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Remote Sensing and GIS for Regional Environmental Applications

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ABSTRACT

Virginia Access (VAccess) is a regional, remote sensing and Geographical Information Sciences project among several educational institutions. It is a prototype for regional projects in other states and other countries, and is funded by NASA's applications program. The user communities VAccess serves are the Commonwealth of Virginia and State of Maryland, local and regional users represented in a Technical Advisory Committee. Remote sensing data include global NASA and NOAA data tailored for regional applications as well as high-resolution multispectral (Landsat, MODIS, etc.), hyperspectral, LIDAR and SAR data sets. Broad beam LIDAR technology can provide canopy structure as well as other information for environmental concerns such as the state of wetlands. The data information system is based on a distributed architecture to serve remote sensing and GIS data to a variety of users via the WWW. Several remote sensing and GIS-based environmental and Earth systems science applications projects are discussed here, including flood and fire hazard mitigation, forestry, land use/land cover and epidemiology projects; as well as innovative data fusion, data access and analysis and various tools serving the users and their applications.

Keywords: Regional Applications, Remote Sensing, GIS, Flash Floods, NDVI, LAI, Epidemiology, Oil Pollution, WebGIS, ArcIMS

1. INTRODUCTION

Remote sensing (RS) data are increasing at ever-expanding rates. Moreover, these data are accompanied by large volumes of model and other types of data, often in Geographic Information System (GIS) formats. They are available to and can be used by diverse communities such as applications users and policy makers. Data require distributed access, via the World-Wide-Web, and the data providers can form different levels of federation, applicable to both Earth system science and applications.

Remote sensing data, whether collected from space satellites or from airborne platforms, and in particular when of high resolution in both spatial and frequency dimensions, are expanding at exponential rates[1]. Federations of data providers, distributed sites with minimal, common standards, protocols and basic similar usage, are forming for both science and applications usage.

In this work, we describe a large applications project funded by the National Aeronautics and Space Administration (NASA). Termed Virginia Access (VAccess), it is a distributed remote sensing data and information project serving the environmental and other applications needs of its stakeholders.

VAccess itself is an alliance between several Commonwealth of Virginia educational institutions. Its current partners are George Mason University (P.I. institution), Hampton University, James Madison University, Old Dominion University,

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University of Virginia, Virginia Tech, Virginia Institute of Marine Sciences and the Virginia Space Grant Consortium. In the second year of the project to begin in September of 2002, the University of Maryland at College Park (UMDCP) will be a full member, thus extending the project to the Mid-Atlantic region. The enlarged project is named VAccess/MAGIC (Mid-Atlantic Geospatial Information Consortium).

The user communities VAccess initially serves are State, regional (at the county level) and even local users represented in a Technical Advisory Committee (TAC). The remote sensing data include Earth system science global data collected by NASA, the National Oceanic and Atmospheric Administration (NOAA), as well as international RS missions. Global data which focus on global change and Earth system science research are tailored in the project for regional applications. Moreover, high-resolution space-borne and airborne multispectral, hyperspectral, LIDAR and synthetic aperture radar (SAR) data sets are being pulled together for VAccess applications and will complement the global data sets. Data sets can be fused, enhanced in terms of their value and made easily available as needed to serve the users.

VAccess/MAGIC is building a distributed architecture and is developing innovative information technology solutions to provide access to its RS and GIS data. Moreover, VAccess/MAGIC is developing training and education courses, workshops and kits in remote sensing and GIS. The main emphasis is to develop RS and GIS-based projects, of interest to the applications communities, including flood and fire hazard mitigation, forestry, land use/land cover and epidemiology concerns, to name a few.

VAccess/MAGIC activities include an emphasis on requirements, needs and priorities of applications to users; working group efforts which represent specific research applications projects, i.e. developing prototypes; developing collaborative work with state and local agencies; ingesting data for prototyping; and creation of useful, complete prototypes. However, the purpose of the project in all its forms and prototypes is not to conduct fundamental scientific research for its own sake but rather develop appropriate research and tools as needed in serving the applications and the users.

VAccess can be a prototype for different end-to-end application projects. The working prototypes described here can apply as a model for other regional applications at different countries and continents, including Europe, Asia and the Far East, Africa, the Americas and Australia.

