Why Web GIS May Not be Enough:
A Case Study with the Virtual Research Vessel

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Abstract

During several decades of investigation, the East Pacific Rise seafloor-spreading center at 9-10°N has been explored by marine geologists, geophysicists chemists, and biologists, emerging as one of the best studied sections of the global mid-ocean ridge. It is an example of a region for which there is now a great wealth of observational data, results and data-driven theoretical studies. However, these have yet to be fully utilized, either by research scientists or educators. While the situation is improving, a large amount of data, results, and related theoretical models still exist either in an inert, non-interactive form (e.g., journal publications), or as unlinked and currently incompatible computer data or algorithms. Presented here is the prototype of a computational environment and toolset, called the Virtual Research Vessel, to improve the situation by providing marine scientists and educators with simultaneous access to data, maps, and numerical models. While infrastructure is desired and needed for ready access to data and the resulting maps via web GIS, in order to link disparate data sets (data to data), it is argued that data must also be linked to models for better exploration of new relations between observables, refinement of numerical simulations, and the quantitative evaluation of scientific hypotheses. For widespread data access, web GIS is therefore only a preliminary step rather than a final solution, and the ongoing implementation of the Virtual Research Vessel (scheduled for final completion in 2004-2005) is a case study for the mid-ocean ridge community to test the effectiveness of moving beyond the "data-to-data" mode towards "data-to-models" and "data-to-interpretation".

Keywords web GIS, computational environment, mapping and exploration, seafloor-spreading, mid-ocean ridges, interdisciplinary science

Introduction

Research in the earth sciences routinely yields a wealth of observational data and results spanning a range of disciplines, including geology, geophysics, chemistry, theoretical fluid mechanics, and biology. In terms of marine geological and geophysical studies focused on the globe encircling mid-ocean ridge, data collections of ship-based of multibeam bathymetry, sidescan sonar, photographic and video imagery, multichannel seismics and the like are growing at a rapid rate (Figure 1). The newest high-resolution mapping systems provide digital images of the seafloor at sub-meter pixel resolution and can generate data at sea on the order of gigabytes per day (Smith et al., 2001).

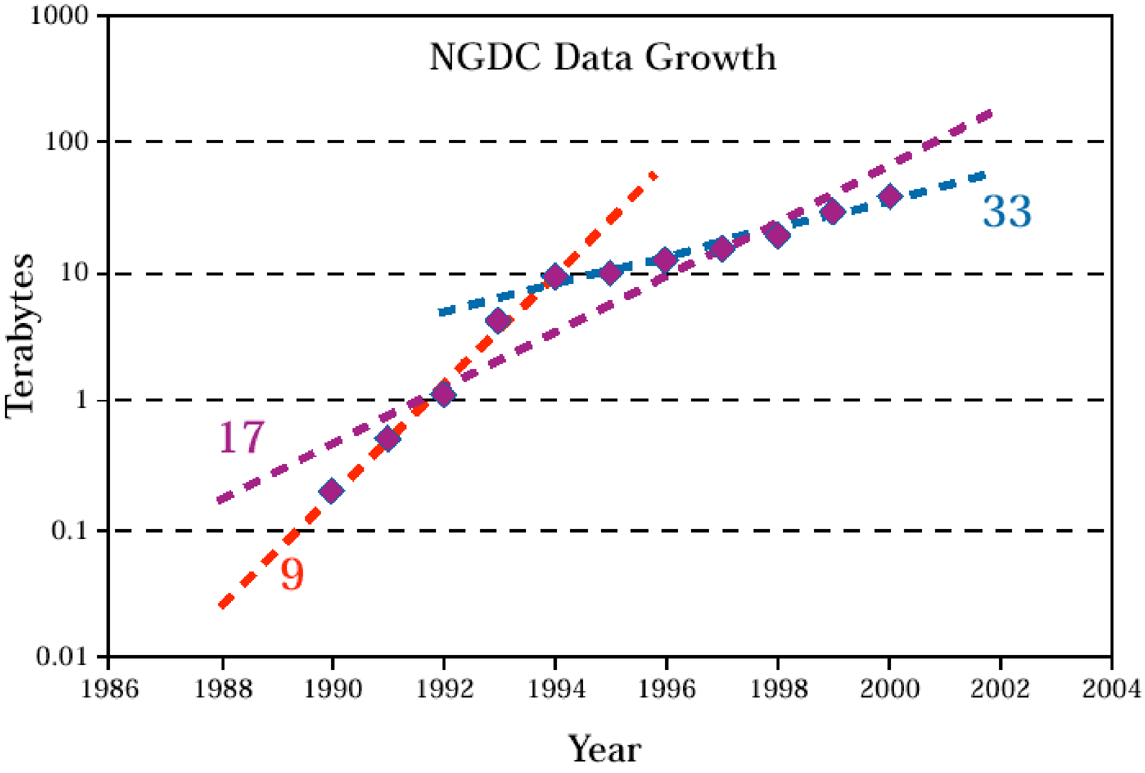


FIGURE 1 Growth in the digital data holdings of marine geophysical data (primarily multibeam and trackline bathymetry, seafloor topography from satellite altimetry, gravity and

magnetics) at the National Geophysical Data Center (NGDC) since 1990 (after Smith et al., 2001). Dashed lines show data-doubling times of 9, 17 and 33 months.

