UNIVERSITY OF CINCINNATI

Date: 13-Aug-2010

I, Andrew J. Rettig **,**

hereby submit this original work as part of the requirements for the degree of:

Master of Arts

in Geography

It is entitled:

An Open Geospatial Consortium Standards-based Arctic Climatology Sensor

Network Prototype

Student Signature: Andrew J. Rettig

This work and its defense approved by:

Committee Chair: Richard Beck, PhD
Richard Beck, PhD

Robert Browning South, PhD
Robert Brown, PhD

Hongxing Liu, PhD
Hongxing Liu, PhD

An Open Geospatial Consortium Standards-based Arctic Climatology Sensor Network Prototype

A thesis submitted to the

Graduate School

of the University of Cincinnati

in partial fulfillment of the

requirements for the degree of

Master of Arts

in the Department of Geography

of the College of Arts and Sciences

by

Andrew Rettig

B.S. Ohio University

June 1998

Committee Chair: Richard Beck, Ph.D.

Abstract

We have constructed a prototype Open Geospatial Consortium (OGC) standards-based Arctic Climatology Sensor Network Prototype (ACSNP) in response to recent developments in sensor technology and Internet Protocol Suite (TCP/IP) wireless communications in Barrow, Alaska for the National Science Foundation (NSF). The OGC standards enable increased, interoperability, scalability, and extensibility for geospatial information at a reduced cost. Our approach for the prototype is to integrate established technologies to create near-real-time geographic information networks (GINs). We linked a variety of meteorological and image sensors to wide area wireless networks in Barrow, Alaska. The network is a TCP/IP-based 700 Mhz WipLL network consisting of a 16 kilometer diameter local cloud as well as Iridium Open Port Units, which allow for global connectivity, at other remote research stations and on ice breakers. The Department of Energy (DOE) building in Barrow is the location of two automatically populated mirrored File Transfer Protocol (FTP) servers running Microsoft Server 2003 within a virtualized environment. High availability for the GIN is met through the use of virtualization as well as redundant power supplies and hardware-based security. The data are automatically harvested from the remote site over redundant 2XT-1 satellite links to the central data center in Cincinnati, Ohio where it is formatted to comply with the OGC database initiatives to create an OGC-compliant geodatabase within Microsoft SQL Server 2008. This cyberinfrastructure is remotely monitored 24X7 tracking network components and mission critical applications providing notification of potential capacity, connection and performance problems. The final web publication is the result of a three part system; geodatabases, web services and web applications. A data harvester is used for automating data retrieval and distribution into a geodatabase. The harvester allows for centralized control and monitoring of transfers through a browser interface and provides a comprehensive built-in scheduler and produces complete reports. A function of the database is the conversion of raw noncompliant sensor data into the standardized OGC geodatabase. For web services we use ESRI's ArcGIS Server technology for retrieval and publication utilizing ESRI's compliance with OGC web services. These web services may then be embedded within clients, such as ESRI's ArcGIS Desktop and Google Earth for analysis, and web applications. The Arctic Climatology Sensor Network Prototype is accessible at OpenSensorMap.com.

Keywords: Spatial Data Infrastructure, Geographic Information Network, Sensor Network, Open Geospatial Consortium, Climatology, Arctic

Acknowledgements

I am very grateful to Dr. Richard Beck, without his encouragement and guidance this thesis would not have been possible. I would like to thank my mentee, Chantal Ivenso, for her work on expanding and continuing my research. I would also like to thank my family and friends for their support while pursuing my Master's degree. Additionally I must mention my brother Tim and INTRUST Group as well as Brian Pick and Linoma Software for their partnerships and technical assistance on the project. Lastly, I would like to thank my colleagues, in particular Yongming Cai, Peter Kimosop, Yu Sun, Ben Thomas, Thushara Ranatunga and Kevin Magee.

Table of Contents

List of Figures

1. Introduction

In 1998, U.S. Vice President Al Gore articulated the term “Digital Earth” for the visionary concept of a virtual earth for interconnecting and georeferencing the world’s digital knowledge. Although the project was relatively eliminated in 2000 after the presidential election, this vision is still being referenced nationally and internationally. The term “Digital Earth” has continued as a rallying point for this concept. In his original California speech Al Gore said, “In the first stage, we should focus on integrating the data from multiple sources that we already have.” The ACSNP continues to work towards better interoperability, a simple idea yet a complex endeavor.

Since the visionary concept, four themes have emerged as keys to achieving the Digital Earth; Organizing Geographic Information, Geography as a Way to Organize Information, Geosensing the World, and Innovation in Supporting Technologies (Craglia et al, 2008). Geosensing the World is having sensors that are geographically referenced, receiving and measuring environmental information (Craglia et al, 2008). The ACSNP is a part of these developments. It uses standardized networks of sensors and computers streaming near-real-time.

The ACSNP is not only considered as contributing to Digital Earth, but also to Spatial Data Infrastructures (SDIs). The top down hierarchy within geospatial technology relevant to this study is Digital Earth with Spatial Data Infrastructures (SDIs) including Geographic Information Networks (GINs) comprised of Sensor Networks(SNs). SDI is the effort for creating standards for interoperability for spatial data. A GIN is a complete end to end network from the source to the final supply of information. The concept of ‘Sensor Network’ or ‘Sensor Web’ have taken on different meanings over the last couple of years. Sensor web was introduced by Delin in 1997 and later he defined it as “allows for the spatial-temporal understanding of the environment through coordinated efforts between multiple numbers and types of sensing platforms, including both orbital and terrestrial and both fixed and mobile (Delin

2002). ” However, ‘Sensor Web’ is often used to refer to sensor pods that wirelessly communicate with each other. With our project using only using TCP/IP to connect sensor information we prefer to use the term ‘Sensor Network’.

The primary tools for the development and implementation of an SDI are the Open Geospatial Consortium (OGC) client-server interface specifications and the standards adopted by the Internatinal Standards Organization (ISO)(Craglia et al, 2008). “The Open Geospatial Consortium, Inc (OGC) is an international industry consortium of 399 companies, government agencies and universities participating in a consensus process to develop publicly available interface standards. OpenGIS® Standards support interoperable solutions that "geo-enable" the Web, wireless and location-based services, and mainstream IT. The standards empower technology developers to make complex spatial information and services accessible and useful with all kinds of applications (OGC, 2010).”   The OGC was established in 1994 with its primary goal to increase interoperability of geospatial information systems through services. The development includes the establishment of the standards and the funding and partnerships to test and implement those standards. The ISO, largest developer and publisher of international standards (ISO, 2010), also contributes with standardized computer protocols enabling interoperability. The OGC and ISO are prominent contributors to standards for the continued development and sharing of technology.

The goal of the ACSNP is to create an end to end Geographic Information Network (GIN) as easily and efficiently as possible while adhering to international standards of the OGC and ISO for integration with geobrowsers.   The project was born out of necessity. Arctic research has very extreme environments to contend with creating very limited times of year for access. The sensor equipment can easily be damaged by physical contact due to the extreme temperatures and leaving the sensor alone is often a good option. Attempting to extract the hard drive or opening the sensor itself in extreme cold can break vital parts. Often times when arriving at a sensor site the sensor is found to have broken or discontinued data collection. Without external monitoring there is no way to be aware of a discontinued data feed. An Arctic near-real-time GIN mitigates these issues. The data are constantly monitored and recorded. The network verifies both the connection and the data feed. The result is up to date information and near-real-time access to data from sensors on the tundra. Additionally, the project strives to solve the problem of connecting sensors to standardized web services. Very little research has been done on this issue leaving a gap between sensor data collection and sensor architectures for web communication and publication.