2. INPUT FROM USER COMMUNITIES

For VAccess, input from the larger user communities is provided through the TAC. The TAC provides input of requirements for applications users (such as policy needs Of State and local agencies) translated into remote sensing and GIS data requirements to satisfy those needs. To provide a comprehensive summary of such needs, VAccess is coordinating data access and usage with the Virginia Geographic Information Network (VGIN), through its Natural Resources (NR) Departments group; as well as the Demographics, Economics, Culture and Infrastructure (DECI) Departments group.

The two main VAccess working groups are subdivided into several, specialized, focused groups. Some of the application projects (primarily from GMU) are described here. Educational activities of various university partners in the overall project are also an integral part of VAccess but will not be described here.

3. HIGH RESOLUTION DATA

Global data sets tend to have lower spatial resolution. For example, the highest resolution for MODIS on board of NASA's *Terra* and *Aqua* missions is 250 meter, designed to be used for the highest possible resolution in continent-size research. Most of MODIS channels actually have lower resolution, 500 m or, most often, 1,000 m and, again, they are designed for continent-size and global change research, i.e. for applications[2] in regions with sizes 1,000's km or more; while Landsat's resolution of 30 m generally limits it to regional-size coverage, 100's km or less, applications.

On the other hand, high resolution data are generally most useful for regional and local applications. These include hyperspectral imaging (HSI), LIDAR, Interferometric SAR, softcopy photogrammetry and other advanced remote sensing approaches. Potential integrated uses of these technologies are being explored in the RS community, such as sensor and data fusion, networking, and onboard data processing.
As a part of estimating and categorizing the flash flood hazard at the intersections of the streams and different types of roads, we used the Bond Branch drainage basin as a pilot area. This location is in the northern part of a region, namely Fairfax County. The ordering of the drainage segments is an important factor to the morphometric analysis of any drainage basins. This task would be a very time consuming activity if it were done manually. We developed a semi-automated routing using Microsoft Visual Basic for Applications (VBA) within ESRI ArcGIS 8.1, and subsequently we used ArcView 3.2 and the Avenue programming environment.

Before the segments could be ordered automatically, we had to ensure that the segments were all turned in the proper orientation. To accomplish this, we used the grid and the stream network. We developed a tool in Avenue that examines the elevation of each end of each stream network segment. If it determines that the end of the stream segment is below the beginning of the stream segment in elevation, then it will flip the segment and update the shape file with this new flipped segment.

After the orientation of the segments had been determined, then Avenue could be used again to order the segments. When ordering the stream network segments, the upstream-most segments are always first order, etc. As the stream continues downstream, any time two segments of the same order meet, the next higher order is applied to the next downstream segment (Fig. 1). The figure below shows graphically what was just described. The end result of this automated process was the assignment of a segment order to each of the segments. The maximum segment order in each basin was copied and applied to the basin shape file for use in later computations.