The East Pacific Rise (EPR) at 9°-10°N is currently one of the best-studied sections of the global mid-ocean ridge (Figure 2). Several decades of shipboard investigation by the full spectrum of ridge investigators, including geologists, geophysicists, chemists, and biologists, has resulted in a wealth of observational data, results and data-driven theoretical (often numerical) studies. However, much of these data and information have not yet been fully utilized, either by research scientists themselves or by professional educators. Most of it exists either in an inert, noninteractive form (e.g., journal publications) or as unlinked and incompatible data sets, algorithms, and models. Mid-ocean ridge scientists have taken the first steps in data archiving, but mere collections of publicly-available data will not be sufficient. Scientists will need a wide range of sophisticated programming support to coordinate not only the access and use of data, but associated computational tools and numerical models across distributed networks of computers.

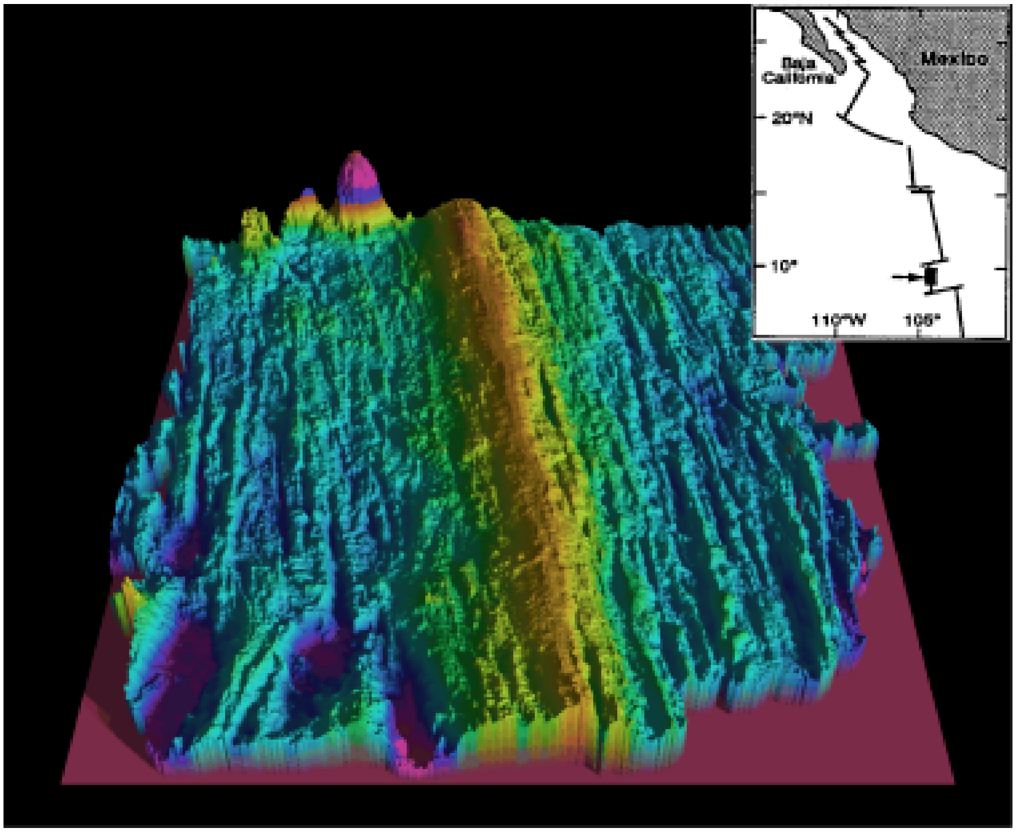


FIGURE 2 Three-dimensional visualization of bathymetric data from the East Pacific Rise, 9-10°N. Visualization developed from a grid of cell size 80 m, vertical exaggeration is 20x. Inset map at top right shows location of the region with respect to Mexico and Baja California. Solid lines trace the axis of the East Pacific Rise; small arrow and rectangle show location the 9-10°N segment.

To cite an example, two topics of particular interest to investigators of the EPR have been the physical structure of axial magma chambers and the nature of hydrothermal convection. To a large degree, studies of these processes have proceeded independently of one another. For example, seismologists have been engrossed with imaging seismic velocity and attenuation of the rise in an effort to map the spatial dimensions and physical properties, such as temperature and melt fraction, of the crustal magma system (Toomey et al., 1990, 1994). Whereas geologists and chemists have been equally engrossed with mapping the surface expression and chemistry of active vent fields (Haymon et al., 1991; Von Damm, 2000), from which attempts are made to infer the nature of hydrothermal circulation at depth (e.g., how deep and in what geometry do fluids penetrate the crust? Cochran and Buck, 2001; Davis et al., 1996). Such independently conducted studies are linked by a common process: the interaction of hydrothermal fluids with an evolving magmatic system.

To date, only first-generation numerical models of axial thermal structure have been developed (e.g., Dunn et al., 2000). Moreover, these models have not yet been used to link in a quantitative manner their numerical predictions with seismic, geologic or chemical observations. While a realistic model of hydrothermal-magma chamber interactions will require years of continued research, the development of such a model will be greatly aided by a research environment that permits models and data to be explicitly linked. Having stated this though, the development of new numerical models is beyond the scope of the VRV project, which is intended primarily as a testbed for existing models.

Recently seismologists have predicted crustal thermal structure from detailed tomographic images (Dunn et al., 2000; Figure 3). Seismically predicted isotherms provide a constraint on numerical models that has not yet been fully utilized. Specifically, previous thermal models have attempted to fit only the depth to the crustal melt lens, assuming that its width was fixed and that convective processes could be mimicked by enhanced thermal conductivity. A linked numerical experiment, one that combined seismic and numerical predictions in a quantitative manner could be used to explore the consequences of these assumptions. Such experiments may help to understand what controls the width of magma chambers and/or to what depths do hydrothermal fluids penetrate. This example is typical of the types of research that could be supported with a database environment that allows coupling of disparate types of data and models. A model that predicts temperature, stress, chemical fluxes, etc., has a great potential for becoming unwieldy unless it can be efficiently verified against actual observables.