2. Previous Work

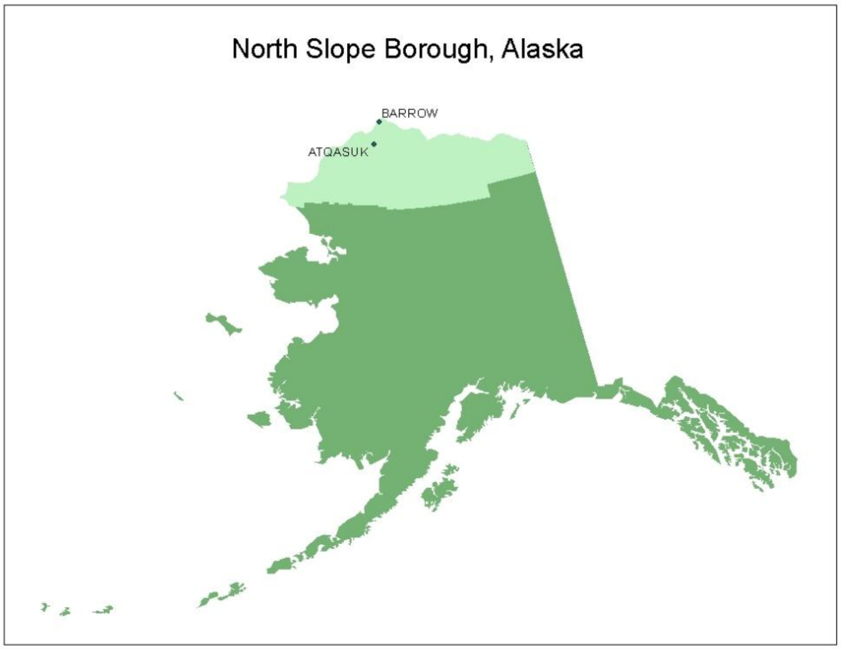
Currently, the OGC is primary the working group for testing and establishing standards for sensors to be accessible over the internet through the OGC Sensor Web Enablement (SWE). This work is in the beta phase of development. This innovation is developing technologies to push the sensor data to the web with standards to allow for automatic registration with a client. Once the sensor has been registered with a server, the user can then request the sensor data to a client browser. OGC SWE is the most likely solution for creating a global interoperable sensor network architecture. Research involving sensor web enablement primarily develops and tests the SWE initiative. Our research is in a niche quite separate of this research. The ACSNP creates a sensor network and then publishes the information with working OGC standards for an applicable network. However our work does contribute to OGC SWE. Jirka et al. 2009 states that a further work item is the integration of sensors into the SWE architecture and that this integration has not yet been specified. They suggest that a first step could be the provision of best practice guidelines of how to create this link. The ACSNP is a technical specification of creating a working sensor network to web services. Although the ACSNP's goal was not to create the link to the

SWE architecture, incorporating the automation to SWE web services could easily be automated into the network.

The ACSNP also contributes to other areas of sensor network research. Kotmaki et al. 2009 considered interfaces very important for the future of their agricultural sensor network as well as data processing. Using Go Anywhere, a data transfer program for Fortune 500 companies, our network has the data processing capabilities. In addition, our Windows-based network has incorporated undergraduate students showing user friendliness to new users. Additionally, a good example of the benefits of the ACSNP approach is with historical information. The ACSPN network is easily queried for historical information in the SQL database. However, most geosensor networks are typically deployed for real-time observations and local analysis (Winter et al., 2006). This highlights the primary problem of geosensor networks, data management (Nittel et al., 2008). For ACSPN, we utilize the market developments of data management that have been well streamlined while incorporating the geosensor at the beginning of the network for data collection.

3. Study Area

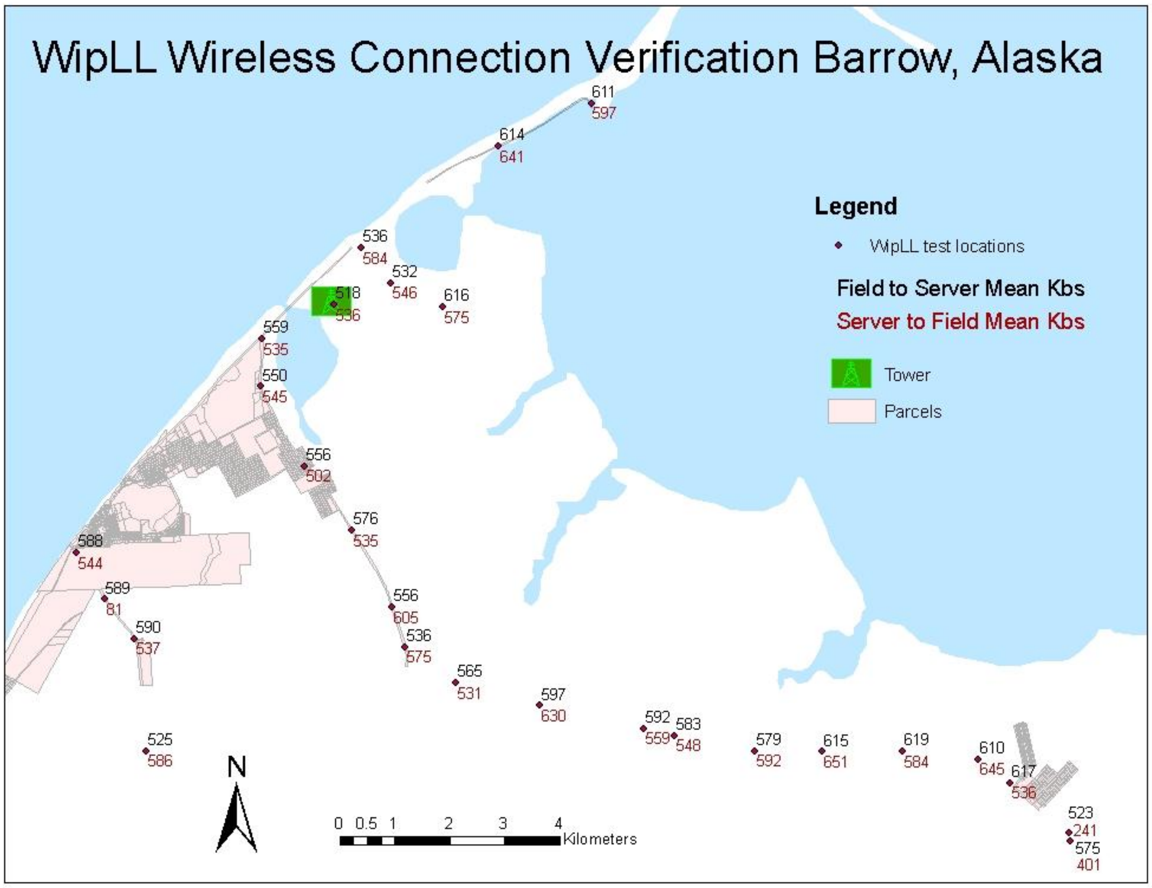
Figure 1. North Slope Borough, Alaska



The ACSNP is located in Barrow, Alaska the northern-most settlement on the continent of North America. Three miles north of Barrow is the northern most point on the continent that the locals call 'Top of the World.' 4,000 people live in Barrow, Alaska. In March 2010, The Smithsonian Magazine published an article titled, "Barrow, Alaska: Ground Zero for Climate Change". The city of Barrow is the location of our ACSNP Servers. Within the city of Barrow is a 700 MHz tower at a building owned by the Department of Energy (DOE). The tower has a cloud radius of 16 kilometers for wireless bandwidth which encompasses the surrounding infrastructure associated with Barrow. The network is a TCP/IP-based 700 MHz WipLL (wireless broadband) network augmented with Iridium Open Port Units, that allow for global connectivity, at remote research stations and on ice breakers.

At the National Science Foundation's (NSF) direction, we installed a 700 MHz WipLL system on the 27th of August of 2008. Initial range tests indicated that the system range exceeds NSF's range requirement of 16 kilometers both at the far end of the most distant road (Barrow has no roads to other communities) and on a USCG buoy tender that was able to connect even several kilometers farther. A map of data throughput experiment values for the WipLL system is shown in Figure 2.

Figure 2. Map of WipLL throughput results



The Barrow area WipLL cloud was augmented with the Low-Earth-Orbit (LEO) satellite Iridium Open Port System. In 2008, the Iridium system released a new per megabyte, always on, Internet-based communications system that communicates at 32kbs in economy mode. We purchased six systems for the NSF ice breakers and two for isolated tundra experiments. The new system is designed specifically for marine use (NSF's icebreakers) but may also be used on land. Its bandwidth is greater than the old Iridium systems and is "always on" making it more suitable for near-real-time sensors on the tundra. Iridium is the only complete global commercial satellite constellation. The only current limitation with sensor locations is the power source. As this is the Arctic, solar is not a viable option during the winter. We have tested solar and wind power for Arctic use and the sensors did turn themselves back on as the sun came back up in the spring. Year round operation will require larger and more efficient battery banks. Meanwhile, our current setups for the prototype are in locations with constant power sources.

Figure 3. Email attachment transmitted from our new Iridium data unit Teshekpuk, Alaska April 18, 2009.

