Brokering Meteorological and Oceanographic Information in Support of Military Operations Using GIS Technology

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***Abstract*-In order to provide timely meteorological and oceanographic (METOC) support to military operations, it is advantageous to provide geospatially enabled information that can be integrated seamlessly into the infrastructure of decision-making tools used by the warfighter. This requires a new technology that can incorporate and transform many types of data into a uniform package of useful georeferenced information. The use of a geographic information system (GIS) is being recognized as the solution of choice to satisfy this requirement.**

Over the past few years the Naval Oceanographic Office (NAVOCEANO) has led the way in the development of this cutting-edge technology. GIS methodology is particularly well suited for collecting, organizing, storing, analyzing, and distributing geological, oceanographic, meteorological, and even space data. As users at NAVOCEANO have come to recognize how GIS tools could vastly improve operations, certain capabilities for processing and distributing relevant METOC information have evolved.

This paper describes certain applications of GIS technology that provide geospatial information to the customer, leading up to the use of ArcIMS, an Internet map server developed by the Environmental Systems Research Institute (ESRI). The overall goal at NAVOCEANO is to provide the warfighter with time-critical information of the environment relevant to the warfare area and pertinent to the mission. To this end, the ArcIMS, coupled with ArcSDE, the spatial data engine, provides an architecture that allows NAVOCEANO to broker between the vast and disparate resources of METOC data and the highly specific military mission requirements. Portrayed in the paper is the history of operational support that lays the groundwork for GIS technology today at NAVOCEANO. Finally, described here is one of the latest functional prototypes of the ArcIMS set up at NAVOCEANO that provides a variety of METOC information layers tailored to certain requirements, initiated by a demonstration proposal for Fleet Battle Experiment – Juliet.

I. INTRODUCTION

Critical to the success of any military operation is battle space awareness, which includes knowledge of the pertinent aspects of the environment. Through the channels within the Navy's meteorological and oceanographic (METOC) community, one can find a plethora of resources consisting of meteorological, oceanographic, and geological data and derived products. Part of the problem is accessing these vast resources and distributing the appropriate information to the operational concern. In addition, it has never been trivial to interpret the information into an answer that is concisely applicable to or made to integrate well with any given warfighter decision apparatus.

An improved infrastructure is needed to provide a highly capable data and information broker with the ability to quickly reach back into various data sources, find specific elements that will satisfy a request, and distribute to those elements accordingly. Since there is such a large variety of data sources in disparate data formats, it has become more resource intensive and time consuming to bring the data items together into a concise package. Because the military customer has been levying increasing demands for specific and time-critical METOC answers, the conventional production line solution is becoming inadequate.

The data and information distribution and interoperability problem is widely recognized, including at the higher echelons of the Navy METOC community. An approach to solving this problem is reflected in the Naval Oceanographic Program Operational Concept (OPCON) [1]. This OPCON is based on the expectations of modern warfare in the Navy, and points to a need to take a fresh look at the way we do business. The METOC community is charged with populating the 4DCube, a concise and complete set of essential relevant elements of information required to support military operations. Producers of METOC data need to organize the data and information spatially and temporally and be able to make timely contributions to the 4DCube. Thus, in order to keep up, our streamlining or revamping efforts may have to involve full automation eliminating the man-in-the-loop.

There have been attempts to deal with this problem with various systems either contrived in-house or available off the shelf. But, these ad hoc solutions did not address the crux of the problem: the ability to interoperate between departments, organizations, or even branches of service. The need for implementing an object model based on well-known data handling conventions and standards has become quite evident. Given this and the desire to latch on to an off-the-

shelf software solution, one can start with the implementation of Geographic Information System (GIS) technology as a platform from which to launch. One specific software solution is Environmental Systems Research Institute, Inc. (ESRI's) ArcGIS, which offers the capability and ideal venue for implementing data and information interoperability.