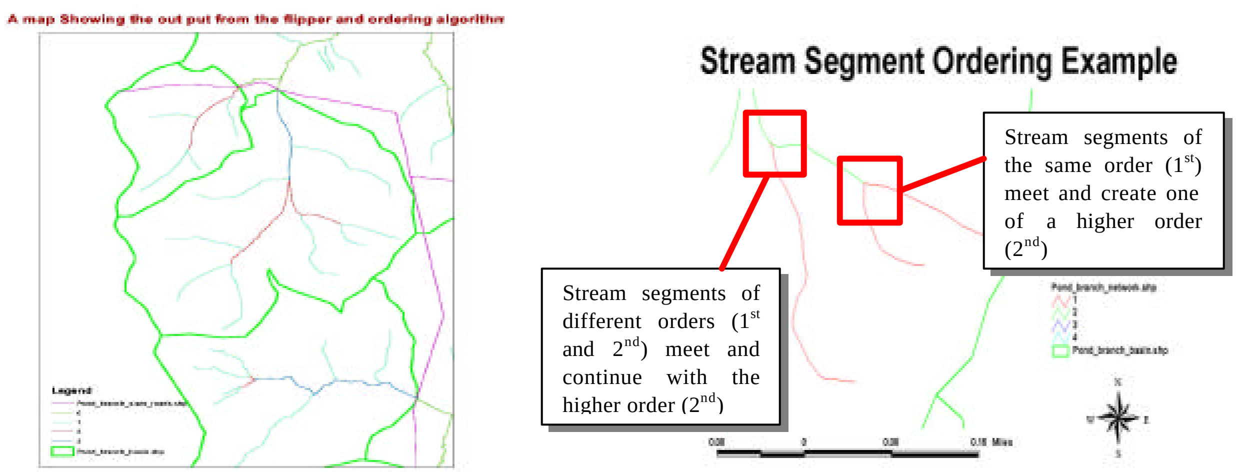

Fig. 1: Outputs obtained after the flipping and ordering processes are done. The level 0 represented in the legend reveals the presence of some non-flipped segments that need to be flipped in order to be ordered in the right order.

4. GLOBAL REMOTE SENSING

One of the aims of VAccess is to identify useful RS products from NASA, particularly *Terra* and *Aqua* products, NOAA as well as other international global coverage satellites tailored for regional use and to work with State agencies users to tailor such data for their use.

4.1 MODIS

We identified the 1 km and 8-day Leaf Area Index (LAI)[3, 5] and Fraction of Photo-synthetically Active Radiation absorbed by vegetation (FPAR)[3, 5] (product MOD15A2) for VAccess local users. LAI[3, 5] defines an important structural property of a plant canopy as the one-sided leaf area per unit ground area. FPAR[3] measures the proportion of available radiation in the photo-synthetically active wavelengths (400 to 700 nm) that a canopy absorbs.

More sample customized (re-projected, subsetted, stitched and GIS compatible) MODIS land surface datasets, such as 250m 16 day vegetation indexes[4, 5] (MOD13Q1) and 250m 8 day surface reflectance[5] (MOD09Q1), and 1km 8 day Land surface Temperature[5] (LST) (MOD11A2), have been processed for VA regions. We finalized NDVI and Land Surface Temperature (LST) demo datasets for the NASA/GSFC Environment & Health Program through the cooperative GMU/NASA Goddard Remote Sensing Information Partner (RSIP).

4.2 Hydrological Remote Sensing

The objective of the hydrological remote sensing VAccess project is to assess the value of remote sensing data in hydrological applications.

A flood risk model that incorporates morphometric data has been developed for a basin in Northern Virginia. Combining all the morphometric parameters ranks the flood risk in the sub-basins. Hourly rain rate data at thirty-five gauges[6] over Virginia are collected and analyzed. Preliminary quality checks have been performed. Statistics such as total number of missing data, percent of rainy observations, and monthly and yearly mean rain rates are computed. Additional statistics to be computed include hourly and 24 hour rain maximum, probability of exceeding a limit and return periods. These statistics will be integrated as additional GIS layers to aid the assessment of flood risk. Stream flow data compiled by the NOAA River Forecast Center will be used for verification of flood risk models.

We plan to add socio-economic data such as population to further improve the model. The Virginia Department of Emergency Management (VDEM) indicated an interest in this product.

Soil moisture estimates are important for long-term weather and flood forecasting, and is a major component for estimating the water budget of water basins[7]. We examined various techniques for estimating soil moisture. Microwave remote sensing seems to provide the best estimates. A set of soil moisture data has been developed by the *Tropical Rainfall Measuring Mission* (TRMM) using the 10 GHz channel data of the TRMM Microwave Imager (TMI). Additional soil moisture products will be available from Advanced Microwave Scanning Radiometer (AMSR) on board NASA's *Aqua* satellite to be launched later this year.

4.3 Ocean Color Remote Sensing

We identify ocean color remote sensing parameters for VAccess users. The 1-km ocean color data, archived at the Goddard DAAC, are Level 1A products[8]. Each file holds part of swath data, which contains the raw radiance count. In order to get the projected useful physical parameter within an interested area, a "Simple, Scalable, Script-based, Science Processor" (S4P) data processing system is under development. This automated system will retrieve data from archive, extract regional data from the original file, process data to calculate required physical parameters, and map data onto a desired projection. The subsetting and data processing will use algorithms in SeaDAS, free software for SeaWiFS data analysis.