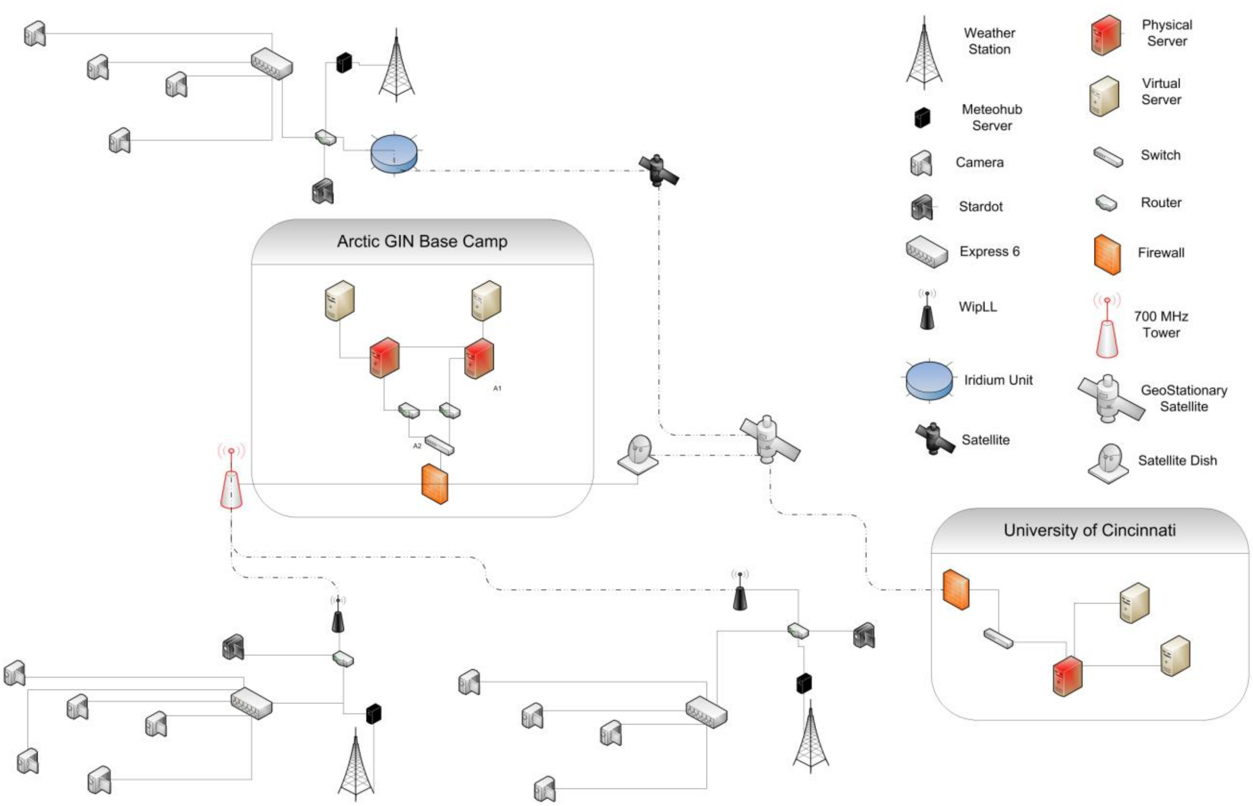
4. Sensors

Sensor technologies are converging to facilitate the construction of GINs with sensor networks. There are numerous reasons to develop sensor networks. These include sensor technology developments, information technology innovations, standardization and advances in client software programs.   A 2008 wireless sensor network survey stated “Recent developments in the miniaturization of electronics and wireless communication technology will enhance the opportunities of sensor networks for real-time monitoring of the natural environment (Yick et al, 2008)." Additionally the availability of various clients for visualization including Google Earth, Bing Maps, ArcExplorer are energizing the market with new API's and clever mash-ups. Nath recently stated "We envision a new class of application that relies on real-time sensor data and its mash-up with the geocentric Web to provide instantaneous environmental visibility and timely decision support (Nath et al, 2007)." Nath went on to isolate the most difficult challenge facing the construction of sensor networks, "Existing applications are mutually incompatible." Nath echoes the sentiment of Al Gore and interoperability.

The ACSNP strived to find sensors that would both survive Arctic conditions and contribute to an idealistic interoperability. The ACSNP has both meteorology sensors and cameras. The meteorology sensor is the Davis Vantage Pro II. The Davis Vantage Pro II meteorological stations have been installed in three locations within the 16 km radius around Barrow and send data to our servers at the U.S. Department of Energy (DOE) site in Barrow. The Davis is a complete meteorological station encompassing the following sensors; rain collector, temperature, humidity, anemometer, solar radiation and UV sensors. This is a commercial stationary sensor that is very affordable and with a Meteohub connection to the internet will generate an XML FTP feed. XML (Extensible Markup Language) is a set of rules for encoding documents electronically. Any sensor with the ability to generate an XML feed can be incorporated into the network.

Twenty cameras have been installed in Barrow and are able to stream data over the WipLL system. There are five Q-See QSDS148DH Weatherproof CCD Cameras with heaters and blowers at each of our three test sites. The basic CCD cameras are connected to Express 6 video servers. The Express 6 is a video server for viewing up to six cameras over the internet and sending camera images via FTP (Stardot, 2010). The Stardot netcam XL is also installed at each of the sites. The Stardot is a standalone network camera with a built in web server, email and FTP client. The Stardot also has the ability to record and stream meteorological data. The test sites also have a web cam mounted inside for additional information recording. Cameras have also been mounted at Teshekpuk and Atqasuk. These remote cameras include the basic CCD cameras, Stardot and webcams. However, the images from these sites are either collected locally on a storage device or transferred via FTP by the Iridium unit. For all the cameras, we have incorporated the images into a folder filing system and web server for image geoinformatics providing near-real-time imagery. The network flow diagram shown in Figure 4 shows how we provide for end to end GIN connectivity with the current *in situ* sensor setups. All of the Arctic sensors have survived at least one winter and we are continuing to explore using cheaper commercial sensors to increase the number of sensors and to reduce costs.

Figure 4. ACSNP Network Diagram



The ACSNP is part of a rapidly growing sensor effort. The use of geospatially referenced sensors is expanding with the advances in technology. Current discussion revolves around a 'data explosion' due to the increase in geospatial sensor data. Google Vice President Marissa Mayer presented a talk titled 'The Physics of Data' in August 2009 at Xerox PARC. She cited three main changes to the Internet lately that are having an effect on data:

1. Speed (real-time data);
2. Scale ("unprecedented processing power");
3. Sensors ("new kinds of data").

The estimates on the amount of data from these sensors are varied and exuberant but one thing is clear, the need for interoperability is paramount as is the need for geographic information networks.

5. Design

The ACSNP transfers data from Arctic weather stations and cameras to Cincinnati for OGC standardization, visualization, analysis and publication. The ACSNP initially was five parts; TCP/IP, Microsoft Windows, File Transfer Protocol, ESRI ArcGIS Server and SQL Server. To complete the network we partnered with two established companies, INTRUST Group Inc., an Information Technology (IT) company from Blue Ash, Ohio and Linoma Software, a provider of innovative software for data movement. These partnerships provided us with the resources and expertise to quickly implement our ACSNP. INTRUST Group advised us on current computer hardware and introduced the Avance platform from Stratus Technologies for remote server mirroring and virtualization. Linoma Software gave us the necessary software for automating data movement. These partnerships have also assisted with the network monitoring and are continuing to prove fruitful with expanding image geoinformatics.

Virtualization

For our Arctic Servers we setup a virtual high availability server. Virtualization, the creation of virtual computers rather than actual, began making resurgence after the turn of the 20^{th} century as modern computers were powerful enough to use virtualization to present many smaller virtual machines (VMs) each running a separate operating system instance (Barham 2003). There are many benefits to virtualization including keeping server applications isolated for stability purposes, and the overconsumption of space, electric, and cooling due to numerous poorly utilized servers. Virtualization also accommodates the newer more powerful servers as well as assisting with common IT tasks such as backups and upgrades. Stratus Technologies Avance software launched in 2009 was chosen to host our Arctic VMs. "Avance software creates a high-availability computing platform using two commodity servers to protect your applications against downtime and data loss. In production, Avance automatically synchronizes the two servers in real-time to ensure data integrity. In case of a fault on one server, your applications keep running on the healthy server without any manual intervention, performance degradation, or business interruption (Stratus Technologies, 2010)." Avance was the ideal solution considering our Arctic server is in a remote location in Barrow, Alaska needing to operate for large portions of the year with no IT support. In Cincinnati, Citrix Xenserver was chosen to host our VMs because its free version provided all the functionality for our needs. The virtualization in Cincinnati accommodated various testing platforms, provided additional backup options, and allowed for the creation of a staging server.

