et al. 2002).

This chapter focuses on three use-case scenarios that use the ARMAP suite. The first WebGIS developed for the ARMAP project was the A2DI ArcIMS application (section 2.3.3), which users can use to view multiple layers of arctic data and utilize GIS functionality in one interface (section 4.2). With the rapidly growing popularity of GE, a KML network link file providing a folder tree of research site data (section 4.1) similar to that found in the IMS was developed for users not familiar with the IMS (section 4.1.1). The third application developed for ARMAP was the ARMAP 3D (section 2.3.4) virtual globe, which was built using AGX for users who prefer 3D Geobrowsers, but requires more GIS functionality than typically found in GE (scenario 4.3).

**Table 5. Summary of the functionality of the three GIS applications used for the initial ARMAP suite. Highlighted cells indicate the application supports attributes listed in the left column. This table provides a useful reference for users to decide which application would best suit for their needs. There is a short version of this table for quick reference on the ARMAP homepage (http://armap.org/Help_ChooseApp.aspx).**

| | ArcIMS (html viewer) | ArcGIS Explorer (AGX) | Google Earth | Comments |
|---|---|---|---|---|
| 3D Geobrowser | No | Yes | Yes | |
| Download and software installation required | No | Yes | Yes | |
| WMS / WFS client (Open Geospatial Consortium standards) | Yes | Yes | Yes * | ·OGC only supported in GE through custom scripts |
| Supplies default imagery | No * | Yes | Yes | *Free base maps and imagery provided by connecting to ArcOnline. Custom data easily integrated. |
| Supplies default terrain | No | Yes | Yes | Custom terrain easily integrated into ESRI products. SRTM and GTOPO base for AGX |
| Supplies default framework data such as roads, placenames | No | Yes | Yes | Custom vector based framework data is easily integrated in all products |
| Widespread appeal | Yes | No | Yes | GE most widely used 3D Geobrowser |
| Speed | Varies | Varies | Excellent | Performance for Arc products varies due to imagery used, WMS, database performance, server capacities, internet hosting, etc. |
| Stability | Excellent | Varies | Excellent | |
| Can make complex searches | Yes | Yes | No | |
| KML support | No | Yes | Yes | |
| Runs on PC | Yes | Yes | Yes | |
| Runs on Mac | Yes | No | Yes | |
| Runs on Linux | Yes | No | Yes | |
| GIS functionality | Yes | Yes | No | |

The development of the ARMAP suite of applications and services has focused on users' requirements and experiences, which have molded applications for different user groups (sections 4.1 – 4.3). The motivation for building ARMAP in a range of different development platforms was to maximize the functionality, usefulness and usability of ARMAP and appeal to a wide array of users. The ARMAP suite has been developed to provide access to and use of data from NSF and other funding agencies

that is not readily available elsewhere, and to benefit to managers, researchers, logististicians, educators and the general public.

**Table 6. Use-case scenarios developed for this project in order of general ease of use of the applications. The target audience and rationale for the scenario are also listed.**

| Ease of Use | Applications | Audience | User decision for application use |
|---|---|---|---|
| 1 | Google Earth | NSF | Needs image for meeting presentations |
| 2 | IMS | Logistics | Need to develop logistics plan for researcher |
| 3 | AGX | Researcher | Researcher need access to and use own data |

The following use-case scenarios demonstrate how ARMAP users can utilize the IMS, GE KML, and AGX to access data and GIS and other functionality (Table 6). These scenarios are presented to demonstrate the utility of the ARMAP suite in solving a range of environmental science challenges in the Arctic. The following use cases are based on known needs in the ARMAP user community but have been enhanced to demonstrate additional user capacities. The scenarios are ordered in text based on ease of use (Table 5 and Figure 5) and steps within each scenario have been given a number for demonstration purposes (e.g., number of steps to achieve user's final goal) to compare with other applications.

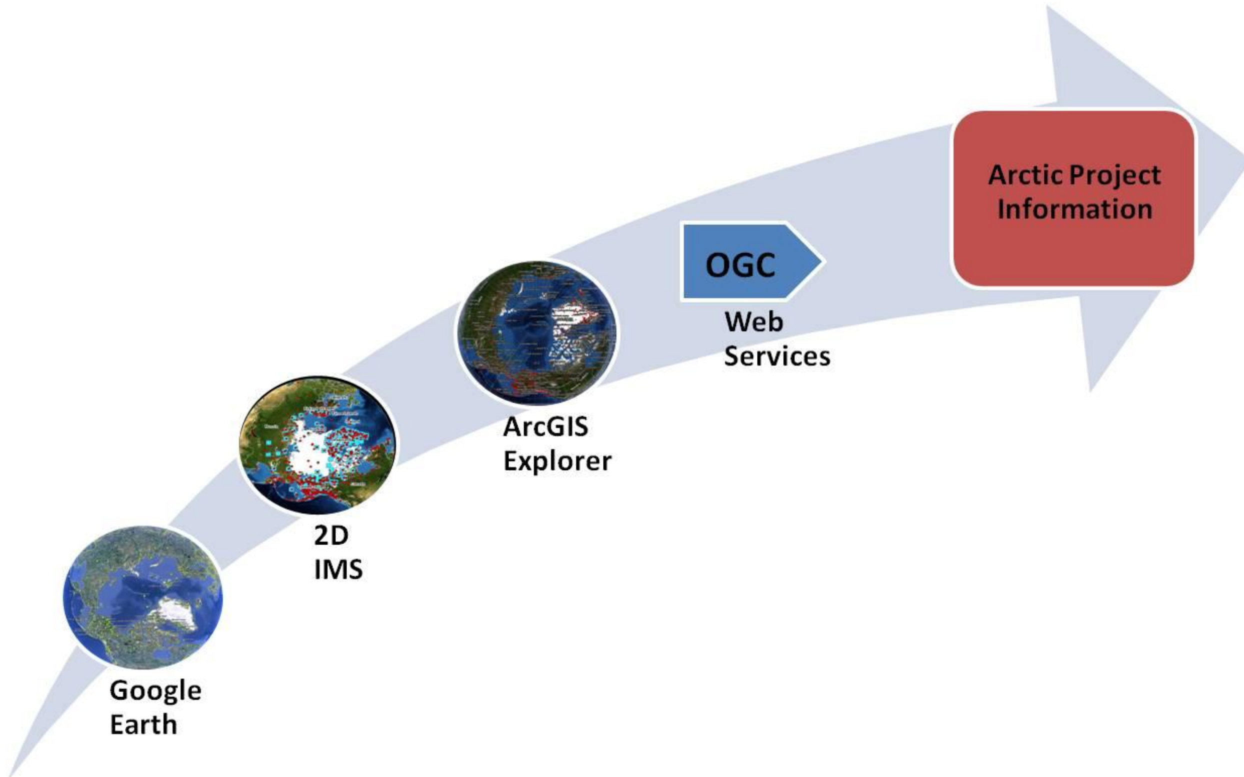


**Figure 5 Visual demonstrating using different applications to access the Arctic project information from ARLSS. The applications follow a sequence of complexity – from easy to use applications such as GE to more complex applications such as the use of web services.**

## 4.1. Google Earth

GE provides an excellent platform for visualization with outstanding performance and imagery (Goodchild 2008; Sheppard and Cizek 2009). Still rapidly growing in popularity since the public release in June of 2005 (Sheppard and Cizek 2009), GE's ever expanding user audience and free availability to download GE gave premise to develop a KML file to link users with ARMAP data. Although the only layers ARMAP serves through the KML Network Link (section 2.3.4) consists of funded research sites

(ARLSS data), other arctic data are becoming available as KML files such as sea ice extents and snow cover provided by NSIDC (http://nsidc.org/data/virtual_globes/). Using a question posed in the 2009 paper by Sheppard and Cizek, “What roles do virtual globes play in official processes for decision-making and design, beyond generation of static maps?” the following scenario demonstrates accessing, viewing, and linking to information provided by ARMAP in GE. Using GE’s functionality to fly-to, click icons for information, and the relative ease of creating your own folder and saving a KML/KMZ file, a scenario has been created to demonstrate the usefulness of the ARMAP in GE’s KML Network Link. The following scenario is hypothetical, but has been developed from past requests of logistic and NSF program managers to develop visualizations for use in decision making and collaboratory meetings.

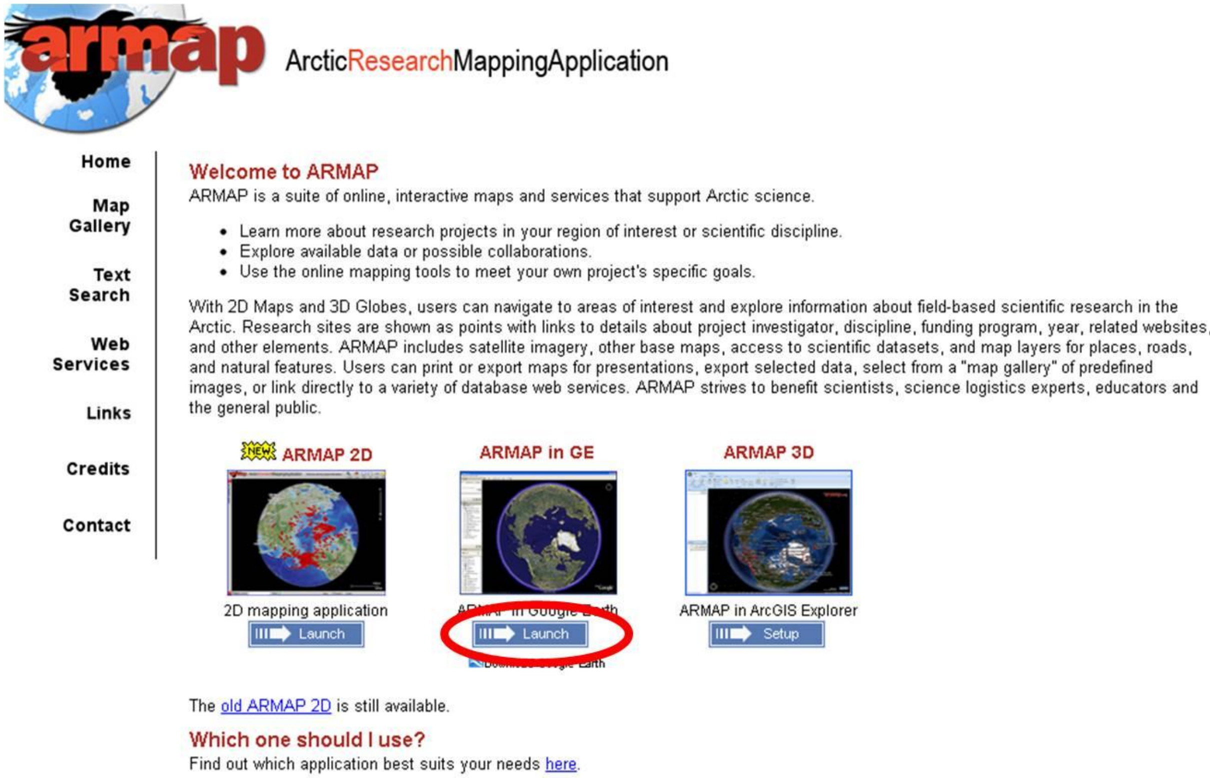


**Figure 6 The ARMAP home page accessed at** http://armap.org**. Clicking the GE icon from home page enables users to download the GE KML network link file.**

### 4.1.1. Google Earth Scenario

Mr. Arctic, the head of NSF's Office of Polar Programs, needed to develop a quick visualization of: 1) Arctic research effort for projects related to Biology (1998 through 2010) for his presentation to Congress where he was providing an overview of arctic biological research; and 2) research efforts in Greenland sponsored by NSF for an international meeting with leading research institutions of Arctic Nation's where he was aiming to demonstrate opportunities for international research collaboration to facilitate understanding of environmental climate change in Greenland. He remembered attending the 2006 ARMAP demonstration of applications and services, which included GE (Table 6). Considering sending the request to the logistics coordinator, he changes

his mind since he is interested in learning to use GE. He also wants to promote the use of ARMAP applications and services to demonstrate how his office has invested in improved WebGIS and information systems to help manage NSF-funded arctic research effort. This scenario assumes that the user already has a version of GE installed.

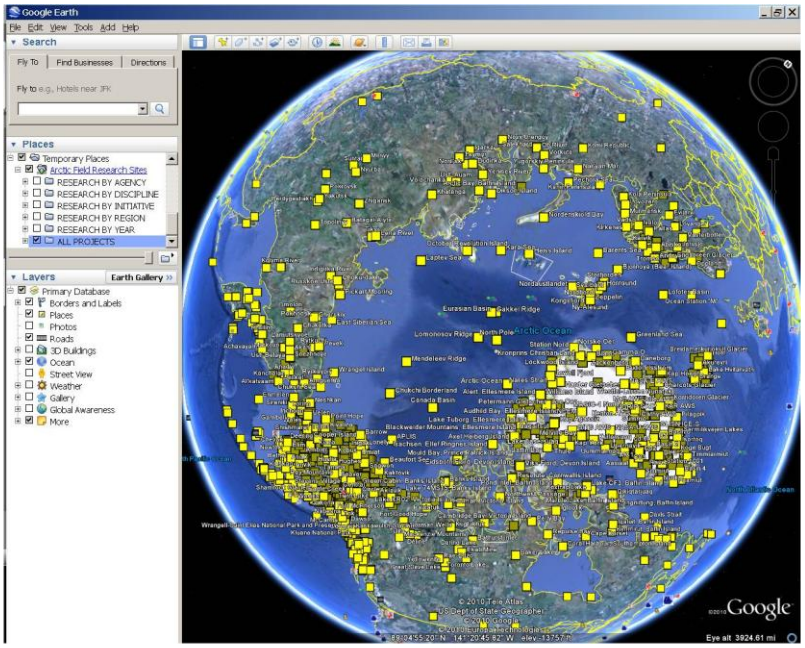

**Figure 7. Default GE view of Arctic Field Research Projects KML.**

Since Mr. Arctic has never used ARMAP in GE, he (1) accesses the ARMAP layer (Figure 6 circled in red) through the ARMAP homepage (http://armap.org) by clicking on the GE icon (Figure 6) to download the associated KML file ("ArcticFieldResearchSites_Net.kml"). Depending on the internet browser being used, he may be required to (2) click on the downloaded file to launch GE which displays the data in form of yellow squares (Figure 7). This KML network link file is associated with a

zipped KML called a KMZ, which is updated weekly and allows access to updated research sites as long as the layer remains in the GE Table of Contents (TOC).

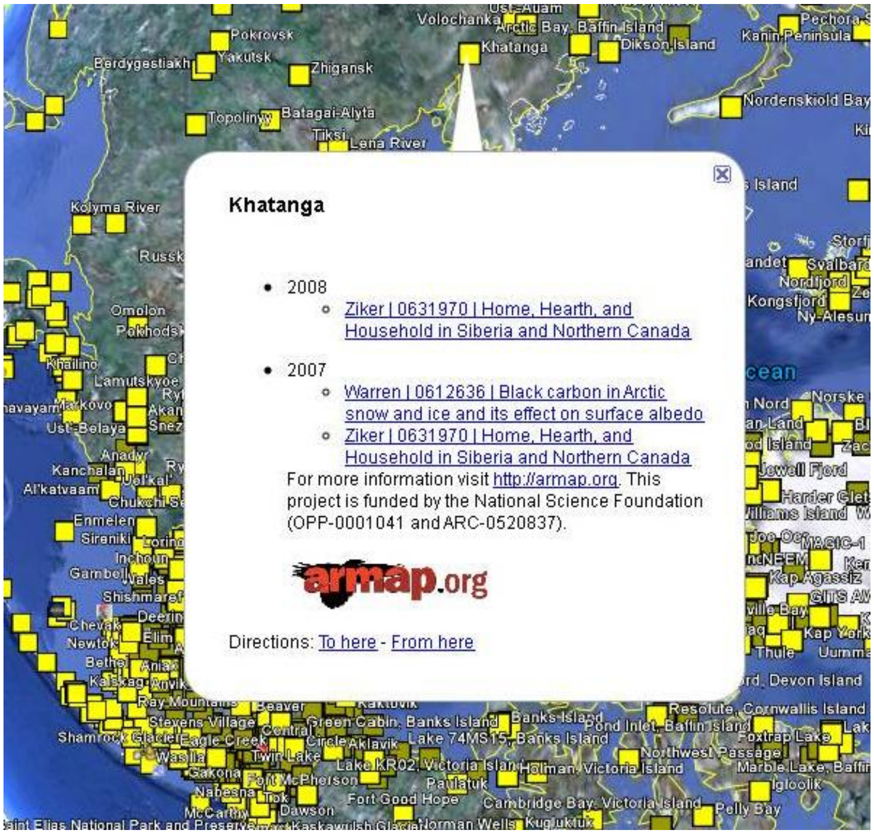


**Figure 8. HTML pop-up displaying information of research site.**

**Arctic Field Projects**

**Project Title:** Home, Hearth, and Household in Siberia and Northern Canada (Award# 0631970)

**PI:** Ziker, John P (jziker@boisestate.edu )
**Phone:** (208) 426.2121
**Institute/Department:** Boise State University, Department of Anthropology
**IPY Project?** YES
**Funding Agency:** US\Federal\NSF\OD\OPP\ARC\ASSP\BOREAS
**Program Manager:** Dr. Anna Kerttula (akerttul@nsf.gov)
**Discipline(s):** | Social and Human Sciences\Archaeology | Social and Human Sciences\Cultural Anthropology | Social and Human Sciences\Historical Demography |

**Project Web Site(s):**

Data: http://anthro.boisestate.edu

Initiative: http://ftp.esf.org/esf_article.php?language=0&domain=4&activ...

Initiative: http://www.esf.org/esf_article.php?language=0&activity=7&dom...

NSF_Award_Info: http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0631...

Initiative: http://www.sami.uit.no/boreas/

**Science Summary:**
This project is one component in an international collaborative project developed for the European Science Foundation under the program "BOREAS: Histories from the North -environments, movements, narratives." This project will focus on the home, hearth, and household in the central Taimyr Region and Vitim River in Siberia, Rae-Edzo, Northwest Territories, Canada, and with the holdings of the National Museum of the American Indian [NMAI] in Washington, D.C. Our research will comprise five activities engaging in detailed ethnographic, demographic, and spatial studies in indigenous communities in the central and eastern Taimyr Region, participatory research exchanges with aboriginal peoples from Canada and Russia, and collaboration between indigenous peoples and museums. Together with its sister projects our research aims to contextualize the vernacular architecture of portable skin lodges in the North, analyze the use of space within contemporary and prehistoric dwellings, and analyze the dynamics of contemporary and historic households. This individual project will contribute intellectually to understanding the dynamics of northern households and their relationships with the environment. Each of the activities will add to contextual knowledge of circumpolar dwellings and their role as arenas of learning, memory, and communication. The project's research activities will investigate the construction of mobile dwellings, the social movement of resources among households, as well as the use of space, including documentation of important features of cultural landscape. This project will expand to new geographic areas the principle investigator's long-term research in the Western Taimyr Region on topics of land and resource use, demography, and cosmology among the Dolgan and Nganasan, and allow for joint publication and repatriation of the information back to local communities. The project will document and support the reinvigoration of traditional knowledge about caribou skin lodges held in the museum collections of the NMAI in Washington DC, uniting museum ethnographers, field anthropologists, and indigenous craftspeople. The project will link contemporary ethnographic and ethnoarchaeological work to recently available historical demographic records. This will support public access to important historical and ethnographic data sets in local languages. Collaboration with regional scholars and indigenous people in the Taimyr Region and in the Northwest Territories of Canada, as well as with scholars in Dudinka and Irkutsk, adds to the study of change and contact of native peoples of the North, while emphasizing the global role of the Arctic region. Boise State University (BSU) is promoting internationalization, meant to educate competent and culturally sensitive citizens as active participants in society. Support of this project will provide opportunities for students in an international pool of applicants to pursue a graduate degree in Anthropology at BSU, including fieldwork in the Taimyr Region. The project will also involve local undergraduate students adding to their educational experience. The project's focus on circumpolar dwellings as arenas of learning and memory, providers of mobility in and interaction with the environment, and the social center of households will add to understandings of cooperation, global interdependence, human rights, and diverse cultural, social, political, and economic systems in the Arctic.

**Logistics Summary:**
This project is part of the large European Science Foundation-led BOREAS coordinated program of research in the North that includes scientists from Europe, the US, Canada, and Russia. In particular, this grant contributes to the Home, Hearth, and Household in the Circumpolar North (HHH) research theme. This project will conduct ethnographic research on the home, hearth, and household in the central Taimyr region and Vitim River in Siberia, Rae-Edzo, Northwest Territories, Canada and with the holdings of the National Museum of the American Indian [NMAI] in Washington, D.C. The PI will concentrate on three research components: a) Contextualising the vernacular architecture of portable skin lodges; b) Analysis of the use of space within contemporary and prehistoric dwellings; c) Analysis of the dynamics of contemporary and historic households. During the summer of 2007 and 2008, a field

**Figure 9. Project report displaying high level project information including Project Title, PI, and links to more information about the project (e.g., project website, data archives, project summary). There is currently an effort to include links to data generated for each project.**

Once open, GE automatically zooms to a North Pole view for exploration of NSF supported research sites (Figure 7). First, Mr. Arctic can find out what each yellow square represents by (3) clicking a square to display a pop-up showing project information for a particular research site (Figure 8). Each pop-up has been arranged by date and has hyperlinks to high level project information (Figure 9). Now that Mr. Arctic has a feel of what he is looking at, he notices that the TOC has a layer called Arctic Field Research Sites with six sub-folders (RESEARCH BY AGENCY; RESEARCH BY DISCIPLINE; RESEARCH BY INITIAIVE; RESEARCH BY REGION; RESEARCH BY

YEAR; and ALL PROJECTS) as seen in Figure 7. The general description of the group of ARMAP layers can be accessed by (4) clicking the main folder (Figure 10).


**Figure 10. General pop-up for the KML network link layer Arctic Field Research Sites found in the Table of Contents of Google Earth when clicked. This pop-up provides the layers general description pop-up.**

To achieve his first objective and create a map of Arctic research effort for research projects focused on biology to present to Congress, he (5) expands each layer and notices there is a pre-defined layer in the TOC called Biology. Clicking this layer displays new icons on the map representing research projects with a focus on biology (Figure 11). This is the map view he needed for the presentation so he saves the map

as a JPG image by (6) choosing “File, Save, Save Image” (Figure 12) and gets a resulting image (Figure 13) that he can insert into his presentation.

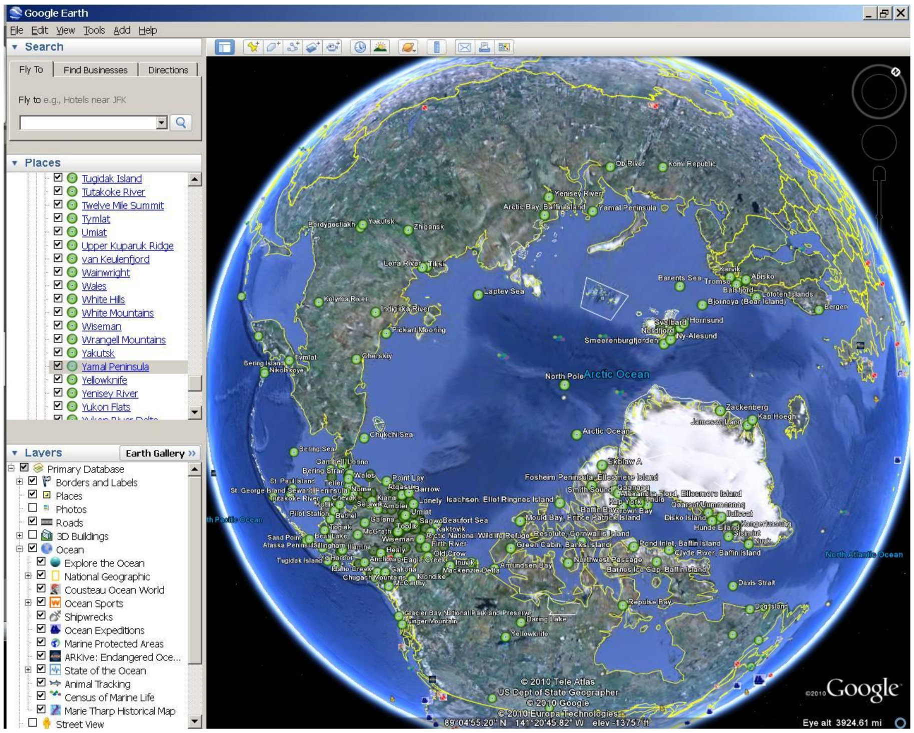


**Figure 11. Polar view of ARMAP biology research sites displayed using pre-defined folder in Google Earth Table of Contents**

Mr. Arctic continues to meet his next objective and create a map for the presentation he will give to leading research institutions of Arctic Nation’s where he was aiming to demonstrate opportunities for international research collaboration in Greenland. He notices that there is already a predefined layer for Greenland in the “RESEARCH BY REGION” folder (Figure 14). (1) Turning off the “All Projects” layer, (2) turning on the Greenland layer, and using (3) GE navigational tools, he (4) zooms into Greenland and orients the map to display Greenland with North to the top of the map (Figure 14). He (5) saves the map and has created two detailed US research effort

pictures for his meetings in a relatively short time. Using ARMAP in GE, Mr. Arctic has used a quick and easy method to create his maps. When he needs to create map images in the future, he can do so with the same few clicks without the assistance of others. With the ease of creating these map images, he decides he wants to create another map image; showing arctic Biology research effort for existing and newly funded research over the next three years (2011-2013) in and around Greenland and finds that this is not possible with the current data unless he either shows all Biology or research projects for those three years, which is not specific enough to meet his needs. He tried to use the built in search, but came up with other results and not the ones focused on ARMAP data. Mr. Arctic has reached the limit of GE's functionality and complex searches such as these will require the use of another tool from the ARMAP suite.

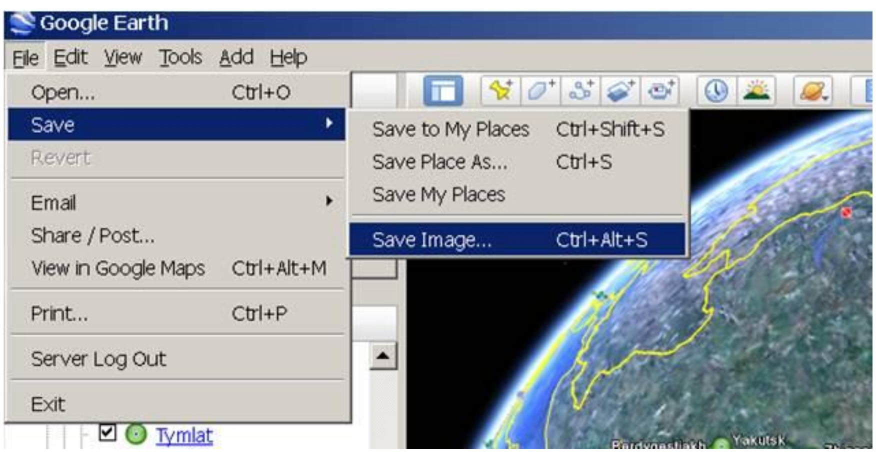


**Figure 12. Google Earth's built in functionality allowing users to save images (JPEG).**

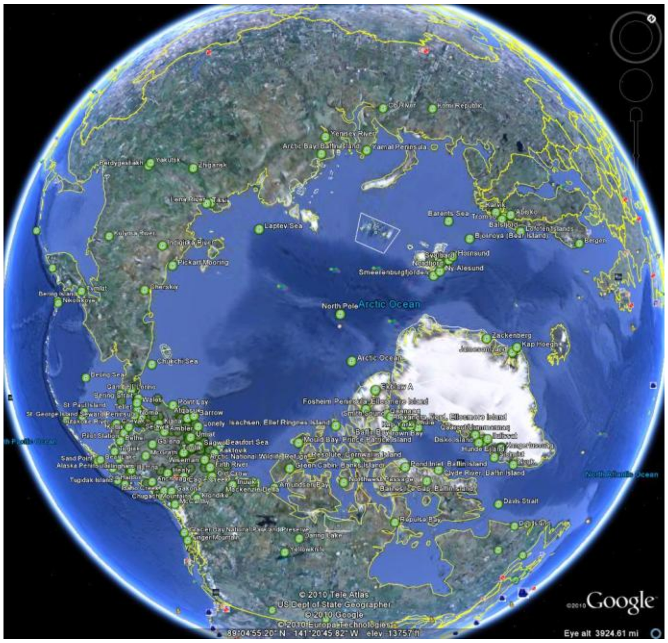

**Figure 13 JPEG Images created using Google Earth's built in functionality.**

### 4.1.2. Google Earth Summary

GE provides an easy way to visualize pre-existing KML/KMZ layers such as those provided by ARMAP and save images for presentations. Using the network link as the primary KML file for ARMAP, users have access to updated data every time GE is opened and have the ARMAP KML saved in the "My Places" TOC. Mr. Arctic's advanced request was ultimately handled by student developers at UTEP using desktop GIS applications using ARMAP web services developed in section 3.4. ARMAP attempts to appeal to a wide range of audiences including facilitating the technical education of its users – particularly when they are in decision making positions. The more advanced functionality needed by Mr. Arctic to create queries and print maps specific to his inquires can be found in both the ArcIMS 2D (section 4.2) and ARMAP 3D (section 4.3) applications.

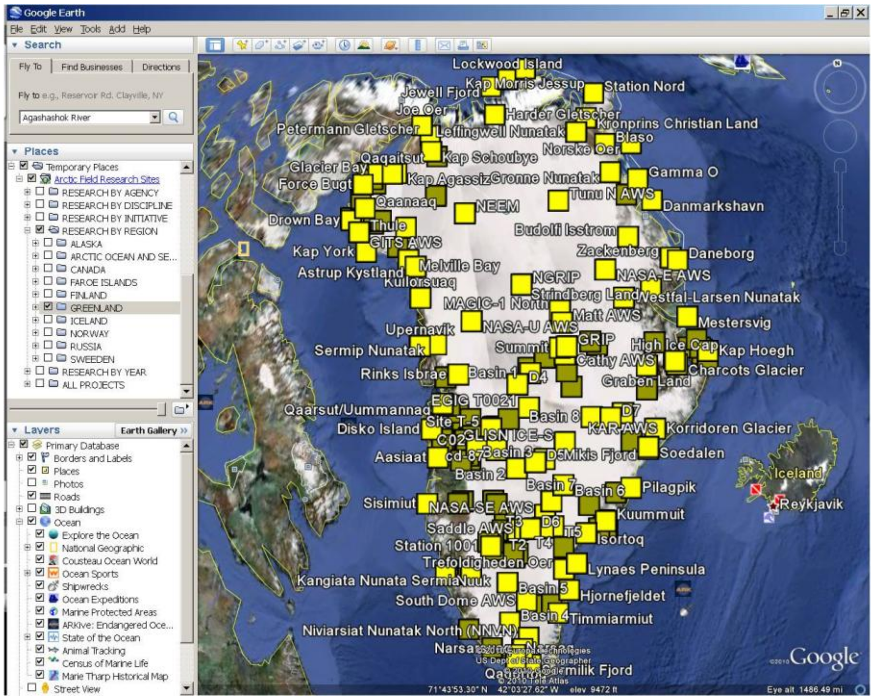


**Figure 14. NSF research projects funded in Greenland displayed in Google Earth.**

## 4.2. Science logistic planning using ARMAP 2D IMS

A2DI is focused on displaying information about federally funded field-based research projects in the Arctic along with a number of other arctic map layers. Data for A2DI are stored in a Polar Lambert map projecting allowing users to re-center and create maps using the '*regional zoom tool'* from the pull down menu at the top of the application window (Figure 16). The A2DI application can be used for a number of different research, education, and logistics activities (Figure 15). The following is a hypothetical situation using real projects and people involved in logistic planning for NSF funded research in the Arctic.