4.4 AVHRR Data

All of the Pathfinder AVHRR Land daily tile data have been made directly accessible by FTP:
http://daac.gsfc.nasa.gov/data/dataset/AVHRR/01_Data_Products/05_Tile_Products/index.html
ftp://daac.gsfc.nasa.gov/data/avhrr/tile_8km/
The total volume of data available via FTP is over 174 GB. The data is in 1,000 by 1,000 km tile regions, so obtaining a subset of Virginia, for all times and parameters is very easy. For example acquiring 20 years of daily NDVI data for the Commonwealth of Virginia from the PAL tile data would require a user to work with114 MB. If a user chose the NDVI data from the original PAL data in HDF format, they would have to work with global files containing all the parameters. That volume of data would be over 1.6 TB.

4.5 GOES Data

We made subsets, for the USA from the Climate Prediction Center/NCEP/NWS GOES Merged IR Brightness Temperature. These data are derived from GOES data and has a 4-km spatial resolution, 30-minute temporal resolution, and is available 4 to 5 days from the date of its collection. Long-term plans are to make this data available through a GRADS/DODS server, at GMU, and to investigate GIS products that could be derived from this data.

4.6 NASA Remote Sensing Information Partner (RSIP)

The GES DISC hosted a RSIP training workshop on January 8, 2002 at NASA/GSFC. The purpose of the workshop was to have RSIP partners get a better understanding of the GDAAC products and the operations of the user support functions of GDSIC. Five people from CEOSR/GMU attended the workshop. The interoperability among the RSIP partners was discussed. A lot of very positive responses from participants were received.

5. Environmental and Health Projects

5.1 Remote Sensing Data for Public Health

Contributions to NASA's Earth Science and Public Health Program consist in the development and implementation of a user-friendly mechanism for the delivery and dissemination of NASA space-based remote sensing data and products to users in the public health community.

Recent work included the identification of NASA satellite derived data/products relevant to the West Nile Virus investigation project lead by Penn State University and establishment of an experimental web site for the delivery of MODIS products in a GIS compatible format. This is the first step in the implementation of an operational multi-scale remotely sensed imagery system to provide satellite data/products accessible to ArcGIS clients (ArcView, ArcEditor, ArcInfo) and assist in the establishment of local and specialized GIS database and ArcGIS servers based on the RSIP concept. Automated procedures to access EOS-HDF MODIS NDVI, Land Surface Temperature (LST) and convert them to the GEO-TIFF (GIS compatible) and JPEG formats are being carried out.

5.2 Plant Canopies

This effort has three tasks: (i) deposition of nitrogen to plant canopies in the Chesapeake Watershed (focus on dry deposition and comparing that to wet deposition); (ii) application of HSI technology to detect contaminants in the soil-plant system; and (iii) application of HSI technology to detect and monitor stress symptomology in plant canopies. For N deposition, the focus has been devoted to acquiring satellite based imagery from which to generate leaf area index (LAI) for the watershed. While "canned" programs are available for determining LAI, newer algorithms have been developed within the last 2-3 years that are more accurate in estimation. These new techniques are being inventoried and evaluated for their application to the estimation procedure.

5.3 Water Quality & Wetlands

The health of wetlands is of great importance to states such as Virginia and Maryland. VAccess focuses on linking existing *in situ* data on wetlands at the county level (Fairfax County) with the satellite data. New avenues for acquisition have emerged for these data.

5.4 GIS Environmental & Health Project Support

Meadowood Farm Bureau of Land Management project:

- BLM data of this farm were obtained from BLM. These data include the boundary of the Farm, which are the most important, and other data layers mainly for surveying purposes.
- Other GIS data layers of the Farm are from the Fairfax County government. These layers include:
    - i) Hydrography: streams and water bodies
    - ii) Contour data at 5-foot interval
    - iii) Transportation network: roads and highways
- Contour data are used to create a Triangulated Irregular Network model to show the topography of the Farm and the region

- 1990 Census data of Population and Housing are also included
- *SPOT* panchromatic scenes of 10 m resolution acquired between 1992-94 are also included
- Land use data from ASTER and NDVI are developed (Fig. 2). These images were converted into raster GIS format to be incorporated with other GIS data layers (Fig. 3).