Network Monitoring

To monitor the ACSNP and ensure reliability the newest technologies were incorporated. Browser based network monitoring applications have been setup. Every IP connection to the ACSNP is monitored for connectivity, isolating connectivity to seconds. Alerting emails or text messages can be sent if any status is altered. Reports may be run or scheduled recording all of the history of the network connectivity. Our Avance console monitors every aspect of the mirrored server including not only the VMs but all the individual components of the physical server such as drives, power supplies, processors, and fans. Avance has the functionality to utilize individual parts from two different damaged physical servers to operate as one functional server. Lastly, GoAnywhere from Linoma has logs of every transaction through its centralized management center. The GoAnywhere dash board has information on all data transfers allowing the user to see the data migration in charts and tables. With this monitoring, our near-real-time Arctic information is assured delivery.

Data Transfer

Automation is needed for near-real-time information data transfer and integration. For ACSNP, Go Anywhere Director from Linoma Software streamlines and manages data movement through an innovative centralized approach. It allows your organization to connect to almost any system (internal or external) and securely exchange data using a wide variety of standard protocols (Linoma, 2010). The GoAnywhere automates FTP processes compensating for connectivity issues. The automation involves parsing the XML data from the sensors into a Relational Database Management System (RDMS). With this solution data processing is monitored through web dashboards and additional sensors are easily incorporated. In addition, GoAnywhere calls stored procedures within SQL server that are written to normalize the data for the OGC database.

Database

For our database, we used Microsoft SQL Server 2008. Microsoft is the primary database partner with ESRI, with SQL Server as the default setup. We use ESRI software as both our GIS system and web services publisher, both of which influenced our database decision. ESRI ArcSDE is used for the business logic layer. ArcSDE manages spatial data in a relational database management system (RDBMS) and enables it to be accessed by ArcGIS clients (ESRI, 2010). SQL Server 2008 is enabled of Geometry and Geography spatial data types. Both Geometry and Geography spatial data types are compatable with ESRI ArcSDE. For this project the Geometry data type was utilized for its compliance with OGC standards. Additional benefits of using a spatial data type include spatial queries, analysis and visualization independent of ArcSDE and of ESRI products may be implemented. This enhanced interoperablitity allows for increased innovatition and greater user access to the Arctic climate information.

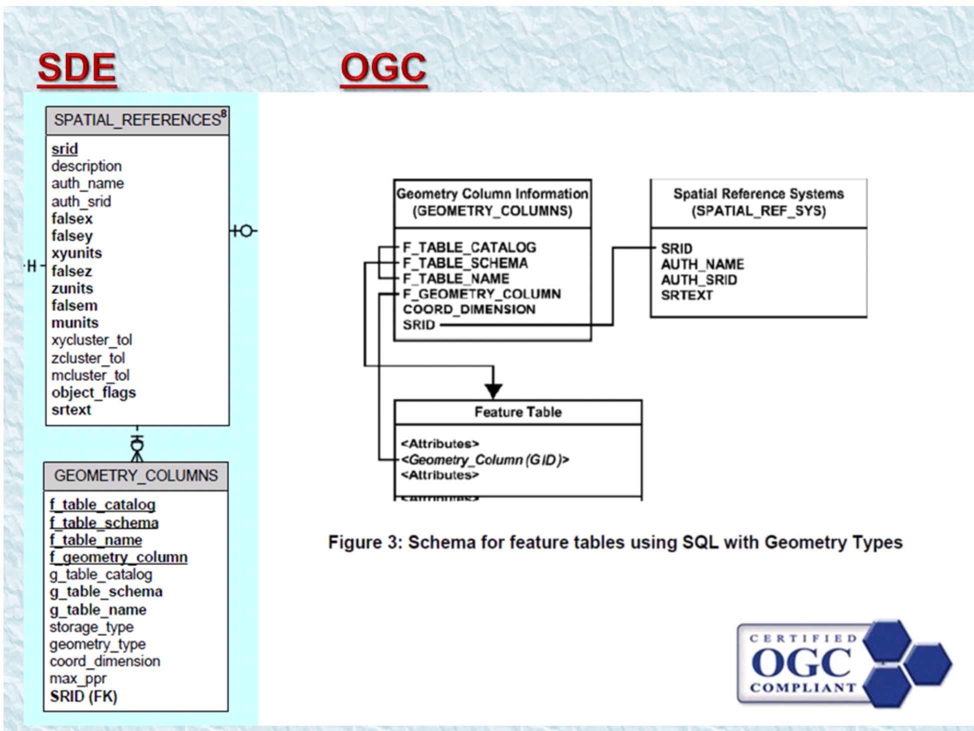
In SQL, three tables are created for sensor data; GA, Weather, and Weather_History. The GA table (See Appendix) is created by the data transfer program, Go Anywhere, to receive the parsed information from each XML file from the sensor. The parsing and table information is defined within the data transfer program. The GA table is truncated after each XML file is both parsed and normalized into the database.

The second table is Weather (See Appendix). The Weather table is created within ArcSDE to receive the current sensor data. The Weather table is used for near-real-time data display storing only the current sensor information. The more records there are in a table the more time it takes to query the table for information. Near-real-time Information for optimal retrieval should not be kept with history information. All of the 'actual' (most recent) information from the Davis Vantage Pro 2 is kept within the Weather table. Since, the Davis is a complete meteorological station encompassing six sensors creating a table for each sensor was considered, however, we concluded that the benfits of that level of normalization are minimal.

The third table is Weather_History (See Appendix). As the current information is updating the Weather Table, a new record is inserted in the Weather_History as well. This table provides all of the history information for the meteorological station. As different types of sensors are added, a current information table and history table will be added for each sensor.

For the spatial data, a feature class was created with the Geometry spatial type. This table is created within ArcSDE. ESRI ArcSDE is compliant with the OGC Feature Class Part II SQL Option, ArcSDE creates the OGC compliant tables wihin SQL with the creation of the sensor feature class. In 2006, the OGC adopted the Feature Class SQL Option as the standard for storing feature class information. Figure 7 shows the ArcSDE tables created that correspond to the OGC standardized tables.

Figure 5. ArcSDE tables and OGC standards comparison

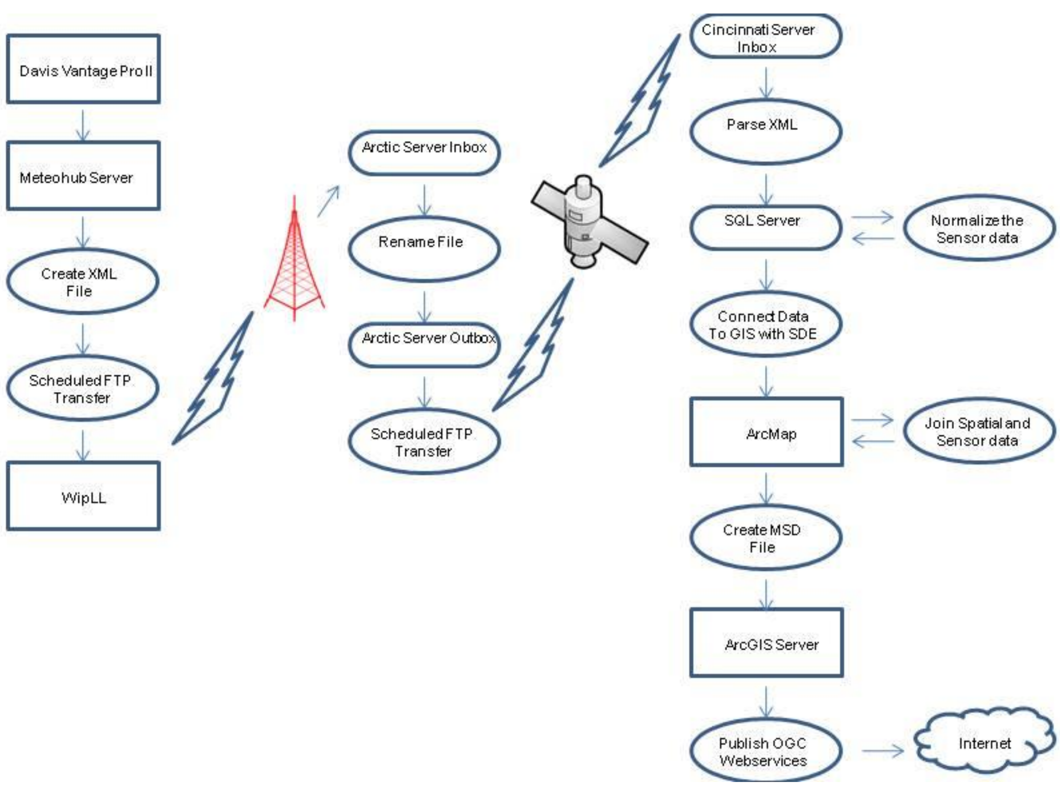


The Geometry_Columns table and Spatial_Ref_Sys table are created automatically within SDE. It is important to note that SQL has two different spatial types, Geography and Geometry. The Geography spatial type is the default yet it has less functionality and also is not OGC compliant. However ArcSDE can be configured to make Geometry the default spatial type. In regards to the sensor information, there are no OGC standards in regards to the sensor data tables.   The standards define the data format but database storage is not discussed. Our research has developpved methods for effective storage methods for relational databases with the Weather and Weather History tables via stored procedures. We plan to continue to develope the database schema to incorporate a wider variety of sensors.