The ArcGIS software suite promises to solve the interoperability problems plaguing us, because there already exists an object model that makes it easy to integrate geospatial data. Still there is much more work ahead in the effort to attribute the data by adopting existing data-coding standards. In addition, we need to agree on the content of the metadata. ArcGIS Version 8 is a potentially good venue for considering the form of the metadata, since ArcGIS already provides a template based on the Federal Geographic Data Committee (FGDC) standard. Before this level was reached, a history of how the METOC community attempted to handle data and information may elucidate why the Navy is so motivated to use inter-operability standards.

Current implementation methods have been explored, and their limitations are described, including the Tactical Environmental Data Server (TEDS), which was designed to be the primary means of exchanging METOC information between military centers.

The evolution of the implementation of increasingly more powerful capabilities lay the groundwork for a mechanism to broker requests levied on NAVOCEANO by military commands.

II. BACKGROUND

A. History of METOC Data Exchange

There has always been a need for a unified, standardized database for the staging of METOC data and information within the Navy and across the military branches. Data interoperability issues became prominent with numerical modeling and coupling efforts between Fleet Numerical Meteorology and Oceanography Center (FLENUMMETOCCEN) in Monterey, California, and NAVOCEANO. The timely delivery of gridded model output from FLENUMMETOCCEN to NAVOCEANO was a primary concern, because that output was critical input to the ocean models run at NAVOCEANO by the Warfighting Support Center (WSC). In addition, the marked increase of observational data from remote sensing sources, such as altimeter and sea surface temperature measurements from satellites, stepped up data assimilation efforts, providing better initialization in both atmospheric and ocean models.

In 1995 FLENUMMETOCCEN provided NAVOCEANO with an installation of the Integrated Stored Information System (ISIS) as the means by which FLENUMMETOCCEN delivered their METOC model output grids to NAVOCEANO. This system ran on machines hosted by DoD's Major Shared Resource Center (MSRC), a coalition of supercomputing resources, major parts of which NAVOCEANO uses for operations. This standardized software was composed of an Empress relational database management system (DBMS) engine accessible only through a layer of interface functions that was linked to software that ran on a Cray C90, a platform better suited for intensive numerical computations. Although ISIS replaced a flat-file-based database system called IPOPS, the DBMS-based system turned out to be less reliable. The Empress license was very expensive, and the software layer used in conjunction with the DBMS was difficult to manage. Since the Cray was not optimized for frequent and high-volume input/output (I/O), the system was too cumbersome and slow beyond practical limits. To cope, the WSC designed and built an in-house work-around to address, in particular, the reading and writing of gridded fields. Circumventing the ISIS layer and its database, the ISIS input files were directly decoded to binary files in an agreed-upon format and eventually encoded into netCDF, a common data format used widely in the weather community. This design evolved into an adaptation of a handful of functions applying netCDF for the staging of METOC model I/O grids. Now under configuration management at FLENUMMETOCCEN, these netCDF functions are used to this day.

In 1999 FLENUMMETOCCEN was chartered to archive their METOC model output for the Master Environmental Library staged at the MSRC at NAVOCEANO to make their output available to the scientific community [2]. This requirement, incidentally, led to model grid delivery by FLENUMMETOCCEN changing from the use of the files native to ISIS to gridded binary (GRIB), a format sanctioned by the World Meteorological Organization. By mid-2000 NAVOCEANO adapted their software and started reading GRIB files delivered via FTP (File Transfer Protocol). In the meantime, FLENUMMETOCCEN developed a hypertext transfer protocol (HTTP) delivery mechanism called METCAST, through which the METOC model output and other data became available in GRIB and other formats. NAVOCEANO slightly modified their software to process files delivered by METCAST as well.

The Space and Naval Warfare Systems Command installed TEDS at NAVOCEANO in 1999. TEDS contains a robust set of database tables and application program interfaces (APIs) and is designed to provide a standardized infrastructure for the handling of a wide variety of data and information required by the tactical user community. At NAVOCEANO it was difficult to figure TEDS into a practical implementation for METOC model production. The ocean modeling group at NAVOCEANO tried to export model output in a form palatable through TEDS, but it was discovered that ocean grids are more problematic and complicated than atmospheric grids.

