[DA-023] GIS&T and Marine Science

Abstract

Image courtesy of the National Academy of Sciences Ocean Studies Board

GIS&T has traditionally provided effective technological solutions to the integration, visualization, and analysis of heterogeneous, georeferenced data on land. In recent years, our ability to measure change in the ocean is increasing, not only because of improved measuring devices and scientific techniques, but also because new GIS&T is aiding us in better understanding this dynamic environment. The domain has progressed from applications that merely collect and display data to complex simulation, modeling, and the development of new research methods and concepts.

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Explanation

1. Definitions

marine - what is found in or produced in salt water, as opposed to freshwater. Synonymous with “ocean” or “sea.” Regarding marine science, marine community, marine applications, marine GIS, etc., these terms also refer to the deep ocean (e.g., Pacific) and marginal seas (e.g., Mediterranean), as well as to estuaries (at the coastal interface between rivers and the ocean), and to the coast itself. In some cases, coastal environments are treated separately because marine and coastal GIS developed fairly independently of each other, and coastal applications of GIS, which incorporating both basic and applied science, also involve policy and management. But this is fast changing because the datasets are essentially the same regardless of how they are used (i.e., for basic or applied science, conservation, education, applied commercial use, etc.).

ocean - equivalent to marine and encompassing both the open ocean and the nearshore or coast. Often referred to in the singular given the ocean as holistic part of the Earth’s system, but can also be equivalent to “oceans” if distinguishing between separate bodies of water such as the Pacific Ocean vs. the Atlantic Ocean.

marine science - Also referred to as ocean science or oceanography. It is a broad science where understanding of the ocean is the common goal. The field is so broad that it is often is broken down into several sub-disciplines based on the nature of the investigations:

- Geological Oceanography (Marine Geology): the study of rocks and sediments found within the ocean, and of the processes responsible for their formation; also, the study of the morphology (shape) of the seafloor.
- Marine Geophysics: the study of the rock structure within the ocean basins, the properties of rocks such as their magnetism, and the occurrence and cause of earthquakes.
- Physical Oceanography -- investigates how and why ocean currents flow, and air-sea interactions such as the generation of waves by the wind;
- Chemical Oceanography -- the study of the composition of sea water and the processes that control and alter this composition, including marine pollution;
- Biological Oceanography (Marine Biology) -- concerned with the organisms that live in the ocean, and their relationships to the environment, including marine ecology and fisheries science.
- Marine Resource Management (Marine Environmental Management): the study and professional practice of resource management as applied to the ocean, often bridging the natural with the social sciences, and including but not limited to coastal and marine spatial planning, marine law and policy, marine education, marine economics, and culture

Although such categories exist, marine scientists tend to be broad in their outlooks and often are not easily placed into only one of the above "boxes." In addition, marine science research tends to be highly interdisciplinary, involving a team of investigators that combine their expertise to better understand the ocean.

maritime - referring more so to the marine industry rather than to marine science. This includes commercial shipping, submarine telecommunication cables, port management, maritime defense/intelligence, offshore energy (e.g., oil and gas, wind, wave, or tidal energy), commercial fishing and aquaculture, engineering firms building underwater lighting, instruments, vehicles/robots, and the use of bathymetry in national and international hydrographic (not hydrologic) offices more so for nautical chart production than for elucidating the shape and structure of the ocean floor for scientific studies.

2. Importance of Marine Science

On a planet where 71% of the surface is covered by water, the ocean is critical for life itself. It feeds us, regulates our weather patterns, provides over half of the oxygen that we breathe, as well as components of our energy grid and economy. An estimated 350 million jobs globally are linked to the ocean. One billion people living in developing countries depend on fish as their primary source of protein. The ocean is critical to national defense and military security. There is 5 times more carbon stored by coastal habitats than by tropical forests. But there is also 5 times more pollution in the ocean now than in 1960, due to agricultural runoff. Eighty-five percent (85%) of the world's fisheries are categorized as either "fully exploited," "over-exploited," or "depleted." Ninety percent of the big fish in the ocean are gone. Climate change threatens coastal communities worldwide. Less than 3% of the ocean is legally protected in parks and reserves, as compared to 12% of global land areas. Only 5-10% of the ocean floor and of the waters beneath the surface have been explored and mapped in a level of detail similar to what already exists for the dark side of the Moon, for Mars, and for Venus.1

GIS has traditionally provided effective technological solutions to the integration, visualization, and analysis of heterogeneous, georeferenced data on land. In recent years, our ability to measure change in the ocean is increasing, not only because of improved measuring devices and scientific techniques, but also because new GIS technology is aiding us in better understanding this dynamic environment. The domain has progressed from applications that merely collect and display data to complex simulation, modeling, and the development of new research methods and concepts.

The importance of GIS&T for Marine Science lies largely in the need to provide effective mapping tools and techniques to respond to enormous disasters such as the Deepwater Horizon oil spill in the Gulf of Mexico and the Tohoku-Oki earthquake and tsunami in Japan. It is also motivated by a sincere desire to assist in the implementation of the national and international ocean policies, particularly in coastal and marine spatial planning (CMSP), for which GIS provides a crucial decision-support engine.