Data Fow

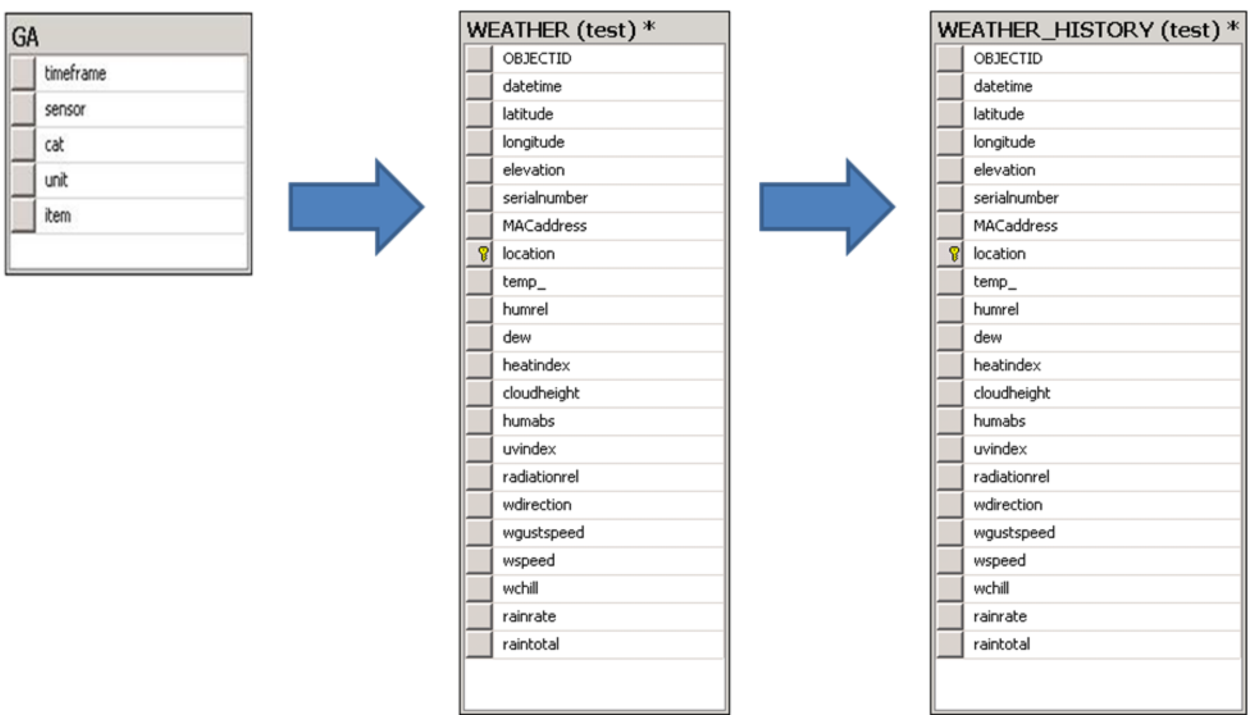
Establishing a near-real-time data flow from the Arctic presented numerous challenges. The first challenge was connectivity of the Arctic sensors to the Arctic Server in Barrow. This was overcome with the use of the WipLL (wireless broadband) radio transmitters. The WipLL system, often used in the Prudhoe Bay area for connectivity, included a router, battery backup, radio and antenna to transfer the sensor data over 700Mhz radio waves. Our data flow example will be the Davis Vantage Pro II meteorological station.   The data from the Davis Vantage Pro II is first converted to an XML file and then transferred via File Transfer Protocol (FTP) with the WipLL to an intermediary Arctic server located in Barrow, Alaska.

Figure 6. Data Flow Diagram of the Davis Vantage Pro II



Upon arrival at the intermediate servers in Barrow, the data are renamed with a unique key comprised of the sensor date and time for historical logging. Every three minutes our data transfer program in Cincinnati checks the FTP folder for new data arrival, grabs any new data and transfers it from the FTP folder into the Cincinnati Server Inbox in Cincinnati, Ohio. Once the data are in Cincinnati the XML file is parsed into SQL Server. The data parsed in SQL Server in Cincinnati is not yet normalized. Normalization is the process of organizing data in a database including making the tables and establishing relationships between those tables according to a set of rules. The rules protect the data while eliminating redundant and inconsistent data (Microsoft, 2007). After the parsing, stored procedures are automatically called to normalize the data and to write them into a new OGC compliant database as well as log the previous data to history.

Figure 7. Normalization in SQL Server



Data tables are created to successfully normalize the sensor data. Generally the non-spatial table would be created directly within SQL Server. However, only certain data field types and lengths from SQL Server are compatable with ArcSDE (See Appendix). Therefore for ensured compatibility, the tables are created within ArcSDE which creates and populates the SQL tables automatically. Having ArcSDE create the SQL tables protects data integrity. The user does lose some data flexibility, however the only disadvantage is some wasted byte space with large numerical fields. With data tables created with numeric, nvarchar and datetime fields the data is efficiently stored for querying both current and historical information.

With adequate database table setup, the data transfer program can call stored procedures to update the information in the Weather table and insert the record into the history table. Microsoft defines stored procedures as a group of Transact-SQL statements compiled into a single execution plan. Transact-SQL is the programming language used to communicate with SQL Server. Figure 8 is an example of a simplified stored procedure in SQL Server for normalizing and inserting a record into the Weather_History table (Figure 8).

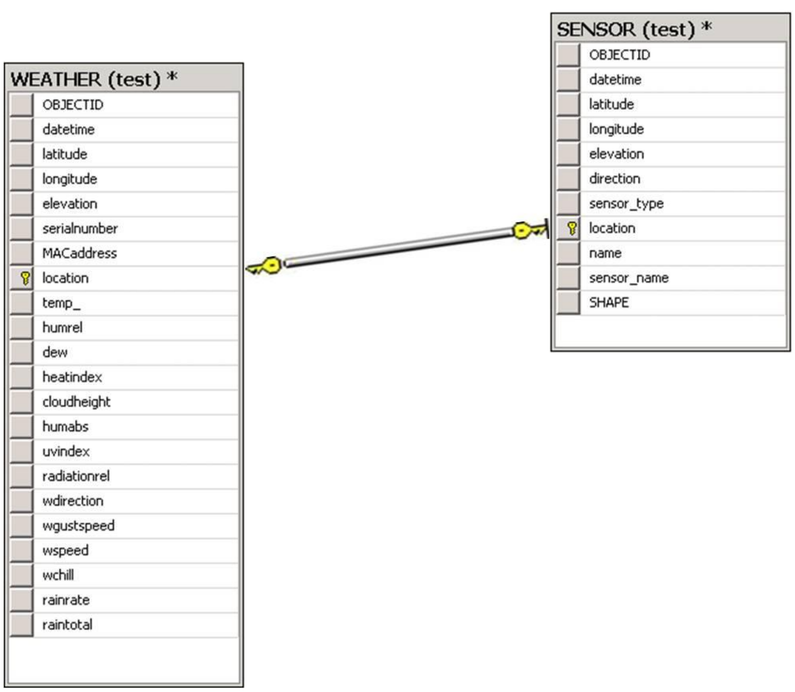
Figure 8. Stored Procedure Simplified Example of Normalizing Data into the Weather_History table

```
INSERT INTO dbo.Weather_History
(date,time, latitude)
SELECT A.item, B.item, C.item
FROM dbo.GA A
Cross join dbo.GA B
cross join dbo.GA C

WHERE (A.timeframe = 'actual' and A.sensor = 'date0' and A.cat =
'puredate' and A.unit = 'utc')
AND (B.timeframe = 'actual' and B.sensor = 'date0' and B.cat = 'time'
and B.unit = 'utc')
And (C.timeframe = 'actual' and C.sensor = 'station' and C.cat =
'latitude' and C.unit = 'decimal')
GO
```