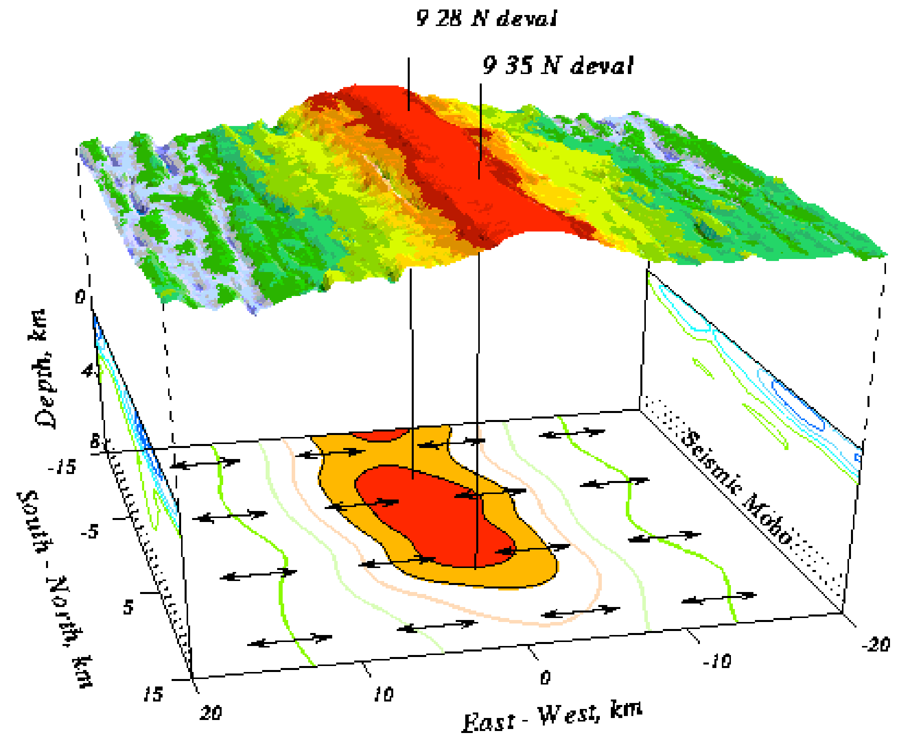


FIGURE 3 Seafloor bathymetry and results of seismic tomographic imaging on the East Pacific Rise, at 9°30'N (from the TIERRA project, http://www.csi.uoregon.edu/projects/tierra/tierra_overview.html and Dunn et al., 2000). Seismic tomography samples the Earth's interior via earthquake waves recorded by seismic instruments. Velocity anomalies are shown at a 0.2 km/s contour intervals, and arrows in the horizontal plane indicate orientation of the fast axis of anisotropy (properties such as temperature, strain, and melt varying in different directions). "Deval" signifies deviation in axial linearity, which may affect the distribution of magma on the seafloor along the axis of the rise.

This paper describes the rationale for a prototypical computational environment called the Virtual Research Vessel (VRV), that incorporates web GIS (for viewing, loading, and selecting subsets of data), but also a separate relational database management system (RDBMS) and application programming interfaces (APIs) to support coupling of numerical models. The goal of such a computational environment is to allow researchers to undertake interdisciplinary experiments that computationally link disparate data and/or numerical simulations, thereby providing unprecedented abilities for exploring new relations between observables, quantitatively evaluating hypotheses, and even refining numerical simulations. An additional goal is the ability for researchers to build self-consistent models of complex phenomena from existing models of isolated phenomena. The prototype, a work in progress, provides a case study for the deep ocean mapping community as to whether this coupling will work for toward the desired goal, and community input and test databases are currently being incorporated. As two of the other major components of VRV come online and are linked to the web GIS interface, follow-up articles will be published describing the results of the coupling of all three technologies.

General VRV Architecture

Identifying which data needs to be accessible to the mid-ocean ridge community and then providing physical access to the data are important first steps. A current inventory of data identified by EPR and other mid-ocean ridge researchers (e.g., Smith et al., 2001; Haymon et al., 1998; Wright et al., 1997; Wright and McDuff, 1998) includes: (a) seafloor geology, including vent locations, swath bathymetry, camera observations, SeaMARC II, HMR-1, or DSL-120 sidescan data, *Argo I* and *Argo II* towed camera and video observations; (b) chemical data from hydrothermal vent or rock samples; (c) geophysical results, including maps of crustal lithology, location, depth and character of the axial magma chamber reflector, crustal thickness, seismic velocity; (d) physical properties inferred from geological and geophysical data, including rock density, temperature, or porosity; and (e) biological vent community distributions.

To move closer toward effective use of the data for computational analyses, the construction of a commonly-accepted data model is also crucial for a community database, as shown by the molecular biology community, (Goodman et al., 1995). In addition to data format, one must also define what metadata will be archived and how commonly-coded values and keywords or thesauri (e.g., the Federal Geographic Data Committee (FGDC) metadata standard or the National Science Foundation (NSF) Long-Term Ecological Research metadata guidelines, which are based on the FGDC standard) will be managed. These three components (data requirements, data model, and metadata requirements) necessary to building the database infrastructure are akin to an architectural blueprint for database construction (Cushing et al., 1994, 1997).