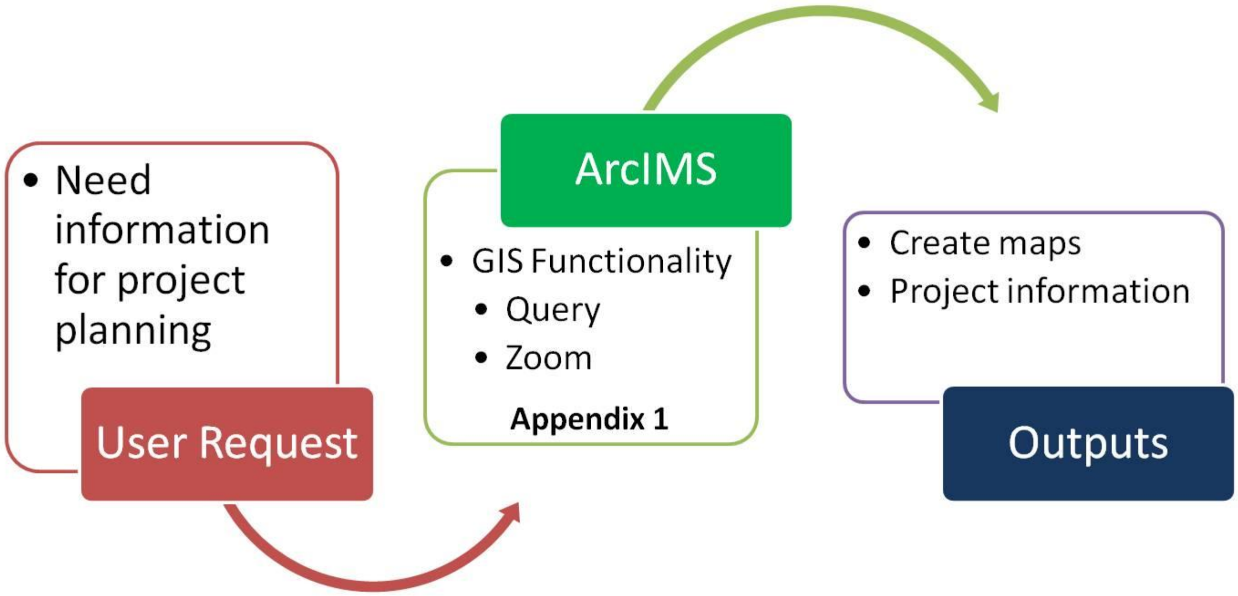


**Figure 15 Simplified workflow of ArcIMS user requirements.**

### 4.2.1. A2DI Logistic Planning Scenario

Due to the remoteness and extreme conditions of arctic research sites, logistic costs are expensive relative to research conducted in more populated and easy to get to places. Where possible, NSF logistic contractors attempt to couple logistics costs between projects to save money. This requires advanced and detail knowledge of not only the proposed research activities, but also logistics options available.

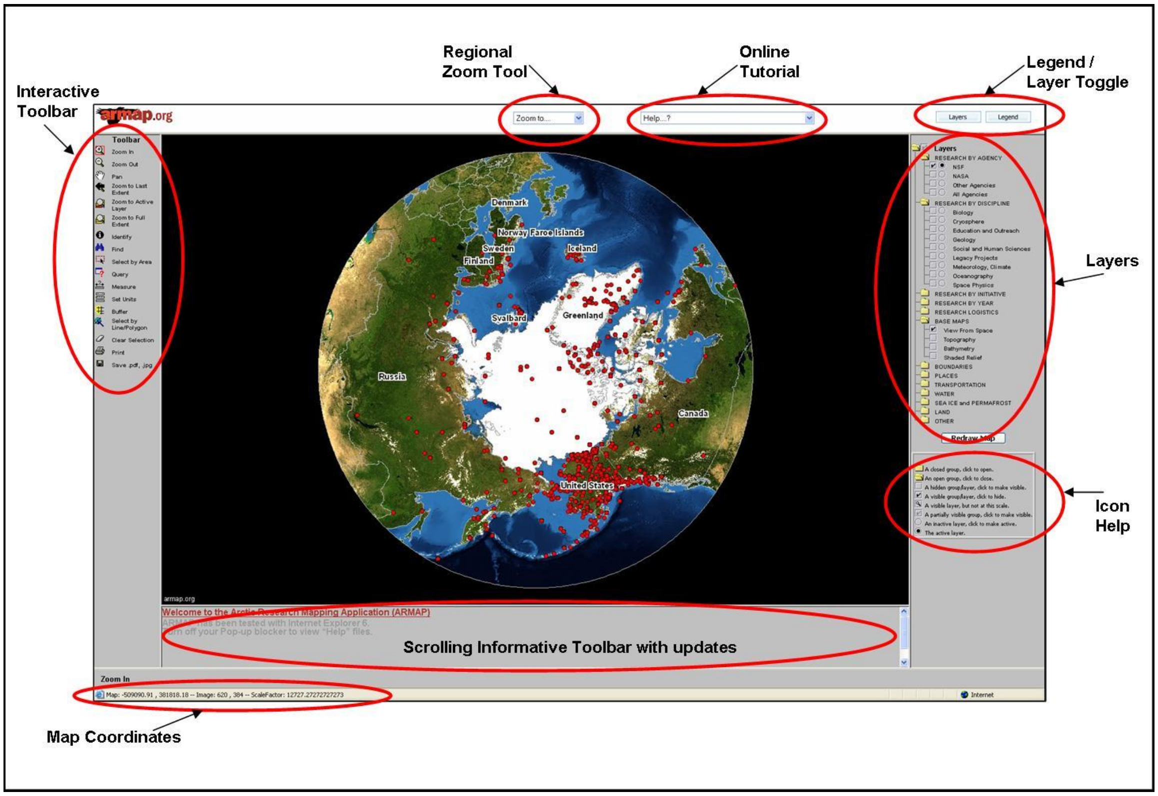


**Figure 16. Overview of ARMAP 2D IMS (A2DI) interface. The "*interactive toolbar*" allows access to GIS tools providing the baseline functionality of the application. "*Regional zoom*" gives users the ability to switch map views between each of the six available arctic views. The "*online tutorial*" provides a links to additional help documents through HTML links. Users can view the legend for active layers and switch back to the list of "*layers*" in the Table of Contents using the "*Legend/Layer Toggle*". Below the Table of Contents and the map view, "*icon help*" and a "*scrolling banner*" gives users information about the application. The bottom left corner of the applications provides map coordinates for the position of the mouse pointer.**

Dr. Romanovsky is an active permafrost researcher at the University of Alaska Fairbanks and has been a part of nine large research projects requiring logistical support in four different countries since 1999 (Table 7). Romanovsky's research focuses on permafrost geophysics, subsea permafrost, seasonally frozen ground, seasonal snow cover, and the relationships between biota, hydrology, and climate. From project descriptions, Dr. Romanovsky's field crew has anywhere from one to eleven personnel in the field at any given time and typically requires truck, airplane or helicopter support for transportation.

**Table 7. Summary of Principal Investigator Vladimir E. Romanovsky's research projects requiring logistical support for field research in the Arctic from 1999 - 2014. There were a total of 30 unique field locations from 9 projects in the ARLSS database requiring logistical support for transportation. Data were derived using publically available data from the ARLSS database using ARMAP's (http://armap .org) text search functionality.**

| **Projects** | **Countries** | **Field Locations** |
|---|---|---|
| **9** | Alaska | Barrow, Chandalar Shelf, Council, Deadhorse, Fairbanks, Franklin Bluffs, Gakona, Galbraith Lake, Happy Valley Camp, Howe Island, Ivotuk, Kaktovik, Nome, Prudhoe Bay, Seward Peninsula, Toolik, Wainwright |
| | Canada | Green Cabin, Banks Island, Isachsen, Ellef Ringnes Island, Mould Bay, Prince Patrick Island |
| | Greenland | Ilulissat, Kangerlussuaq, Nuuk, Qaanaaq, Qaarsut/Uummannaq, Sisimiut |
| | Russia | Batagai-Alyta, Mirnyy, Vorkuta, Yakutsk |
| **TOTAL** | **4** | **30** |

Dr. Romanovsky is interested new field locations in Eastern Russia to increase his field observational network. He contacts Robbie Cooper, Special Projects Manager at CH2M Hill Polar Field Services, Inc., who is responsible for developing and budgeting field plans. Dr. Romanovsky will subsequently submit this cost estimate along with his scientific proposal to the NSF. Cooper decides to use the A2DI application for the creation of maps and logistic planning. She has used the A2DI application before so she is familiar with the GIS functionality and (1) opens the ARMAP home page (Figure 17). She then (2) clicks on the text "old ARMAP 2D" (Figure 17 circled in red) which automatically opens in her web browser (Figure 16). To create a regional specific map, she (3) uses the regional "Zoom To.." drop down at the top of the application to rotate the map orientation to an optimal view of Russia (Figure 16). She then proceeds to (4)

zoom in on eastern Russia using the “Zoom In” tool located in the Interactive tool bar (Figure 16). To get the layers needed to produce the information need for this requests, she (5) un-checks the “Auto draw map layers” found below the Table Contents (TOC). This functionality allows users to draw a new map with multiple selected or deselected at one time avoiding having to redraw the map each time a layer is selected or deselected; saving time since redrawing a map with one layer is similar to redrawing a map with several layers (section 3.2). She uses the TOC (6) to click on corresponding layers to display Cryosphere and Meteorology/Climate projects to view research sites that have locations near main transportation infrastructure. She then checks the corresponding boxes next to the road and airport layers and turns off the NSF layer by (7) un-checking the box to display the layers selected above. She then (8) clicks the “Redraw Map” button above the “Auto Draw Map Layers”, which draws a new map. She decides to get the information for airports in the area to start creating a table for flight availability and costs. She does this by (9a) activating the airports layer by clicking the radio button, and using the “select by area tool” from the “interactive toolbar” by (9b) clicking the tool icon and selects the airport map icons by (9c) left clicking her mouse and drawing a bounding box around the region of interest. This action results in a table at the bottom of the application where she (9d) selects the table, copies, and pastes it into her spreadsheet program (e.g., Microsoft Excel) for further compilation.

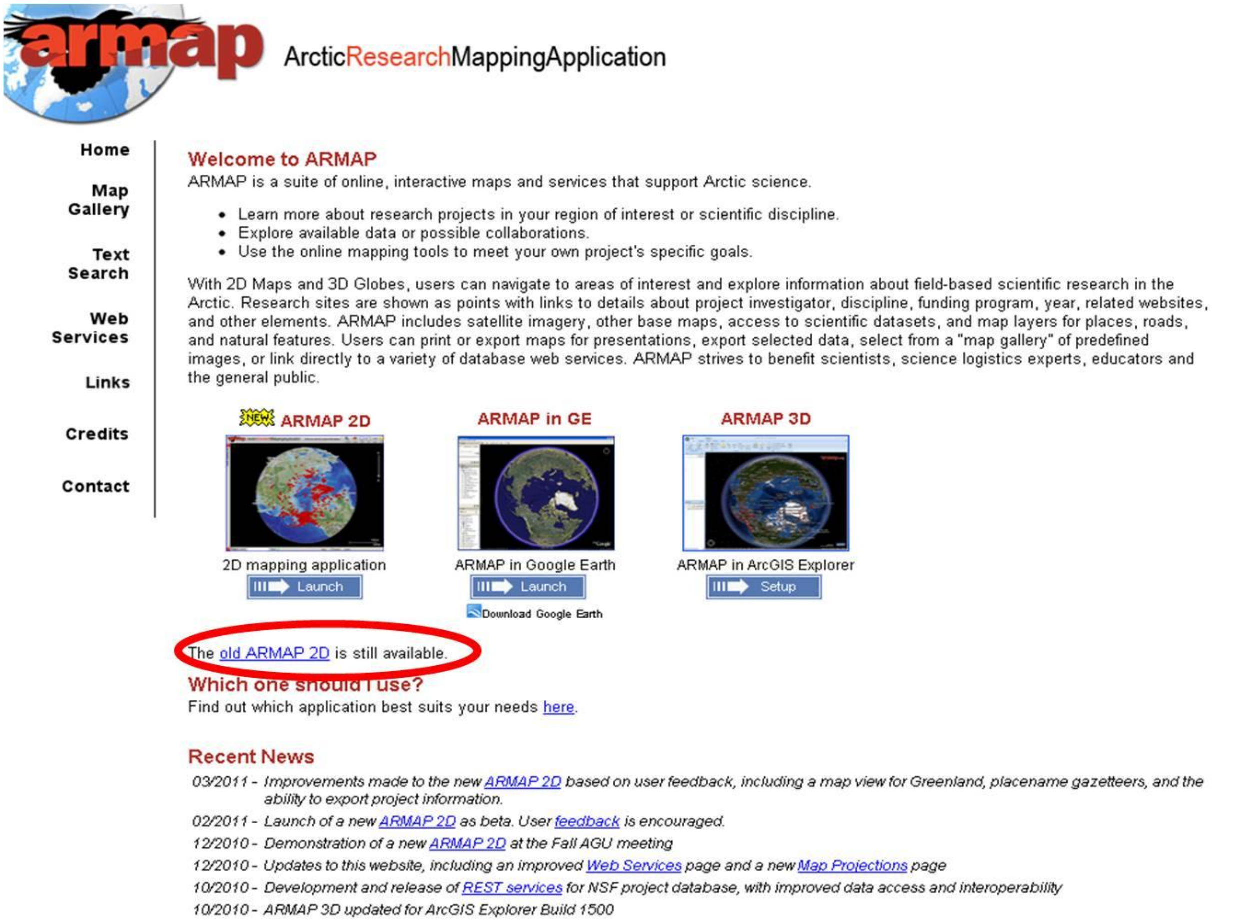


**Figure 17 The ARMAP home page accessed at http://armap.org. Clicking the "old ARMAP 2D"link circled in red on the home page opens up the A2DI application in a new window.**

Cooper now wants to determine if there may be other projects in the area that could cost-share logistics with Romanovsky. To find out which PIs are currently doing research in the area, she (10) activates the corresponding radio button for Cryosphere and uses the select by area tool by (10b) clicking the tool and placing a bounding box around the research sites. This results in a table of projects at that location. The resulting table shows a large amount of research sites that Cooper scrolls through to find projects for future years and accesses more information such as pop-ups to see

what previous research has needed for logistics in the area. These reports can be accessed by (11) clicking the blue text for ‘project ID’ that contains a hyperlink to the project page from ARLSS.

Ms. Cooper now proceeds to develop a table for the Meteorology and Climate layer repeating the steps she executed previously for acquiring information about cryosphere projects. Since the select tool returned many projects outside her interest area and looking through tables can be time consuming, she decides to use the query tool to narrow her search. She activates the layer by selecting the corresponding radio button. After clicking (13) the Query tool, a window pops up at the bottom of the application where query information can be entered. She (13a) types the following text into the query window “Region = "Russia" AND Year_ >= 2011” (which is accessed using drop down lists in the tool window) and clicks execute. Not as many results are returned with this query and they are more specific to the years she is looking for. She subsequently accepts the query results, copies, and pastes the table into her spreadsheet as described previously. She accesses projectreports as before by clicking the blue text for project ID, which contains a hyperlink to the project page derived from ARLSS.

Ms. Cooper can now proceed to calculate distance between research locations and transportation hubs. Since current road infrastructure in Eastern Russia is limited in the areas of the proposed research locations, helicopter will be the best mode of transportation. Using the buffer tool, she creates a buffer 500 km around Cryosphere and Meteorology research sites to identify candidate airports that could be used for staging air operations. Before a buffer can be created, she needs to select the (14)

primary layer to buffer against (i.e., Cryosphere). Once selected, the buffer is created by selecting the (14a) buffer tool, (14b) selecting the layer to buffer against, (14c) entering the buffer distance, (14d) checking the "Display Attributes", and (14e) clicking the create buffer button. These steps are repeated again for a buffer around Meteorology. She copies the tables from the two queries for use in her spreadsheet as described above.

Cooper decides to use A2DI's functionality to produce maps for her final report to Dr. Romanovsky. She uses the "Save .jpg" to (15) export and print the aforementioned queries in illustrated map views. She also selects additional layers to include that are relevant to Romanovsky's research including the Permafrost map and Legend that can be found in the "Land" folder of the TOC. Printing maps with legends can be executed by (16) clicking the "Print" icon, (16a) entering a user-defined title for the map "Potential research location for permafrost research activities", and (16b) clicking the "Create Print Page" button. Using outputs of the select functions and queries, Cooper now has information regarding surrounding airports and a list of other researchers who may be able to share logistics expenses, and proceeds to write up a report of her findings including other PI contact information, projected costs, and the map images she produced using the application.

### 4.2.2. A2DI Scenario Summary

A2DI allows users to interact with and visualize a range of arctic data layers and provides the functionality to save images for reports, publications, or presentations. Appendix 1 contains a user guide developed for this use case that can be utilized by logistics and researchers to obtain information needed for their respective activities. Using standardized GIS tools such as the query, select by area, zoom, and buffer

functions, this scenario has demonstrated how a logistician (Cooper) was able to query the ARLSS database for a specific research year and location (Russia and projects from 2011 on), find project information on a researcher's past and planned research activities, find transportation locations within a distance of 500km from research locations, and display these alongside other data such as airports, roads, and permafrost maps in 51 steps. Examples of such functionality as well as other capacities of A2DI are provided through a series of help documents found at the top of the application (Appendix A). There are a number of other arctic data layers that can benefit researchers from multiple disciplines to help plan future research activities, search for other data sets that may be relevant to their work, visualize where they have done research, and print maps. With respect to other ARMAP applications, A2DI provides the most comprehensive range of arctic data (125 layers in 6 projections) in a freely available interactive map viewer that does not require a plug-in (JavaScript) or download (.exe), which can limit use on many government or non-personal computers.

There is a large amount of information and a range of different function that can be executed through an IMS. As such, the use of IMSs can take a number of steps and be cumbersome for some users. This complexity can reduce usability and result in a steep learning curve for users to become familiar with the various tools and functionality available. Generally the number of steps needed for a given execution decreases as the complexity of the executable function increases, which is generally dependent on the expertise of the user.

For other uses not described in this section, such as adding one's own data to the map, A2DI has reached its limit since there is no tool available for this level of

functionality in the IMS. Adding one's data into an ArcIMS requires extensive programming and this functionality has been developed in a more user friendly platform, AGX. ARMAP 3D was created to provide users of ARMAP data with the ability to query and add their own data for more advanced visualization in a 3D globe. This application will be featured in the following scenario.

### 4.3. ARMAP 3D ArcGIS Explorer (AGX)

The ARMAP 3D application was the third application developed in the ARMAP suite and was originally developed with ESRI's free ArcGIS Explorer (AGX) Build 500 virtual globe software released in December 2008. Subsequent updates have rebuilt ARMAP 3D for AGX builds 900, 1200 and most recently 1500. AGX software and the ARMAP 3D application are available from the gateway website at: http://www.armap.org.

Similarities between ARMAP in GE and ARMAP 3D include the ability for users to 'fly' to areas of interest, visualize terrain, and explore U.S. Federally funded arctic research projects. Functionality of ARMAP 3D includes a query (search and advanced search) and distance measuring tool, capacities for incorporating additional spatial data from OGC web services or from a user's hard drive, and printing. Users can also utilize the presentation functionality to create a presentation similar to Microsoft PowerPoint, but with the added functionality of being able fly around the map during presentations. AGX also allows users to save map tours or map locations and email these directly from the application. These are beneficial attributes that allow for application sharing. With use of a Software Development Kit (SDK), AGX can be programmed to include many different tools (e.g., a custom analysis from ArcGIS Desktop).

ARMAP 3D is a customized skin for AGX that includes a bundle of tasks and modifications beyond the default interface. This custom skin is downloaded when a user accesses the ARMAP 3D home server (as a series of .dlls). As with other virtual globe software (e.g., GE), users must download and install the AGX software prior to accessing the custom ARMAP 3D skin.

The customized add-ins developed for ARMAP 3D were created using ArcGIS Explorer SDK and Visual Studio 2008, which are loaded with a configuration file. ARMAP 3D has been customized to include a default arctic view and a KML layer that displays all the arctic research projects from ARLSS. This layer is updated weekly, providing users with the most recent version of ARLSS data every time they open ARMAP 3D. Appendix C contains a help guide providing steps to complete the tasks in the following scenario.

### 4.3.1. ARMAP 3D AGX Scenario

Dr. Sulina is a Russian Arctic Biologist who is studying IUCN Red listed lemming populations in the Arctic. His focus is on climate change impacts on lemming populations and would like to explore US projects active in the arctic and focused on climate change and biological systems. He is looking for an application that gives him access to US research data and information, and is interested in forming collaborative ties with US researchers. He contacts the U.S. NSF Arctic Program and they suggest he explores the ARMAP suite of applications.

By browsing the homepage (Figure C1) and viewing the “which ARMAP application should I use” table, he decides the best choice for him would be the AGX

application since this combines the data he needs with a Geobrowser that will enable him to add his own spatial data (Figure 18). Following directions from the home page (Figure C2), he downloads an executable and configuration file for the ARMAP 3D. ARMAP 3D opens with a splash screen (Figure C3), followed by an overview screen (Figure C4), and a pop-up asking the user if they would like to see a tutorial (Figure C5). The default ARMAP 3D view is focused on the Arctic and includes the most recent research sites layer (Figure 19). Dr. Sulina reviews the tutorial prompted at the start up screen and learns about the many features of ARMAP 3D including querying for project, region, or site specific information, and adding your own data.

## Application Choices

| Features | ARMAP 2D | ARMAP in GE | ARMAP 3D |
|---|---|---|---|
| 2D Maps | ✓ | | ✓ |
| 3D Globe | | ✓ | ✓ |
| Software download & install req'd | | ✓ | ✓ |
| Performance | Excellent | Excellent | Varies |
| Make complex searches | ✓ | | ✓ |
| GIS functionality | Limited | Limited | Substantial |

Q: Which ARMAP application should I use?

- Choose "ARMAP in Google Earth" if you are familiar with the interface, and would like to quickly explore an area that interests you.
- Choose "ARMAP 2D" if you would like a fast and intuitive map in your browser, as well as greater functionality – such as the ability to search for projects by discipline, keywords, and other types of information.
- Choose "ARMAP 3D" if you would like the full functionality of an online, geospatial database within a three-dimensional map environment.

You can also directly open ARMAP datasets in a variety of GIS programs using web services.

**Figure 18 ARMAP homepage support document that contains information about each of the ARMAP applications allows a user to select the best application for their needs.**

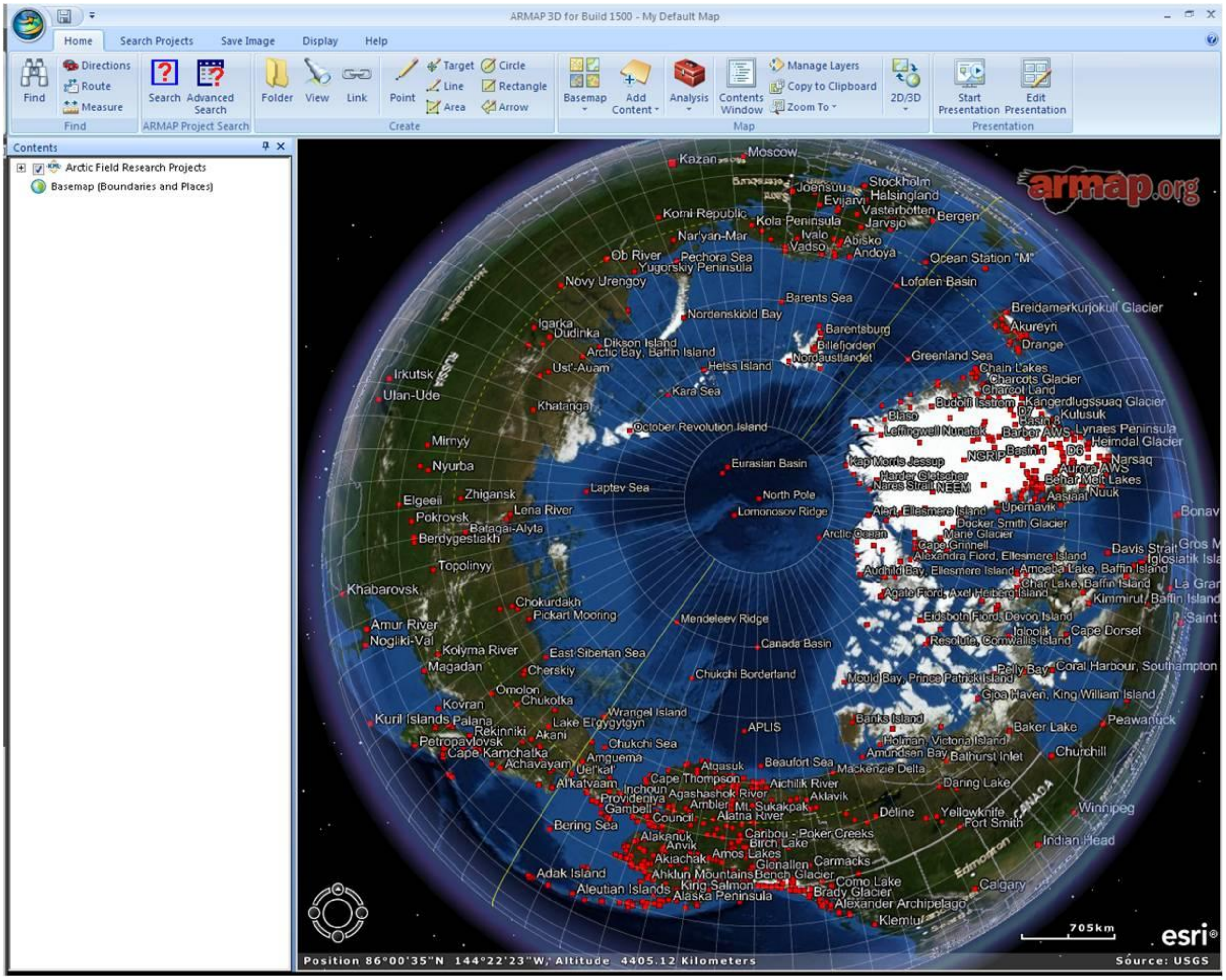

**Figure 19 Opening view of ARMAP 3D developed on the ESRI ArcGIS Explorer framework. The default view includes a recent updated KML file displaying US-federally funded Arctic research sites from the ARLSS database**.

Using the customized ARMAP 3D query tools, he queries the ARLSS data for research with a focus on Biology using the “Simple Search” tool (Figure C7). Following selection of “Discipline” for the Field option and “Biology” for the Value option, he runs the query (Figure C8). Results span a Circumarctic spatial coverage (Figure C9), well outside his focus on Alaska, so he decides to use another tool to narrow his results. He uses the “Advanced Search” tool to develop the query and using the drop down boxes within the tool he uses the query builder to create a SQL statement for [Discipline] = "Biology" And [Region] = "Alaska" (Figure C10). This tool queries the ARLSS database

directly giving access to the most up-to-date project information in an Alaska view (Figure 20). He browses the projects by clicking on project location icon on the map screen, which opens a window displaying projects found at that location (Figure C12). Needing to finding research that is close to permafrost habitat types and similar to his research, he decides to add some of his own data layers and some other Arctic data layers to create a reference map.

With the ability to add geospatial data to ARMAP 3D using the “Add Content” tool found in the ribbon at the top of the application (Figure C13). Sulina uses the tool and adds GIS data stored on his desktop computer, including his study sites and a map of Arctic permafrost distribution (Brown 1998) that he originally downloaded from the NSIDC arctic data archives (Appendix C - 7b). With the previous query and the permafrost layer loaded, he visually explores the area using the fly-through functionality embedded in AGX and selects research projects that are spatially constrained to permafrost classes similar to where his past and future research projects are focused. During his exploration, he creates a list of PI contact information and project information including links to project websites and data archives.

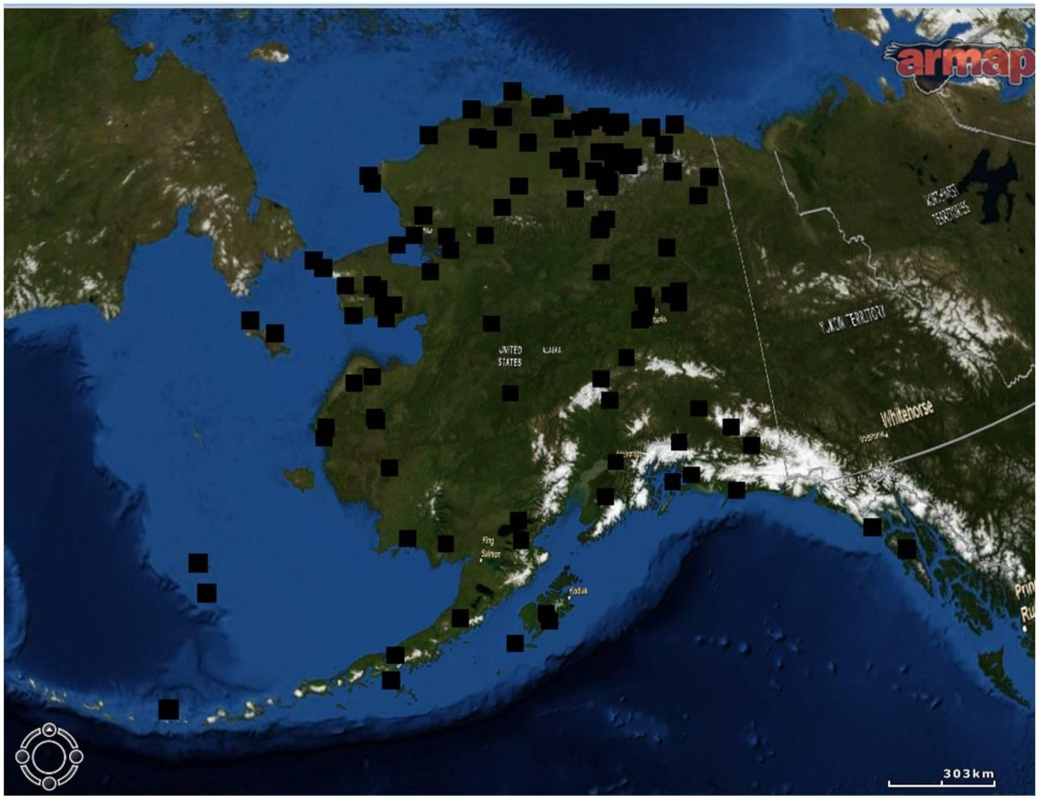


**Figure 20 Result from running Advanced query in ARMAP 3D for Biology related research projects in Alaska, Black squares were selected as the icon in the tool.**

Using this information, Sulina wishes to access more information and run more complex GIS analysis, but Sulina has reached the functional limits of ARMAP 3D and needs a more powerful platform (i.e., desktop GIS) to meet his spatial analysis needs. Although such tools can be developed, they have exceeded the scope of ARMAP 3D development to date. Importantly, however, the ARMAP webservices allow users to download ARMAP project information from ARLSS and execute such queries on their own computers.

### 4.3.2. ARMAP 3D AGX Summary

By querying and visualizing project information contained in ARMAP 3D over high spatial resolution base imagery, a foreign researcher has been able to compare his research data with project level information associated with US federally funded arctic research. The researcher has also been able to enhance data exploration by uploading their own data into the ARMAP 3D environment. Specifically, ARMAP 3D provides a 3D Geobrowser for arctic researchers, logistic planners, and educators to visualize data from multiple sources controlled by end users.

As an off the shelf technology, AGX is limited to basic GIS functionality (e.g., zoom to, add points, measure, buffer) but programmers with expertise in .Net can develop tools with advanced functionality or embed other published AGX specific tools (e.g., from ArcOnline). Through ARMAP, OGC web services were developed for users to ingest ARMAP data layers in their own GIS platforms; promoting interoperability (section 3.4). ARMAP 3D has been acknowledged by NSF and Arctic users as a valuable tool and was the featured applications (Johnson 2009) and the most viewed ESRI 3D blog post for 2009 (ArcGIS Explorer Team 2009).

## 5. General Discussion and Conclusion

ARMAP has targeted the needs of NSF program managers, science planners, scientists, educators, and the general public and appears to have gained their support. With much success, ARMAP has sustained funding for development and maintenance contracts for the continued development of 3D ArcGIS Explorer and new technologies such as the lightweight Adobe Flex 2D application that incorporates IMS functionality. Although no formal analysis has assessed the impact of the ARMAP suite on Arctic science, the continued funding, ongoing collaborations, and the recent accepted manuscript has shown the acquiescence of ARMAP. The ARMAP suite of applications have been presented at 35 local, national, and international meetings; 12 in the first year alone following the public launch of the A2DI during the 2006 American Geophysical Union (AGU) conference held in San Francisco, CA.