Once the sensor data have been normalized within SQL Server, the next step to establish a geographic information network is to create a spatial data relationship. In the previous step, the data is not only normalized by the stored procedure but unique keys are also created. A unique key uniquely identifies the sensor record populating the Weather table corresponding to the sensor spatial location in the sensor feature class table. For our prototype, sensors are often replaced; therefore the serial numbers or MAC addresses are not viable unique keys for sensors. Latitude, longitude, and elevation were used to create the unique key. (A direction and sensor type field will be added to the Sensor Spatial table for the future inclusion of other sensors to the ACSNP) However, location is not a unique key for a mobile network. Mobile networks would incorporate Universally Unique Identifiers (UUIDs). A live GPS could be used for mobile sensors however development has not yet been done on this functionality for the ACSNP. With the Davis sensors it is possible to hard code in some of the data being sent. The latitude, longitude and elevation are hard coded so that every file sends the unique key for linking to the spatial data. Although, a new replacement sensor can be distinguished by the serial number or MAC address to test data integrity. Using these unique keys a one-to-one inner join relationship is created between the sensor data and spatial data to spatially locate and display the sensor information. The one-to-one inner join ensures that only one sensor data record will match with one spatial location.

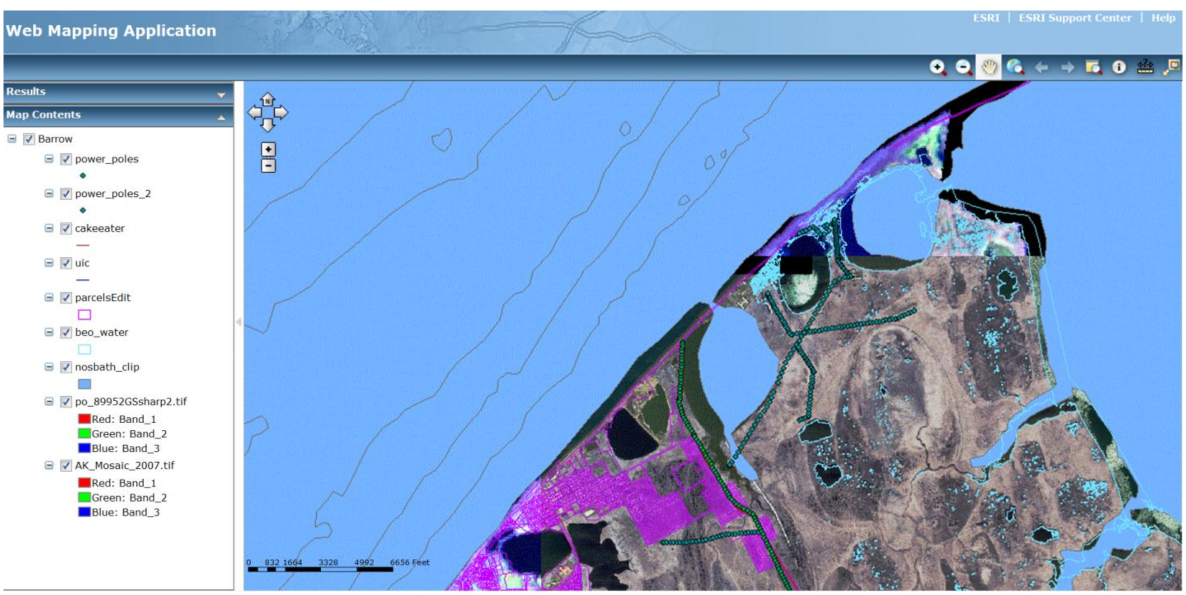
Figure 9. Non-Spatial and Spatial Data Relationship



Visualization

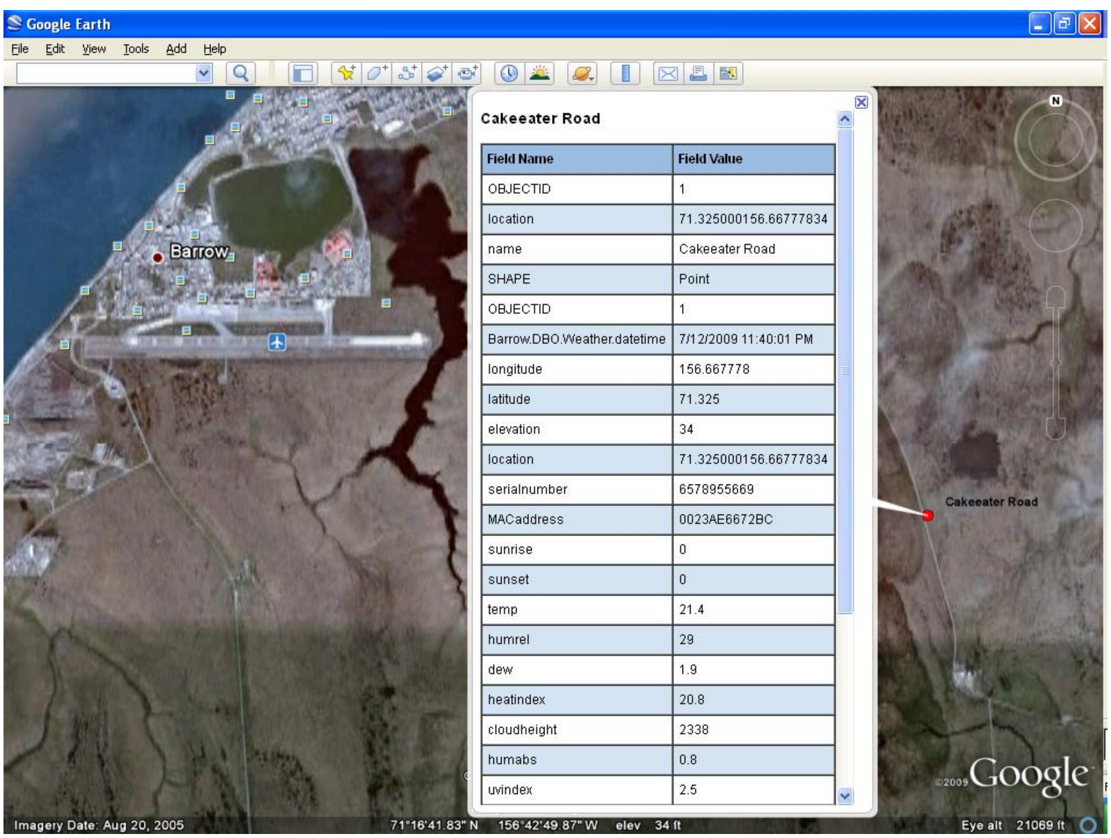
Once the spatial and non spatial data are successfully within SQL via ArcSDE, a MSD is created to publish the data through a map web service. ESRI's GIS program is ArcGIS. A MSD document is the extension of the saved map document in ArcGIS for optimizing map documents for map web services. The inner join of the sensor and spatial data is created in the MSD. The join is established by the unique IDs based on location created in the database. With the established join in the MSD as the sensor data is updated by the stored procedures the corresponding web service will instantly update the information. (An alternate solution for establishing a join is creating a more permanent join in Arc Catalogue, with the ArcSDE user interface.) Near-real-time data are available through automatic updates of SQL Server. As the SQL database is updated with weather data from the Arctic, the webservices update as well.

Figure 10. Sensor Web Mapping Application



Once sensors have been networked and their data both recorded and normalized, they must be made accessible to users. We use web mapping technology in the form of OGC compliant Web Services to search, retrieve and visualize the OGC format database. For web services, ESRI's ArcGIS Server technology is used for retrieval and publication. These web services may then be embedded within various web application or clients such as ESRI's ArcGIS Desktop, ArcGIS Explorer, and Google Earth for analysis. For this prototype we use both a real-time WebGIS based on ESRI's ArcGIS Server technology for retrieval and visualization and a KML feeds to demonstrate interoperability. For the KML feed example, ArcGIS Server can generate KML files for Google Earth. KML, an OGC standard, has become the defacto standard for globe visualization and an early realization of the visionary concept of Digital Earth. ACSNP also contributes to Common Operation Picture (COP). Government and business will often request a COP approach for spatial data an approach were the client is able to display all of the data. Ultimately, the goal of a COP is making the data easily accessible to the users.