Even with such design documents, however, a basic computational environment for mid-ocean ridge data cannot be constructed with current technology because one technology alone cannot currently meet the needs of the mid-ocean ridge community. This is supported by the recommendations of a recent NSF workshop that identified major problems inhibiting the exploitation of multidisciplinary collaboration in scientific analysis, in particular a lack of technology to make information accessible for interpretation and sharing (Patrikalakis, 1998). An additional challenge is that commercial database systems available to researchers were in fact, designed and built for business applications, not science, and thus need additional functions appropriate for scientists. This is slowly improving however, with the introduction of revisions such as Oracle 9 that can now handle spatial data. Finally, mid-ocean ridge scientists will need to move smoothly between different components of a system, between GIS and functional data without being a GIS expert. Such “glue” is not available commercially.

Part 1 of VRV: Web GIS

While GIS has existed for over three decades, the development of web GIS is a recent phenomenon. The huge popularity of the Internet around 1995, spurred the development of new resources for networking GIS data. The variety and types of distributed geographic information applications have grown since then, consisting of formats ranging from static and dynamic map images to more advanced web GISs that offer greater functionality (Xue et al., 2002). With the development of web GIS, the Internet is now becoming a portal for GIS functionality as well as data distribution. This development is following a natural progression of increasing efficiency in GIS (Chueng, 2001), but as is discussed below, is also subject to some of the same challenges. Versions of web GIS have been continually improving in functionality, from simple data viewing abilities to performing spatial analysis and collaborative efforts in real time from remote locations (Plewe, 1997). Indeed, many experts predict that web GIS may eventually become the dominant format for accessing GIS (Longley et. al. 2001; Xue et al., 2002), which is an issue that was taken into account in the development of the VRV as an initial data portal for the EPR scientific community.

With the current level of functionality of web GIS, the concept is ideal to use in lieu of a full GIS program for users that only have simple GIS needs. It provides a method for people who do not have in-depth GIS skills to view data specific to an area of interest by using a simplified interface that the site creator can customize to meet specific needs. A full GIS requires the local installation and licensing of expensive software, as well as powerful hardware with considerable storage space for very large GIS data sets.

The VRV web GIS is based on ESRI's ArcIMS v. 3.1, and runs on a 800 Mhz, Windows 2000 Dell Precision Workstation220, with 384 Mb of RAM in 2 processors. The web server is Apache 1.3.23 with Jakarta Tomcat Servlet Engine, and Java™ 2 SDK with Java Runtime Environment. The basic structure of ArcIMS consists of the server (the distributor) and the client (the viewer) functions, in addition to the web server, servlet engine, and the web browser on the client end (Figure 4). The ArcIMS Spatial Server is where all of the client requests are processed, while the ArcIMS Application Server acts as a secretary, handling requests and keeping track of what services are running and where. ArcIMS Connectors are written in ArcXML, a variation on Extensible Markup Language (XML), to structure data and to facilitate communication between the web server and the ArcIMS Application Server. ArcIMS Manager is a web-based interface where MapServices (files that store the spatial data to be displayed online) are created, the web pages designed, and the site is administered. Data sets used to create a MapService may be stored as ASCII text files on the system, or by way of Arc Spatial Database Engine (ArcSDE). Finally, ArcIMS Viewers determine how the web site will be displayed, either through an HTML viewer that is accessible to all browsers, but limited in functionality, or via a Java Viewer, with greater functionality but more limited browser accessibility (clients must have Java plug-in that runs best on Windows 2000 Internet Explorer). O'Dea (2002) provides additional details on web GIS installation, functionality, and site design.

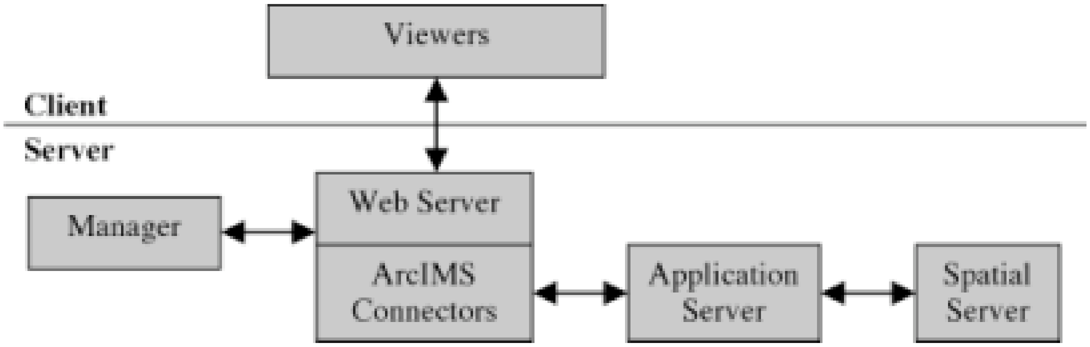


FIGURE 4 General architecture of ArcIMS (after Environmental Systems Research Institute, 2000).

Figure 5 shows an example of how the web GIS, similar to its desktop GIS parent, provides the ability to organize, retrieve and view data spatially, enabling scientists to integrate several databases into a single, georeferenced system. Logical queries can be made and spatial relationships can be seen between various layers or themes of data. This provides a rapid, “unselfish,” and logical way of disseminating knowledge to the community for rapid response to future mid-ocean ridge events such as megaplumes or volcanic eruptions indicated by seismic events. This component of VRV is meant to be an exploratory tool for EPR scientists to view simple spatial relationships between various data sets, many of which may still be foreign to them. For instance, vent biologists may not be familiar with what chemical or geological data exists near the sites that they have sampled on the seafloor with a submersible. Or geophysicists may want to plot earthquake epicenters from beneath the seafloor through time, note the clustering of those events, and how that clustering might be related to the locations and temperatures of hydrothermal vents on the seafloor itself.