Capacity building and student involvement were a major focus of the ARMAP project. A great deal of programming in Java, C#, HTML, XML, Flex, and .Net languages has gone into the developments of these desktop and WebGIS applications. With development, management, and implementation of data and services, high-end server configuration and networking have aided in the development of best practices for WebGIS application development; and spatial data and metadata documentation standards. Utilization of the resources and expertise UTEP and SEL has to offer has been key in the cost effectiveness of the development of the ARMAP suite and will continue to play an integral role for improving human capacities for CI development and future innovation of geospatial products for the environmental sciences.

Leveraging new resources, students, and professors from the Cyber-ShARE Center of Excellence intend to enable future in-depth studies of both cyberinfrastructure and user experiences that will create research and training opportunities for other graduate students. With the emergence of new fields such as Ecoinformatics, it is important to quantify the usability and usefulness of both desktop and WebGIS applications in terms of the capacity to facilitate data exploration, dissemination, visualization, and analysis. These are essential for addressing some of the most challenging questions facing the environmental sciences. Technology development is advancing at rapidly and understanding the needs of users' and what is needed from applications to get to and process reliable data needs to be tied to such development.

Task-based testing of ARMAP applications should be considered further to facilitate the development of additional resources for Arctic science applications. The methods for software and application development and testing are well accepted and could be transferred to enhance assessment of WebGIS applications. In addition, the use of server load/request monitoring software packages and collaborations with the IT department could be incorporated into the workflow of the ARMAP suite to help optimize plans for infrastructure growth and expansion (Coughlan and Macredie 2002). Operational assessment like this could provide a useful context for the development and expansion of other hardware at UTEP.  Also, partnerships with senior computer science software design classes have the potential for establishing a development environment for the creation of analytic monitor tools for WebGIS applications, and other tools that could document how end users interact with the ARMAP suite and how ARMAP tools

can be tailored to best meet their needs. Typically, the cost for these types of monitoring systems is substantial.

Ecoinformatics is an emerging field in the ecological and environmental sciences that merges CI tools with in ecological and environmental data sets. The need of these tools to be able to access interoperable information and produce reliable and useful datasets are a must to address environmental challenges such as climate change (Cranston et al 1999; Jones et al. 2006; Kouda and Takarada 2007). The ARMAP project follows best practices of creating reliable data and metadata. ARMAP also is similar to other ecoinformatics projects such as EcoTrends (www.ecotrends.info) and HerpNet (www.herpnet.org), which bring together reliable information in a user-friendly graphical user interface (GUI) that also provides metadata for the available datasets. Other considerations for information portal development include - capacity to maintain usability across disciplines and allow access to information pertaining to who is doing what and where; link to detailed information and metadata about the research with data sets (i.e., raw and derived data); create not just another website, but applications that are seamless and provide ease-of-use in the derivation of information to develop end products with help documentation; and the development of free access GUIs that enable multiple users the ability to derive data products that promote information sharing and decision making (Gohnai et al. 2006). ARMAP has achieved the majority of these needs.

Future plans for the ongoing development of ARMAP include addressing best practices for increasing the availability and exchange of data through Open Geospatial Consortium (OGC) (Kenyon 2010; Liang et al. 2005; Tu et al. 2004), Arctic Spatial Data

Infrastructure (Sorenson et al. 2001), and the IPY Data and Information Service (IPYDIS 2008). Best practices include employing Web Map Services and Web Feature Services for the integration of additional layers hosted by several data centers. The acceptance of the North Pole Lambert Azimuthal Equal Area map projections and the regional variations as recognized EPSG codes has enabled adherence to best practices in the sharing of ARMAP arctic data for use in other GIS applications.

While the needs of the science community to create more reliable data sets that enhance knowledge about environmental issues is important, it is also as important to begin using ecoinformatics for synthesizing information to help meet current challenges in the environmental sciences. Since the field of ecoinformatics is still relatively new, computer science, CI, and environmental sciences are still evolving to develop the technical expertise required to build new innovative software projects. The ARMAP effort demonstrates the merging of GIS, the web, CI, and expert and student developers focused on the development of a usable information system for Arctic science and serves as a model for development of new geospatial systems.

## 5.1. Reflections

ARMAP applications and services have been used in outreach activities ranging from presentations at national and international conferences to presentations, training sessions for program managers at NSF and other agencies, and numerous workshops for the promotion of data visualization for an ASDI. These activates have received widespread acknowledgement in news articles and blogs, and have lead to continued funding for the support and development of new ARMAP tools and services. ARMAP tools have won 2nd and 3rd place at two different conferences (ESRI Users Conference

2007 & 2009). A manuscript describing the development of interoperable tools has been accepted for publication (Johnson et al. accepted).

Personally, I have gained knowledge and have a greater understanding of the issues that plague data management in science (e.g., storage, dissemination, visualization, standards, metadata, and recognition for publishing data). I also have great respect for those individuals and groups that devote numerous hours attempting to archive historical data and make these data available to a broader range of users. As such, this project encompassed more than just the development of applications, information documentation and presentation at conferences; it was a chance to meet the many individuals that compose an innovative community of current and future developers, researchers, and decision makers. Conferences and workshops allowed me to participate in discussions that opened my eyes to the challenges facing the advancement of research and use of data to help solve questions that no one research group can solve independently – such as the many challenges facing the climate change sciences.

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## Appendix A – ArcIMS Scenario Help Guide

ESRI ArcIMS application platform was used for the development of A2DI. The following is a workflow following the described scenario in section 4.2.1. Each number in the text represents an image or a task in order from beginning to end to achieve the end product, the users request from the application. This is a simple “How-to” guide to follow for achieving informational products from A2DI.

1. Open the ARMAP home page via http://armap.org.

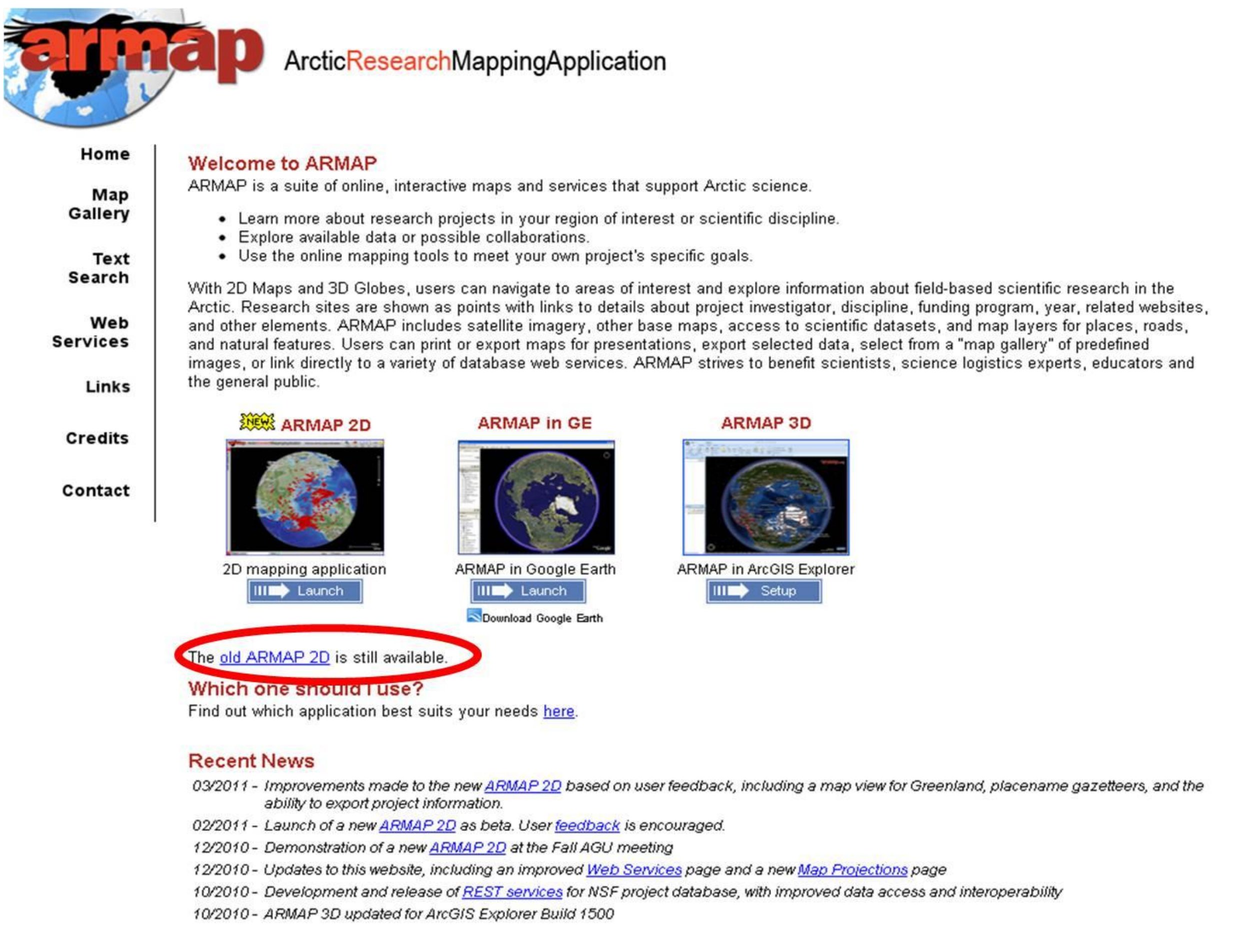



**Figure A1**

2. Open A2DI in web browser by clicking on the text highlighted in blue “old ARMAP 2D” (Figure A1 circled in red).

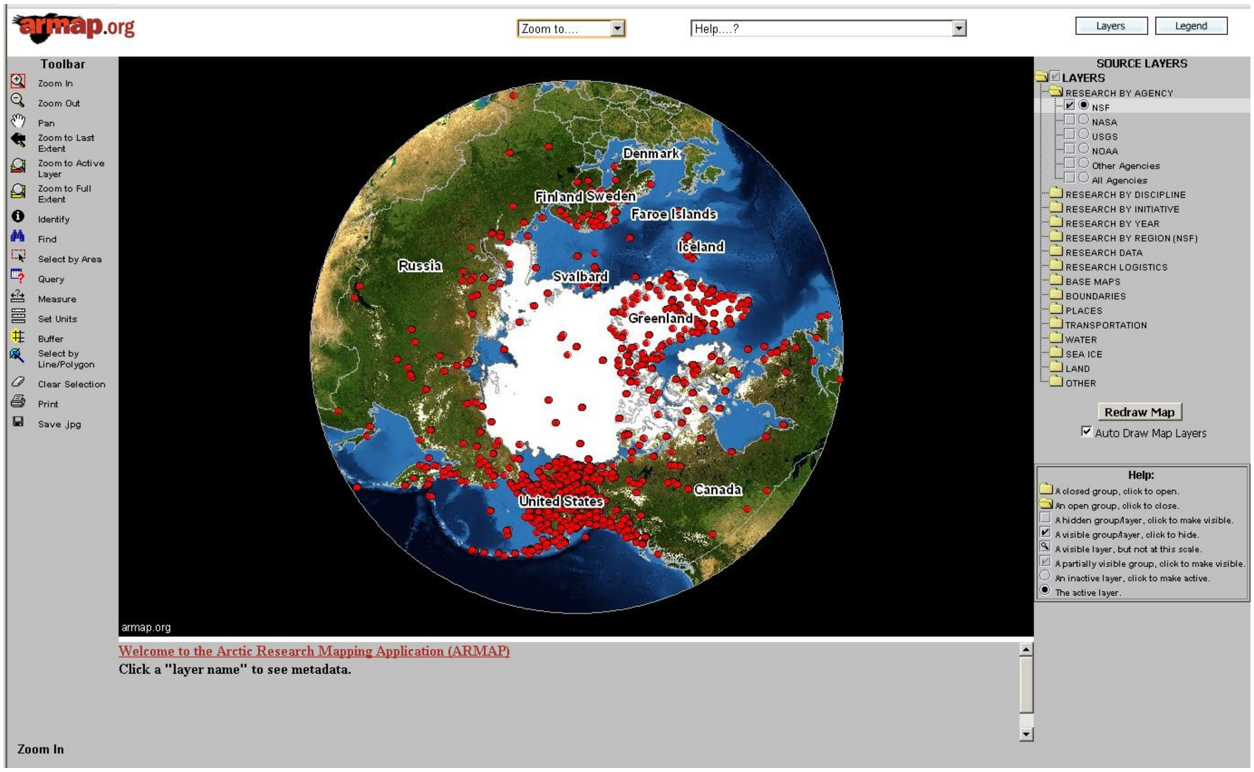



**Figure A2**

3. To create a regional specific map:

    a. Select the "Zoom To.." drop down along the top of the application. This tool allows for the rotation of the map orientation to an optimal view of six different ARMAP arctic projections, in this case Russia

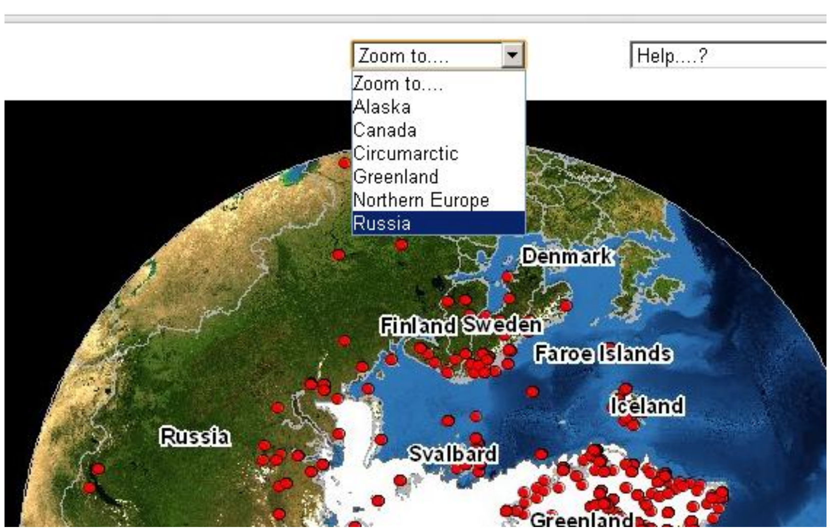



**Figure A3**

4. To zoom to a location on the map:

    a. Use the “Zoom In” tool located in the Interactive tool bar on the left hand side of the map document

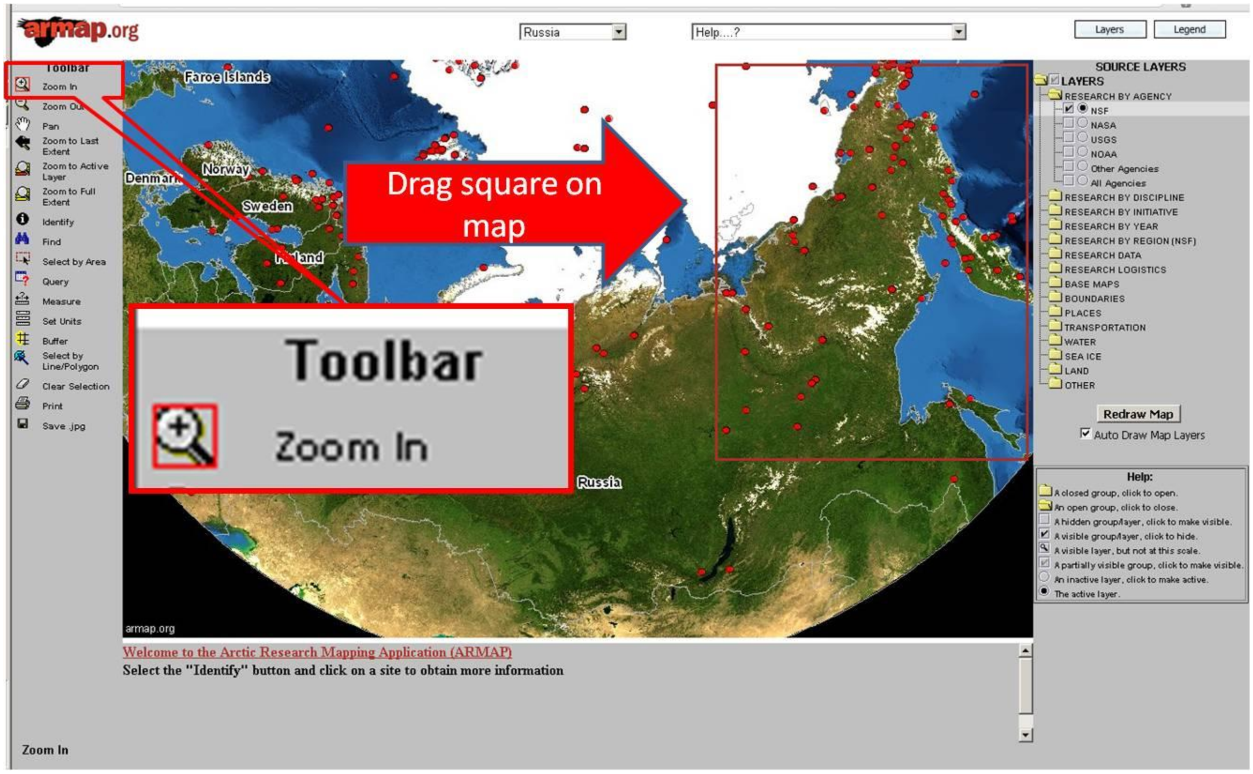


**Figure A4**

5. To turn layers on and off in the map

    a. Check the check box to turn layers on or uncheck the check box to turn layers off.

Note: If you uncheck the “Auto draw map layers” found below the Table Contents (TOC), you can select multiple layers to turn on or off at one time. Drawing or undrawing layers together avoid having to redraw the map each time a layer is selected or deselected saving time.

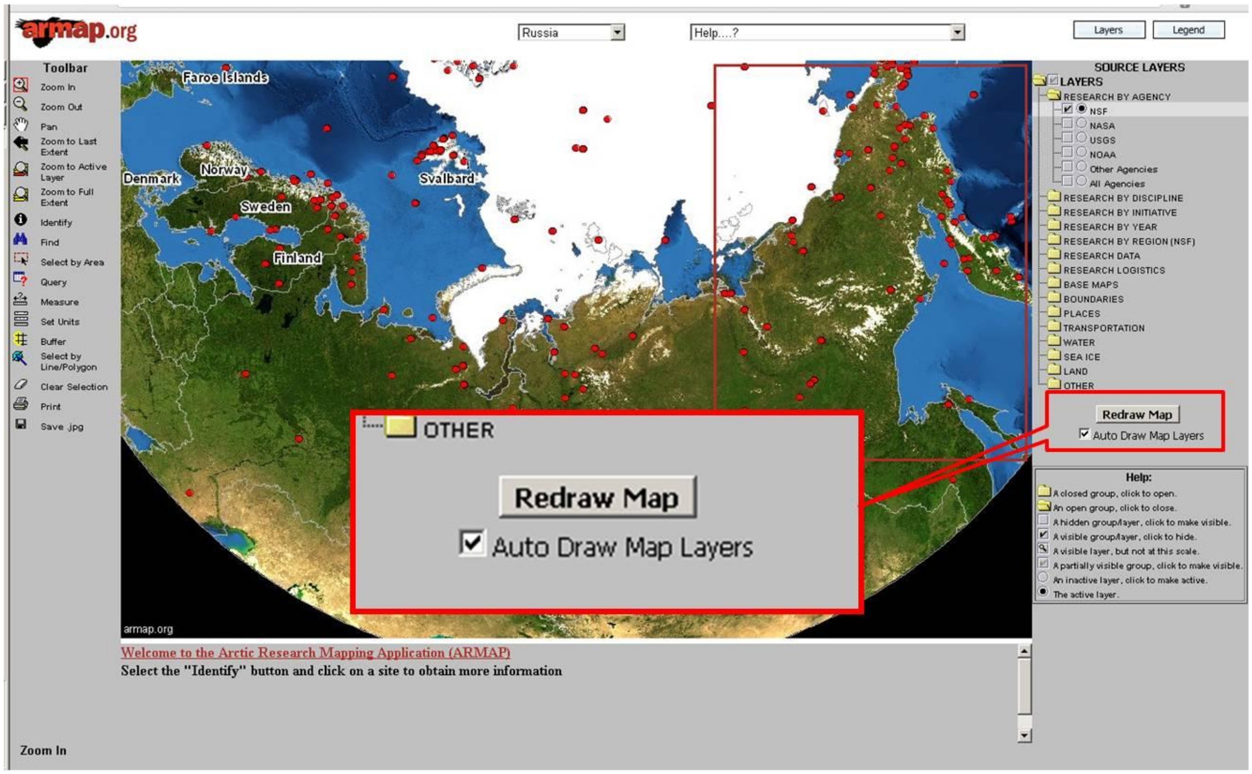



**Figure A5**

6. In the example, to view research sites which have locations near to main transportation infrastructure for project support, the user selects the corresponding layer's checkbox by checking:

    a. Cryosphere

    b. Meteorology/Climate

    c. Road

    d. Airport

7. Since the example does not need all the NSF sites turn off the NSF layer by un-checking the corresponding check box.

8. To display the layers selected above in step 6 and 7, click the "Redraw Map" button above the "Auto Draw Map Layers" which draws a new map (Figure A5).

9. To get information about features in the map, (e.g., airport information for flight availability and costs) you need to:

    a. Activate the layer (e.g., airports) by clicking the radio button next to layer,

    b. Use the “select by area tool” from the “interactive toolbar” by clicking the tool icon,

    c. Select the map icons (e.g., airport) by left clicking your mouse and drawing a bounding box around the region on interest (Figure A6),

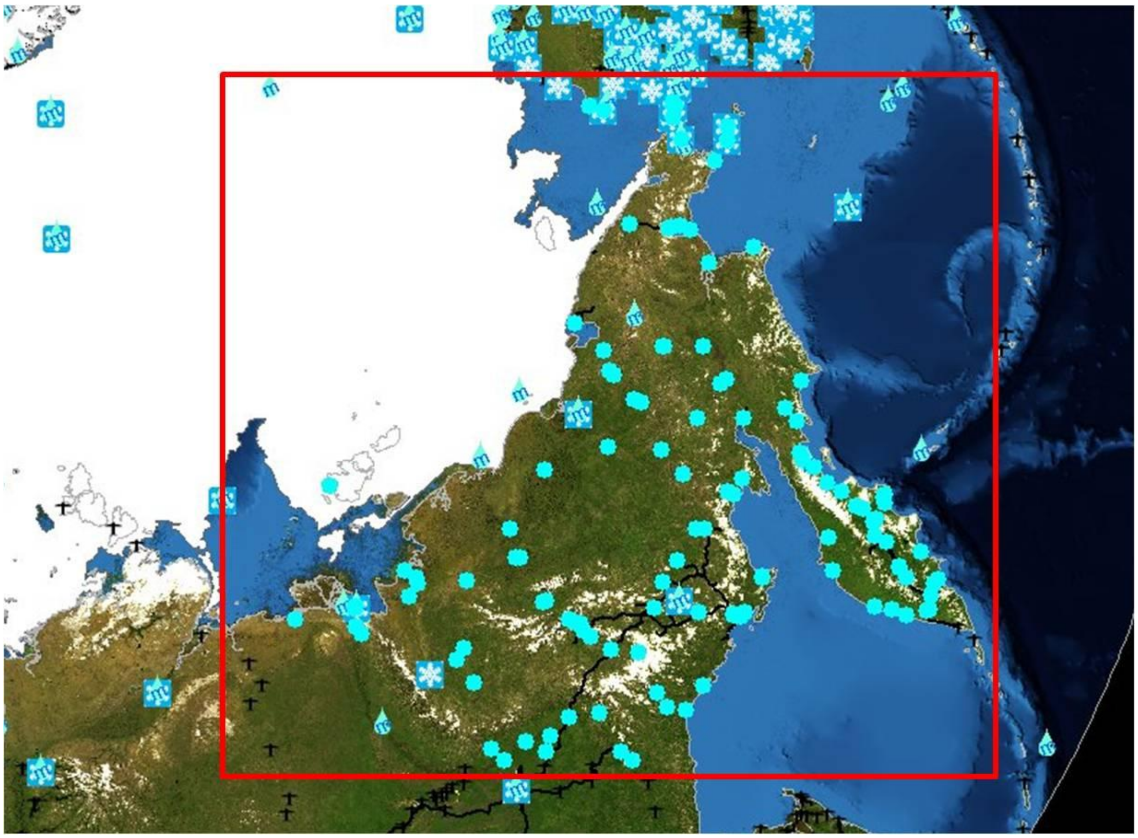


**Figure A6**

    d. Selected map features results in a table at the bottom of the application (Figure A7).

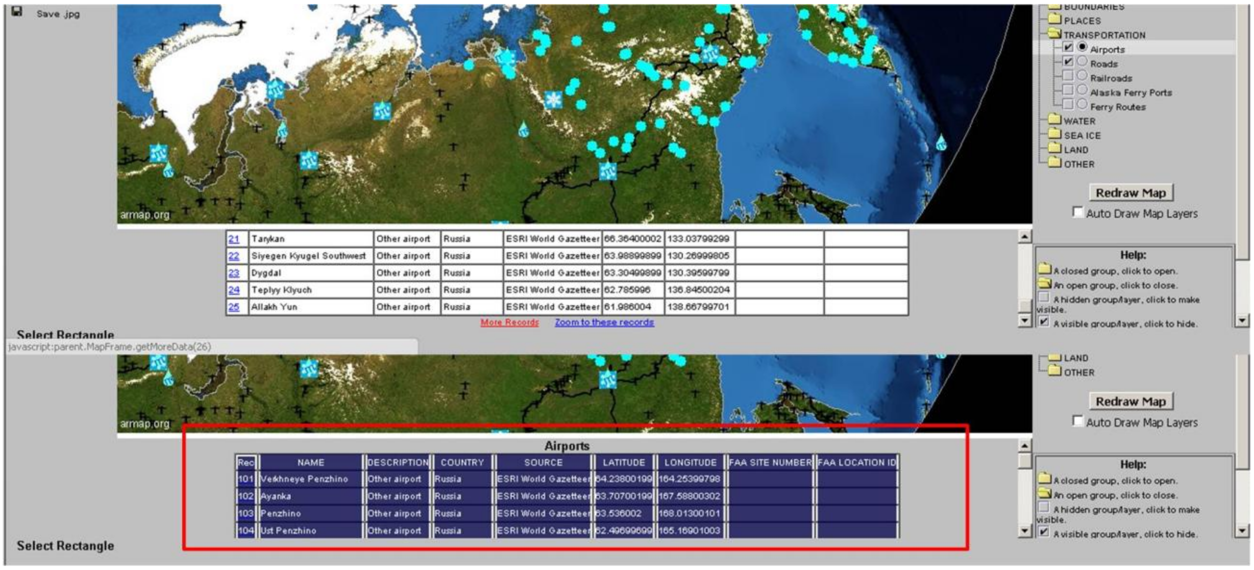


Figure A7

Note: You can copy the table by selecting the table, copy and paste into a spreadsheet program (e.g., Microsoft Excel).

10. If you are interested in finding out who (Principal Investigator) is currently doing research in a particular field.

    a. Activate the corresponding radio button for the layer (e.g., Cryosphere),

    b. Use the “select by area tool” from the “interactive toolbar” by clicking the tool icon,


Figure A8

    c. Selecting map features results in a table at the bottom of the application. In this example, the table shows a large amount of research sites you can scroll through to find projects.

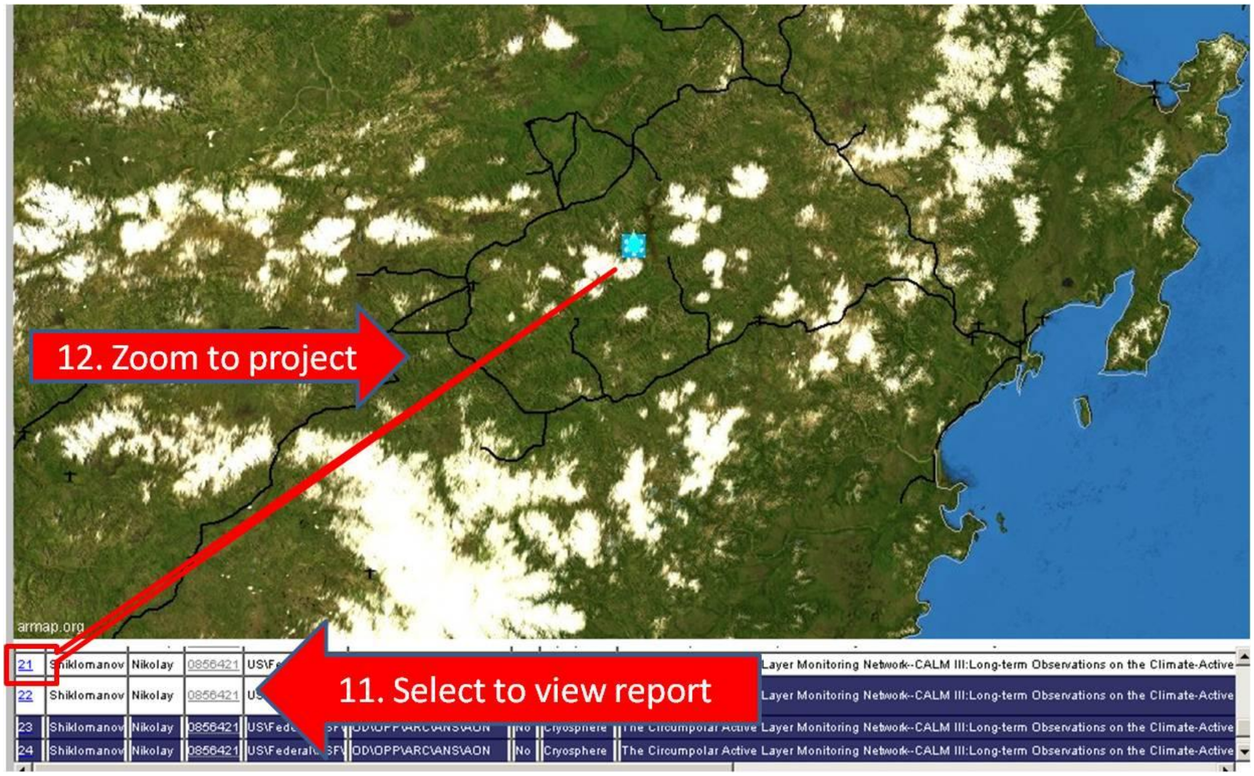



**Figure A9**

11. To access more project information reports (e.g., logistics needs for previous research), you can select, by clicking, the blue text for "Project ID" which contains a hyperlink to the project page from ARLSS.

**Project Title:** The Circumpolar Active Layer Monitoring Network--CALM III: Long-term Observations designed on the Climate-Active Layer-Permafrost System (Award# 0856421)

**PI:** Shiklomanov, Nikolay (shiklom@gwu.edu )
**Phone:** (202) 994.3966
**Institute/Department:** George Washington University, Dept. of Geography
**IPY Project?** NO
**Funding Agency:** US\Federal\NSF\OD\OPP\ARC\AON
**Program Manager:** Dr. Martin Jeffries (mjeffrie@nsf.gov)
**Discipline(s):** | Cryosphere\Permafrost | Meteorology and Climate |

**Project Web Site(s):**
NSF_Award_Info: http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=0856...
Project: http://www.udel.edu/Geography/calm/

**Science Summary:**
This award is funded under the American Recovery and Reinvestment Act of 2009 (Public Law 111-5). This award will support the continuation of the Circumpolar Active Layer Monitoring (CALM) program as an integral part of the Arctic Observing Network (AON) and the Study of Environmental Arctic Change (SEARCH). The active-layer network of 168 sites represents the only coordinated and standardized program of observations using standard measurement protocols designed to observe and detect decadal changes in the dynamics of seasonal thawing and freezing in high-latitude soils. The 'Intellectual Merit' of this study lies in the need for long-term time series of active layer depth, ground temperature, and thaw settlement measurements at the same locations and across diverse terrain types and regions in order to identify scales of spatial variation, establish trends, and validate models. The data will also contribute to detailed process studies, and validating and developing climate change, ecology, hydrology and geocryology models. Education and outreach are essential components of the 'Broader Impacts' of CALM. The project will provide opportunities for field experience and educational participation at levels ranging from elementary school through postdoctoral. Local, predominantly indigenous people, will assist with the observations at remote sites. CALM will continue to incorporate data into its Web-based database, and transfer all existing and new data to the AON archive CADIS.