Also incorporated into TEDS is a specialized set of static databases from the Oceanographic and Atmospheric Master Library (OAML). The various types of data in OAML cover the globe and include bathymetry, acoustic databases, climatology, and tidal constituents.

B. Evolution of GIS Implementations

The earlier uses of GIS at NAVOCEANO were instigated by a desire to utilize general-purpose tools instead of reinventing in-house solutions. This was well demonstrated with a quality control system designed at NAVOCEANO to compare model output points to observation data [3], using

the Geographic Resources Analysis Support System (GRASS). Originating with the Army Corps of Engineers, GRASS is open-source, free software GIS with raster, topological vector, image processing, and graphics production functionality. Until recently, GRASS was the engine behind a real-time satellite observation and modeling viewer accessible on the web, a.k.a. the Satellite Model Web Viewer (SMWV), developed in the WSC [4].

The SMWV transitioned from using a GRASS GIS to using ArcINFO Version 7 developed by ESRI. The SMWV evolved into the Real-Time Ocean Products Viewer and is available on the NAVOCEANO web site at http://www.navo.navy.mil. Here, one can view the latest wave heights and wind speeds from observations and model output and their comparisons. In addition, sea surface temperatures from buoys and multi-channel temperature analyses are displayed. This tool has been invaluable in aiding the wave modeler in product quality control.

In 1998 the Satellite Analysis Data Fusion Branch in the WSC was responsible for processing, analyzing, and disseminating remotely sensed oceanographic data, which was compiled into a static product. In October 1998 a plan to produce a fused, digital, attributed, geolocated product with particular emphasis on perishable data sets was initiated. Thus, the Environmental Thematic Rapid Assessment Program (ENTRAP) was created in-house to process METOC data sets into georectified formats. For vector data the format was shapefile, a de facto GIS standard developed by ESRI. ENTRAP shifted the emphasis toward better satisfying customer needs for the tactically significant information in a "smart" form.

A free commercial off-the-shelf (COTS) GIS browser, ArcExplorer, was developed to view and manipulate geospatial layers using a project file. The viewer and static METOC layers including georectified imagery were pressed onto a CD-ROM, labeled, and delivered to customers. Links to dynamic, perishable data that could overlay the static data were made available on the web. This concept was called the Rapid Environmental Assessment Chart-Tactical (REACT) and became the primary dissemination of geospatially enabled data to the field.

The Regional Analysis Division in the WSC builds oceanographically focused image map products. The Satellite Analysis and Geographic Exploitation (SAGE) [5] database was developed to allow imagery analysts to extract and store image-derived features into a GIS database. The SAGE application links to the Earth Resources Data Acquisition System (ERDAS) Imagine toolbar, the primary imagery analysis software used by the WSC, and stores oceanographic features in ArcINFO Librarian, an ESRI-developed database control tool.

In 2001 licenses of ArcSDE were installed at NAVOCEANO. ArcSDE, the Spatial Database Engine developed by ESRI, is a GIS gateway to a DBMS containing geospatial layers [6]. Vector data in shapefile format or geo-rectified imagery could be loaded into the ArcSDE, which would serve various ESRI-designed clients for the display of those layers in a common geographic display. With guidance from ESRI [7], the value of being able to load disparate data sets was soon recognized, and the ArcSDE became a database engine into which different data sets from various groups in NAVOCEANO were loaded as geospatially enabled layers.

Following the momentum to web-based, network-centric architectures, the client and server concept was taken another step further with the installation at NAVOCEANO of ESRI's Internet Map Server, the ArcIMS, described later in this paper. The immediate advantages of this move promulgated the notion of efficient interoperability using COTS software.

