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Guest Editorial

Data from the deep: implications for the GIS community

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Abstract. The traditional home of GIS in terms of managing, mapping, modelling and making decisions based on spatial data has been in the land-based sciences and professions. This has resulted in a concentration of GIS on land-based 'application domains' (sets of GIS applications with common properties and data formats), with a relatively homogeneous group of users and applications addressing the solutions of largely related problems. This atmosphere has tended to obscure the essential nature of GIS as an ubiquitous, heterogeneous tool, having utility far beyond land-based problems. We must consider remedying this if we expect GIS to play an increasingly important role in Earth system science or global change research. We therefore propose the expansion of a largely land-based GIS research agenda to the development of systems focusing more on the marine environment, for there are many ways that GIS may be improved by tackling the problems associated with oceanographic data. The discussion is confined largely to deep ocean science which rarely appears in the GIS or geographical literature (as opposed to coastal zone studies). We identify research issues endemic to oceanographic applications of GIS that will advance the body of knowledge in GIS design and architecture, as well as the body of knowledge in the broader field of geographical information science. They include the development of spatial data structures with the ability to vary their relative positions and values over time, geostatistical interpolation of data that are sparse in one dimension but abundant in the others, and new data models that make the feature-based query, search and retrieval of objects and continuous fields in very large spatial databases more efficient.

1. Introduction

Jerome Dobson in a recent *GIS World* article (Dobson 1995, p. 40), raises an important issue: 'What fascinating new frontier will captivate the public and serve pragmatic interests as vital as the military's, while creating vast opportunities for jobs and investment? I find it difficult to propose a surefire winner on all counts, but I will nominate my favorite contender: the ocean.' Indeed, the oceans cover 70 per cent of Earth and provide a window to the planet's most powerful and destructive force, plate tectonics. And yet we still know more about the topography of Venus (99 per cent of which has been mapped in enough detail to reveal features on the order of 50 m in height) than we know of our own ocean floor (less than 10 per cent has been charted at a similar resolution). The situation is improving as multi-agency and multi-disciplinary national and international research programmes continue to push back the barriers in understanding this final frontier. Two examples of such megascience research programmes are the Ridge Inter-Disciplinary Global Experiments (RIDGE) initiative for understanding the geophysical, geochemical and geobiological aspects of the global seafloor spreading system (Detrick and Humphris 1994) and the Global Ocean Observing System (GOOS) for observing and predicting global climate (Van Dop 1993). And the recent (July 1995) declassification of data from the U.S. Navy's Geosat satellite, combined with European ERS-1 satellite data, will give oceanographers an unprecedented ability to study in finer detail the global plate tectonic activity that has occurred on the ocean floor over the last several million years (Carlowicz 1995). So at long last there is no lack of high resolution data for imaging and understanding the deep oceans on a global scale, as well as the coastal environs.

This is perfect fodder for GIS, whose data integration, display, and analysis capabilities are playing a greater role in helping marine scientists to unravel the mysteries of the deep (e.g., Li and Saxena 1993, Mason *et al.* 1994, Wright 1996, Bobbitt *et al.* in press). The cost alone of acquiring oceanographic data (e.g., an oceanographic research vessel normally costs $15 000–$20 000 per day to operate) justifies the development of dedicated systems for the integration and interpretation of these data. The ability provided by GIS to synergize different types of data collected from multiple sampling platforms has provided the oceanographers community and policy decision-makers with more information and insight than could obtained by considering each type of data separately (e.g., Hall *et al.* 1995, Wright *et al.* 1995, Fox *et al.* 1996). And yet, despite this potential there are a number of impediments that stand in the way of a more complete integration of GIS with the marine environment, particularly the deep ocean. The situation is analogous to the call for a better integration of GIS with environmental models and global change as evidenced by NCGIA Initiative 15 (Goodchild 1993, Goodchild in press).

The traditional home of GIS in terms of managing, mapping and modelling spatial data and associated attributes, as well as spatial decision-making, has been in the land-based sciences and professions. And through processes of legacy and commercial interest, it has also inherited its data models from terrestrial sources. Data models lie at the very heart of GIS, as they determine the ways in which real-world phenomena may be represented in digital form. It is therefore the underlying data model that constrains what levels of processing, analysis, modelling and perhaps interpretation, are possible with the GIS. Improvements in or extensions to data models are possible only through a greater understanding of the data in question. In terms of oceanographic data, it is important to understand how it is different from terrestrial data and what opportunities this presents for improving GIS, regardless of application domain. What follows is a discussion of what sets marine data, and ultimately a marine GIS, apart from the land-based domain. Lockwood and Li (1995) provide a brief treatment of this in a recent special issue of *Marine Geodesy*, devoted to marine GIS. We add to their comments and propose a specific research agenda along the way.