**Logistics Summary:**
The Circumpolar Active Layer Monitoring Network (CALM), established in the early 1990s, observes the long-term response of the active layer and near-surface permafrost to changes and variations in climate at more than 125 sites the world over. This grant continues operation of the monitoring network at 41 sites each in Alaska and Russia, and funds annual visits to many of the sites, from 2009 to 2013. (All Canadian and Nordic CALM sites are managed by others and not part of this grant.) Alaska CALM sites include ten 1 km2 grids at Atqasuk, Barrow, Ivotuk, Betty Pingo, West Dock, Happy Valley, Imnavait Creek, Toolik Lake, Kougaruk and Council, and ten smaller plots in the Kuparuk River basin. Several research groups will maintain the CALM sites, with responsibilities being assigned geographically: one group will focus on eastern sites along Dalton Highway; another will focus on Barrow-area sites; and a third will focus on the Seward Peninsula area. Researchers will make subsidence measurements using DGPS and LIDAR annually in late August. In addition, in 2010 and 2013, they will take cores along two transects in April, and then measure ground heave in mid-June. To maximize logistics, researchers will combine sites in the Anadyr' region of Chukotka with the Seward Peninsula work. The Russian CALM network extends from the European tundra of the Pechora and Vorkuta regions to West Siberia and the Lena Delta, eastward to the lower Kolyma River, and to Chukotka and Kamchatka. Russian sites have grids ranging from 100 m2 to 1 km2, and most of these sites are within the continuous permafrost zone. Field work in Russia will be conducted annually during June-September by eight field parties from different research and educational institutions. Senior personnel and graduate students will attempt visits to as many Russian sites as possible and as budgets allow from 2009 to 2013. Majority of field work in Russia will be funded from collaborating Russian Institutions with small contribution from the CALM grant. However, annual logistic support is requested for work in Low Kalyma region (Cherskiy) and Lavrentia area of Chukotka. In August of 2009, teams of up to 5 people will visit CALM sites around Alaska. US investigators plan no Russian visits in 2009; however, Russian collaborators do plan some efforts. Note: While this grant was in effect, the PI moved to George Washington University necessitating that NSF issue the project a new grant. For information related to work conducted beginning in 2010 see 1002119.

| Season | Field Site | Date In | Date Out | #People |
|---|---|---|---|---|
| 2009 | Alaska - Atqasuk | 08 / 19 / 2009 | 08 / 19 / 2009 | 4 |
| 2009 | Alaska - Barrow | 08 / 13 / 2009 | 08 / 21 / 2009 | 4 |
| 2009 | Alaska - Council | 08 / 21 / 2009 | 08 / 25 / 2009 | 4 |
| 2009 | Alaska - Ivotuk | 08 / 17 / 2009 | 08 / 17 / 2009 | 3 |
| 2009 | Alaska - Nome | 08 / 21 / 2009 | 08 / 25 / 2009 | 4 |
| 2009 | Alaska - Prudhoe Bay | 08 / 15 / 2009 | 08 / 21 / 2009 | 5 |
| 2009 | Alaska - Seward Peninsula | 08 / 21 / 2009 | 08 / 25 / 2009 | 4 |

**Figure A10**

12. You can also zoom to specific projects by clicking the corresponding number. This selection for research sites to obtain project information using the "Select by Polygon" tool is a handy, but returns many records including records not needed for your purposes. This can be overcome by using the querying functionality

which returns fewer records and provides information more closely to a specific request.

13. The “Query tool can be accessed by activating the layer of interested by selecting the corresponding radio button and clicking the tool in the “interactive toolbar”.

    a. When selected, a window pops up at the bottom of the application to enter in information to query. For example, to generate a table of future Meteorology/Climate projects in Russia, you can type the following text “Region = "Russia" AND Year_ >= 2011” or select values using drop down lists in the tool window and click execute.

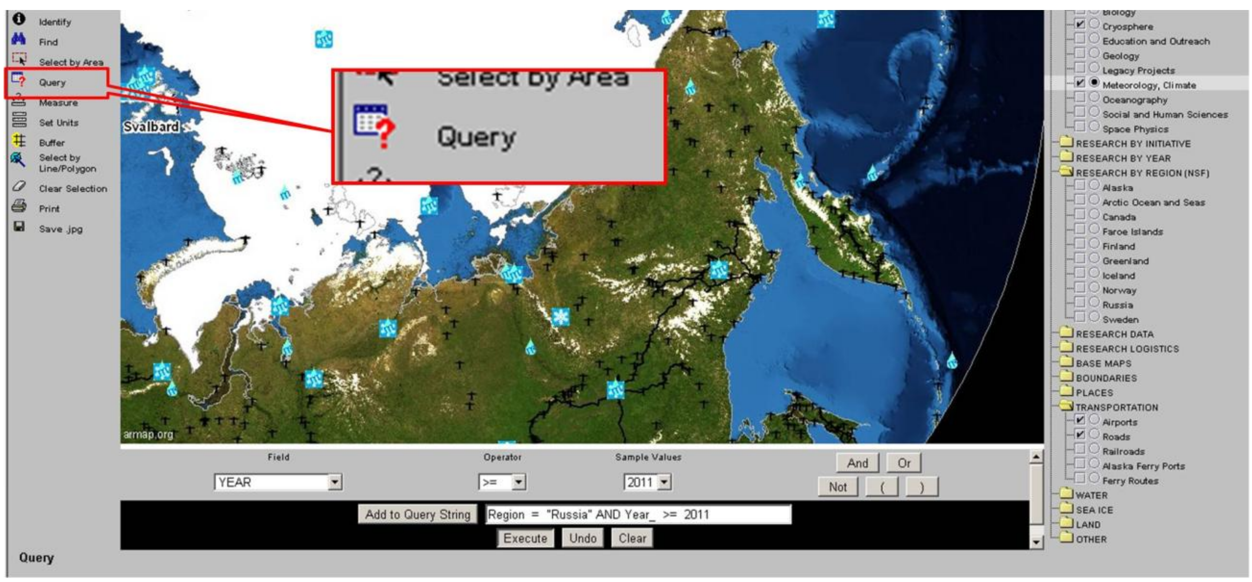



**Figure A11**

Using this precise query returns fewer results and are specific to the future years in question. As in previously mentioned above, you can copy the resulting table into a spreadsheet and access more information using hyperlinks.

Another feature of the IMS is the buffer tool. You can use the buffer tool to identify and select map features based on a buffer criterion of a particular layer. The example from the use case has the user needed to calculate and view distances to/from research locations to transportation hubs due to lack of road infrastructure in Eastern Russia. Due to helicopter cost time being based on distance, the limitation of gas for long flight paths, and the necessity of being close in case of emergencies, a buffer will be created for 500 km in the following example:

14. First, the layer of interest (e.g., Cryosphere) needs to be activated by selecting the corresponding radio button,

    a. The “Buffer” tool can be accessed by clicking the tool in the “interactive toolbar”, which opens a window at the bottom of the application to enter the buffer properties.

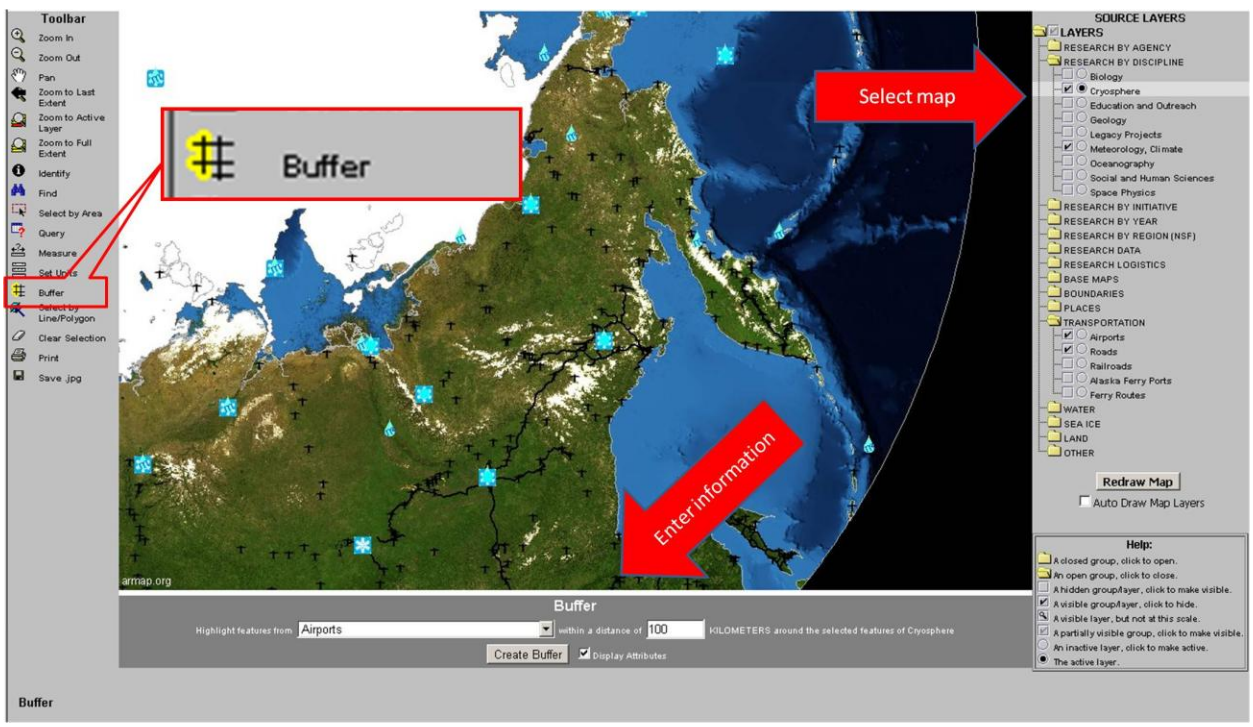
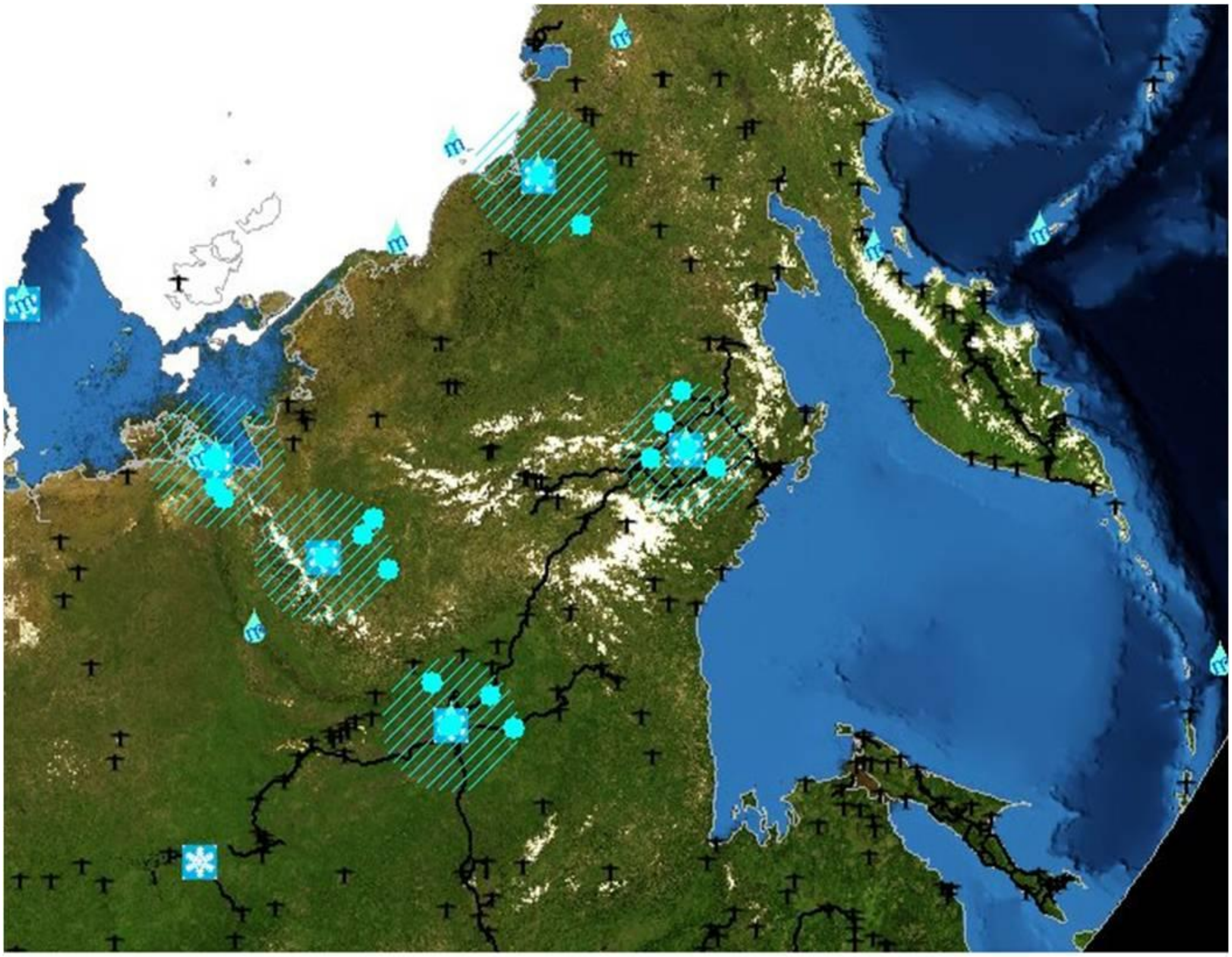



**Figure A12**

b. Enter in the layer you want to select with the buffer in the “Highlight features from” text box,
c. Enter in the buffer distance,
d. Check the “Display Attributes” check box (this enables a table of the map features selected to open),
e. Click the “Create Buffer” button resulting in a visual display on the map and a table of the selected features.



**Airports**

| Rec | NAME | DESCRIPT | WITHIN | Source | LATITUDE | LONGITUDE | FAA_SITE_NO | FAA_LOC_ID |
|---|---|---|---|---|---|---|---|---|
| 1 | Verkhoyansk | Other airport | Russia | ESRI World Gazetteer | 67.52599897 | 133.41199701 | | |
| 2 | Batagay | Other airport | Russia | ESRI World Gazetteer | 67.651 | 134.69501005 | | |
| 3 | Tiksi | Other airport | Russia | ESRI World Gazetteer | 71.697004 | 128.909 | | |
| 4 | Tiksi West | Other airport | Russia | ESRI World Gazetteer | 71.681002 | 128.66200395 | | |

**Figure A13**

Users can also create maps using the IMS application. In this example, the user needs to produce maps to include in a report for a researcher. There are two different tools that can be used in A2DI to produce map images: “Print” and “Save .jpg”.

15. The “Save .jpg” tool does not include a map Legend and can be accessed by clicking the tool in the “interactive toolbar”,

a. Click the “Save.jpg” icon to enable it which opens a window in the bottom of the Map window where click the “Create Layout” button.

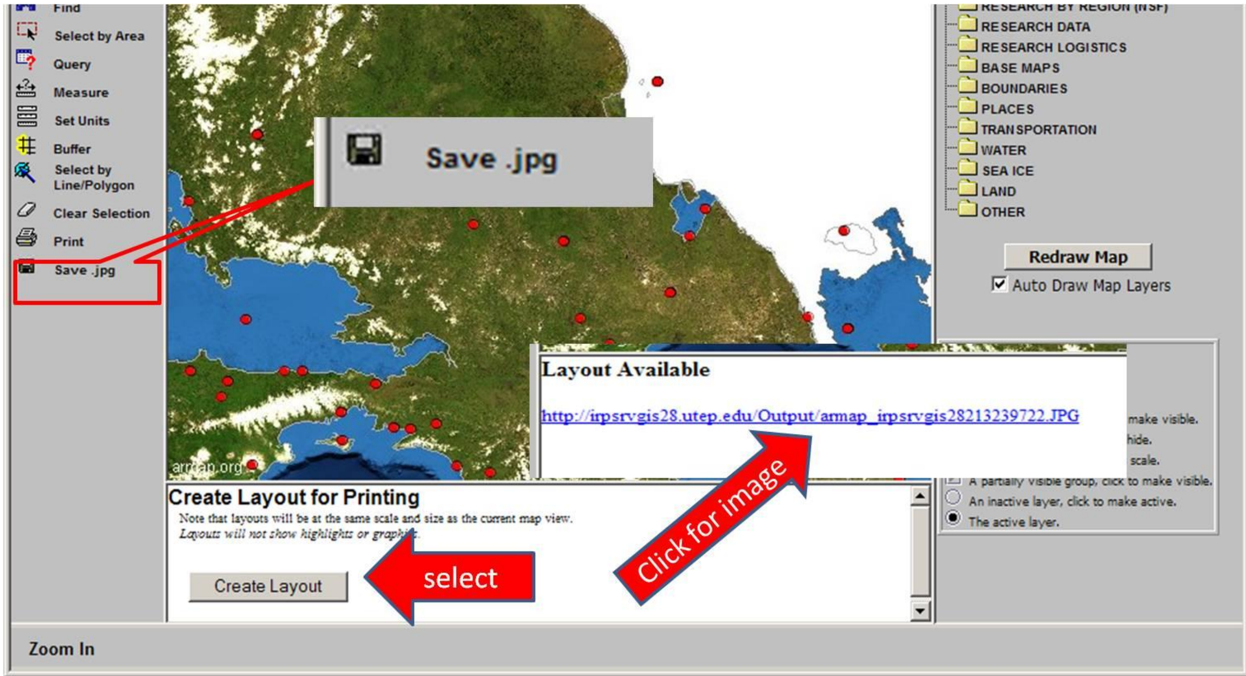



Figure A14

b. This opens up in a new web window with an image you can right click and save a JPEG image.

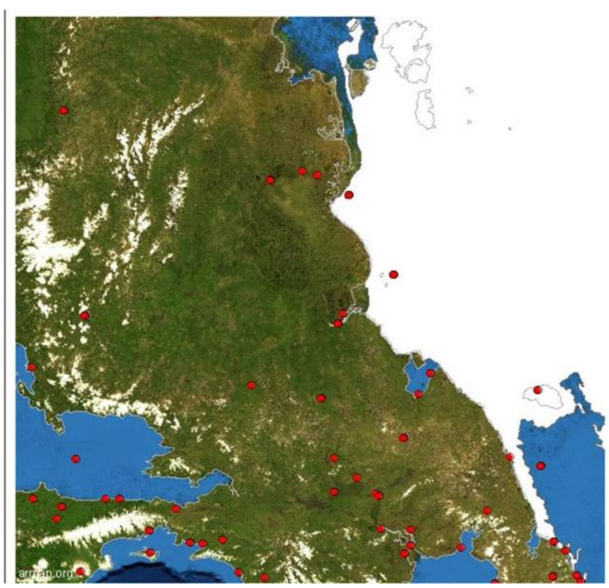


Figure A15

16. The “Print” tool includes a map Legend and can be accessed by clicking the tool in the “interactive toolbar”.

   a. Click the “Print” icon to enable it which opens a window in the bottom of the Map window where you can add a map title,

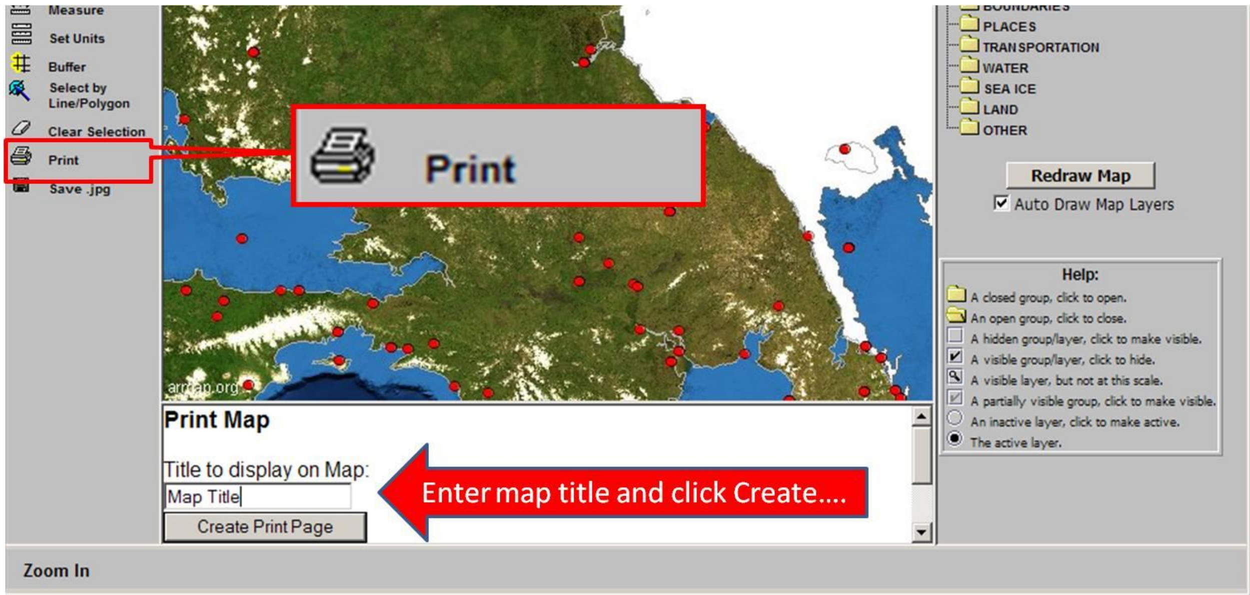



**Figure A16**

   b. Click the “Create Print Page” button to create the map which pops up in a new web window.

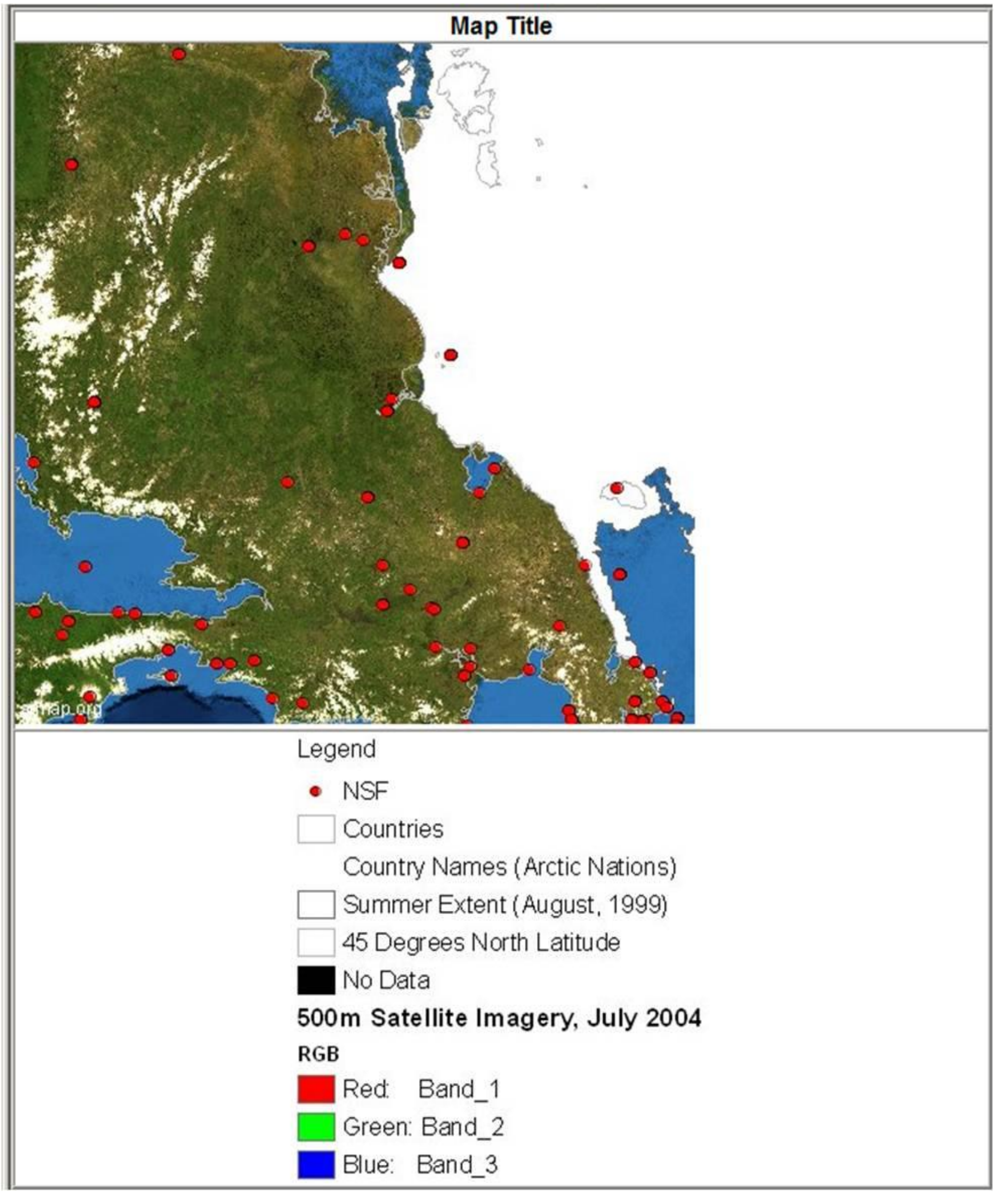



**Figure A17**

Using the examples in this text, a user can use some of the primary tools of the A2DI application. By changing layers and steps around, users have access to mass amounts of Arctic information provided a great service to the NSF Arctic Program managers and the logistic providers to create cost plans as well as providing a useful tool for researchers to view and plan collaboratory research activities with others in their fields or doing research in similar areas.

## Appendix B – ARMAP IMS Online Help Documents

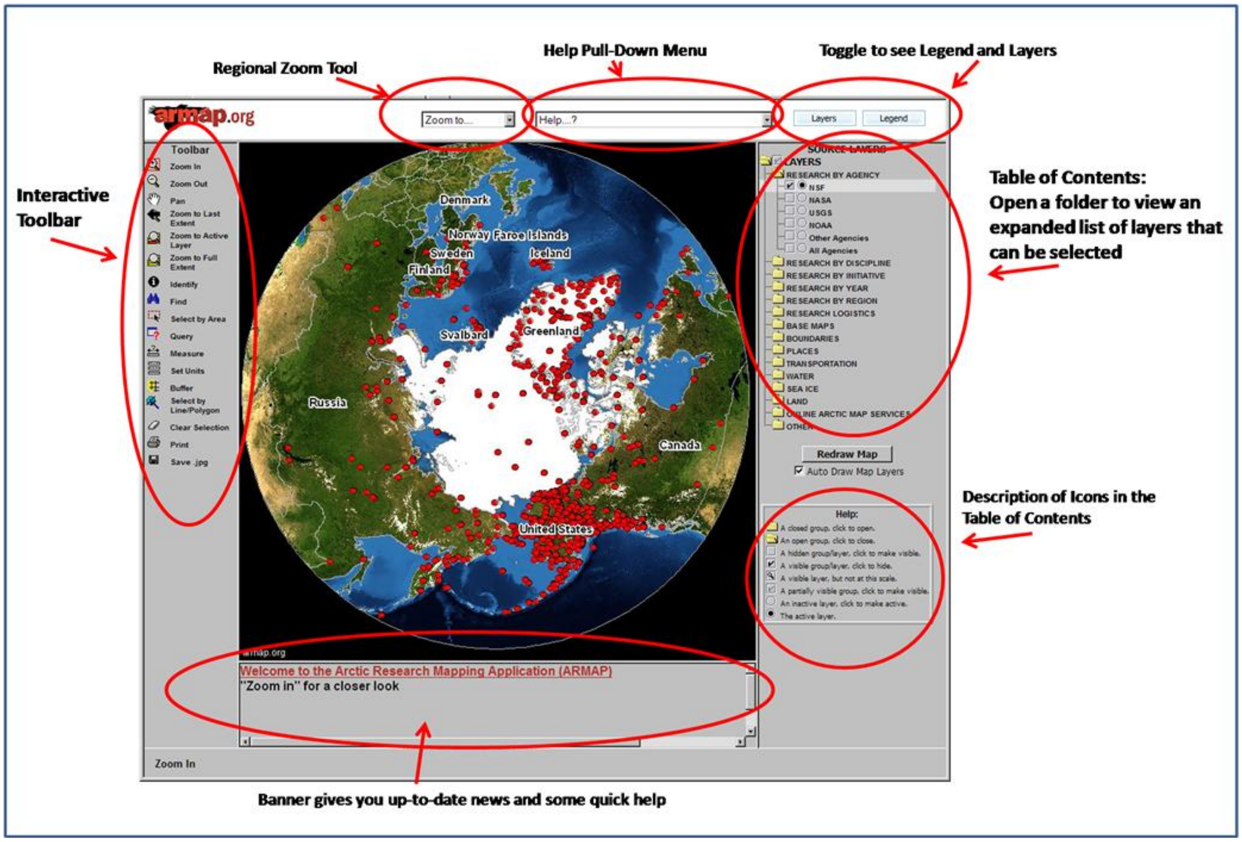
Customized help documentation was developed for the ESRI ArcIMS A2DI application for users to have a quick way to access help while using the application. Each help document is accessed through a pull-down menu by a hyperlink which opens a new webpage. The following contains all the help created for the application.

---

4/11/2011 Arctic Research Mapping Application - …

**What are the components of the ARMAP application?**

**ARMAP Application Interface** **To Refresh Application -- Do not use the back button on your browser (CTRL F5 to refresh)**!



# What are the buttons on the Toolbar?

| ICON | TOOL | DESCRIPTION |
|---|---|---|
|  | Zoom In | Allows the user to zoom in by either clicking in the view area or dragging the + cursor to create a boxed area that will determine the extent of the new view. |
|  | Zoom Out | Allows the user to zoom out by either clicking in the view area or dragging the + cursor to create a boxed area that will determine the extent of the new view. |
|  | Pan | The "Pan" button allows the user to take the cursor, click on the view and while still holding the mouse button down, drag the view in any direction to obtain a new view of the desired area at the same scale. |
|  | Zoom to Last Extent | This button takes the user back to the scale and position of the last view. |
|  | Zoom to Active Layer | Allows the user to zoom to the extent of all features contained within the active layer. |
|  | Zoom to Full Extent | Allows the user to return to the original view of the Earth north of 45 degrees north latitude centered on the North Pole. |
|  | Identify | The Identify button allows the user to view the attributes of a particular feature. In the Layer view in the far right frame simply select the layer desired to be active before using the Identify tool. It will only return attributes for the active layer. The attributes will be displayed on the bottom of the view area. If the desired layer/feature for which attributes are desired isn't listed in the Layer view, zoom in until it is displayed, then identify it |
|  | Find | The Find button allows the user to search for a text string in the "active" layer. This search is case sensitive so to search for a particular city (for example) the user will need to capitalize the first letter. |

| | | |
|---|---|---|
| | **Select by Area** | **Allows the user to drag a box with the cursor to define an area of selection. Any "active" feature that touches or falls within the box will be selected. The selected set will be highlighted. Once features are selected, other functions can be performed on this selected set.** |
| | **Query** | **The "Query" button allows the user to select features based on a filter of selected fields of that feature. Hit the Query button to call up the query frame near the bottom. In the field area, there is a pull down menu that can be used to select the field of interest. Then choose an operator such as =, >, or LIKE to define a specific value of the field. In the value box, type the value of what you're searching for based on the field. Then hit the "Get Samples" button to see a sampling of what can be typed in this field. If the desired value is listed, simply click on that value. Once all 3 fields are complete, hit the "Add to Query String" button and hit the "Execute" button. This will perform the query and return the results as well as zoom into the area of interest which highlights the query results.** |
| | **Measure** | **The "Measure" button allows the user to click on 2 or more points and return the distance in the current units (see "Set Units" button). It keeps track of the length of the segment as well as a running total in case there is a need to obtain the length of a route between multiple points. The readout is at the top of the view screen.** |
| | **Set Units** | **Allows the user to set the map units in Degrees, Feet, or Meters, and display units in Feet, Miles, Meters, or Kilometers.** |
| | **Buffer** | **This button is used to create a zone around a specific feature at a designated distance from the feature. It can also be utilized to highlight another feature that falls within the defined buffer zone. The** |

| | | |
|---|---|---|
| | | checkbox beside the Create Buffer button will display the attributes of the feature highlighted, if any. A feature(s) has to be selected before a buffer can be performed. |
|  | Selct by Line/Polygon | This button allows the user to create a line route upon which all "Active" features the line crosses will be selected or to create a polygon upon which all features touching or contained within that polygon area will be selected. To create a line, click on one or more points in the view and then hit the “Complete Line & Select” button and the selected set will be highlighted and it's attributes will be displayed in the lower window. To create a polygon, click on the view in selected points until the desired area is defined then hit the “Complete Polygon & Select” button to highlight the selected set as well as display the attributes. If a point is hit mistakenly, just hit the “Delete Last Point” button to take it off. |
|  | Clear Selection | This button will clear any selected features or remove any added graphics such as lines or polygons used with the Line/ Polygon tool. |
|  | Print | This button creates a printable, simple map layout of the current view area along with a legend. |
|  | Save .pdf, .jpg | This button allows the selection .pdf or .jpg format for the printed map. |

## What web browser do I need to have?

This site is has been tested for Internet Explorer 6.0. The ARMAP mapping application is best viewed using Internet Explorer on a PC or Safari on a Macintosh. Some features will not be compatible with other web browsers.