III. BASIC CONCEPTS

A. GIS Concept

All the geophysical data collected, processed, and disseminated have some reference location on the earth. The plethora of data types and the volume of information all need to be organized. The natural scheme is to organize the different data types by location or spatial orientation. Through such a reference frame, one can interact with many geographic data objects more quickly than with the conventional relational database. The old relational database method required performing exhaustive searches through entity relationship tables, whereas the concept of data objects organized geospatially facilitated locating points by an efficient hierarchical search.

With a GIS, every singular point or every point of a well-defined grid can easily be located through a user interface or an API. And each point may have one or more attributes or pieces of information associated with that point. Thus, it has become easy to access the attributes of these spatially related points for comparison. For example, to match variously located observations of wave height to the corresponding grid points of a wave model output grid, no one has to write complicated software in order to find data values within the grid. First, the data points and attributes need to be ingested into the GIS database; then the desired location, usually in latitude and longitude, is specified; and then the GIS returns the attributes. Internal format is not a concern, but the GIS has to be set up to be able to interpret the ingested information to avoid intense user "fat fingering."

In addition to points, vector data in the form of lines and polygons can be used in a GIS. Thus, within a GIS, points can be matched with vectors, and vectors can be overlaid over each other. Using a graphical user interface, one can view the layers together and extract only those points, polygons, and lines of all the layers within a geographical box. Only the applicable data attributes tabulated with location information is extracted out of the database. Any extracted data can then be manipulated in other applications such as with a spreadsheet.

B. Web-based Services

It is one thing to run a local application and get good results, but more useful is the ability to access through a standard web browser the server database to view and manipulate the data. Such a thin client connects to a server where most of the work actually is done. The server generally transmits hypertext markup language (HTML)

documents and associated images and applets, and is occasionally called upon to send a data-intensive object.

This network centric approach alleviates the need to gather large data sets first and then to process these sets locally with potentially expensive software [8]. For example, here are two ways to obtain tidal predictions for any coast in the world. One way is to install and run a tidal prediction software package or model. In addition the software may require the associated databases, which may include tidal harmonics in a grid covering the globe and global bathymetry. Alternatively, one can go to a tidal prediction website, enter the desired location, and let the site do the rest. Clearly the latter approach has its advantages.

C. Customer Support

The primary goal of a service-oriented organization is to provide exactly what the customer requires. Naturally, the servicing organization needs to know as much about the requirement as possible. Thus, the function of customer support is to act as a broker, looking for what is available that fits the customer needs, arranging for product availability, and then soliciting customer feedback.

Often servicing organizations build what is perceived as the right product without knowing the real requirements. Or, to minimize overhead, a summary product is built to try to generally satisfy everyone. Personally answering every minor request easily becomes too expensive.

IV. DEMONSTRATION TECHNOLOGY

The concepts described above drove the development of a highly useful technological combination, which promises to answer the problem plaguing the METOC community all along: the exchange of METOC information. The end game is to provide the METOC contribution to the 4DCube. Intermediately, the various components of the METOC community need an efficient way to share disparate types of information between each other. These goals brought about the installation and testing of ESRI's Internet Map Server, the ArcIMS.

Coupled with ArcSDE, ArcIMS is a powerful tool for handling and staging geospatially enabled information. NAVOCEANO is embarking on an effort to demonstrate how all interests within and without the METOC community can easily interact with the information. With this goal in mind, the Future Systems and Technology Exploitation Branch in the WSC set up an ArcIMS prototype in support of Fleet Battle Experiment – Juliet (FBE-J), a military exercise conducted by the Navy from 24 July to 15 August 2002 to test new technology.

A. Notional Architecture

Fig. 1 is a schematic layout of the METOC broker architecture tested in this experiment. One data source, an ArcSDE (and there can be more than one) could be located anywhere and act as server of their own data sets for clients. Although the ArcIMS connection to the data sources is the main focus of discussion here and the data arrows denote a one way flow, other clients may be allowed to access the databases for direct data interaction, particularly to populate these databases. Note that the connection between the databases and the ArcIMS are broadband connections. The full character of the data must be accessible at all times for ArcIMS processing. It is reasonable to assume reliable, high-speed Internet connectivity between the ArcSDEs and the databases.