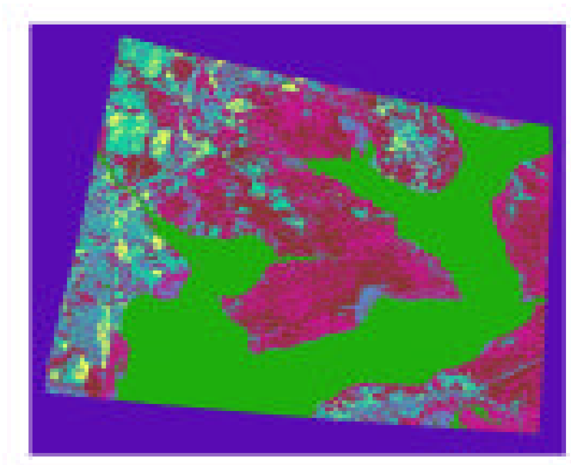

Fig. 2: Raster data from ASTER

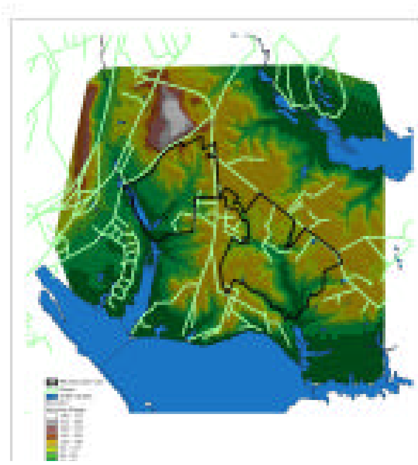

Fig. 3: Basic GIS data layers

All these data are brought into ArcView / ArcGIS with layers overlain atop each other. Maps are generated to be used for field study and data collection.

5.5 Mosquito Spatial Surveillance Model

Other work involving one of the VA ccess partners, Old Dominion University, focuses in building its GIS database and preprocessing needed satellite (Landsat) imagery for West Nile vector disease mitigation.

- RS data and GIS data are utilized for an effective mosquito monitoring framework.
- We have identified the vulnerable population groups as children and elders.
- Facilities likely with clusters of these population groups are identified. They include child-care facilities, elementary schools, and elderly facilities.
- Addresses of these three types of facilities are obtained through data from the states and counties. An address-matchable road database based upon 2000 TIGER has also been compiled. Addresses of facilities are then matched to the road database to derive their locations. More than 80% of the facility addresses were matched.
- Buffering these facilities can identify areas within which the clustering of mosquitoes' population may be alarming (Fig. 4).
- When potential breeding sites of mosquitoes are identified by remote sensing data, these locations will be and can be used in conjunction to RS data to derive an effective spatial monitoring framework.

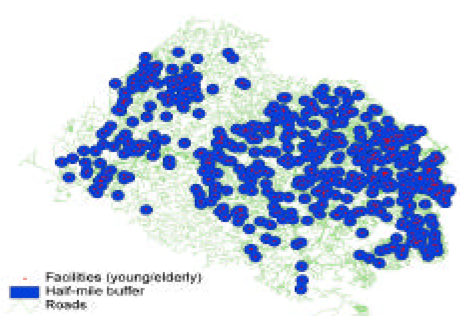

Fig. 4: Mosquito Spatial Monitoring

5.6 Hyper spectral Image Classification For Detecting Oil Contaminants Of Wetland

Using Hyperspectral imagery, as an advanced remote sensing technology, it is more reliable to minimize the limitations of conventional remote sensing techniques to detect oil spills. The preliminary results of this research show that the signature matching method is more accurate than the conventional techniques, which is based on the visual interpretation of oil color and appearance in the satellite images. In this part hyperspectral data from AISA images were used for monitoring the effect of the oil pollution on the area surrounding the river. The damaged grass was observed on the banks of the river and also in the small streams (Fig. 5a). The first part of this study shows that the oil spill was extended in most of the river and its branches. This study provides an emphasis on the effect of oil pollution on the surrounding environment (Fig. 5b).