**What do I do if the application fails to load?**

---

Please try to start the application again in a new browser window.
If the application still does not load, please e-mail Dr. Craig Tweedie

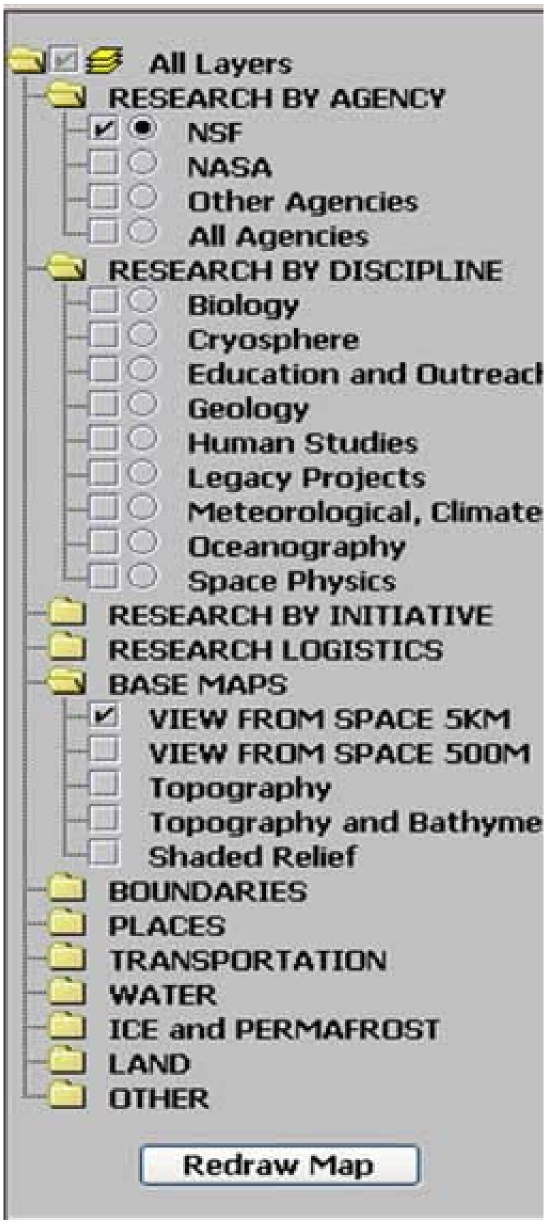
Please include in your e-mail the date and time of your problem, and what web browser you are using.
To view a list of the compatible browsers click here.

**How do I use the Table of Contents?**

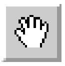
The table of contents can be found along the right hand side of the map view. The table of contents has been designed to work like the windows explorer with folders than can be opened and closed. Following is a list of tools that you will use to interact with the table of contents. Use these tools to change the map view by making layers "visible" or "active" to run queries.

A closed group, click to open.
An open group, click to close.
A map layer.
A hidden group/layer, click to make visible.
A visible group/layer, click to hide.
A visible layer, but not at this scale.
A partially visible group, click to make visible.
An inactive layer, click to make active.
The active layer.
Click layer name for metadata.

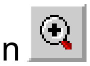
The table of contents expands to show the data layers contained in each folder and their associated legend information as shown in the sample table of contents below:

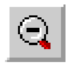

All Layers
RESEARCH BY AGENCY
NSF
NASA
Other Agencies
All Agencies
RESEARCH BY DISCIPLINE
Biology
Cryosphere
Education and Outreach
Geology
Human Studies
Legacy Projects
Meteorological, Climate
Oceanography
Space Physics
RESEARCH BY INITIATIVE
RESEARCH LOGISTICS
BASE MAPS
VIEW FROM SPACE 5KM
VIEW FROM SPACE 500M
Topography
Topography and Bathyme
Shaded Relief
BOUNDARIES
PLACES
TRANSPORTATION
WATER
ICE and PERMAFROST
LAND
OTHER
Redraw Map

**How do I move around in the map view?**

 The pan tool allows you to move the map view up, down, right or left.

**How do I "zoom in" and "zoom out"?**

To change the scale of the map view you can select the "zoom in" button  and then either click or drag a box around the area you want to see close up.

Select the "zoom out" button  and click or drag a box to see a larger area.

**How do I "Zoom to the Full Extent" of the ARMAP map view?**

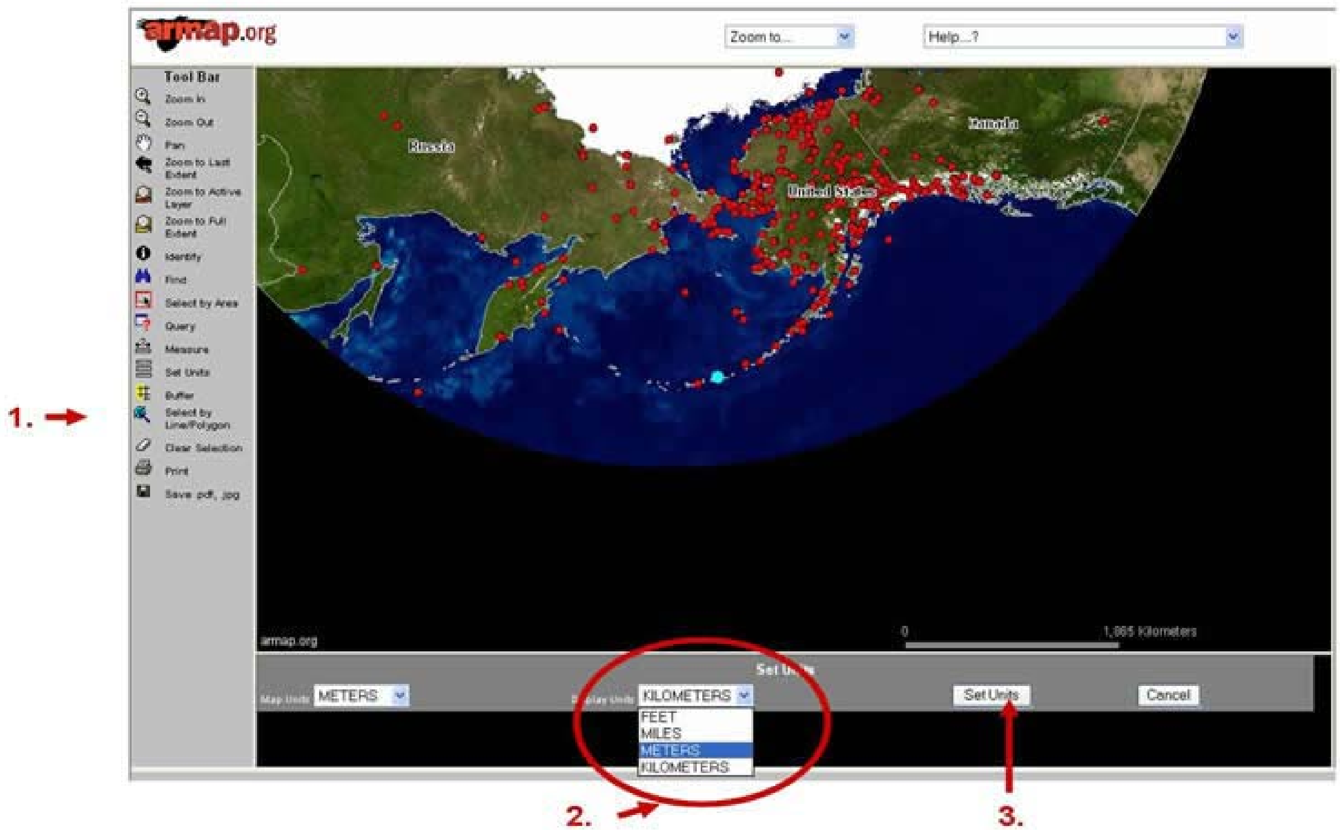
Click on the "Zoom to the Full Extent" button  to return to the area of interest covered by ARMAP.

**How do I go back to my last zoom extent?**

Use the "Back to Last" extent button .

**How do I set the map units and measure distance?**

Click on the "Set Units" button on the toolbar along the left hand side of the application as shown below (#1):

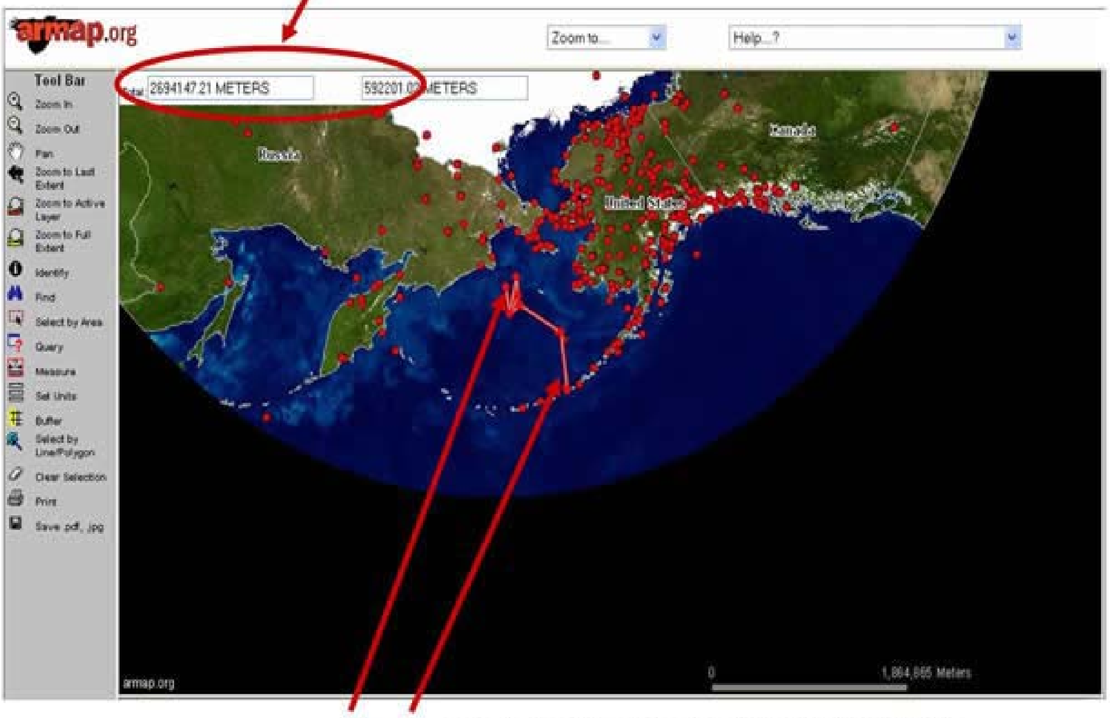



Then use the pull down menu (#2) to select the units and click on the "Set Units" button (#3) to confirm your selection.

Now you are ready to measure distance in meters using the "Measure Distance" tool which is also located on the toolbar along the left hand side of the application. In the example below, students doing research on Russia are curious to know the approximate distance across the Chukotka Peninsula, a result of "2610.73 km" is obtained.

4. Result (Measured Distance)

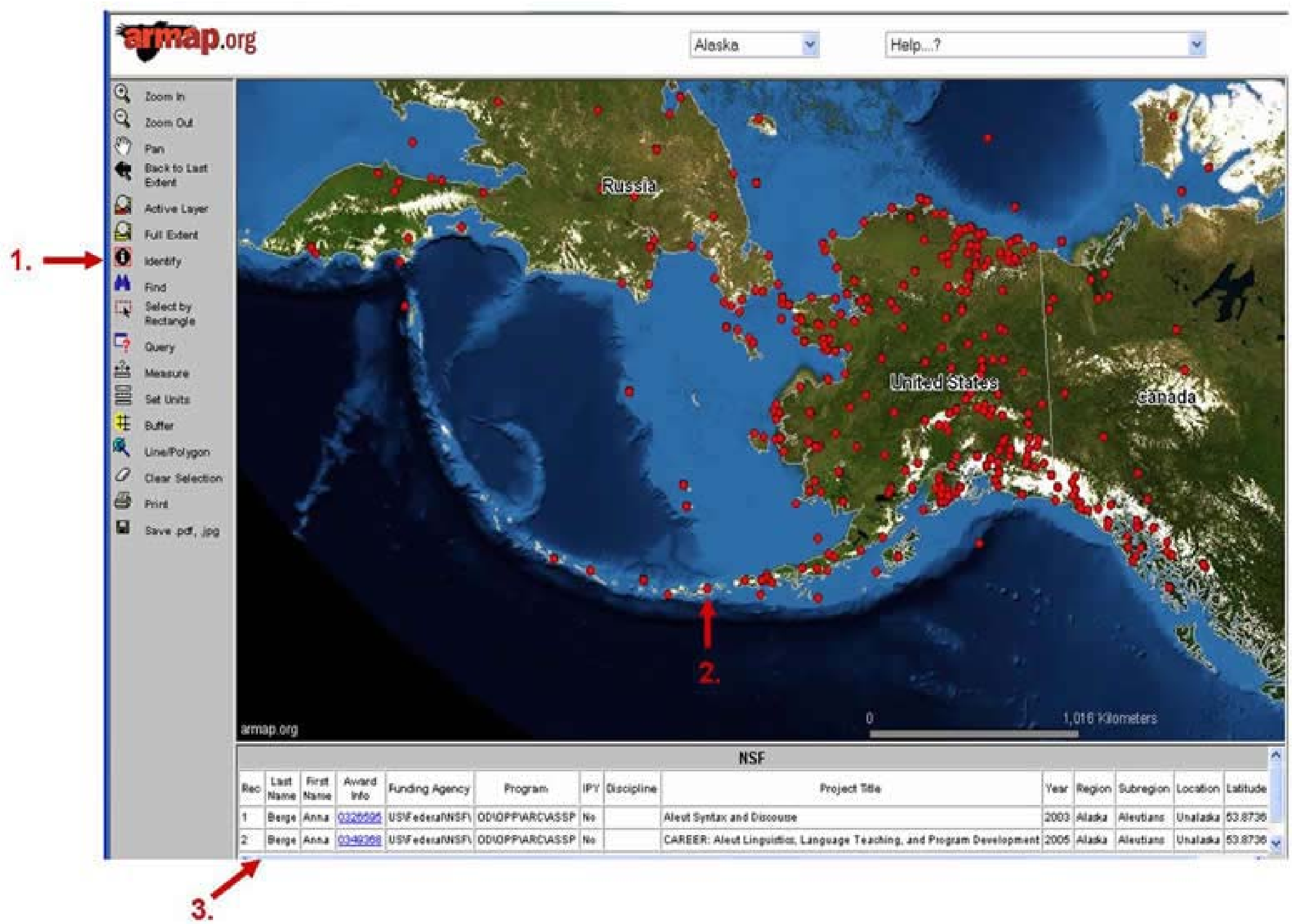
1. → Select Tool.




2., 3. Click on one endpoint, then the next point.

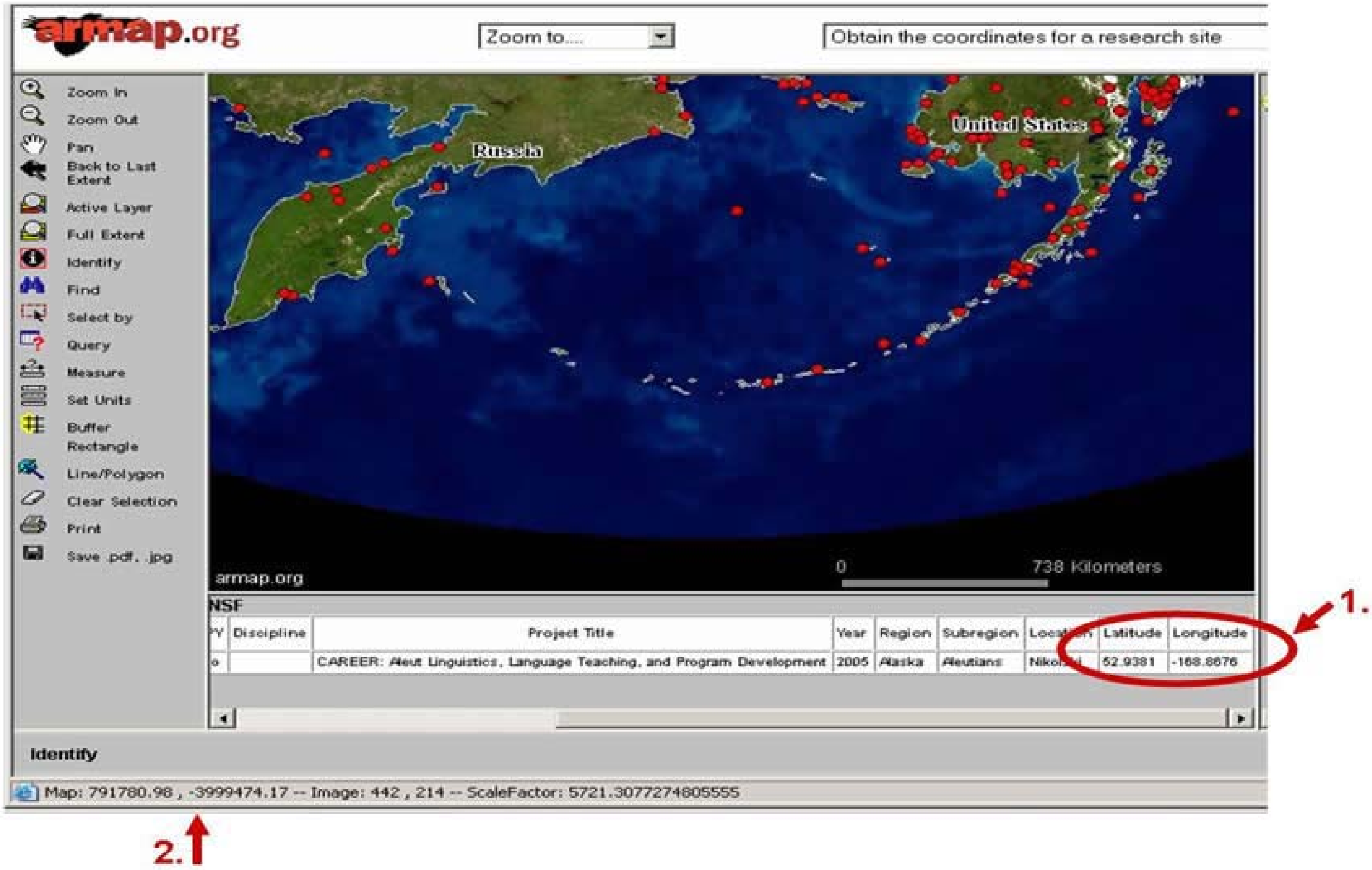
**How do I identify and "Get Info" on a research site?**

1. Access the "Get Info" button along the toolbar at the left hand side of your screen.
2. Click on a research site.
3. Note the information returned about that site at the bottom of the screen.



**How do I obtain the coordinates for a research site?**

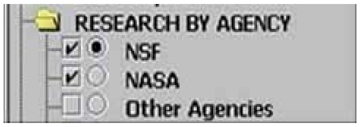
The coordinate values for each research site are available in the database table associated with the data layer (1.) (this information is returned after using a "Find", "Query" or "Get Info" tool ). Coordinate values are also shown in the map frame (2.) as shown in the example below.



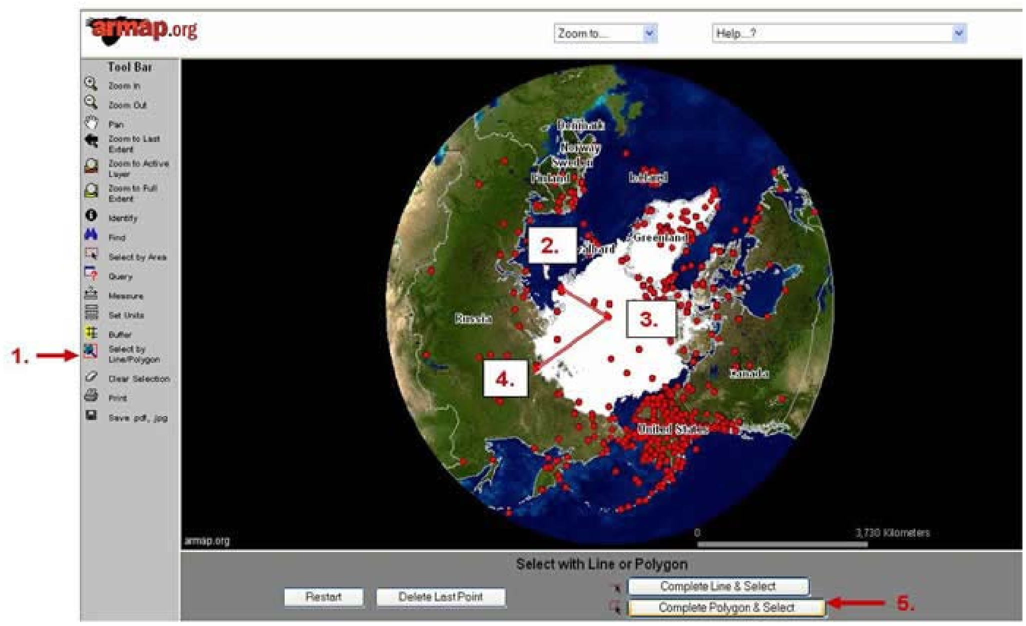
**How do I select a group of research sites?**

There are two ways to graphically select a group of research sites.

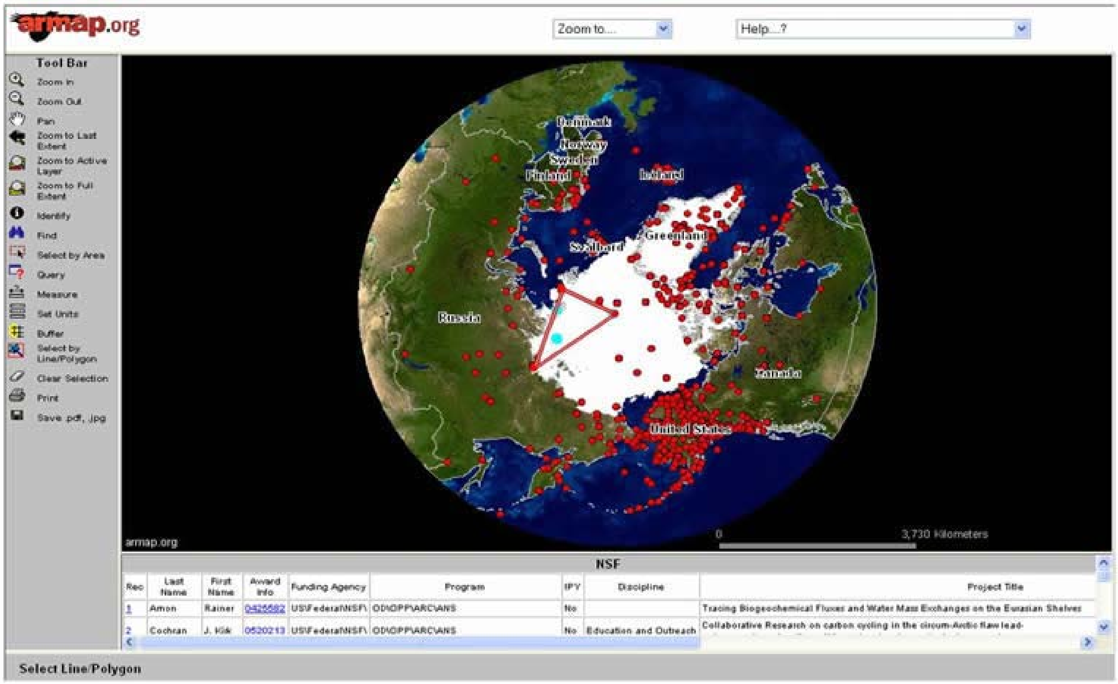
Note: before trying either approach make sure that the "research sites" theme is active in the table of contents.



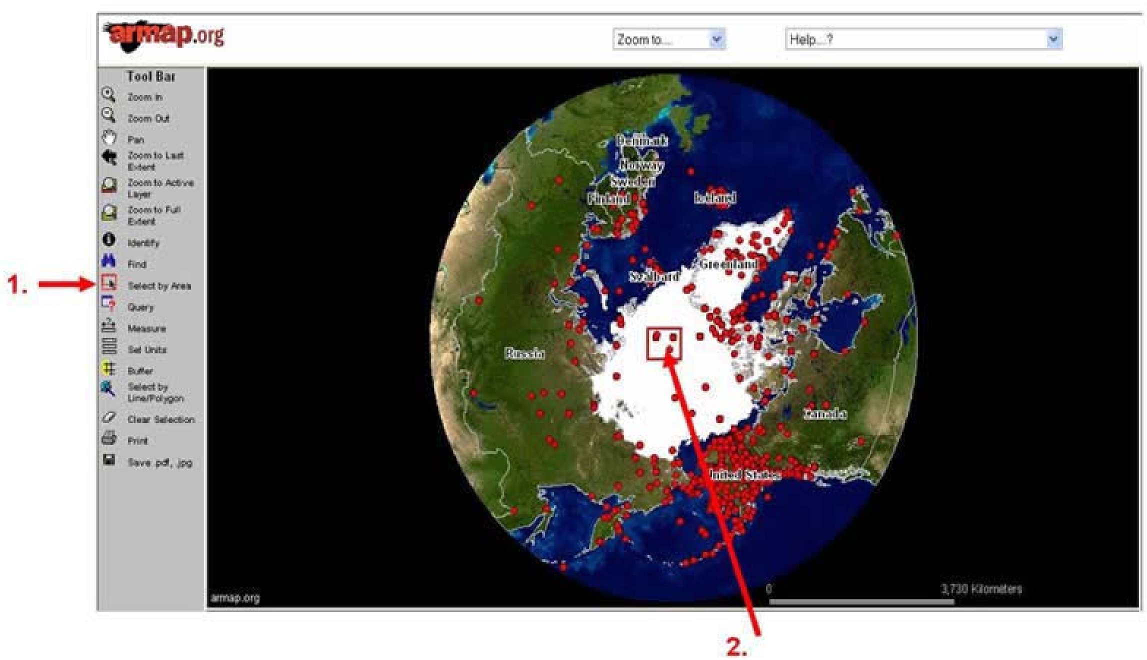

1. Choose the "Select by Line / Polygon" button from the toolbar (#1) along the left hand side of the application. Now click on the map view where you would like to begin drawing (#2) and then click again in a new location to draw the first segment (#3). (Be patient. It will take the application a few seconds to process each line segment of your drawing request.) Draw another segment (#4) and then consider closing the polygon with the "Complete Polygon and Select" button at the bottom of the screen (#5).



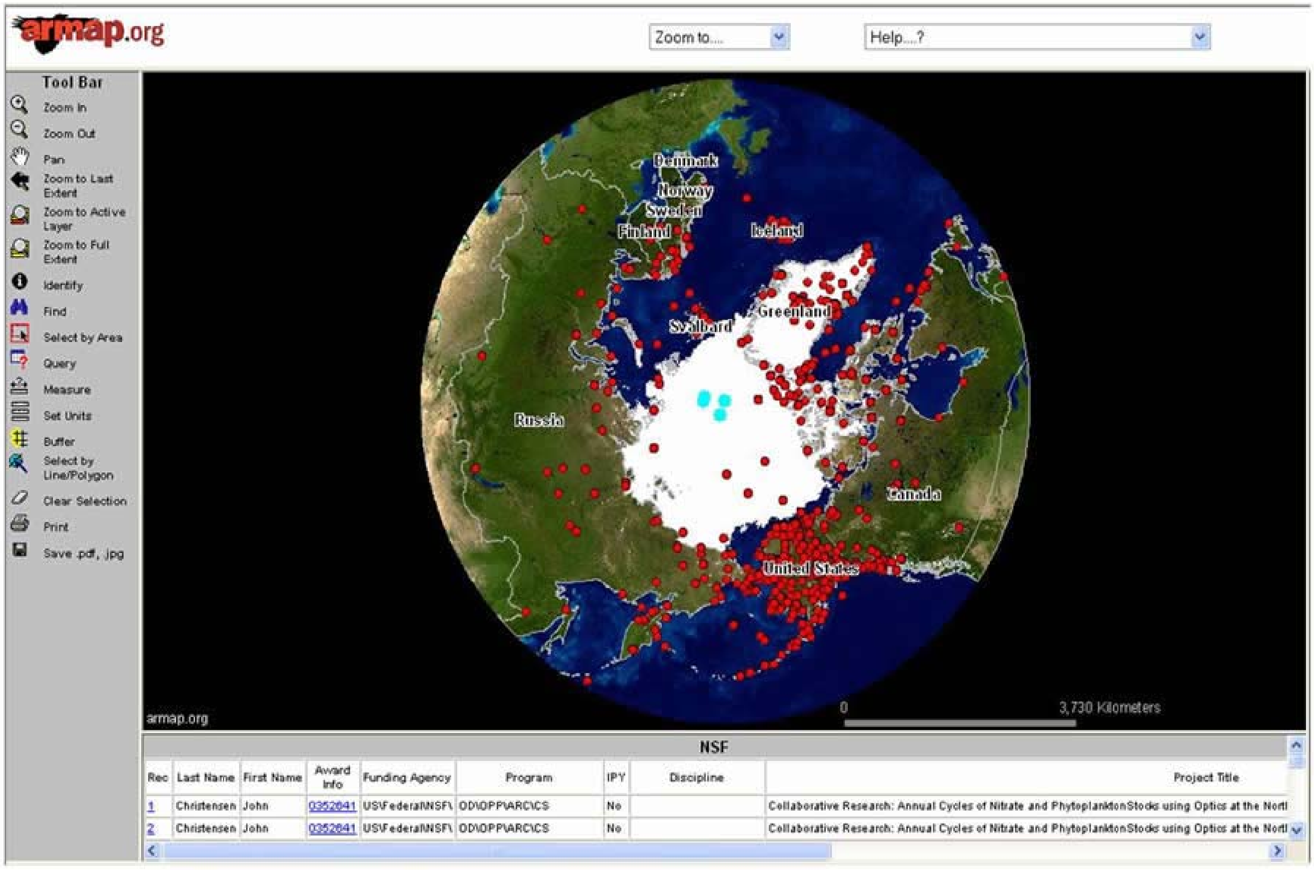

Below you will note the results which include a group of research sites highlighted in blue and the associated database records below the map view.




2. In the second approach to selecting a group of sites we will use the (#1) "Select by Area" button which is found on the toolbar along the left hand side of the application and (#2) draw a box around a group of sites you wish to view.