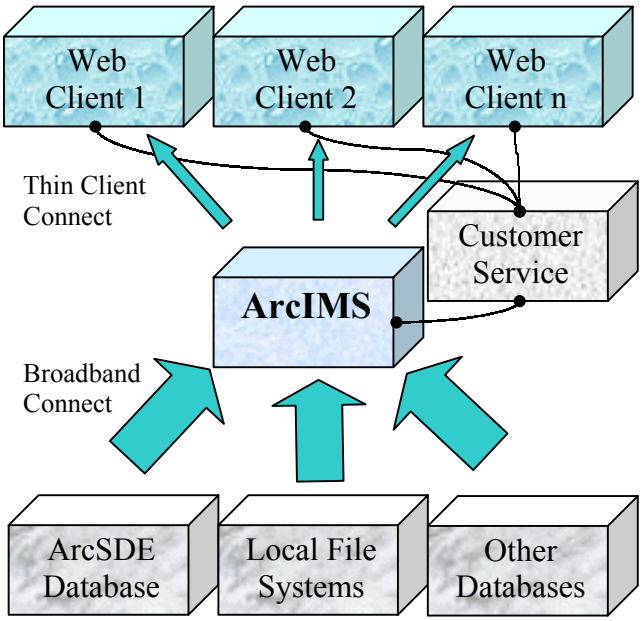

Fig. 1. METOC broker architecture tested in FBE-J. Blue arrows indicate data flow. Arrow width indicates broad or narrow bandwidth. The lines indicate the connection the Customer Service Division should have with the web client users and the ArcIMS group.

On the other hand, the connectivity between the ArcIMS and web clients are assumed to be of moderate to narrow bandwidth, because normally just graphic renditions of the data are transmitted on the network. Only, occasionally are larger data sets accessed through these lines. The web clients are various customers anywhere with authorization to access the ArcIMS through a thin client. Typically these web clients would use a standard web browser to access information by HTTP. However, this is easily expanded to include selected download capability.

To make the broker architecture complete, customer service is included to manage and closely monitor the ArcIMS. Human intervention is necessary to see to it that all reasonable requests are filled, by initiating a request to the organization that can produce the needed information. Since not everyone's processing is fully integrated into a geospatial database, arrangements have to be made for the transfer of that information into the format useable by the brokering system, i.e., available in a geospatial format for ArcIMS.

B. ArcIMS Demonstration

FBE-J provided an ideal venue for addressing customer service issues, because in the scenarios that are out in this exercise, requests for specific METOC information are posed just like in a real-world operation. A perfect opportunity was provided to demonstrate how ArcIMS could quickly answer a request as specifically as necessary. To this end a web site

was set up on the military access network to host the ArcIMS.

Fig. 2 shows the first web page that is presented to the user. From the beginning, selections are organized into categories by warfare and geographic areas of interest. Immediately upon selecting the desired categories, only the appropriate layers are made available for selection and identification, eliminating excess clutter and unnecessary information.

As soon as you make your selection, the ArcIMS service goes into action and introduces a preliminary view such as the one illustrated in Fig. 3. Along the top are buttons that give the user some basic controls over the data view. The first set of buttons includes zooming and panning the imaged view. The second set offers capabilities to extract additional information or attributes regarding points, lines, or polygons, i.e., the vector layers within the view. The third set is additional functions that are self-explanatory. Particularly, the extract feature allows the user to download vector data in shapefile format.

The center frame displays an image of vector layers and imagery data within a common geographical reference. The left side of the display allows the user to pick the layers for display. Many of these layers are dynamic and, thus, are organized by time. For example, sea state forecasts are available for the current time and for every 12 hours up to 48 hours from the current time. So, for a selected time in coordinated universal time (UTC), the dynamic layers valid for that time are available for selection. The right side shows the legend for the displayed vector layers.