Fig. 5(a): Damaged grass on river banks

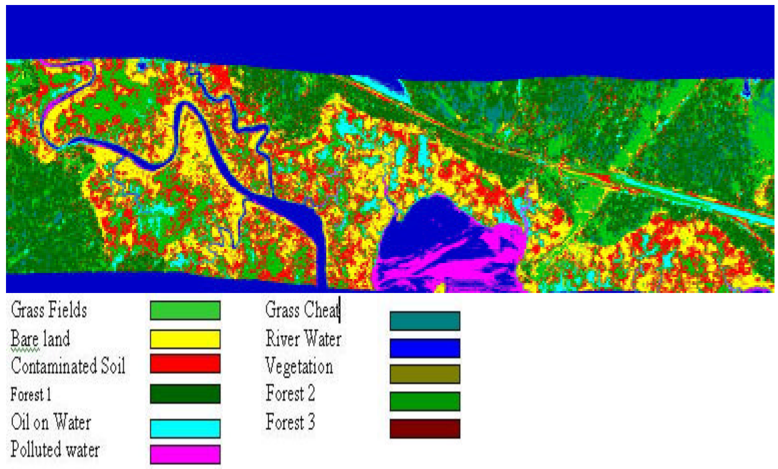

Fig. 5(b): supervised classification results. The contaminated soil with oil appeared in red and the oiled water on wetland appeared in cyan, the polluted water appeared in magenta.

Different methods for image classification are used to identify oil spills and the contaminated areas using the Linear Spectral Unmixing technique, supervised and unsupervised classification techniques which used to compare the level of accuracy of the output results for each methodology[9]. This part of study will emphasize the oil contamination in wetland, soil, streams, and grass, in addition to identifying oil pollution effect on the shoreline borders and soil on stream banks of the Patuxent River basin in Chesapeake Bay (Fig. 6a).

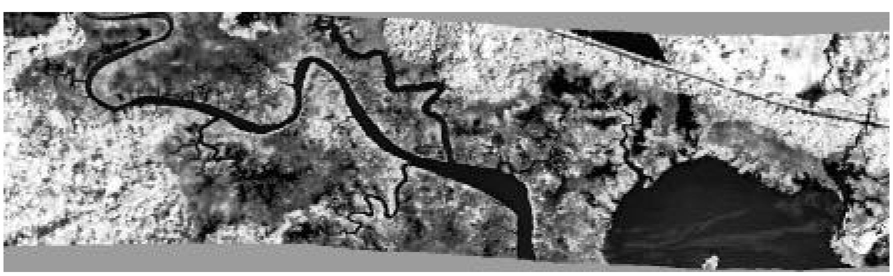

Fig. 6(a): The rule images of the linear spectral unmixing classification. It shows the oil appeared in Black surrounding the small streams on the river banks.

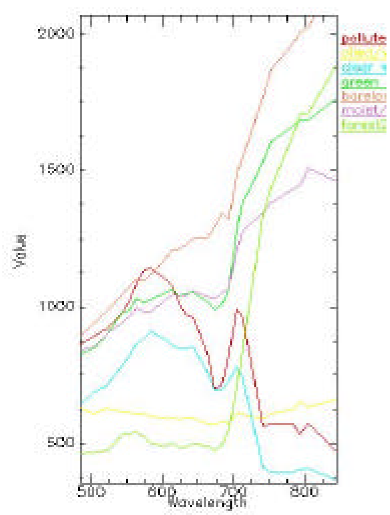

Fig. 6(b): Spectral Library

There is difficulty in distinguishing between different materials mixed with oil, and the land features are composed of mixtures of materials; pure pixels are extremely rare. The spectral linear unmixing technique was selected to examine the ability of hyperspectral sensors to determine the relative abundance of materials depicted in

multispectral imagery based on materials' spectral characteristics.
The knowledge about the performance of classification algorithms in this situation would help select an appropriate procedure to quickly and easily identify these contaminated regions. (Fig. 6b) shows the spectral library extracted and used as an end member for linear spectral unmixing classification.

6. Information Technology

6.1 Infrastructure

An important focus of VAccess is to build and enhance the IT infrastructure at CEOSR. We are building a RS/GIS lab for training graduate students and developing RS tailored products. VAccess has acquired a NOAA AVHRR[10] and NASA SeaWiFS satellite antenna. We will be developing higher-level data products from direct broadcast Level-0 data, such as Level 1, 2 and 3 (Fig. 7). These products will be tailored for regional applications. Due to the large swath of AVHRR, a single granule covers the eastern part of the U.S., including the areas of interest to VAccess. We also plan to use this antenna for receiving other RS data by acquiring the right software. Specifically, we have plans to receive the Chinese series FY-1C etc. data which are comparable to NOAA polar series missions.