As a result of this selection, a group of sites is highlighted in blue and their associated database records are shown at the bottom of the screen as seen below:

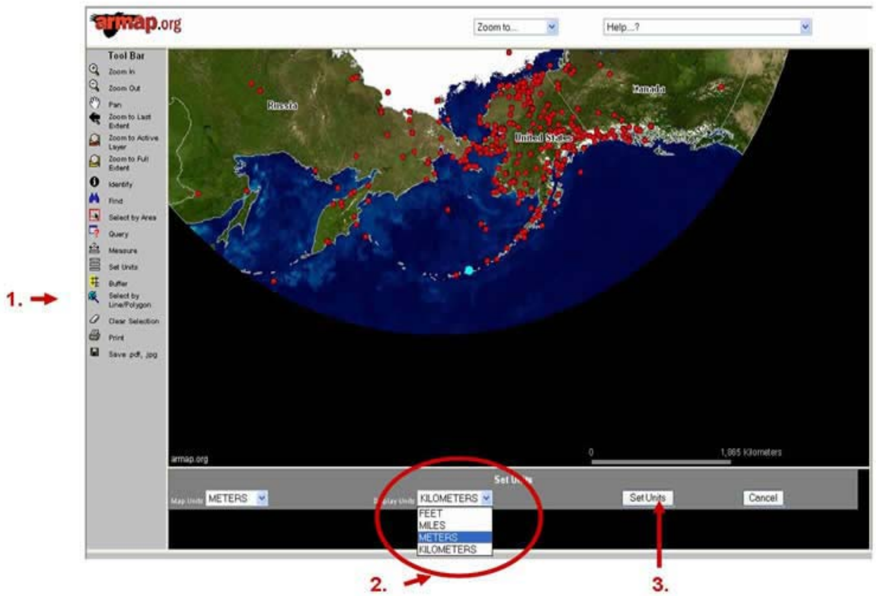

armap.org
Zoom to....
Help....?
Tool Bar
Zoom In
Zoom Out
Pan
Zoom to Last Extent
Zoom to Active Layer
Zoom to Full Extent
Identify
Find
Select by Area
Query
Measure
Set Units
Buffer
Select by Line/Polygon
Clear Selection
Print
Save .pdf, .jpg
Denmark
Norway
Sweden
Finland
Iceland
Svalbard
Greenland
Russia
Canada
United States
armap.org
0
3,730 Kilometers
NSF
Rec
Last Name
First Name
Award Info
Funding Agency
Program
IPY
Discipline
Project Title
1 Christensen John 0352641 US\Federal\NSF\ OD\OPP\ARC\CS No Collaborative Research: Annual Cycles of Nitrate and PhytoplanktonStocks using Optics at the Nortl
2 Christensen John 0352641 US\Federal\NSF\ OD\OPP\ARC\CS No Collaborative Research: Annual Cycles of Nitrate and PhytoplanktonStocks using Optics at the Nortl

**How do I create a buffer?**

Use the "Buffer" button on the toolbar along the left side of the map view. The "Buffer" tool often requires several settings.

In the example below, we've created a 2000 m buffer around "Biology" research sites to look for "Human Study" sites.

Step 1: Choose the units you wish to work with. In this case we used the "Set Units" button to change the units to "Meters" as demonstrated below:

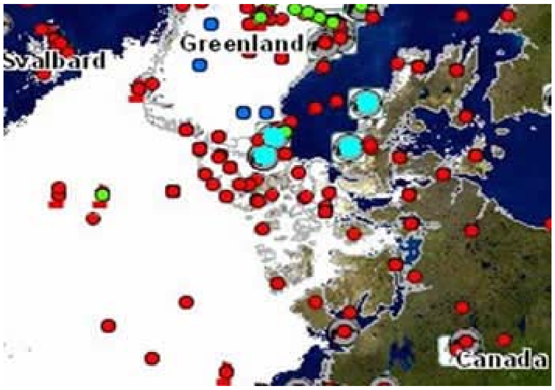



---

Step 2: To buffer a data layer, make sure it is turned on and active in the table of contents as shown below:

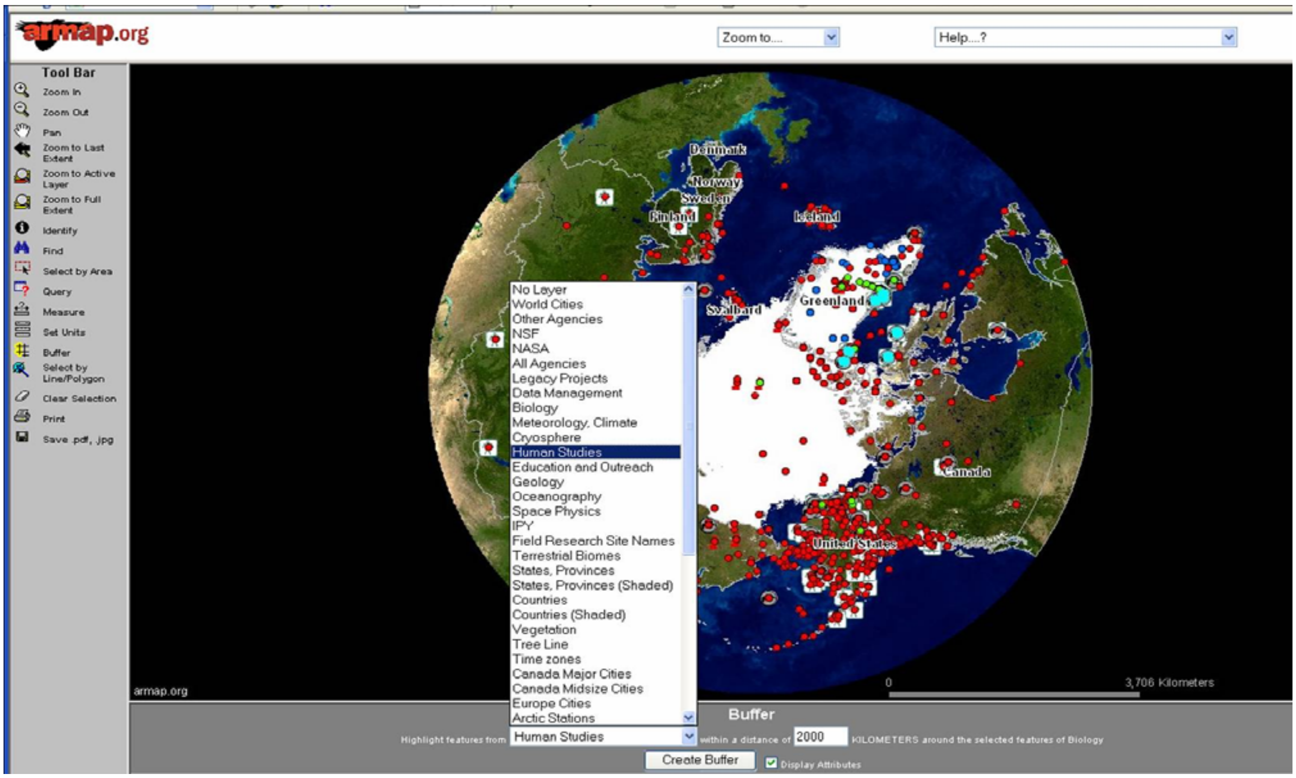

---

Step 3: Next select the features you wish to buffer. In this case, we used the "Select by Area" button to draw a box around the research sites.



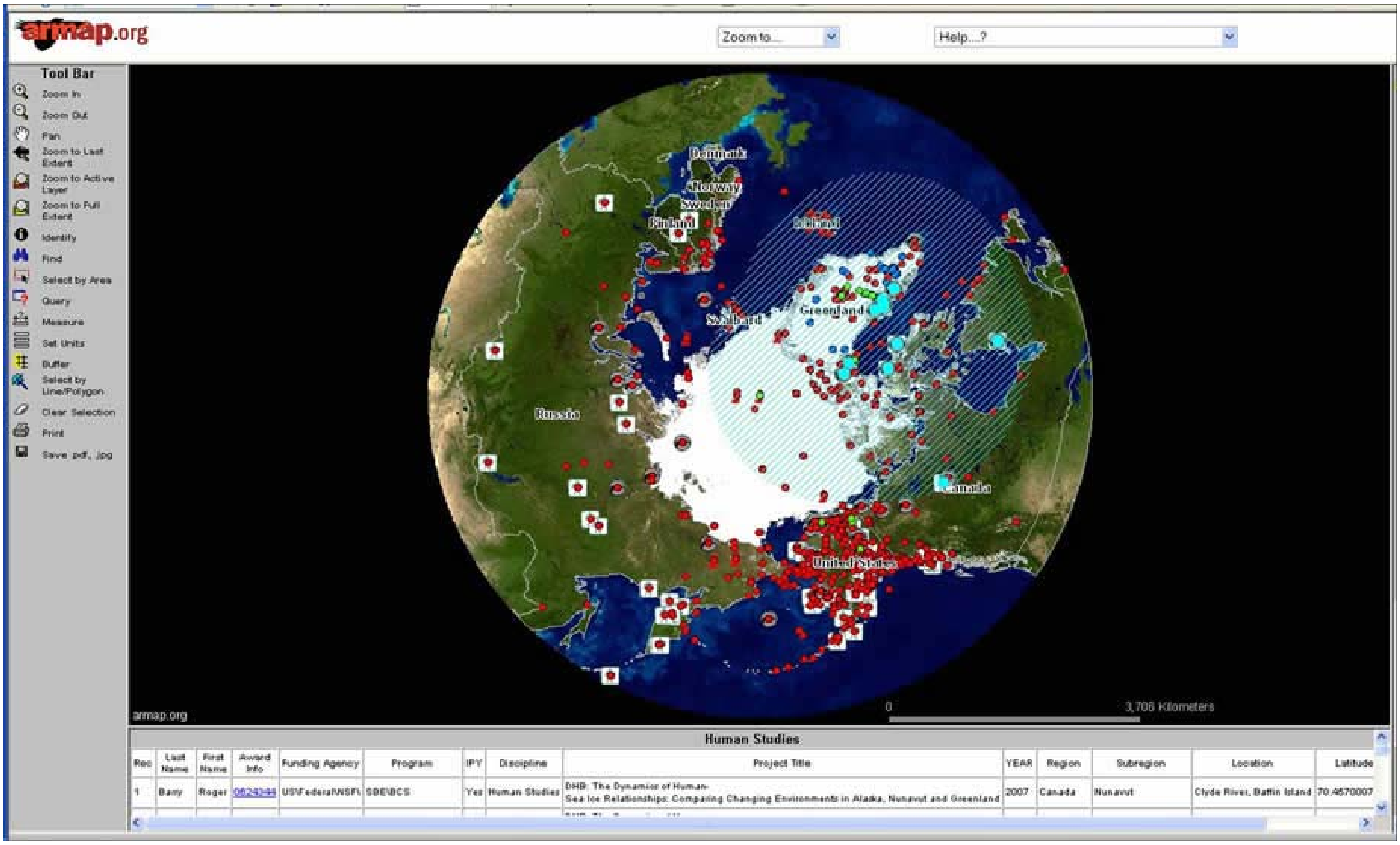

---

Step 4: Next we clicked on the "Buffer" button from the toolbar on the left side of the application (#1 below) which brings up the buffer options below the map view. We choose to "Highlight features from Biology" (#2) at a distance of 2000 meters (#3) and checked the box to "Display Attributes" (#4). Last, we clicked on the "Create Buffer" button.




---

The results of the buffer function are seen below. Note the 2000 meter area shaded in blue around "NSF" sites, the selected "Human Study"research sites in light blue and the database information associated with each site displayed at the bottom (Please note that some of the "NSF" highlighted sites are at the same location as "Human Study" sites).


armap.org
Zoom to...
Help....?
Tool Bar
Zoom In
Zoom Out
Pan
Zoom to Last Extent
Zoom to Active Layer
Zoom to Full Extent
Identify
Find
Select by Area
Query
Measure
Set Units
Buffer
Select by Line/Polygon
Clear Selection
Print
Save pdf, jpg
Denmark
Norway
Sweden
Finland
Iceland
Greenland
Svalbard
Russia
Canada
United States
armap.org
0
3,706 Kilometers
Human Studies
Rec | Last Name | First Name | Award Info | Funding Agency | Program | IPY | Discipline | Project Title | YEAR | Region | Subregion | Location | Latitude
1 | Barry | Roger | 0624344 | US\Federal\NSF\ | SBE\BCS | Yes | Human Studies | DHB: The Dynamics of Human-Sea Ice Relationships: Comparing Changing Environments in Alaska, Nunavut and Greenland | 2007 | Canada | Nunavut | Clyde River, Baffin Island | 70.4570007

**How do I print the results of a query?**

After performing a query that returns a list of records, you can select the list with your cursor and then right mouse click to obtain the "Print" option. Note: you can also copy the records from the database into a spreadsheet such as Microsoft Excel.


**Select with cursor, right click, then select print.**

 **Print a map**

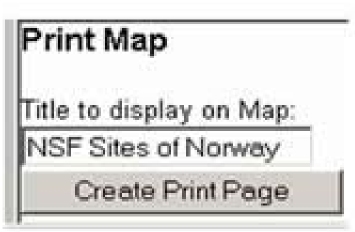
When you select the Print tool a new window will pop-up.

Follow the instructions below.

1. Click On the Print  Button.

2. Enter "NSF Sites of Norway" Text For Map Title.

For example:




3. Click "Create Print Page" Button.

4. Print window will be displayed, follow normal printing protocol (either click on the "Print" icon or File>Print and follow instructions).

**How do I view metadata associated with a data layer?**

From the table of contents along the right hand side of the application, open a folder and click on the layer name to bring up its associated metadata record.

Below is an example of the table of contents. Note how the data layer is underlined when you move the cursor over it.

Clicking on the "**Vegetation** " data layer will bring up the metadata in another window.

Click the "View extended FGDC Metadata Record" to view complete metadata for your layer of choice.

## Advanced Search Tool

### What does this tool do?

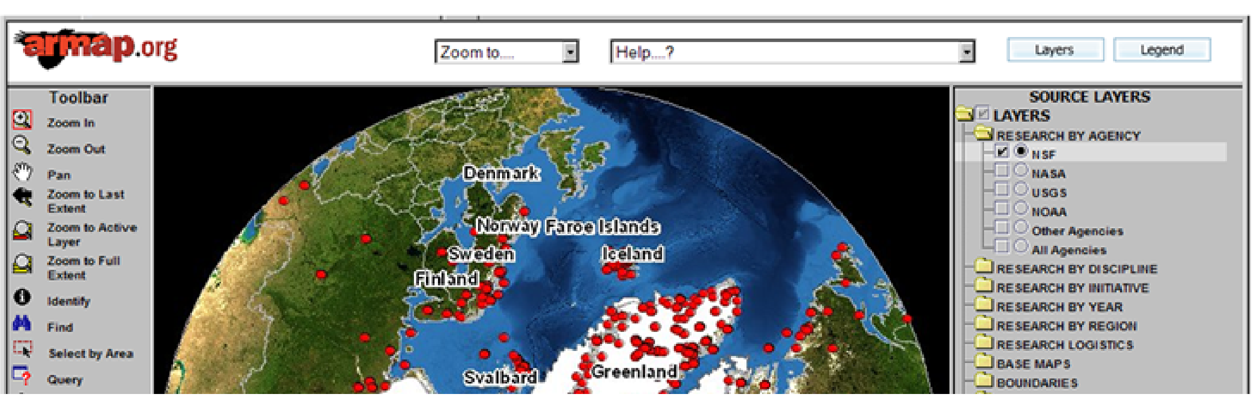
*Advanced Search* allows users to search for information about a selected layer found on the Table of Contents located on the right hand side of the map frame. Search results are highlighted on the map and are listed below the map in the table frame. Users can view more information about a particular record by selecting the hyperlinked font.

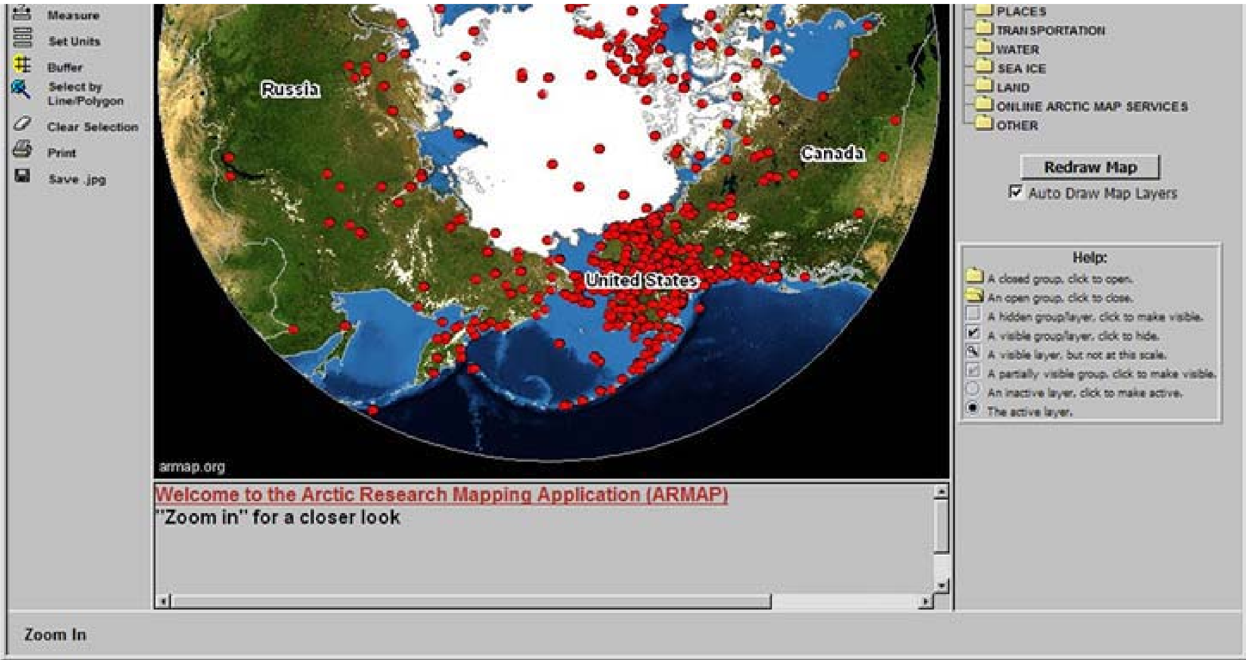
### Step me through a simple example:

*How do I search for a research site by Award Number?*

### Step me though a more advanced example:

*I need to know which biological sciences projects were funded in Alaska in 2005.*






This is the general default ARMAP IMS interface. To learn more about the interface, please visit the components page.

---

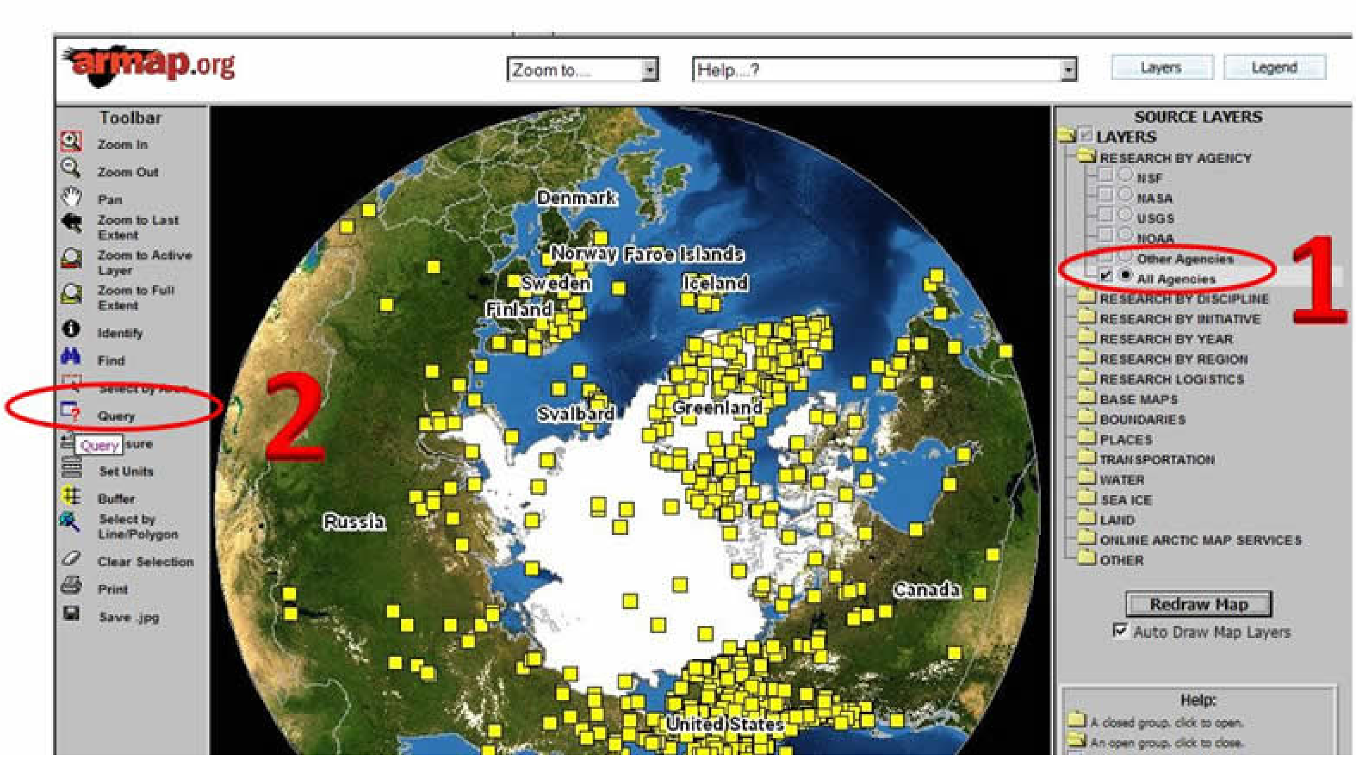
**Step me through an example:**

*How do I search for a research site by Award Number = 0000315?*

If you know what category the research site is under, you may select that layer. If not, then select the "**All Agencies**" layer under the "Research By Agency" folder.

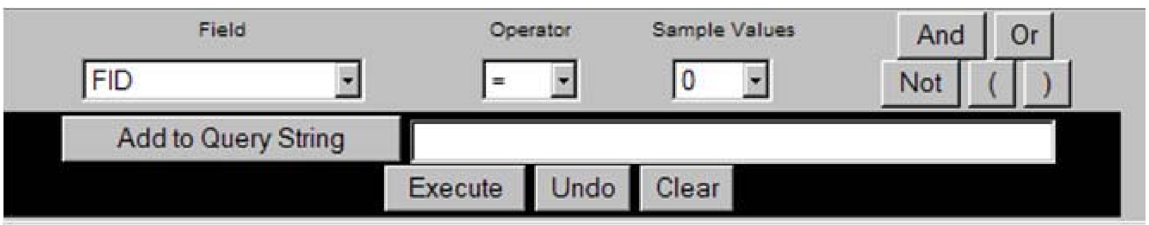
1. **Check** the box and **Select** the radio button next to the "**All Agencies**" Layer on the *Table Of Contents*.

*Note: Clicking the radio button makes the layer available for searching.

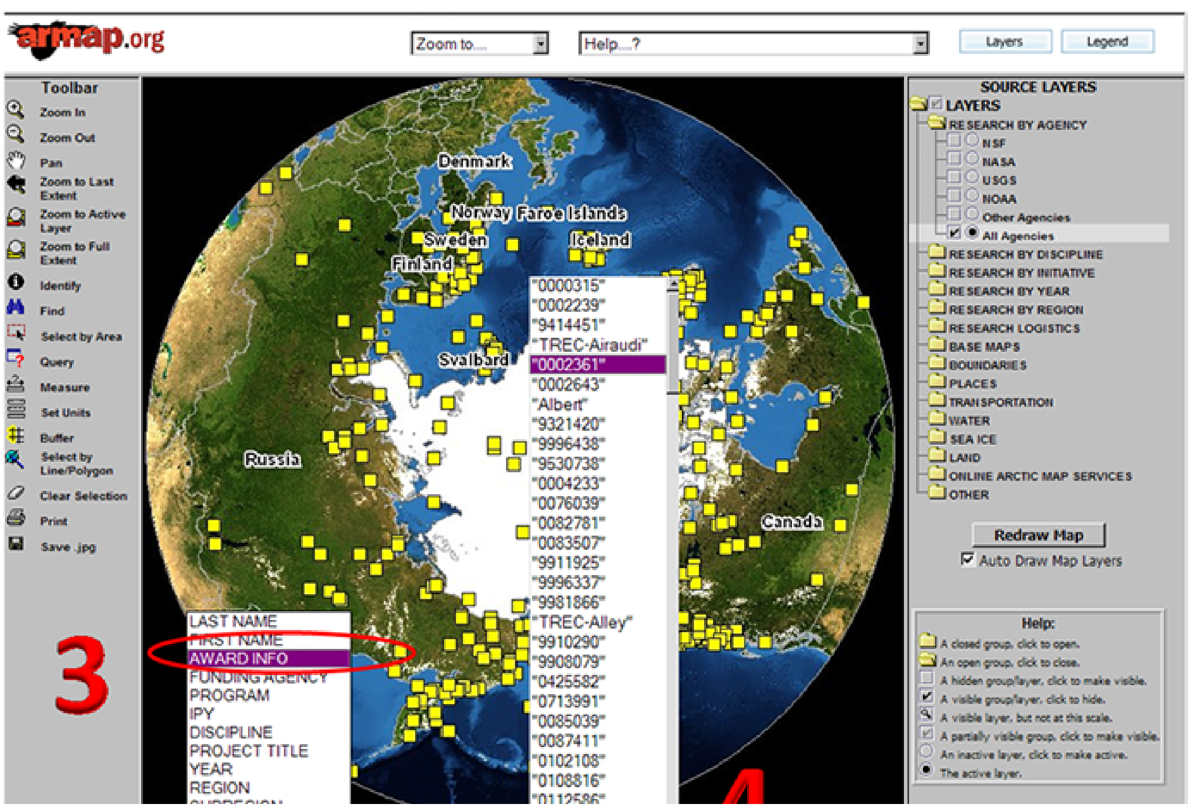


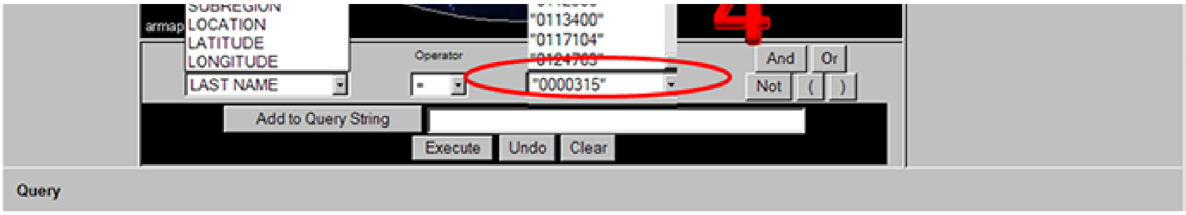

2. Select the "Advanced Search" tool from the toolbar menu.

In the bottom part of the Map Frame, a SQL query builder with pop-up. The left side displays the fields available for searching, the middle displays the operator value you wish to use (=, <, >, <=, =>, and LIKE), and the right side provides you sample values.




3. From the **Field** pulldown menu, select "*Award Info*". From the **Operator** pulldown menu, choose the "=" symbol.






4. Select **0000315** from the **Sample Value** pulldown menu. (If the number is not one of the sample values, just type it in the query box surrounded by quotations marks)

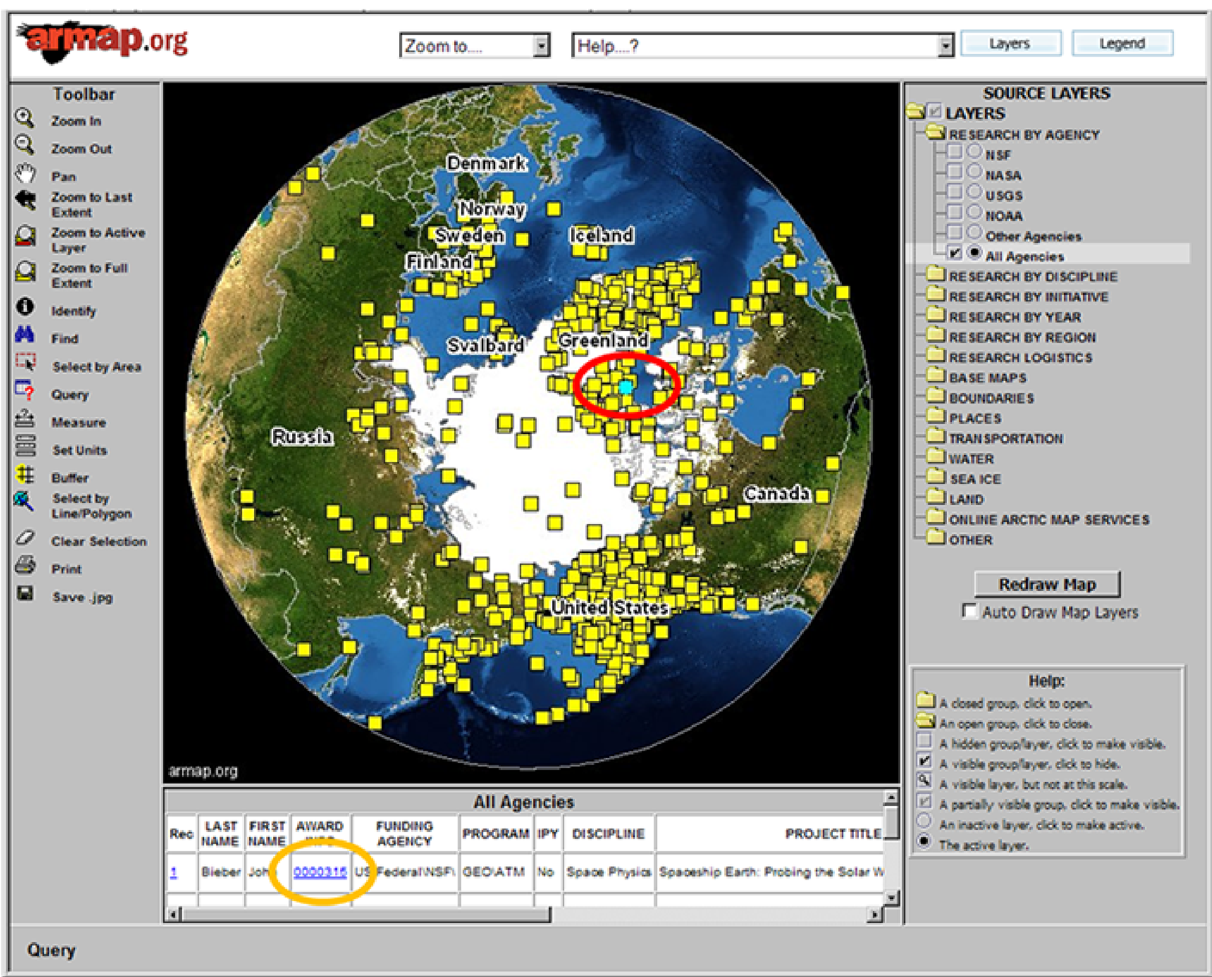
5. Click the "Add to Query String" button.

* Note you may also just type in the query in the box next to "Add to Query String" if you know what you are looking for, in this case:

***Award_Info = "0000315"***


6. Click "Execute".

**Your map view should look similar to the image below:**



**Notice the research site highlighted in light blue (drop the red circle on the map frame) and the Award Info hyperlink in the table below the map. "0000315" is hyperlinked to a report with more information about the project.**

7. To view at a report, click on the hyperlinked number (highlighted blue) in the **"Award Info"** column.

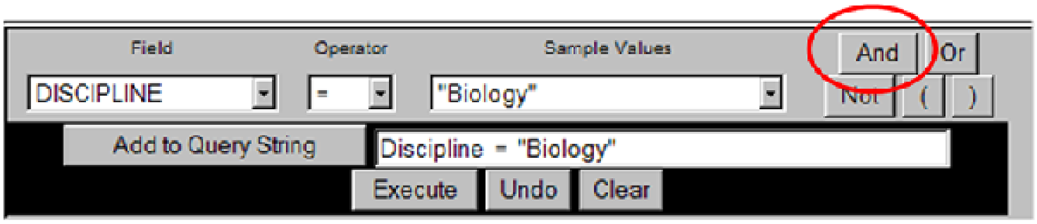
---

**Step me through an example:**

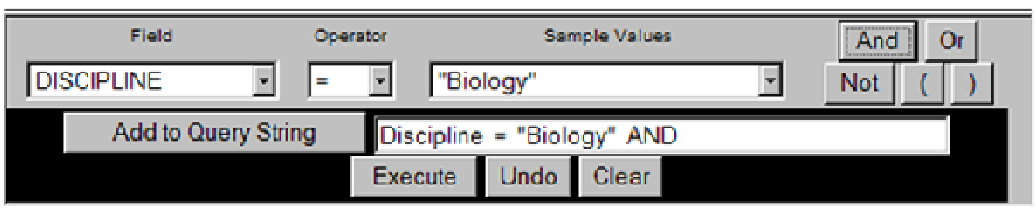
*I need to knowwhich biological science projects were funded in Alaska in 2005.*

1. Select **"Discipline"** from the **Field** pulldown menu**, equals (=)** for the **Operator** menu, and **"Biology"** from the **Sample Value** menu.