Fig. 4 is an example of zooming in on an area where the layers on display include sediment type and flood and ebb currents. The bottom frame displays the result of a query of one of the points for ebb flow. Any attributes

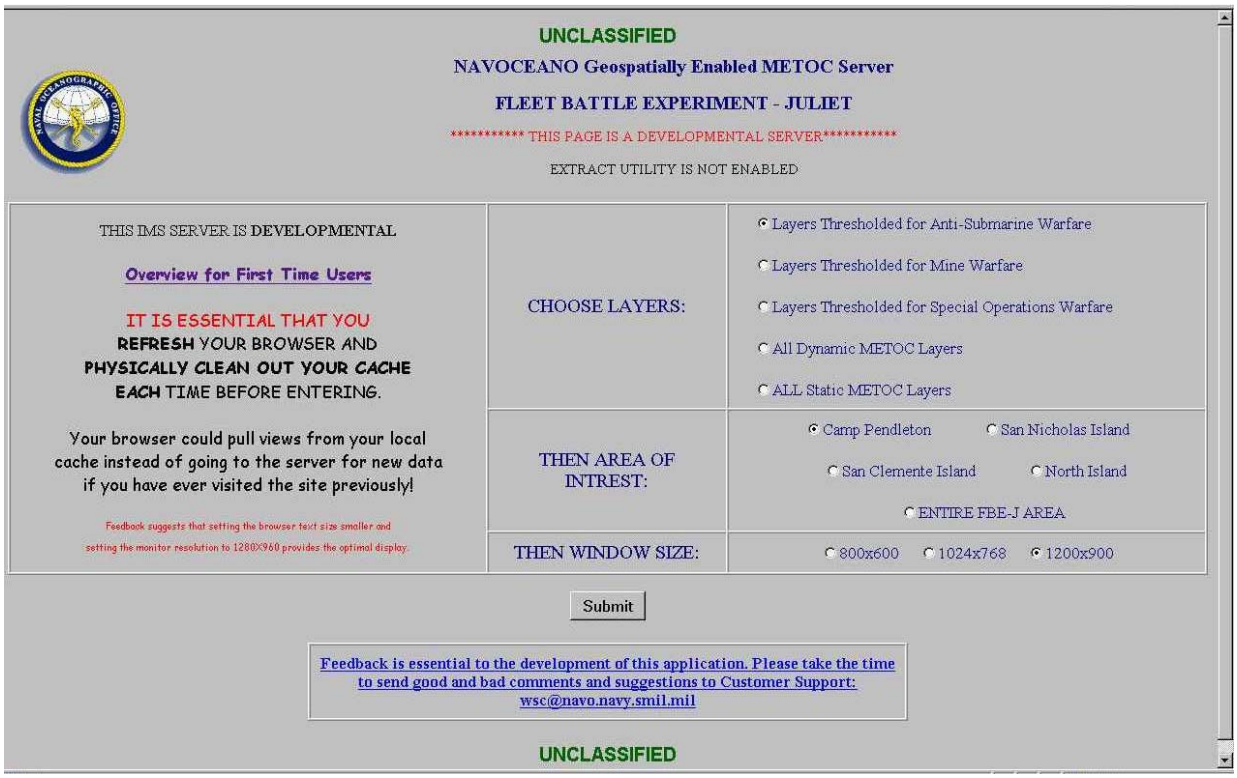

Fig. 2. This is the first page you would come to regarding access to the ArcIMS.