Fig. 7: Direct Receiving HRPT Station

We have tested all processes for setting up a distributed GIS system based on GIS products from ESRI. We also setup the infrastructure for managing the metadata for data sets in the VAccess project. Both systems are ready for accommodating data. In addition, we have been leading the effort for designing and building information distribution systems for the project.

6.2 NASA HDF-EOS Web GIS Software Suite - NWGISS

GMU, as a member of the Open GIS Consortium (OGC), has a group, the Laboratory of Advanced Information Technologies and Standards (LAITS) doing research on Web Mapping Test bed (WMT) and OGC Web Service (OWS) to develop heterogeneous geo-processing systems that communicate with each other, and to allow dynamic, interoperable, geospatial processing and location service across the web. LAITS is developing a prototypical software suite (NWGISS) that meets OGC specifications and makes HDF-EOS data available for GIS applications. (Fig. 8a) below, OGC Compliant WebGIS, depicts the architecture on which NWGISS is built.
The Graphic User Interface (GUI) for NWGISS (Fig. 8b), is easy to use and easy to setup. A demonstration site for NWGISS map and coverage servers has been prototyped and is accessible at:

Map server: http://heineken.gsfc.nasa.gov:8910/cgi-bin/WGISS?request=capabilities

Coverage server: http://heineken.gsfc.nasa.,gov:8080/cgi-bin/dib/wcshdfeos?request=getCapabilities

Currently, MODIS level 1B, TOMS ozone and other selected datasets are accessible with more data being added regularly.

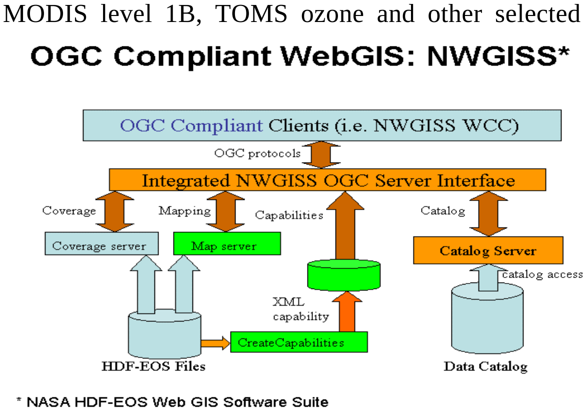

Fig. 8(a): NWGISS Architecture

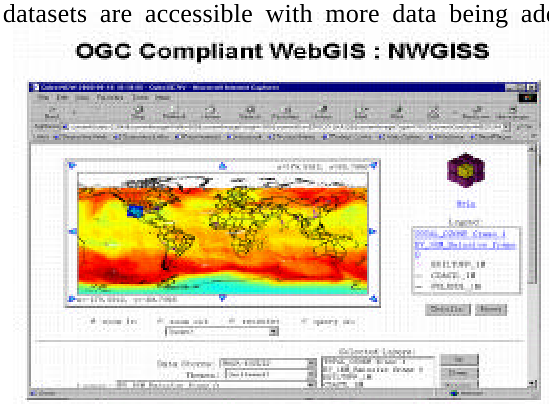

Fig. 8(b): NWGISS Graphic User Interface

The map server can be accessed by map clients: e.g.

Cubewerx client: http://209.217.120.146/wmt/cubeview/cubeview.cgi

NASA Digital Earth client: http://viewer.digitalearth.gov

Our site is called NASA-EOSDIS and has been setup and used in many places. Screen capture of Cubewerx client accessing data in our map server is shown in the figure above. No good client coverage clients exist today, but several companies and agencies are developing such a client (including NWGISS).

6.3 Remote Sensing Data and NASA GIS Data Synthesis in a Web-Based Environment

Due to the special importance of the Chesapeake Bay, our efforts emphasize the Bay area. It is home, within its watershed, to around 15 million people in six states and Washington, DC. Three NASA facilities, Goddard Space Flight Center, Langley Research Center, and Wallops Flight Facility, are located in that Chesapeake Bay region.