2. Click the "**Add to Query String**" button.



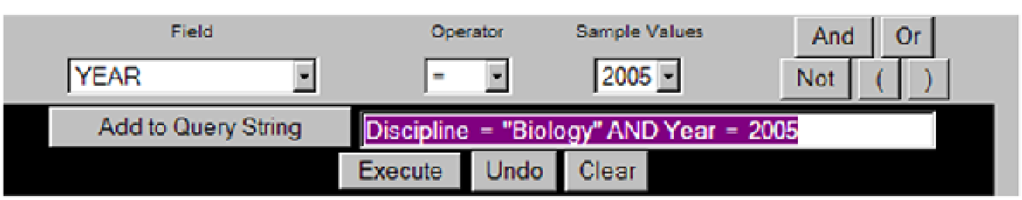

3. To build an advanced search, click the "**And**" button or type "**AND**" in the text box after "Biology".



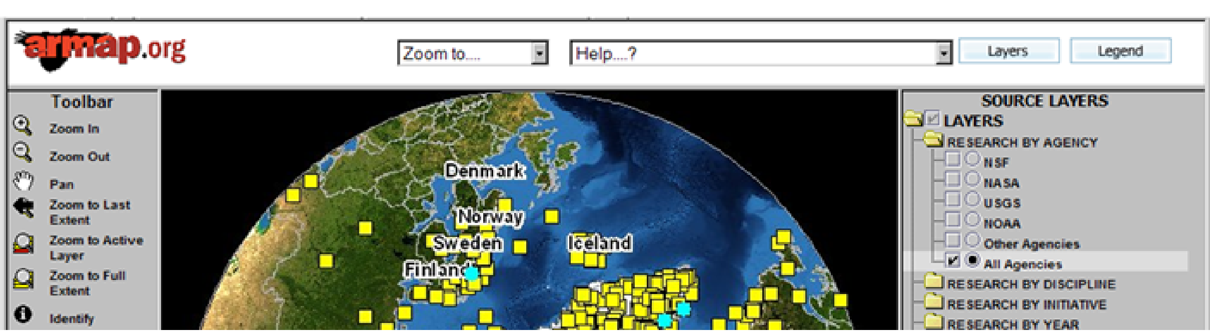

4. Select **"Year"** from the **Field** pulldown menu**, equals (=)** for the **Operator**, and **"2005"** from the **Sample Value** menu.

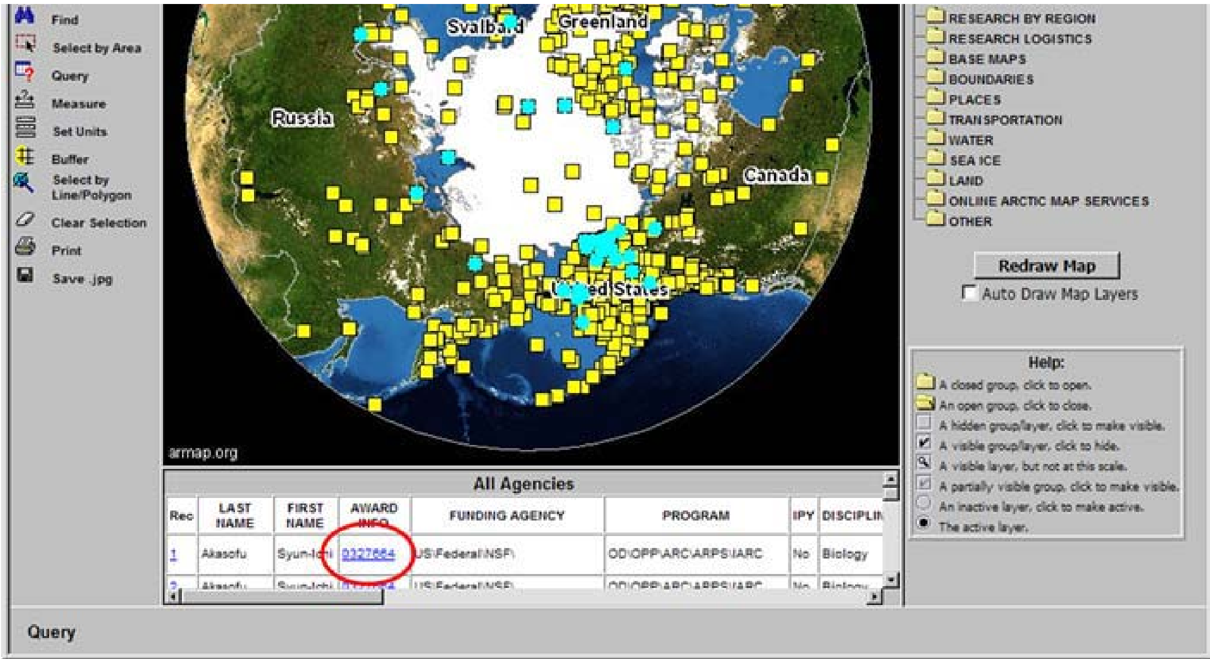
5. Click the "**Add to Query String**" button.

6. Click "**Execute**".




**Your map view should look similar to the image below:**






7. To view at a report, click on the hyperlinked number (highlighted blue) in the **"Award Info"** column.

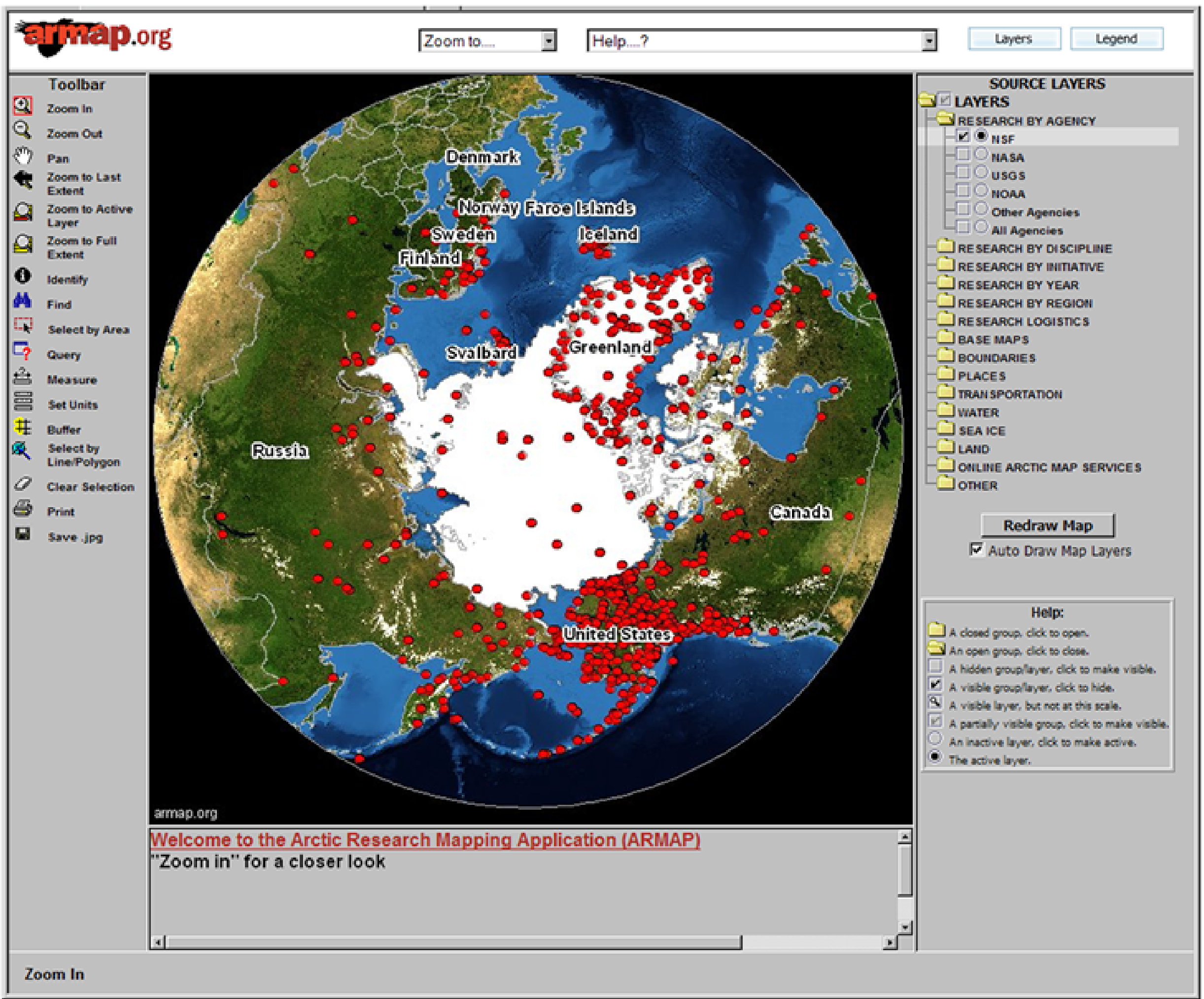
# Find Tool

## What does this tool do?

The *Find Tool* allows users to search for information about a selected layer found on the Table of Contents located on the right hand side of the map frame. Search results are highlighted on the map and are listed below the map in the table frame. Users can view more information about a particular record by selecting the hyperlinked font.

## Step me through a simple example:

*How do I find projects that have snow as part of the record?*




This is the general default ARMAP IMS interface. To learn more about the interface, please visit the components page.

---

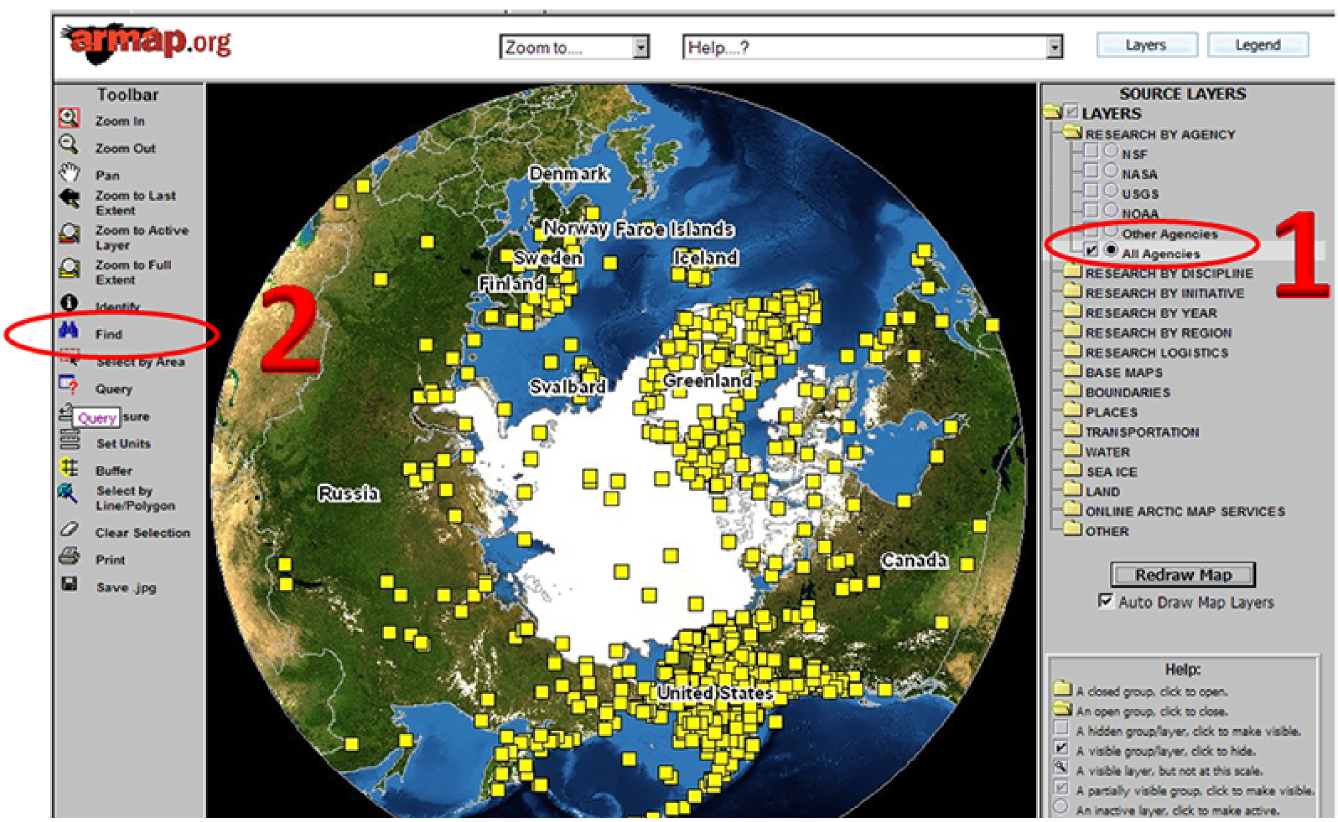
## Step me through an example:

*How do I find projects that have snow as part of the record?*

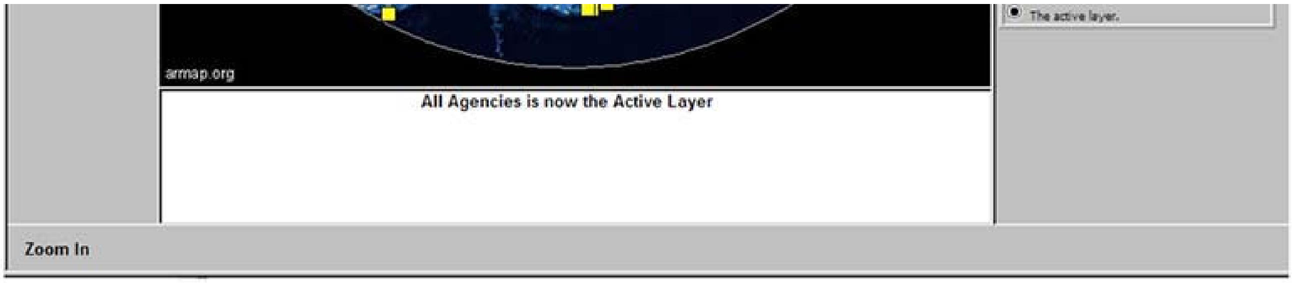
You may run the “Find” tool to search any layer on the *Table of Contents,* but in this example we will search the **“All Agencies”** layer under the **“Research by Agency”** folder.

1. **Check** the box and **Select** the radio button next to the "**All Agencies**" Layer on the *Table Of Contents*.

*Note: Clicking the radio button makes the layer available for searching.



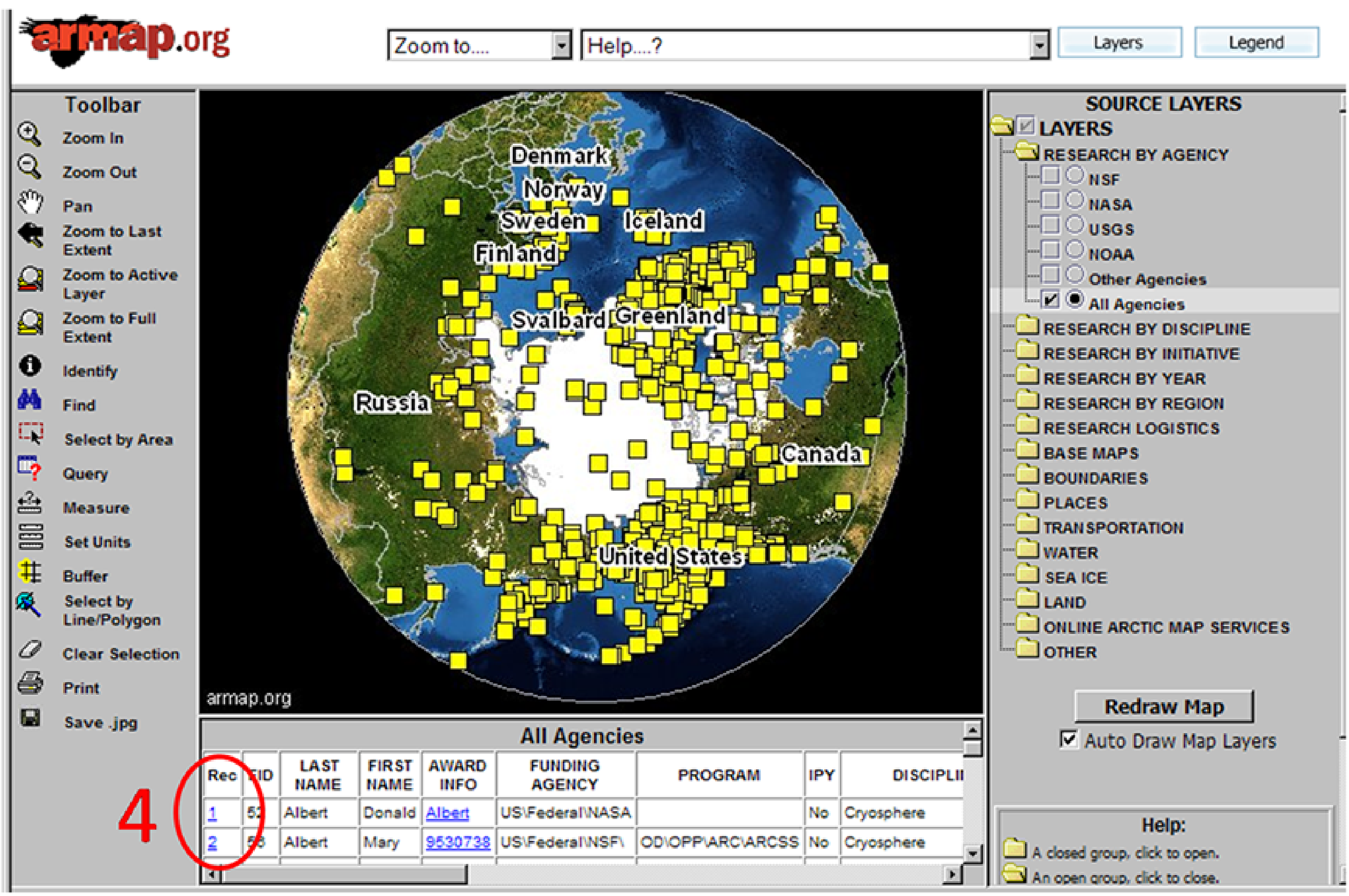
armap.org
Zoom to....
Help....?
Layers
Legend
Toolbar
Zoom In
Zoom Out
Pan
Zoom to Last Extent
Zoom to Active Layer
Zoom to Full Extent
Identify
Find
Select by Area
Query
Set Units
Buffer
Select by Line/Polygon
Clear Selection
Print
Save .jpg
2
1
Denmark
Norway
Faroe Islands
Sweden
Iceland
Finland
Svalbard
Greenland
Russia
Canada
United States
SOURCE LAYERS
LAYERS
RESEARCH BY AGENCY
NSF
NASA
USGS
NOAA
Other Agencies
All Agencies
RESEARCH BY DISCIPLINE
RESEARCH BY INITIATIVE
RESEARCH BY YEAR
RESEARCH BY REGION
RESEARCH LOGISTICS
BASE MAPS
BOUNDARIES
PLACES
TRANSPORTATION
WATER
SEA ICE
LAND
ONLINE ARCTIC MAP SERVICES
OTHER
Redraw Map
Auto Draw Map Layers
Help:
A closed group, click to open.
An open group, click to close.
A hidden group/layer, click to make visible.
A visible group/layer, click to hide.
A visible layer, but not at this scale.
A partially visible group, click to make visible.
An inactive layer, click to make active.



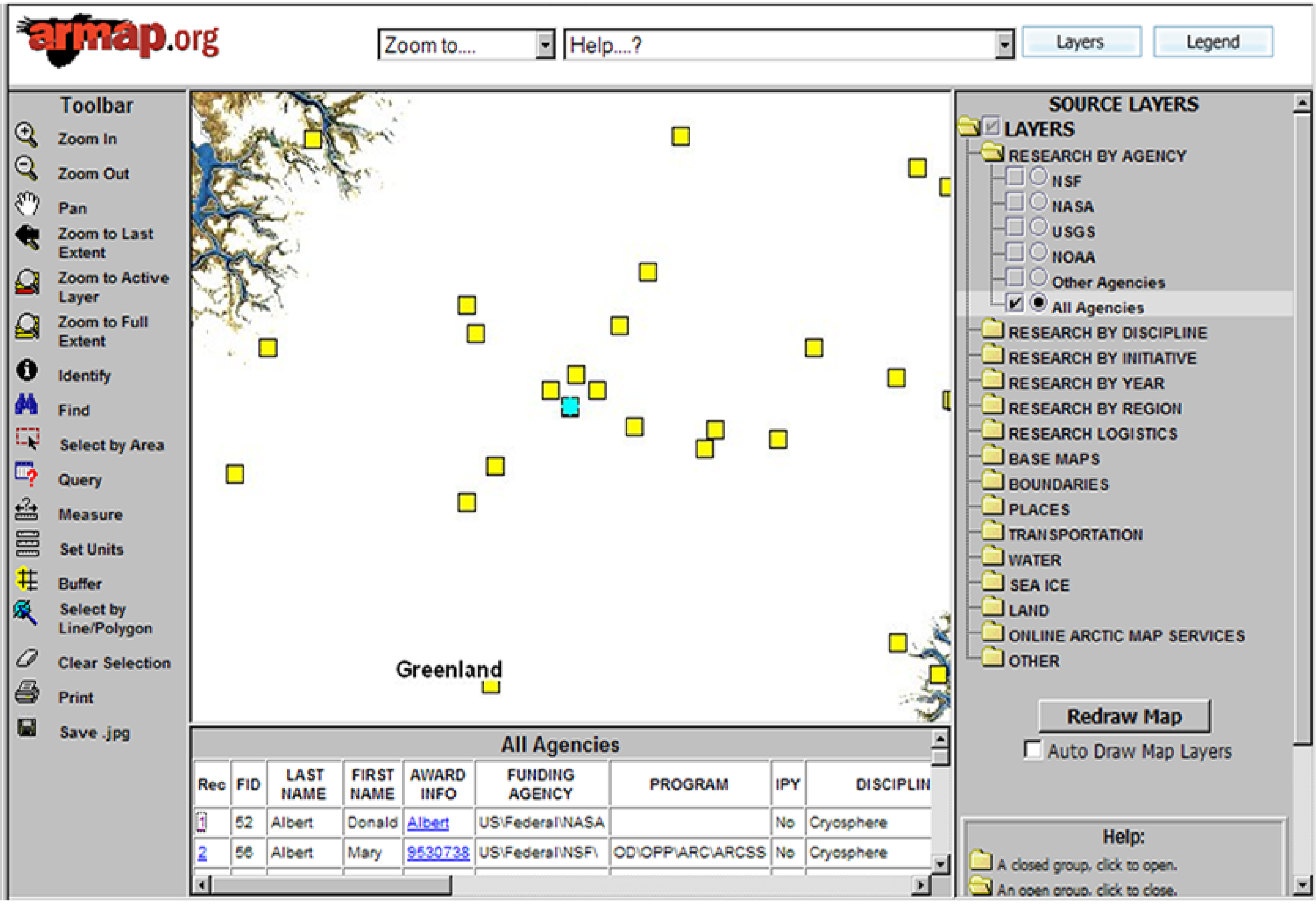

2. Select the "**Find**" tool from the toolbar menu.


3. Type in "**Snow**" into the text box to the right of "Enter String to Find in All Agencies and click "**Find String"**.


**Notice the Find Tool does not highlight research projects unless you zoom to record, but returns which records from the layer contain the word "Snow" in one of the column records .**



4. To zoom to a record, click on the hyperlinked number in the (blue highlighted number) in the **"Rec"** column.



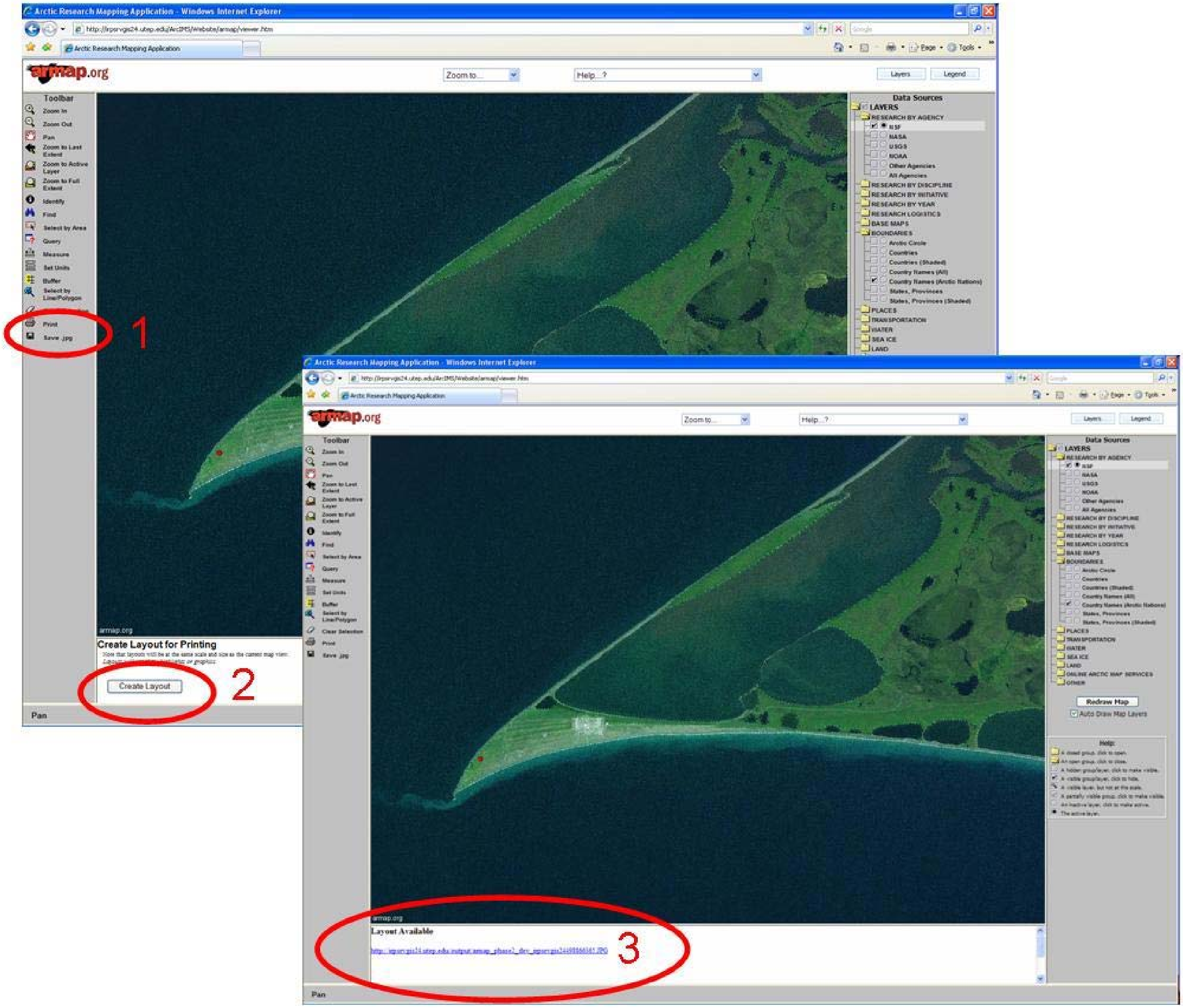

5. To view at a report, click on the hyperlinked in the (blue highlighted number) in the **"Award Info"** column.

**To save the map view as a JPG:**

1. Click the "Save .jpg" tool on the bottom of the toolbar.

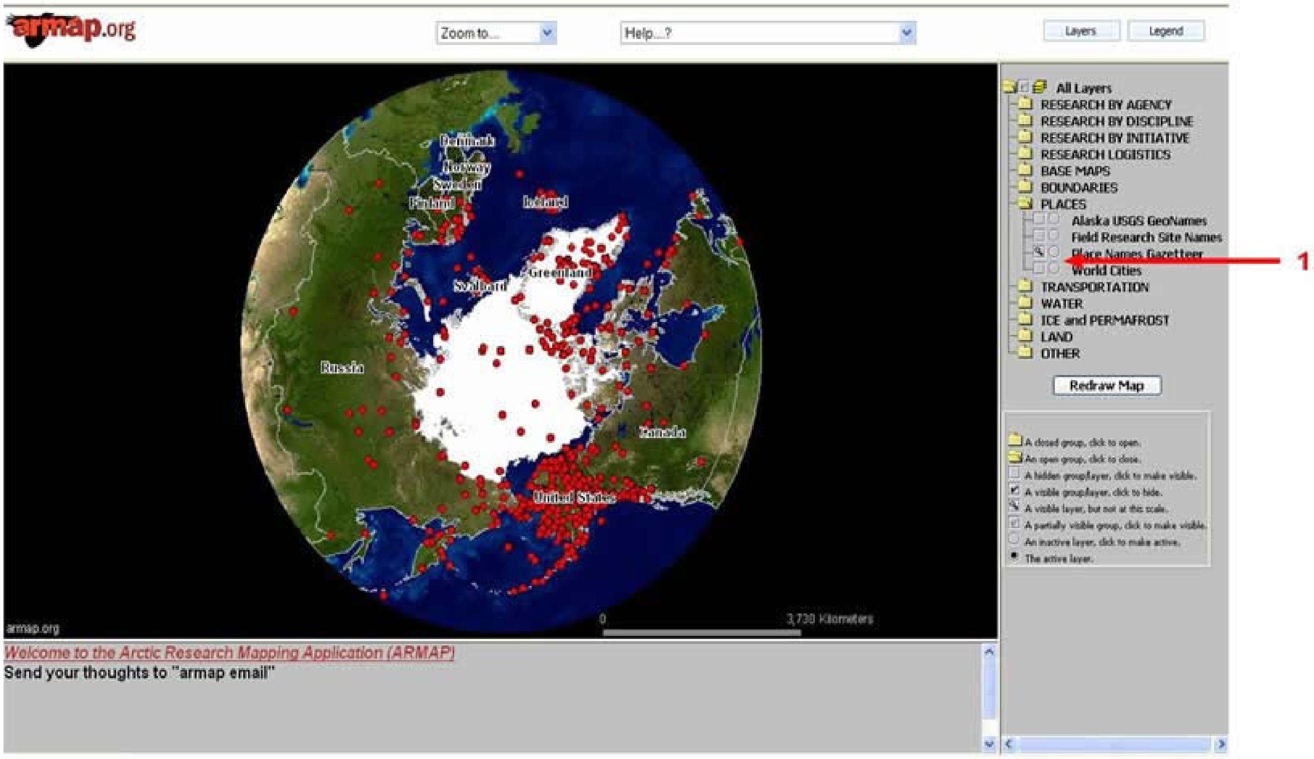
2. Click the "Create Layout" button in the lower frame.

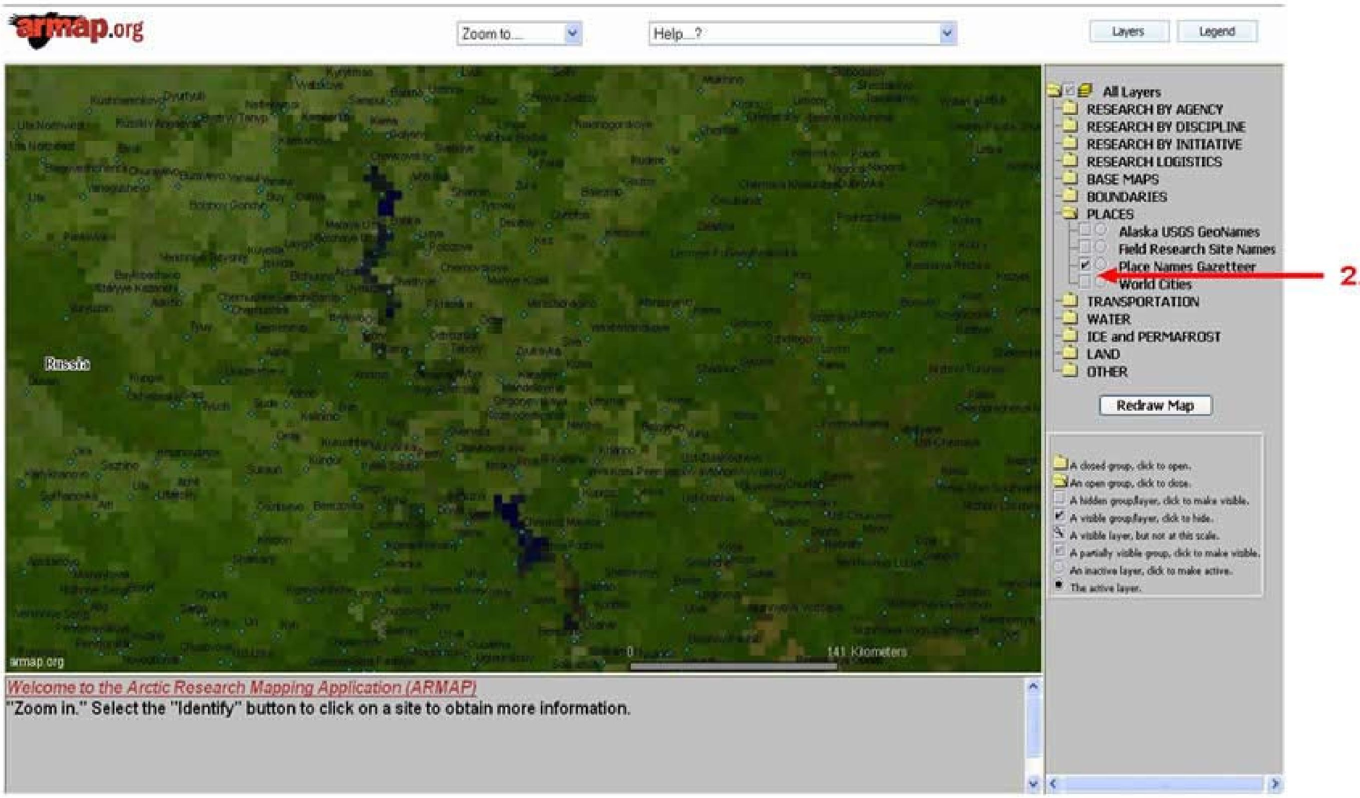
3. Notice that a URL link is generated for the jpg in the lower frame. Right click on the URL and save it to an appropriate location on your hard drive.