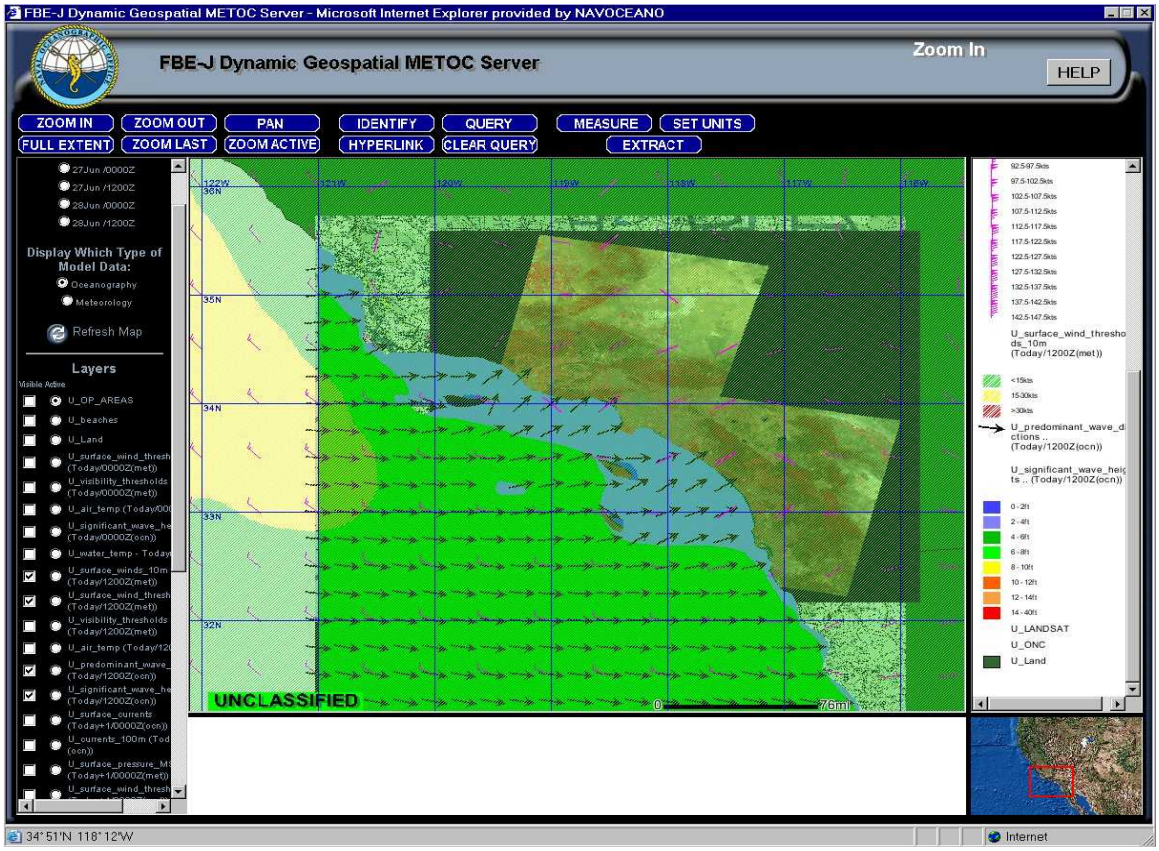

Fig. 3. An example of a first opening page in ArcIMS.