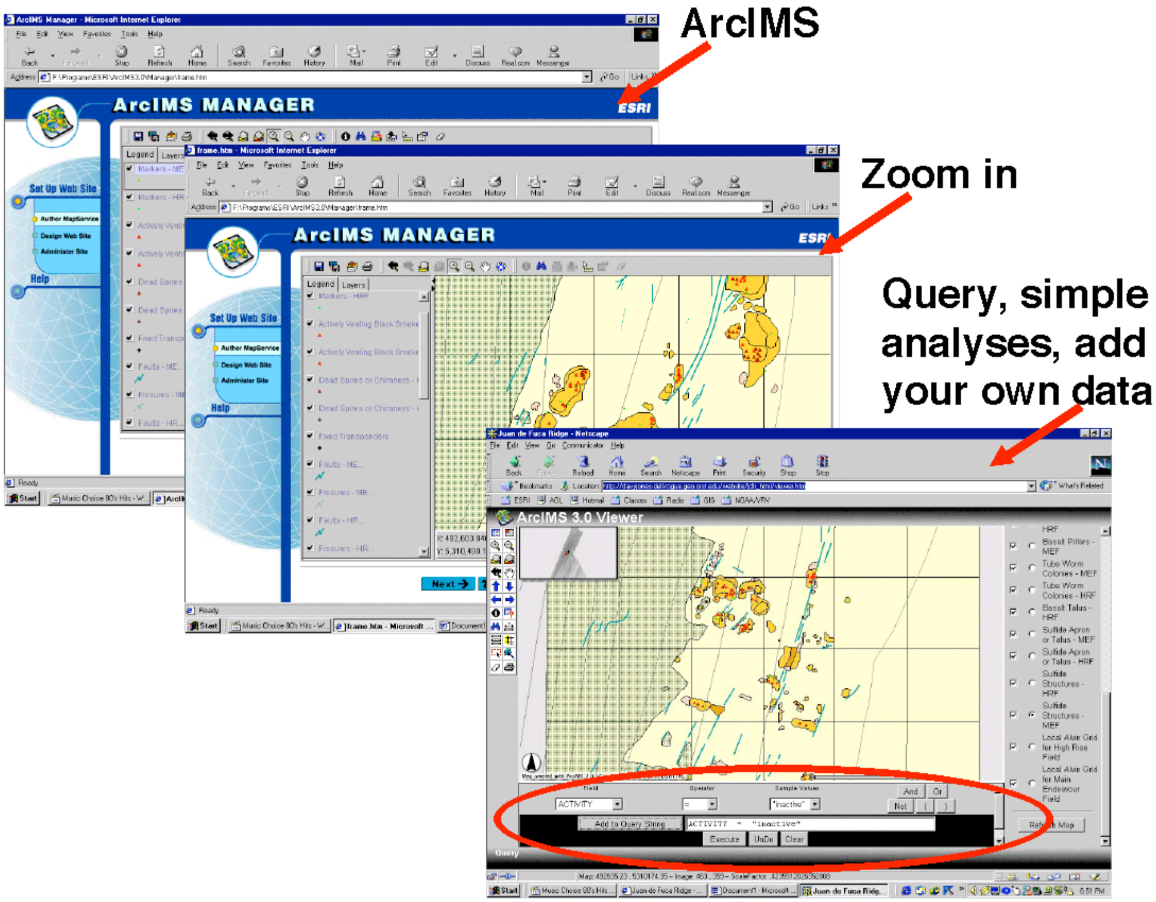
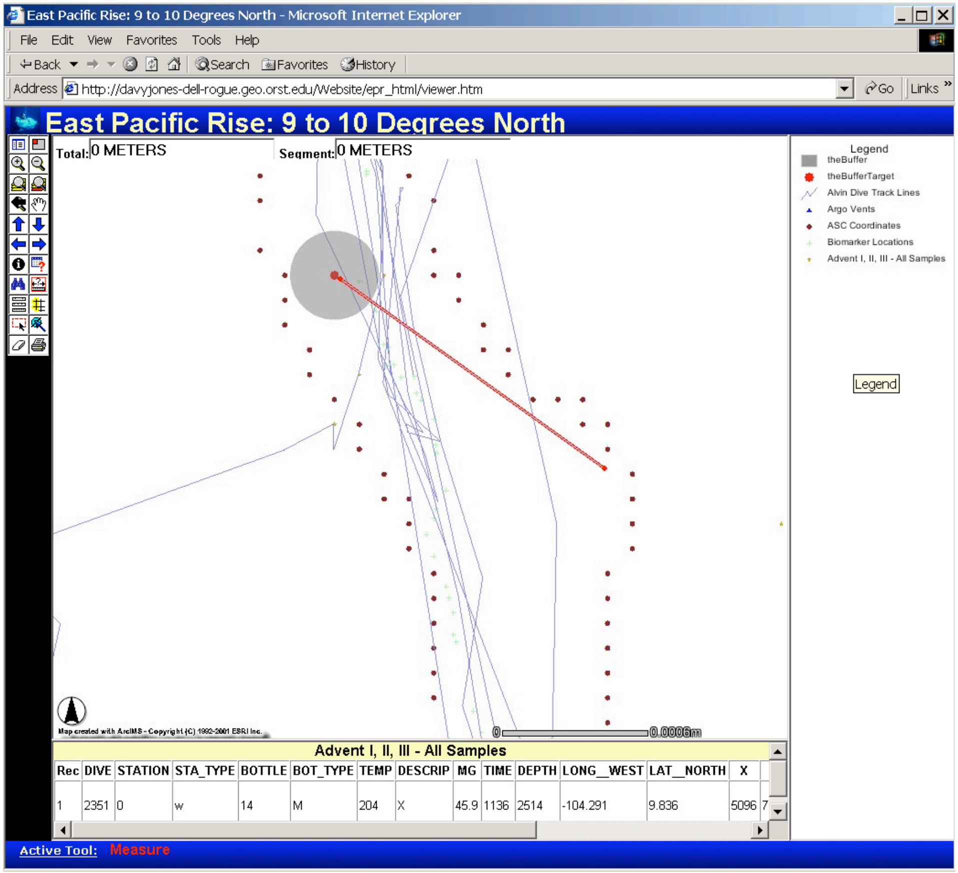