**Why do features appear and then go away when I zoom in or out?**

This application features "Scale Dependent Data." The Place Names Gazetteer is an example of a data set that has a scale dependency. To avoid overcrowding the map view, this layer is set to appear only when a user zooms in (Note: the scale dependent icon on the table of contents)




armap.org
Zoom to...
Help...?
Layers
Legend
All Layers
RESEARCH BY AGENCY
RESEARCH BY DISCIPLINE
RESEARCH BY INITIATIVE
RESEARCH LOGISTICS
BASE MAPS
BOUNDARIES
PLACES
Alaska USGS GeoNames
Field Research Site Names
Place Names Gazetteer
World Cities
TRANSPORTATION
WATER
ICE and PERMAFROST
LAND
OTHER
Redraw Map
A closed group, click to open.
An open group, click to close.
A hidden group/layer, click to make visible.
A visible group/layer, click to hide.
A visible layer, but not at this scale.
A partially visible group, click to make visible.
An inactive layer, click to make active.
The active layer.
2.
Russia
141 Kilometers
Welcome to the Arctic Research Mapping Application (ARMAP)
"Zoom in." Select the "Identify" button to click on a site to obtain more information.

## Appendix C – ArcGIS Explorer Scenario Help Guide

ESRI's ArcGIS Explorer application platform was used for the development of ARMAP 3D. The following is a workflow following the described scenario in section 4.3.1A2DI Logistic Planning Scenario. Each task in the text represents a process in order from beginning to end to achieve the end product, the users request from the application. This is a simple "How-to" guide to follow for achieving the search for information and displaying map data in ARMAP 3D.

1. Open the ARMAP home page via http://armap.org.

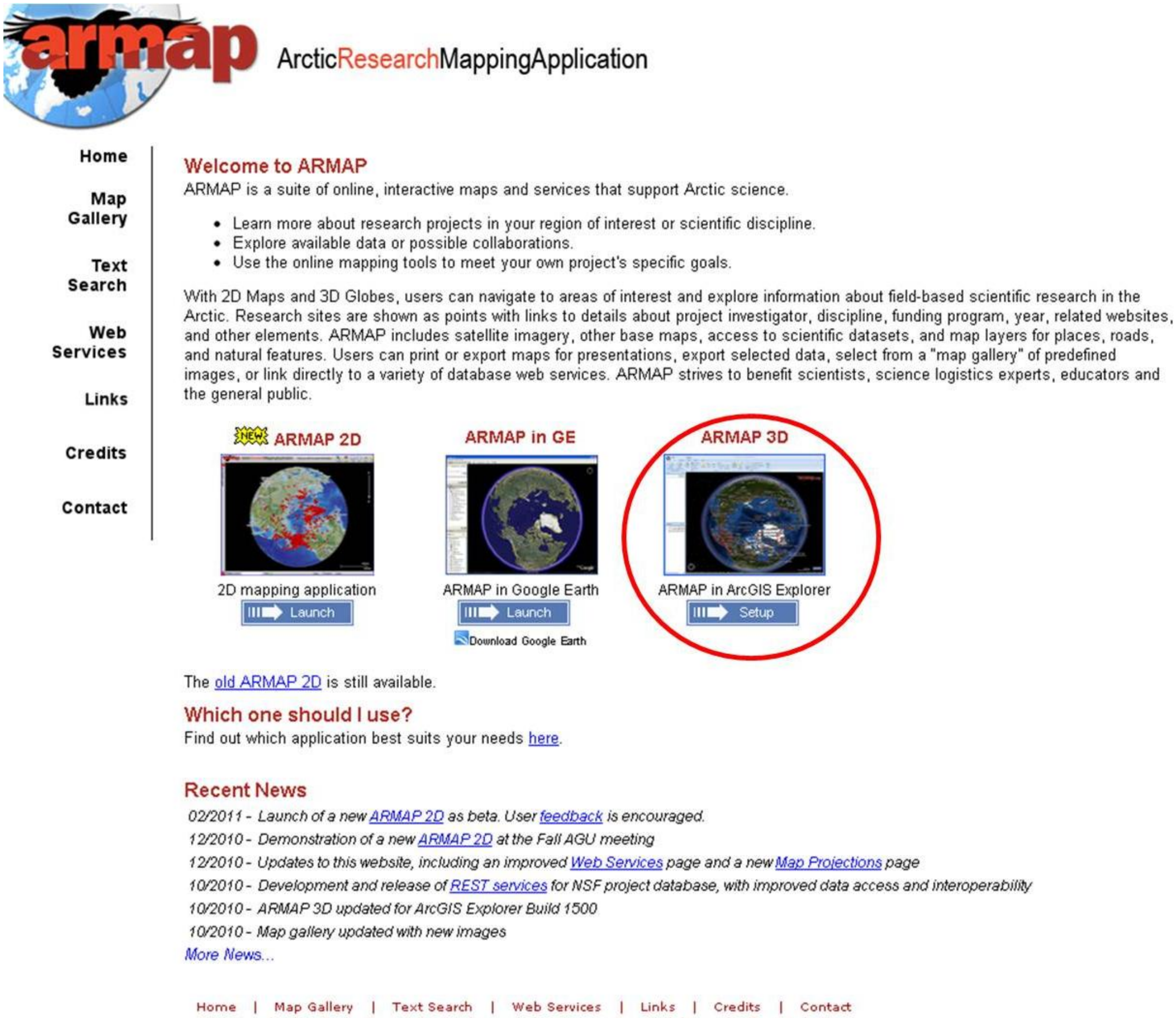



**Figure C1**

2. If you have used AGX and have it installed on your Windows machine, please skip to number 3. If you do not have AGX installed, you must download the application.

   a. By clicking the icon (Figure C1, circled in red), it opens up a page that contains link to the install directions and a link to the configuration file (Figure C2). Following the directions as stated on the ESRI webpage to install AGX. You will need administrator privileges to install AGX.

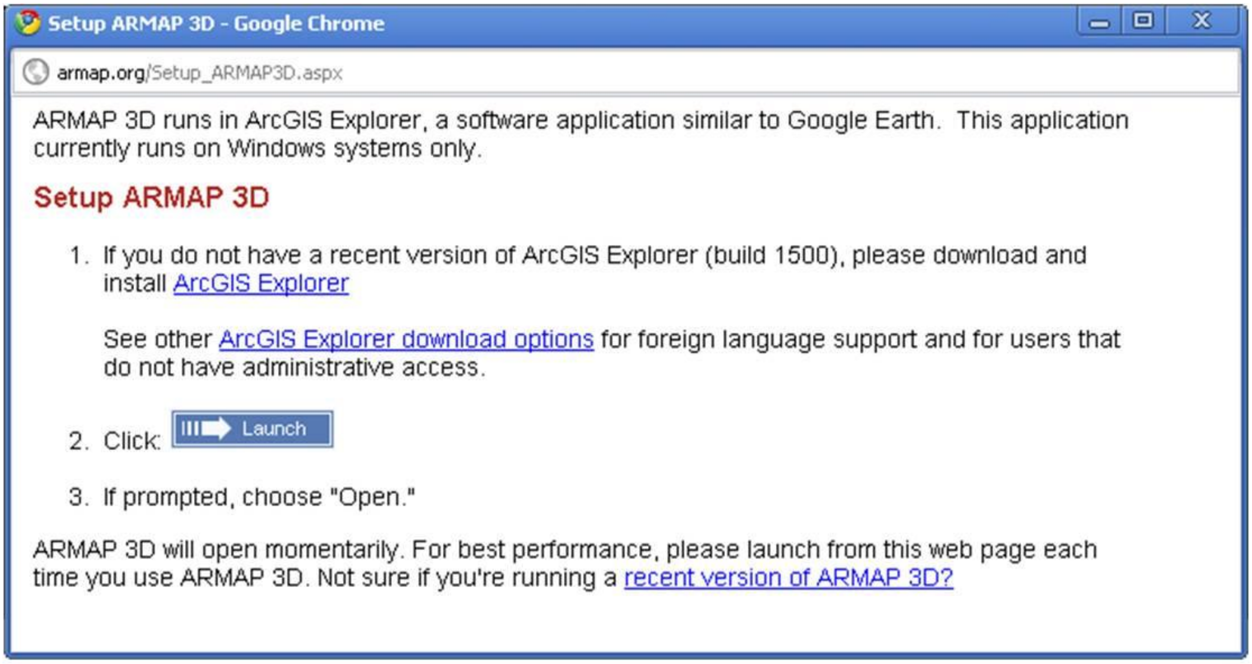



**Figure C2**

3. After installation, you can open up AGX through the start menu or by clicking the shortcut located on your desktop. In order to get the ARMAP tools and data layer, you should open the configuration file from the “Click Launch” Icon (Figure C2). You will see the following by opening the configuration file.

    a. ARMAP 3D splash screen,


**Figure C3**

    b. Overview screen,

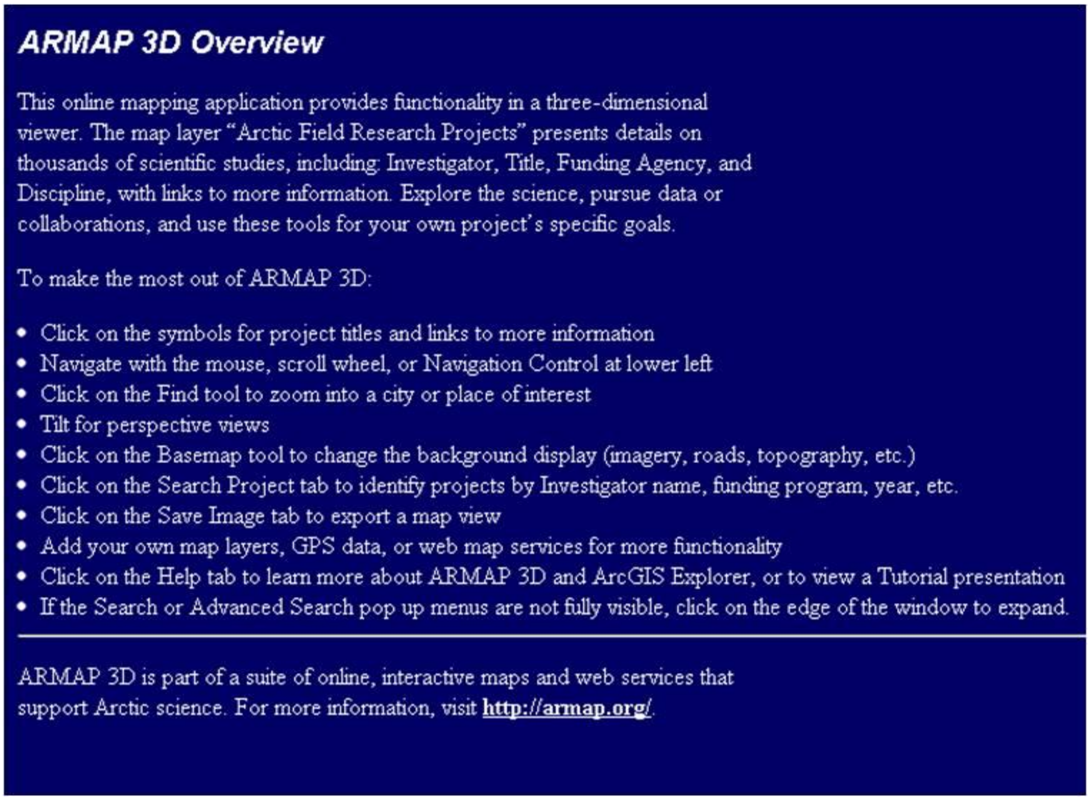



**Figure C4**

c. A pop-up asking "would you like to see a tutorial" (Fig C5). The tutorial is a short presentation and can be viewed at anytime using the help found in the ribbon toolbar.


**Figure C5**

The default ARMAP 3D view is focused on the Arctic and includes the most recent research sites layer which is linked using a KML network link file.

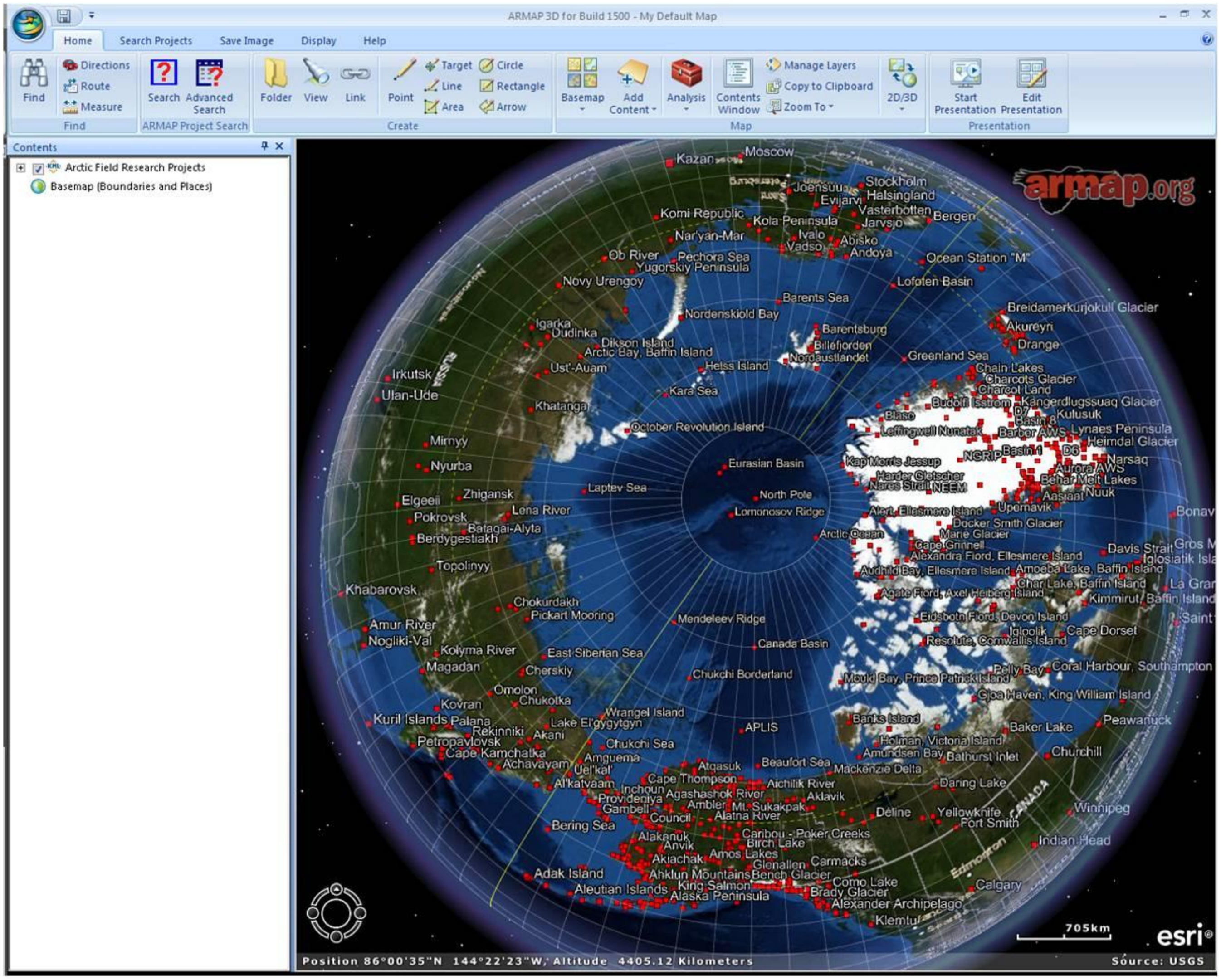



**Figure C6**

ARMAP 3D has many feature out of the box including creating points and shapes that can be attributed for descriptions of places, measuring distances, a buffer tool, a presentation feature, adding your own GIS data available from local and external sources. Custom tools include querying for project, region, or site specific information.

4. To use the customized ARMAP 3D query tools to query the ARLSS data, you have two options, 1) Search (for simple searches) and 2) Advanced Search for more complex searching.


**Figure C7**

a. In the example from the paper, a user wishes to do a search on Biology. Using the "Simple Search" tool. Entering the information to match the images below will return the Biology related research projects.

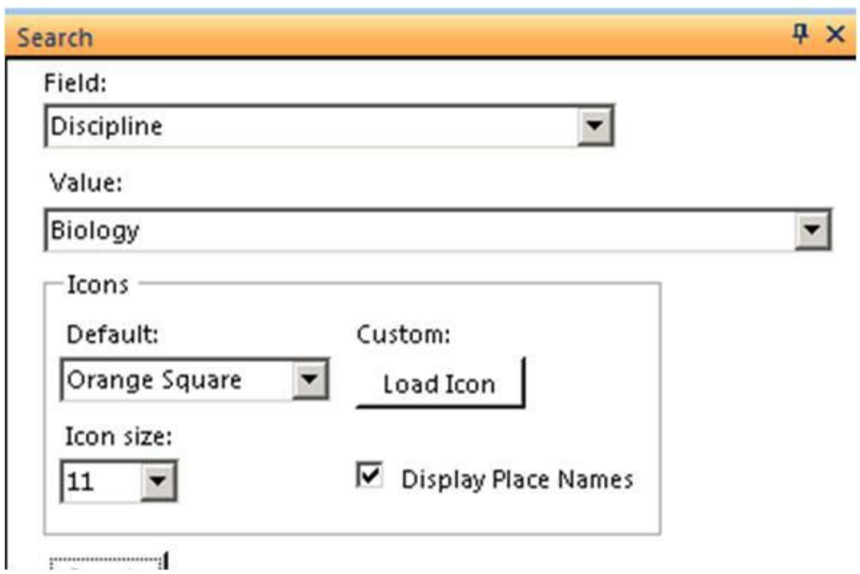



**Figure C8**

The result would look something like this:


**Figure C9**

5. ARMAP 3D allows users the ability to refine searches to make specific requests of the application.

    a. For example, if a user would like to look at research and data available in Alaska focused on Biology, they would use the “Advanced Search” tool to develop the query and using the drop down boxes within the tool to create a SQL statement for [Discipline] = "Biology" And [Region] = "Alaska".

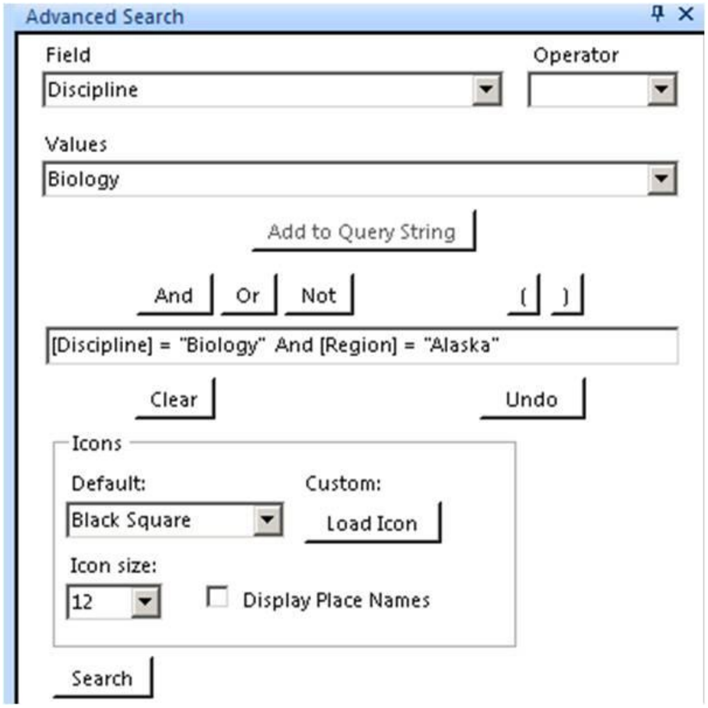



**Figure C10**

6. . Selecting the “Search” button, the user would get a result like this:

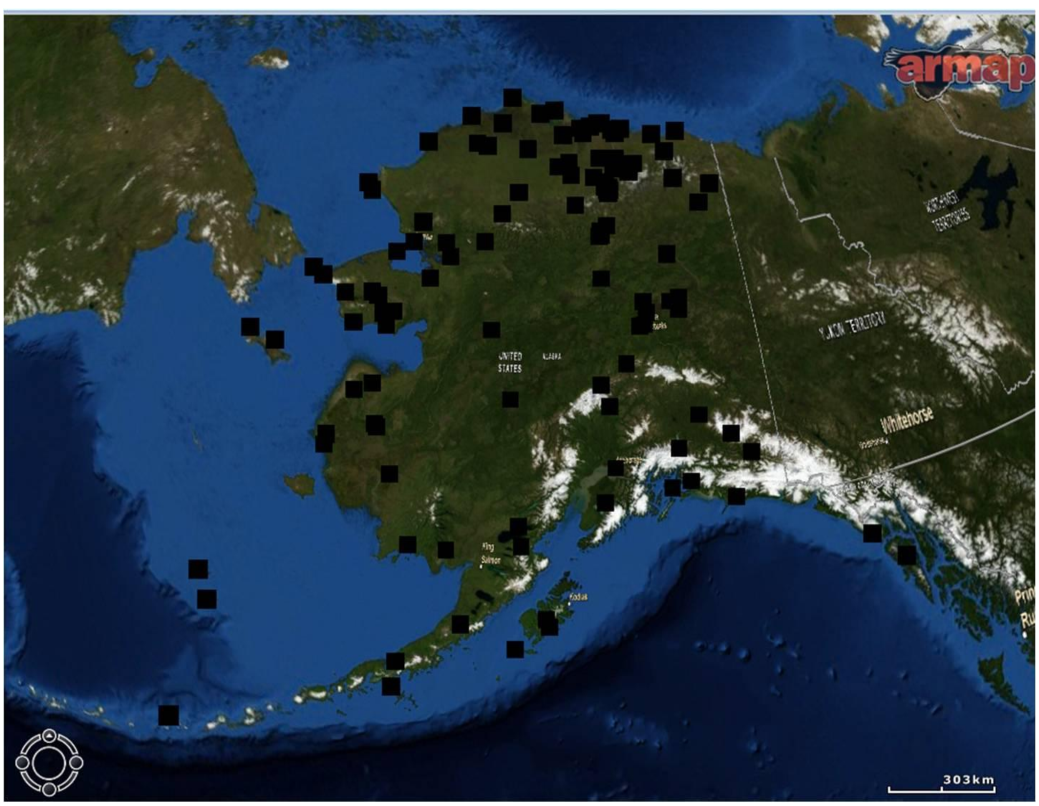



**Figure C11**

These tools query the ARLSS database directly giving access to the most up-to-date project information. Access to the information reports is obtained by clicking on one of the map features which returns a pop-up with links to the project report page.


**Figure C12**

7. You can add your own spatial data to the map.

    a. By clicking the “Add Content” button on the ribbon, you get a number of different data options to add.

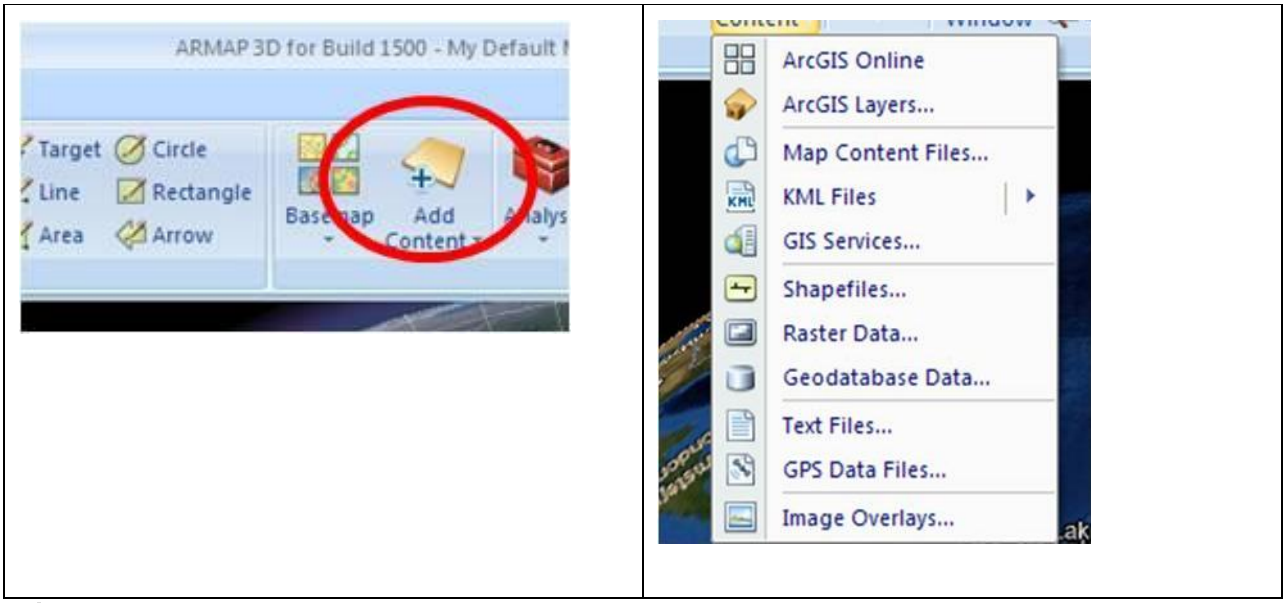



**Figure C13**

b. Selecting “Shapefiles..” allows you to browse to a folder on your machine and open up that file into the application. The shapefile can have different projections and will still be handled by AGX.

c. Selecting “GIS Services…” allows you to link into the vast amounts of ArcGIS Server, ArcIMS, WM, and GeoRSS data services by entering in a service path.

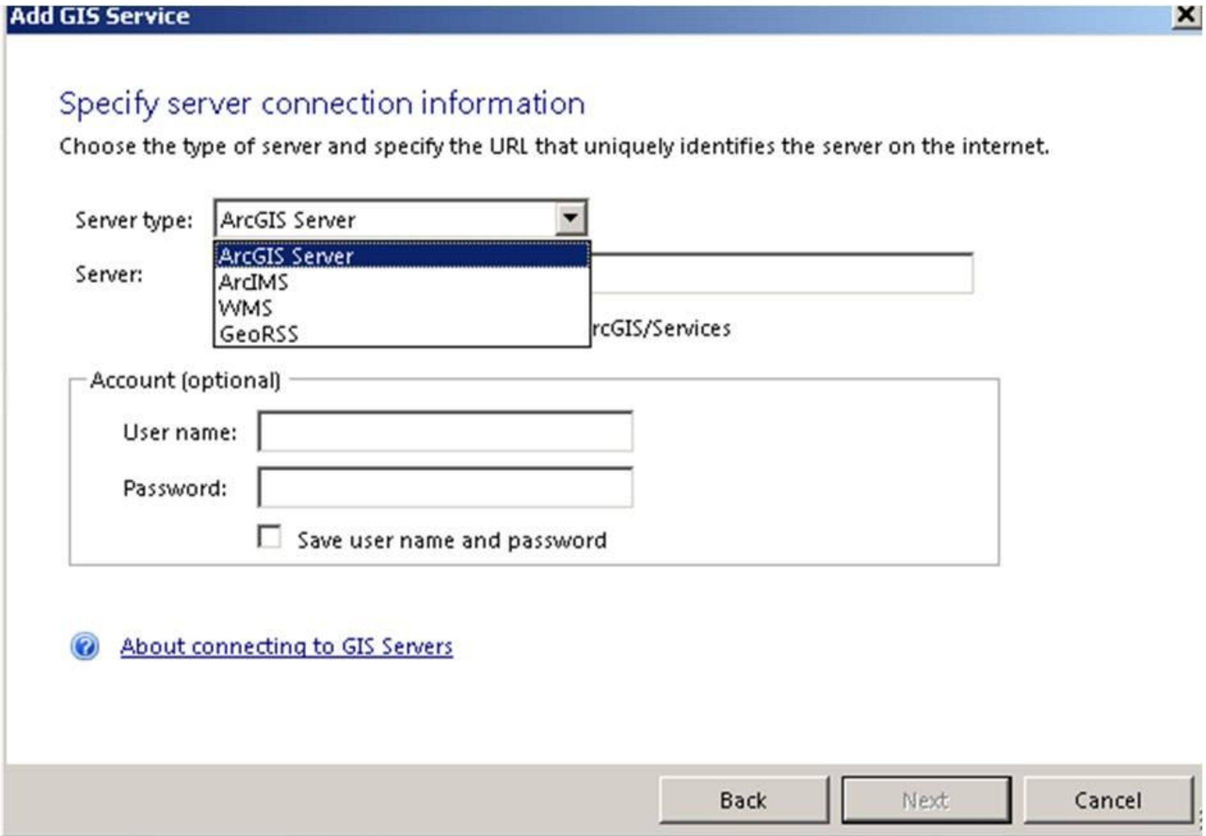



**Figure C14**

i. For example, to link into the UTEP hosted Arctic services you would select http://arcticdata.utep.edu/ArcGIS/Services


**Figure C15**

ii. Click next and should see the window below


**Figure C16**

## Curriculum Vitae

G. Walker Johnson was born in El Paso, TX. The first son of Jerry and Kathy Johnson, he graduated from Stephen F. Austin High School in El Paso, Texas, in the spring of 1995 and entered the University of Texas at El Paso in 2000. while pursuing a bachelor's degree in biological science, he participated in the Bridges to the Future Program where he gained both field and laboratory research experiences, tutored at El Paso Community college for the Biology department and the RISE to the Challenge Program where he later became the program assistant. After receiving his B.Sc., he continued as a program assistant for the RISE program and then took a position as a research technician with the University of Nevada, Reno where he assisted with the Multiple Species Habitat Conservation Plan in primarily monitoring populations of desert tortoise (Gopherus agassizii) in Nevada, California, Arizona, and Utah. During this experience, he developed a great fondness and knowledge of Geographic Information Systems (GIS) which he decided to pursue a graduate education using these techniques to promote scientific knowledge. In the fall of 2006, he entered the Graduate School at the University of Texas at El Paso. During the graduate experience, he developed and assisted in the management of numerous GIS applications, presented at a multitude of local, national, and international meetings and published a manuscript for which this thesis is based.

Through these activities, he built the capacity to think both as a scientist as-well-as a software developer giving him the foundation to manage ideas and go between the science needs and the technical development of applications. This project expanded beyond the initial development of the IMS and created much more information than he

and the ARMAP team had expected expanding to think logically about the many issues with data standards, sharing, and visualization of information in science. He hopes to continue these types of interactive learning activities beyond the completion of his thesis working with the future evolution of the both desktop and WebGIS tools to help promote the sharing of scientific data and knowledge promoting scientific discovery and decision making efforts for research. He plans to use the experience and knowledge gained throughout this thesis to promote the ideas of data sharing the use of GIS technologies for these efforts with the USDA Forest Service through his recently accepted position as a federal contractor with METI (Management & Engineering Technologies International Inc.).

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El Paso, TX 79912