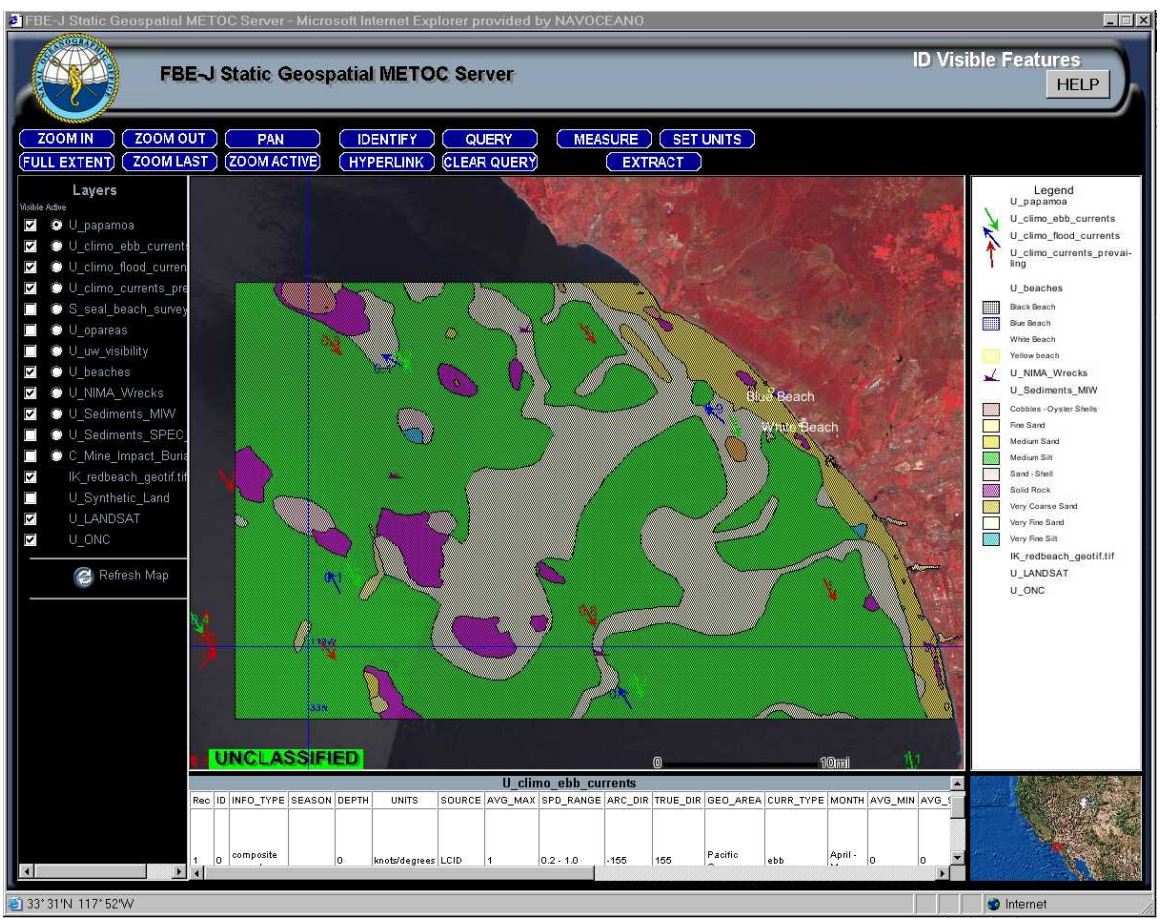

Fig. 4. An example of a zoom-in in the middle frame with attributes displayed in the bottom frame resulting from a vector query.

could be associated with this particular vector with any name as desired. This page offers selections for information that happens to be important for mine warfare.

V. LIMITATIONS

There seems to be a free license to name the data files, the metadata, or even the attributes whatever anyone likes. Eventually, users of this kind of data brokering system will need to agree upon naming conventions, especially for the attributes. This problem is not new. ISIS could not function without a standard naming convention for all the model output parameters. A coding standard is essential for the efficient manipulation of the data. Perhaps a data model sanctioned by the government, such as the FGDC, or by an international community, such as the International Organization of Standardization, would be considered.

Specific data and information resulting from METOC processing are made available through either individual queries or by using the extract function, both manual processes on the ArcIMS. But, there are various applications or locally run models running automatically on the client side, which need to get data without human intervention. Clearly an easy way to download data automatically and seamlessly through some sort of a subscription service is required.

As it stands, the ArcIMS does not allow on-the-fly annotations, looping of a series of views, or 3-D visualization. Users with special software on their machines would have to download the shapefiles or images and process them locally. For such an on-the-fly annotation capability, the ArcIMS would need to serve Java applets, or a plugin would be required.

VI. CONCLUSION

It is not that we are trying to feed data to the masses. The customer wants data, information, and knowledge that may be in a form of a picture, a massive grid of parameters to be plugged into a TDA, or just a short one-sentence summary of pertinent conditions. Ultimately, the warfighter has to make a decision based on environmental conditions, present and future. The answer regarding the environment the warfighter is looking for may have been processed in many ways and finally collected and collated using sometimes mundane routine procedures by a support METOC person savvy to the needs and desires of his supported organization. Much of this process burden can be lifted from the person in the loop with this ArcIMS technology.

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