FIGURE 5 Example of a web GIS prototype for the VRV, using ESRI's ArcIMS, to provide simultaneous access to both data from a web server and local data from a desktop client,

streaming of vectors instead of pixels for better looking maps, and functions for spatial query and analysis. Data are from the EPR (Haymon et al., 1991; Kurras et al., 1999; and Wright et al., 1995), as well as the Endeavour Segment of the Juan de Fuca Ridge in the northeast Pacific (Wright and McDuff, 1998).

Figure 6 illustrates some typical web GIS operations that an EPR scientist might execute. It should be noted that EPR scientists are typically not GIS power users and wish to use the web GIS mainly for data exploration and validation. The dots show the location of the outer wall of the axial summit caldera on the EPR within which most volcanic and hydrothermal activity of interest occurs. The location of a hydrothermal vent has been buffered (gray circle in Figure 6) out to a distance representative of a hydrothermal plume that might emanate from the vent, which can then be compared to current and planned tracklines of submersibles or remotely-operated vehicles in the area. The user may also measure distances, such as the distance from the vent site to the opposite wall of the caldera where another sample has been gathered (red line in Figure 6). Images or video clips may also be incorporated via "hotlinks" to locations on web maps such as these. And the user may have simultaneous access to both data from a web server and local data from the client’s desktop, along with the ability to dynamically edit and annotate maps. For the VRV, functions are also being written to allow users to contribute their own spatial data layers, and to export layers to formats that can be converted to 3-D for input to scientific visualization packages on the desktop and to Parts 2 and 3 of VRV (see sections below).



Total: 0 METERS

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Advent I, II, III - All Samples

Rec	DIVE	STATION	STA_TYPE	BOTTLE	BOT_TYPE	TEMP	DESCRIP	MG	TIME	DEPTH	LONG__WEST	LAT__NORTH	X	
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FIGURE 6 Second example from the web GIS prototype for the VRV, showing typical operations that a scientist might execute. See text for explanation. Data are from the EPR (Haymon et al., 1991).

Web GIS is therefore deemed as an effective way for an entire community of EPR scientists from several different labs and academic institutions around the world to initially encounter data before proceeding to transfer data to associated computational tools and numerical models. Current data consist of vector layers such as locations of hydrothermal vents, colonies of important vent biota (e.g., tubeworms, clams, mussels), faults, fissures, and lava flows, and tracklines and sample stations underwater vehicles, as well as raster layers of bathymetry that are being integrated via ArcSDE. In sum, the web GIS interface may be used as an atlas to find, view, and query the data, but also to translate between data formats and to execute simple spatial analyses (buffering, data clipping), and dynamic editing of data and annotation of resulting maps. The web GIS prototype is available at http://oregonstate.edu/dept/vrv.

Why Not Web GIS Only

Despite the increasing popularity of the web and web GIS as a means to disseminate information in the form of maps and digital data, many barriers to efficient and effective use persist (summarized as pertaining to government applications by Evans et al. 1999; McKee 2001). And while web GIS offers very effective ways to build and view mid-ocean ridge databases, there remain a number of shortcomings in using it as the sole environment for data storage and analysis. Indeed it is more effective when coupled with an "industrial-strength" RDBMS such as SQL Server, Sybase, Oracle or GemStone, as well as with numerical models. If one defines web GIS, at least in the way that it is implemented for the VRV prototype, as merely the front end of an "industrial strength" GIS that might be running on a single server or desktop, it follows that the general shortcomings of GIS will propagate to the realm of web GIS. While the situation is improving, specific issues that remain for the oceanographic community include the following.

*Management of Non-Spatial Data***.** Combining spatial and non-spatial data presents unique challenges to data management and access over the web. Few web-based GIS environments have tools "out-of-the-box" for importing data and validating that data against a metadata profile as it is loaded into a database. Similarly, while GIS provides excellent end-user query capabilities, and simple data export capabilities to spreadsheets or single user databases, they are built around having a “map coverage” as the organizing principle of any particular data set (e.g., a map file and an associated attribute file), which can be problematic for the calculation of parameters that are not quite ready to be mapped in a traditional x-y or x-y-z space (such as calculated isotherms of temperature in x-z as predicted from seismic measurements). And although many web GIS have simple RDBMS environments imbedded in them it is not easy to connect them to more powerful products such as Oracle, Sybase, or DB2. These RDBMSs have better tools for reorganizing and packaging data for export to *non-spatial* uses and the technology for multi-user access and security is more well-developed.