We collected remote sensing data related to environmental characteristics of the bay area. We added value to standard remote sensing products to make them suitable for researchers working on the bay in related environmental studies. We also prototyped a WebGIS-based system for data dissemination, particularly for the data collected by NASA about its facilities. Finally, we integrated the available NASA data and the new remote sensing data products and made both accessible to researchers through an intranet under one working environment.

We collected SeaWiFS data and AVIRIS data from various sources. We are comparing ocean colors derived from the two different instruments. The difficulties for doing that is that it is very hard to find data sets that cover the same areas over the same time period. Due to the relatively short time scale of ocean color data collection, the comparison of data collected at different times is not of significant scientific value. Even with this difficulty, the remote sensing data can be used as a baseline for future changes over the covered areas. For that purpose, we created sample data sets from both SeaWiFS and AVIRIS, and made them suitable for data integration with NASA facility data.

We designed and setup a WebGIS-based data information system for supporting NASA facilities data and associated remote sensing data within CEOSR or broader communities. The system architecture is shown in (Fig. 8a). We use the GIS products from ESRI to implement a prototype. One example of the client is given in (Fig. 9a), on which, the data from NASA facilities and the remote sensing data are integrated together. Users can overlay them together through the web-based GIS clients. Users with other GIS client tools such as ArcMap, ArcEditor, and ArcInfo can directly access the data through the network, and use the data in the same way as using local data.

6.4 Conclusions and Future Work Recommendations

By integrating the heterogeneous data into a uniform projection and coordinate system, we built an intranet/internet GIS system for supporting environmental data near NASA facilities in the Chesapeake Bay area. The system can be accessed through either the Internet or an intranet for researchers to conduct their research activities (Fig. 9b). In the process of conducting this project, including remote sensing data acquiring and analysis and system development, we gleaned the following major "lessons learned" and suggestions.

- High spatial resolution data are needed to study environmental problems at local scales. Relating global datasets to local areas provides baseline and some gross trend information only.
- Well-designed experiments are needed to support cross instrument studies of phenomena with short temporal scales.
- The performance of ArcGIS is not acceptable when serving as a data center as used in this project. We need to adopt new ways to support more efficient data access.
- Sustainable, historical, environmental data are needed for scientific research on the impact of NASA facilities on their surrounding environment. Data mining technology could be used for knowledge extraction as long as we have such data sets.

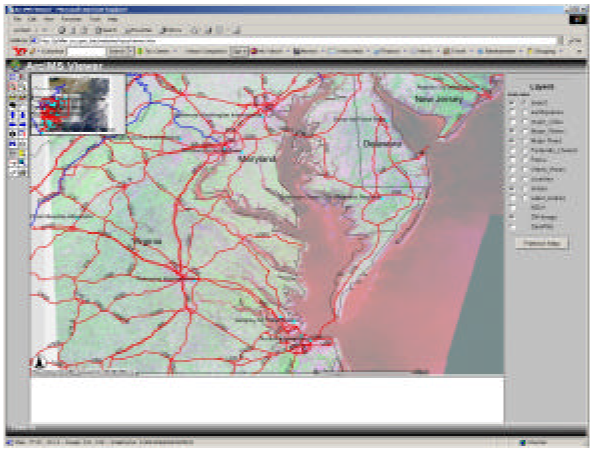

Fig. 9(a): An example of the ArcIMS client GUI

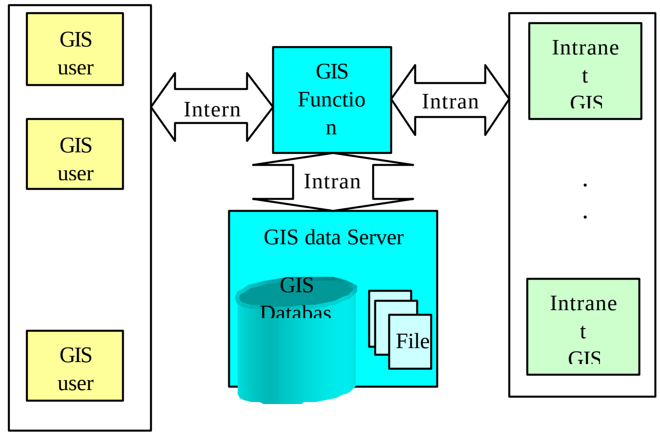

Fig. 9(b): The architecture of the WebGIS-based data

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