Figure 11. Sensor KML displayed in Google Earth



6. ACSNP Benefits

International Standards

The primary standard for the network is TCP/IP that is the set of communication protocols for the internet. This was the obvious choice, being the mostly widely used communication protocol. In addition, the network is using the File Transfer Protocol Technology (FTP). FTP is the standard protocol for transferring files from one machine to another over the TCP/IP network. Adding a sensor is as easy as having a user FTP an XML to our server for inclusion. Standardized setups are created for individual sensors so that the business logic can ingest the registered sensor. The network database is utilizing the OGC Feature Class SQL Option Part 2 for the implementation. Geodata services can be offered allowing others to access this standardized database. Of course the web services are standardized as well with KML as the featured service. Other standardized OGC web services offered by ArcGIS Server on the network seen in Figure 12 are; Web Map Services (WMS) for map images, Web Feature Services (WFS) for vector features and Web Coverage Services (WCS) for raster coverages. All of standards in the network allow for a more cost efficient cookie cutter approach that encourages the sharing of technology.

Figure 12. ArcGIS Server Web Services and Standards Table

	WMS	WFS	WCS
Map services	X	X	X
Geodata services		X	X
Image services	X		X

(ESRI, 2010)

Extensibility and Scalability

Due to its use of current technology and international standards the ACSNP is very scalable. Each of the components to the network can be modified to add additional sensors. This functionality has already been tested with our prototype, data and imagery have be added from a Lake Erie Aerostat project utilizing the data transfer program, windows servers and ArcGIS Server software. The ability to stream this live information from an Aerostat to web services and OGC clients has just been implemented. Ultimately, any third party sensor can be added that generate XML or image files. The XML or image files can be easily added by registration with the data transfer program. The only programming required is creating the stored procedure in SQL with T-SQL to account for the XML file produced by the new sensor type. The sensor XML setup is documented and then used if additional sensors of that type are incorporated to create identical XML file setups.

Interoperability

In Marriam-Webster Dictionary interoperability is defined as the ability of a system to work with or use the parts or equipment of another system. The ACSNP is interoperable both with its OGC standards and web services but also with its cross platform software utilization. The ACSNP uses Microsoft Windows as the primary operating system used for data capture, storage, retrieval and publication. The academic environment in the United States primarily relies upon Microsoft. Worldwide, Windows owns over 91% of the Operating System (OS) market according to NetApplications June 2010 (NetApplications is a primary company for tracking browser and OS market shares.). The familiar software environment has resulted in student assistants who are able to contribute to the network very easily and professors who are encouraged by the involvement of new users. However, the ACSNP does have interoperability with its ability to include Linux. Linux is an open source operating system more commonly used for GINs. Linux can be installed on a virtual machine if needed for expansion purposes. The data transfer program can work with Linux as well. The ACSNP could easily connect the two operating systems together with a simple data transfer between them. This interoperability is also important because possible expansion of the network will include Delay Tolerant Networking (DTN/IP). If DTN is included, a Linux virtual machine will be installed as a storage point for sensor data until it is transferred into our SQL Server database. It is important to have interoperability at both the infrastructure layer and the web services layer. Interoperability continues to increase innovatition and greater user access of the Arctic climate information.

7. Conclusion

The ACSNP is an elegant solution to an end to end geographic information network. Our original sensors in the Arctic had no infrastructure for automating the movement of data from the Arctic location to usable sensor information. For translating information a reliable network for the movement and processing of *in situ* commercial sensors was needed for Arctic climate research. Adhering to OGC standards and storing the data was essential. The network also needed to publish the data to the web in a timely manner. The ACSNP can easily be altered at the server level to automate web services to incorporate the SWE initiatives. With the automation of web services for SWE this research is a viable contribution to the gap in linking sensors and sensor networks with SWE initiatives.

However, even though the OGC SWE has made enormous strides, a common sensor network architecture in the near future is not likely (Jabeur et al., 2009). Until that time an applicable scalable extensible and interoperable cockie cutter method for creating sensor networks is essential. The ACSNP is that cookie cutter solution. This Windows-based network is a practical and applicable solution utilizing OGC standards with database storage and web services to provide near-real-time information. Through the use of standards and the adaptation of current technologies we have enhanced the extensibility and scalability of sensor network based GINs. The incorporation of the Windows operating system and browser based user interfaces supports previous works citing the need for better user interaction. This network also provides a test bed for evolving database setups, for sensor technologies, web services and applications. A higher level archetecture for the sensor and spatial data can begin to be established. The network can easily be reproduced and applied as a commercial product. The ACSNP can be implemented in any established academic or business entity. The project encourages the sharing of data via a standardized database. The standardized web services can easily be incorporated into a COP. The ACSNP application and web services can easily be found at OpenSensorMap.com.

Bibliography

Botts, M., Percivall, G., Reed, C. and Davidson, J. (2006). OGC White Paper – OGC Sensor Web Enablement: Overview and High Level Architecture, OGC 06-046r2, Wayland, MA, USA: OGC.

Chen, N., Di, L., Yu, G., Gong, J., and Wei, Y. (2009). Use of ebRIM-based CSW with sensor observation services for registry and discovery of remote-sensing observations. Computers & Geosciences, 35(2): 360-372.

Conover, H., Berthiau, G., Botts, M., Goodman, M. H., Li, X., Lu, Y., Maskey, M., Regner, K., and Zavodsky, B. (2010). Using sensor web protocols for environmental data acquisition and management. Ecological Informatics, 5(1): 32-41.

Craglia, M., Goodchild, M., Annoni, A., Camara, G., Gould, M., Kuhn, W., Mark, D., Masser, I., Maguire, D., Liang, S. and Parsons, E. (2008). Next-Generation Digital Earth, International Journal of Spatial Data Infrastructures Research, 3: 146-167.

Delin, K. (2002) The Sensor Web: A macro-instrument for coordinated sensing, Sensors, 2(7): 270-285.

Delin, K., Jackson, S., Johnson, D., Burleigh. S., Woodrow, R., McAuley, J., Dohm, J., Ip, F., Ferré, T., Rucker, D. and Baker, V. (2005) Environmental studies with the sensor web: Principles and practice, Sensors, 5(1-2): 103-117.

Dragovic, B. (2003) Xen and the art of virtualization, ACM SIGOPS Operating Systems Review, 37(5): 164-177.

ESRI (2010), OGC Support in ArcGIS Server 9.3, http://webhelp.esri.com/arcgisserver/9.3/java/index.htm#working_with_gis_svr.htm, last access: 08/08/2010

Herring, J. (2006) OGC Standard – OpenGIS Implementation Specification for Geographic information - Simple feature access - Part 2: SQL option, OGC 06-104r3, Wayland, MA, USA: OGC.

Iridium http://iridium.com/, last access: 07/29/2010.

Jirka, S., Bröring, A. and Stasch, C. (2009). Applying OGC Sensor Web Enablement to Risk Monitoring and Disaster Management. GSDI 11 World Conference, Rotterdam, Netherlands

Kiehle, C. (2006). Business logic for geoprocessing of distributed geodata. Computers and Geosciences, 32(10): 1746-1757.

Kotamäki, N., Thessler, S., Koskiaho, J., Hannukkala, A.O., Huitu, H., Huttula, T., Haventon, J. and Järvenpää, M. (2009). Wireless in-situ sensor network for agriculture and water monitoring on a river basin scale in Southern Finland: evaluation from a data users perspective. Sensors, 4(9): 2862-2883.

Liang, S., Croitoru, A. and Tao, C. (2005). A distributed geospatial infrastructure for Sensor Web. Computers & Geosciences, 31(2): 221-231.

Linoma Software http://linoma.com/, last access: 07/29/2010.

Linoma Software Case Study (2010). University of Cincinnati takes GoAnywhere™ Director to the Extreme, http://www.linomasoftware.com/case_studies/UCCaseStudy.pdf, last access: 05/15/2010.

MacManus, R. (2010). The Coming Data Explosion, ReadWriteWeb, http://www.readwriteweb.com/archives/the_coming_data_explosion.php, last access: 07/29/2010.

Microsoft (2007). Description of the database normalization basics, http://support.microsoft.com/kb/283878, last access: 8/16/2010.

Nath, S., Liu, J. and Zhao, F. (2007) SensorMap for Wide-Area Sensor Webs, Computer, 40(7): 90-93.