*Accessibility***.** Within the community of EPR researchers we cannot assume that everyone is using GIS, and various data formats (GIS or non-GIS) vary according to the underlying data structure (vector or raster). However, RDBMS technology for providing web-accessible databases in flexibly specifiable formats, and for uploading and validating data via the web, is currently well understood. Following the example of the USGS EROS Data Center, EPR data within VRV are viewed cartographically, but available for download to the user via RDBMS. In this way the data may be still be imported to an offline, desktop GIS local to the scientist.

Time Series Data. Most GISs, web-based or desktop, currently have only rudimentary support of time series data. RDBMS support for maintaining and viewing data as a time series is better understood, primarily because of heavy use of time series by banks and stock exchanges who have lobbied DBMS companies for this functionality. As the VRV prototype progresses, links will be provided from the web GIS to special purpose programs that provide time series analysis.

Three-dimensional (3-D) Visualization. While current web GIS environments support two-dimensional geographic distributions very well, they do not provide easy-to-use 3-D or volumetric analysis in concert with the web mapping. In fact, RDBMSs do not provide this capability directly either, but it is probably easier to provide data directly to a web-based scientific visualization application from an RDBMS than from GIS. Most RDBMS' can export data sets to simple x-y-z files in one or two steps, whereas it is still difficult to export the proprietary formats of commercial GIS packages to formats seamlessly readable by packages such as Dynamic Graphics, IBM Visualization Explorer, or Spyglass. However, this is fast changing, and a good example is the new ArcConverter software filter that transfers data layers from an ArcView project directly to a format that can be interpreted by the Fledermaus visualization system (Fonseca et al., 2002). However, ArcConverter must still be run manually on the desktop and is not yet integrated into a web environment, nor is Fledermaus. A stop-gap solution may be to export everything to VRML but it would be difficult to access the attributes of the data.

Computational Models and Experiment Flow. GIS have excellent capabilities for connecting maps to computational models or for linking programs running on one platform to those running on another. And rigorous models are slowly being incorporated into GISs (e.g., MODFLOW for the hydrological community). However, these inclusions and linkages remain in the realm of terrestrial surface hydrology, groundwater contamination, and climate, and are not common within the mid-ocean ridge community. And there still remains no way to schedule even one, let alone a series of, computational experiments within a GIS, web-based or desktop, or to easily provide templates in a computational tool description for extracting data or importing results.

VRV Web GIS Empowered by Parts 2 and 3: Database Support and Model Coupling

This section suggests some solutions to the shortcomings previously outlined. First, appropriate database design elements for a computational environment such as VRV should not only include data access via web GIS, but a data model and data dictionary component with commonly used mid-ocean ridge data structures, tables of commonly used coded values, a dictionary of commonly used instruments (used for data *collection*), a thesaurus of commonly used terms, and a hierarchically organized list of commonly used keywords. These will enable mid-ocean ridge scientists to describe their data using consistent descriptors, and allow researchers from different sub-disciplines to navigate databases efficiently.

VRV Part 2 focuses on common data models that can provide data, programs and metadata in a uniform manner, and includes: 1) a data model for marine geology data that abstracts across cruise formats; 2) an infrastructure so that metadata for data sets published with different formats, or buried within data files, can be viewed as if they were all of the same format; and 3) a distributed infrastructure so that data files and application output could be viewed as database queries. The metadata viewer (2) and the infrastructure for integrating marine geology data and applications (3) use LeSelect, a framework for accessing heterogeneous data and programs over Internet environments developed by E. Simon and colleagues at the Institut Nationale pour Recherche en Informatique (INRIA), France (http://www-caravel.inria.fr/~leselect/). LeSelect provides an underlying mechanism for distributed access to files, databases and programs. For VRV, it is extended by providing wrappers that map marine geology data files, metadata and programs onto commonly recognized names and formats, and clients that provide a uniform application interface for marine geology (Figure 7).