2. The nature of oceanographic data: research opportunities for the GIS community

Although oceanographic data are geographically referenced, oftentimes locations and boundaries are fuzzier than in terrestrial environments, where there are fewer control points with known coordinates such as street intersections or building corners. Also, entities in the marine environment are more likely to change location than in a terrestrial environment. The location may change due to the physical processes (currents, lava flows on the move, etc.) or due to the varying resolution or frame of reference of the vehicle or instrument that derived the location. For example, in marine geology, bathymetric data (i.e., depths to the seafloor) collected from a swath mapping system located *underneath* a ship may be georeferenced to underwater video images or sidescan sonar data (i.e., images acquired by measuring the back-scatter strength of a reflected sonar signal from the seafloor) collected from a vehicle towed *behind* the ship at tens to thousands of metres *above* the seafloor, to geological samples sites, observations, temperature measurements, etc. collected from a submersible launched *away from* the ship and operating directly *on* the seafloor. The frame of reference may change based on the positioning of underwater microphones placed on the seafloor for the navigation of vehicles and submersibles. These microphones are often recovered and redeployed with a study area and may be shifted about on the seafloor by currents or volcanic activity. In terrestrial applications GIS data are often created by measuring the positions of features with respect to the geodetic control network, or features with known locations. This happens in traditional surveying, and also in the process of registering images, and registering maps for digitizing. The USGS and other agencies produce Digital Line Graphs (DLGs) and other data sets that provide a framework function by allowing other features to be registered to them. In the oceans where there is no geodetic control or framework, measurements are often collected with respect to the locations of objects like ships, which are themselves moving, and may have poorly determined locations. It would make sense if GIS designed for these kinds of applications could store locations in relative form, and if the locations of framework monuments such as ships could be stored in ways that capture movement through time and uncertainty of position. This kind of architecture, emphasizing relative position rather than position with respect to a fixed Earth frame, has been talked about in terrestrial GIS for many years, but not widely implemented. It has sometimes been termed measurement-based GIS, to distinguish it from traditional coordinate-based GIS. Research is needed on the development of measurement-based spatial data structures that would be able to vary their relative positions and values over time, depending on the physical process or frame of reference of the data collection instrument. This does not appear to be feasible with static arc-polygon structures, but Gold and Condal (1995) propose the dynamic Voronoi tessellation as a possible answer.

The dimensionality of oceanographic data poses somewhat of a different challenge to GIS than terrestrial data. Oceanographic data may also be sparse in one or two dimensions as compared to others (as with seafloor borehole data or vertical casts for salinity/temperature/density where sampling is frequent in the vertical direction but sparse in the horizontal). In this case, it is extremely difficult to provide input data for all points in the sample space. Adequate interpolation methods will therefore be needed in GIS to fill this type of sample space adequately. Oceanographic data area also generally obtained along the transects or shiptracks that follow different directions, with data density being the greatest alongtrack in comparison with trackline spacing. Once again, a suitable interpolation method is needed to fill this unique sample space. The Voronoi methods of Gold and Condal (1995) are the only published attempt that we are aware of.

Related to the higher-dimensionality of oceanographic data is the large size of oceanographic data sets. A data set which is relatively small in two-dimensions may become very large with the addition of depth and time. A similar challenge is present in land-based applications, mainly with regard to time as a third dimension. However, the oceanographic application faces the additional problem of new data sets arriving at a significantly higher rate, due to the dynamic nature of the marine environment. These data sets require longer processing times and interactive response time is slower. In light of this, oceanographic applications will most likely require the GIS to be able to read data from secondary storage, such as optical or compact disc, as requested by the user. Research will need to continue on issues such as new techniques for data compression in large spatial databases, searching on thematic attributes, devising indexes for handling locational attributes, and overlaying three- and four-dimensional data sets (e.g., Smith and Frank 1989, Hamre 1993, Mason *et al.* 1994). Li *et al.* (1995) present a hypergraph-based conceptual model for bathymetric data management which significantly improves the efficiency of feature-based query, search and retrieval of objects and continuous fields in large bathymetric databases. Similar approaches are needed for data such as seafloor backscatter imagery and water column volume visualizations.

The functionality required for handling the input and processing of spatial oceanographic data are still largely unavailable in commercial GIS. Data conversion functions are also largely unavailable. Most commercial GIS import, export and convert spatial and attribute data to and from various formats, such as Arc, DXF, and Digital Line Graph, but these are not applicable to common oceanographic data formats. Standard oceanographic grids that should be considered for standard input to GIS include the Digital Bathymetric Database 5 of the U.S. Naval Oceanographic Office, Sea Beam Instruments multibeam bathymetric grids, or the seasonal 5° latitude/longitude grids of ocean temperature, salinity, dissolved oxygen, potential density, and specific volume from the Climatological Atlas of the World Oceans, NOAA National Oceanographic Data Center. Acceptance of these standard formats should remove many of the impediments to automated processing of oceanographic data, especially if results are needed in real-time at sea. The needs outlined here highlight the additional need for research into more efficient methods for archiving and distributing spatial oceanographic data.