Net Applications (2010). Operating System Market Share, http://www.netmarketshare.com/operating-system-market-share.aspx?qprid=8, last access: 07/29/2010.

Nittel, S., Labrinidis, A. and Stefanidis, A. (2008). Introduction to Advances in Geosensor Networks, GeoSensor Networks: Computer Science: Springer Berlin / Heidelberg, pp. 1-6

OOSTethys http://oostethys.org/, last access: 06/26/2010.

Open Geospatial Consortium, Inc. http://www.opengeospatial.org/, last access: 07/29/2010.

Reiss, B. (2010). Barrow, Alaska: Ground Zero for Climate Change. Smithsonian Magazine, March 2010.

Sensor Map http://www.sensormap.org/sensewebv3/sensormap/, last access: 06/26/2010.

Shin, J., Kumar, R., Mohapatra, D., Ramachandran, U., and Ammar, M. (2007). ASAP: a camera sensor network for situation awareness. In Proceedings of the 11th international Conference on Principles of Distributed Systems (Guadeloupe, French West Indies, December 17 - 20, 2007). E. Tovar, P. Tsigas, and H. Fouchal, Eds. Lecture Notes In Computer Science. Springer-Verlag, Berlin, Heidelberg: 31-47.

Stardot Technologies (2010) http://www.stardot-tech.com/products.html, last access: 08/08/2010.

Winter, S. and Dupkez, S. (2008). Queries for historic events in geosensor networks, Journal of Location Based Services, 2(3): 177-193.

Yick, J., Mukherjee, B. and Ghosal, D. (2008) Wireless sensor network survey, Computer Networks, 52(12); 2292-2330.

Appendix

ESRI Desktop 9.3 Help

SQL Server data types

When you create a feature class or table in ArcGIS, there are 11 different data types available for each column. These types are mapped to SQL Server types in the following table.

ArcGIS data type	SQL Server data type	Notes
OBJECTID	INT(4)	NOT NULL
SHORT INTEGER	SMALLINT(2)	
LONG INTEGER	INT(4)	
FLOAT	REAL	
DOUBLE	DOUBLE	If scale is set to greater than 0 in ArcGIS, the SQL Server data type is NUMERIC.
TEXT	NVARCHAR(n) or VARCHAR(n)	The data type is NVARCHAR if your geodatabase stores Unicode text. With NVARCHAR, you can have up to 4000 characters. If you are not using Unicode, text fields are VARCHAR. For VARCHAR, you can have up to 8000 characters. If you create a field with a value larger than the maximum allowed for that data type, the field will be converted automatically to a BLOB type.
DATE	DATETIME	
BLOB	IMAGE	
GUID	UNIQUEIDENTIFIER(16)	
GEOMETRY	IMAGE	
RASTER	IMAGE	

GIN ODBC Guides

PURPOSE

The purpose of these guides is to introduce the user to the Arctic Geographic Information Network(GIN) tables. Included is a discussion of the fields as well as the type and length.

OVERVIEW

These guides are to explain the GIN friendly ODBC connection Table Guides

- Weather
- Weather_History
- Sensor
- GA

Tables Linking

The weather tables are able to link to the sensor point table by the primary keys of longitude, latitude and elevation. (direction is needed for camera sensors)

Weather Guide

PURPOSE

The purpose of this guide is to introduce the user to the Weather table. Included in this guide is a discussion of the fields within the Weather as well as the type and length.

(The Weather_History table fields are identical to the live table)

Overview

The Weather includes all the fields relevant to a live Davis Vantage Pro 2 xml data feed.

Field Definitions

datetime **datetime**

- Date and time the sensor readings were recorded

latitude **numeric(38,8)**

- The latitude of the sensor hard coded in during installation

longitude **numeric(38,8)**

- The longitude of the sensor hard coded in during installation

elevation **numeric(38,8)**

- The elevation of the sensor hard coded in during installation also used for calculating certain sensor readings

serialnumber **nvarchar(50)**

- The serial number of the installed Davis Vantage Pro 2

MACaddress **nvarchar(50)**

- The unique address for the Davis Vantage Pro 2

location **nvarchar(50)**

- The concatenation of the latitude, longitude, and elevation

temp **numeric(38,8)**

- The temperature in Celsius

humrel **numeric(38,8)**

- The humidity in rel

dew **numeric(38,8)**

- The dew point in Celsius

heatindex **numeric(38,8)**

- The heat index

cloudheight **numeric(38,8)**

- The cloud height in meters

humabs **numeric(38,8)**

- The humidity in abs

uvindex **numeric(38,8)**

- The UV index

radiationrel **numeric(38,8)**

- The radiation in rel

wdirection **numeric(38,8)**

- The wind direction in degrees

wgustspeed **numeric(38,8)**

- The wind gust speed in kilometers an hour

wspeed **numeric(38,8)**

- The wind speed in kilometers an hour

wchill **numeric(38,8)**

- The wind chill in Celsius

rainrate **numeric(38,8)**

- The rain rate in millimeters

raintotal **numeric(38,8)**

- The rain total in millimeters

Weather_History Guide

PURPOSE

The purpose of this guide is to introduce the user to the Weather_History table. Included in this guide is a discussion of the fields within the Weather_History as well as the type and length.

(The Weather_History table fields are identical to the live table)

Overview

The Weather includes all the fields relevant to a live Davis Vantage Pro 2 xml data feed.

Field Definitions

datetime **datetime**

- Date and time the sensor readings were recorded

latitude **numeric(38,8)**

- The latitude of the sensor hard coded in during installation

longitude **numeric(38,8)**

- The longitude of the sensor hard coded in during installation

elevation **numeric(38,8)**

- The elevation of the sensor hard coded in during installation also used for calculating certain sensor readings

serialnumber **nvarchar(50)**

- The serial number of the installed Davis Vantage Pro 2

MACaddress **nvarchar(50)**

- The unique address for the Davis Vantage Pro 2

location **nvarchar(50)**

- The concatenation of the latitude, longitude, and elevation

temp **numeric(38,8)**

- The temperature in Celsius

humrel **numeric(38,8)**

- The humidity in rel

dew **numeric(38,8)**

- The dew point in Celsius

heatindex **numeric(38,8)**

- The heat index

cloudheight **numeric(38,8)**

- The cloud height in meters

humabs **numeric(38,8)**

- The humidity in abs

uvindex **numeric(38,8)**

- The UV index

radiationrel **numeric(38,8)**

- The radiation in rel

wdirection **numeric(38,8)**

- The wind direction in degrees

wgustspeed **numeric(38,8)**

- The wind gust speed in kilometers an hour

wspeed **numeric(38,8)**

- The wind speed in kilometers an hour

wchill **numeric(38,8)**

- The wind chill in Celsius

rainrate **numeric(38,8)**

- The rain rate in millimeters

raintotal **numeric(38,8)**

- The rain total in millimeters

Sensor Guide

PURPOSE

The purpose of this guide is to introduce the user to the Sensor table. Included in this guide is a discussion of the fields within the Sensor table as well as the type and length.

Overview

The Sensor includes all the fields relevant to the location of sensors. The table is modeled after the OGC standards table for feature classes in SQL server.

Field Definitions

ObjectID **integer**

- ObjectID used for ArcSDE database connections

datetime **datetime**

- Date and time of the geocoding

latitude **numeric(38,8)**

- The latitude of the sensor

longitude **numeric(38,8)**

- The longitude of the sensor

elevation **numeric(38,8)**

- The elevation of the sensor

direction **nvarchar(50)**

- The direction of the sensor

location **nvarchar(50)**

- The concatenation of the latitude, longitude and elevation

name **nvarchar(50)**

- The name of the location

sensor_name **nvarchar(50)**

- The name of the sensor

sensor_type **nvarchar(50)**

- The name of the type of sensor

shape **integer**

- Geometry Column (GID)

GA Guide

PURPOSE

The purpose of this guide is to introduce the user to the GA table. Included in this guide is a discussion of the fields within the GA as well as the type and length.

Overview

The GA includes the parsed raw data via Go Anywhere from the live Davis Vantage Pro 2 xml data feed. This table is truncated before each file is parsed.

Field Definitions

timeframe **varchar(18)**

- The timeframe specified by the sensor for the relevant readings

sensor **varchar(18)**

- The sensor responsible for the reading

category **varchar(18)**

- The category for the sensor reading

unit **varchar(18)**

- The unit used for the sensor reading

item **varchar(50)**

- The sensor reading

Video

Arctic Climatology Sensor Network Video