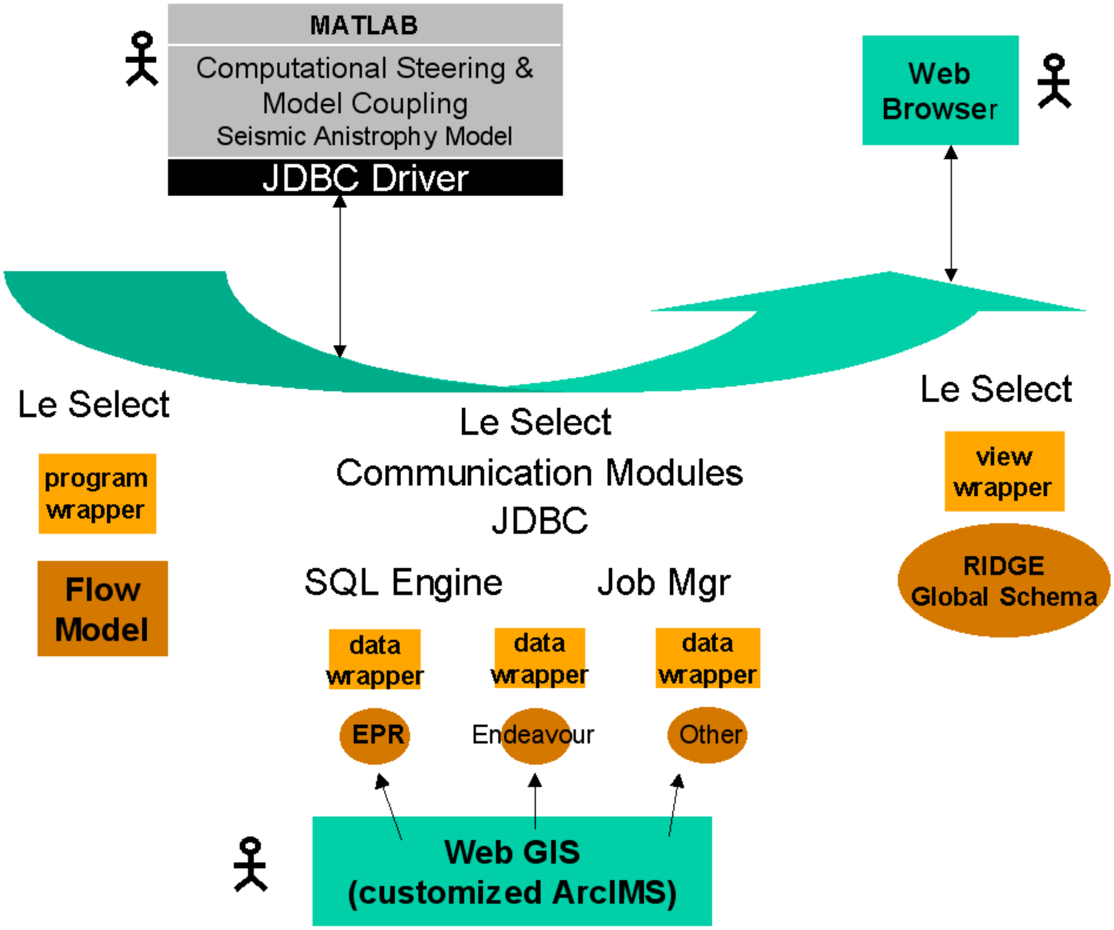

FIGURE 7 Design diagram for how various parts of VRV may work together. An existing tool, LeSelect, can be used in combination with web GIS, RDBMS and model coupling applications to run across platforms. In this hypothetical example, Le Select is allowing publishers of EPR, Endeavor and other mid-ocean ridge data to make those data appear similar to the global schema (also published, at right) by writing data wrappers that describe the data sources in terms of one or more tables and variables in each table. A data source may be an SQL database, or a flat file, or an XML file, etc. A data wrapper establishes correspondence between the names that the API (or user at the web browser) expects and those explicitly in the data source. Le Select allows the user to issue an SQL query against the published data sources. Locations of data sources appear similar to URLs. Le Select also allows the publication of programs that execute on foreign hosts. Input to a published program can be given as an SQL query (which will be issued by Le Select). Output from the program will be deposited as a file described by an output query (which must be issued by the user or API to get the data).

Second, many computational models of isolated phenomena are now well understood and captured in robust programs. The challenge now, for the ridge community as well as many other scientific communities, is to couple these models into self-consistent representations of more complex processes (Cuny et al., 1997). Coupling is more complex than program composition. Scientists are faced with the poorly understood task of establishing sophisticated time-varying relationships between models and large, multi-dimensional data that are heterogeneous in quantity, quality, scale, type, and ultimately importance. To accomplish this, they will need more than standard coupling mechanisms; they will need support for dynamically exploring model correlations and relationships at a very high, domain-specific level (Figure 7).

Work in progress for VRV Part 3 includes building the infrastructure to support the fast prototyping of model couplings. Robust, abstract descriptions of existing computational models (existing code) will be made available in a common SQL database, a graphical interface will allow scientists to easily specify couplings between models, and the required interfaces and runtime monitor will be automatically generated.

□

Conclusion and Future Directions

VRV represents a unique case study for the mid-ocean ridge community to test the effectiveness of moving beyond a "data-to-data" mode (linking disparate data sets together) towards "data-to-models" and "data-to-interpretation". VRV is a prototype, the development of which is still ongoing, with the completion of Parts 2 and 3 expected in late 2003/early 2004. One portion of VRV supports the viewing, loading, selection of subsets of mid-ocean ridge data via web GIS, but it is argued here that web GIS may not be enough. While an infrastructure for ready access to data and maps is certainly desired and needed, data must also, at times, be linked to numerical models for better exploration of new relations between observables, and the quantitative evaluation of scientific hypotheses. For widespread data access, web GIS is therefore only a preliminary step rather than a final solution. VRV is therefore endeavoring to incorporate three technologies (none of which alone can meet the needs of mid-ocean ridge researchers): web GIS, a separate, more robust RDBMS, and APIs to support the coupling of numerical models.

As this environment is developed outreach and ongoing communication with the mid-ocean ridge community, including workshops, demonstrations, test deployments of the system and documentation, will help to refine the final product. Initial workshops are planned in 2004 to help define the data model and metadata requirements and to teach the basic operation of the VRV prototype to a wider audience. As all three parts of the prototype come together demonstrations will be conducted at mid-ocean ridge scientific meetings, and the entire prototype, along with sample EPR databases, will be deployed to selected laboratories.

Once the VRV prototype is refined and stabilized (including documentation for the software), a final teaching and system evaluation workshop in late 2004/early 2005 will be conducted for EPR researchers, including solicited feedback from the focus laboratories that have tested VRV. Particular attention will be paid to the possible deployment of a desktop version of VRV, that researchers will be able to run locally, should access to the web prove impractical on visits to the field (i.e., going to sea) or too slow for certain kinds of data analysis.

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