3. Conclusion

As much as the potential for oceanography to benefit from GIS is evident, there also exists a potential for GIS to benefit from oceanography. Research issues endemic to oceanographic applications of GIS, such as the handling of spatial data structures that would be able to vary their relative positions and values over time, geostatistical interpolation of data sparse in one-dimension as compared to the others, volumetric analysis, and the input and management of very large spatial databases will advance the body of knowledge in GIS design and architecture, as well as the body of knowledge in the broader field of geographical information science.

GIS applications now span a wide range, from sophisticated analysis and modelling of primarily spatial data to simple inventory and management (Goodchild 1993). Since land-based applications account for the lion's share of the commercial market for software, they also dictate the development directions for much of the industry. Given the importance of what was discussed at the beginning of this editorial as the final frontier, the time is ripe for the GIS research agenda to consider the marine science user community, and to emphasize support for environmental modelling *offshore*. Hopefully, the increased attention to problems of global change, the growing size of the marine resource management and marine science markets, and the undoubted advantages resulting from the symbiosis of modeling, GIS, and visualization systems will increase the likelihood of the appearance of more oceanographically-oriented GIS packages in the future.

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References

Bobbitt, A. M., Dziak, R. P., Stafford, K. M. and Fox, C. G., GIS Analysis of oceanographic remotely-sensed and field observation data. *Marine Geodesy*, **20,** 153–161.

Carlowicz, M., 1995, New map of seafloor mirrors surface. *Eos, Transactions of the American Geophysical Union*, **76,** 441–442.

Detrick, R. S. and Humphris, S. E., 1994, Exploration of global oceanic ridge system unfolds. *Eos, Transactions of the American Geophysical Union*, **75,** 325–326.

Dobson, J. E., 1995, What's the next 'final' frontier? *GIS World*, **8,** 40–42.

Fox, C. G., Bobbitt, A. M. and Wright, D. J., 1996, Integration and distribution of deepsea oceanographic data from the NE Pacific using Arc/INFO and ArcView. In *Proceedings of the 16th Annual ESRI User Conference* (Redland: ESRI) CDROM.

Gold, C. M. and Condal, A. R., 1995, A spatial data structure integrating GIS and simulation in a marine environment. *Marine Geodesy*, **18,** 213–228.

Goodchild, M. F., 1993, The state of GIS for environmental problem-solving. In *Environmental Modeling with GIS*, edited by Goodchild, M. F., Parks, B. O., and Steyaert, T. (New York: Oxford University Press), pp. 8–15.

Goodchild, M. F., in press, Multiple roles for GIS in global change research. In *ESF-GISDATA/NSF-NCGIA Summer Institute in Geographic Information*, edited by Craglia, M., and Onsrud, H. (New York: Taylor and Francis).

Hall, R. K., Ota, A. Y. and Hashimoto, J. Y., 1995, Geographical information systems (GIS) to manage oceanographic data for site designation and site monitoring. *Marine Geodesy*, **18,** 161–171.

Hamre, T., 1993, Integrating remote sensing, *in situ* and model data in a marine information system (MIS). In *Proceedings Neste Generasjons GIS 1993* (Ås, Norway, Norwegian Library House), pp. 181–192.

Li, R., Qian, L. and Blais, J. A. R., 1995, A hypergraph-based conceptual model for bathymetric and related data management. *Marine Geodesy*, **18,** 173–182.

Li, R. and Saxena, N. K., 1993, Development of an integrated marine geographic information system. *Marine Geodesy*, **16,** 293–307.

Lockwood, M. and Li, R., 1995, Marine geographic information systems: What sets them apart? *Marine Geodesy*, **18,** 157–159.

Mason, D. C., O'Conaill, M. A. and Bell, S. B. M., 1994, Handling four-dimensional georeferenced data in environmental GIS. *International Journal of Geographical Information Systems*, **8,** 191–215.

Smith, T. R. and Frank, A. U., 1989, Research Initiative 5: Very Large Spatial Databases. Report on the Specialist Meeting. Technical Report, 89–13, National Center for Geographical Information and Analysis.

Van Dop, H., 1993, Global change research: Analytical report. 93 (9), Megascience Forum, DSTI/STP/MS, Organisation for Economic Co-operation and Development, Washington, D.C.

WRIGHT, D. J., 1996, Rumblings on the ocean floor: GIS supports deep-sea research. *Geo Info Systems*, **6**, 22–29.

WRIGHT, D. J., HAYMON, R. M. and FORNARI, D. J., 1995, Crustal fissuring and its relationship to magmatic and hydrothermal processes on the East Pacific Rise crest (9°12′–54′N). *Journal of Geophysical Research*, **100**, 6097–6120.