Further, we know that the ocean can also be a dangerous place. The news is replete with stories of the hazards of hurricanes, tsunamis, rogue waves, sea level rise and coastal flooding, shark attacks, toxic spills, oxygen-poor "dead zones," even modern-day pirates. This is reflective of the ocean in a state of deep crisis. Hönisch et al. (2012) discuss how the ocean is acidifying faster today than in the past 300 million years due to absorbing the vast amounts of carbon dioxide that humans have put into the atmosphere since the start of the Industrial Revolution. We have changed the ocean to the point where there will be serious impediments to the marine biological carbon pump which ultimately controls the climate system, oxygen levels will plummet, and there will be a wide range of negative consequences for ecosystems, fisheries, and tourism (e.g., National Research Council, 2010).

3. Common Application Areas

A continuing engagement between the GIS&T and marine science communities is critical, as complex marine science questions and data are increasingly used to inform the responsible use and governance of the ocean, as well as effective management and conservation. Common application areas include, but are definitely not limited to:

Research and Exploration, including

- Seafloor mapping and sampling, geomorphological studies and tectonophysics;
- Benthic habitat mapping for estimating species abundance, essential fish habitat, and ultimately conservation of sensitive or endangered areas;
- Shoreline analysis, including calculation of rate-of-change statistics from multiple shoreline positions to analyze historic shoreline change;
- Climate change, including measuring or simulating the potential impacts of sea level

rise on shorelines and wetlands, impacts of storms due to increasing ocean temperatures, impacts to ecosystems due to increasing ocean acidification, and global energy transfer;
- Hazards, including the analysis of risk and potential loss of buildings and infrastructure due to hurricane winds, coastal floods, tsunamis, and nearshore or onshore earthquakes.

Ecosystems and Environment, including:

- Coral reef health and structure, mangrove assessment, estuary restoration, interaction of coastal ecosystem services, and management of seascape to optimize services;
- Coastal and pelagic animal tracking, marine mammal genomics;
- Marine debris mapping and tracking, especially in situ as small plastics are not detectible with satellite imagery.

Coastal Protection and Marine Spatial Planning, including:

- National Ocean Policy Regional Ocean Partnership mandates;
- Marine protected area design and designation;
- Offshore wind-energy, wave-energy, or tidal-energy development;
- Beach and fisheries access;
- Aquaculture permitting.

Fisheries and Aquaculture Management, including:

- Mapping of U.S. fishery management plans, such as boundaries of Groundfish Essential Fish Habitat;
- Analysis of trends in nearshore and estuarine capture of fisheries globally;
- Fish habitat and distribution;
- Analysis of fishery closure areas, protected resources, Gulf Coast Environmental Sensitivity indices, at-risk Species, and Federal Status to illustrate some of the environmental impact of the 2010 Deepwater Horizon spill.

Recreation and Adventure, including:

- Professional and amateur boat racing, voyages for various causes, and unusual high-publicity sporting events at which we can offer and advertise live, map-based tracking of assets and participants.

4. Research Challenges

Although the number and type of marine science applications of GIS&T continue to grow, there still exist overall inconsistencies in ocean data models, formats, standards, tools, services, and terminology. In addition, a paradigm shift is afoot that is driving an evolution from desktop and server enterprise solutions into a Software as a Service (SasS) model in the cloud. As such, marine science applications of GIS&T are building upon that important shift. Research challenges include:

4.1 **Vertical datum calculations (decimeter- or centimeter-level) to help researchers transform data between ellipsoidal, orthometric and tidally-referenced elevation data at the shoreline.** This is absolutely critical for coastal surveying, coastal geomorphology, and coastal terrain models that connect nearshore bathymetry for terrestrial DEMs that are used for storm surge, hurricane, and tsunami inundation modeling. This will involve deciphering which vertical datums are most important to our users, finding out if transformations between them already exist that are trusted and authoritative by industry, how they are implemented and despite what limitations, and how best to implement in GIS&T. Users need the ability to combine several datasets that may be expressed in incoherent vertical datum/coordinate systems and vertical positioning that is precise (i.e., not just a “z” value, but a “z” value relative to a precise reference).

4.2 **Improvements in visualizing multivariate data that changes in time and space, including on the web and in mobile devices.** Satellites can clearly map the ocean surface, and acoustic sensors (as well as aircraft satellites to a very limited extent) can map the seafloor, given time and coverage. But marine scientists currently have a limited view of the water column between the sea surface and the seafloor. This view is also extremely limited in real time and with a limited capacity to store the data, replay the data or run further types of analysis. Water column data need to be integrated with other data sets such as bathymetry, bottom backscatter, subbottom, seafloor characterizations and more, so that a complete picture of the ocean environment under analysis can be obtained. There is a critical need to study the internal structure of features in the water column such as plumes (hydrothermal vent plumes, oil well plumes as in the Gulf of Mexico spill) or schools of fish to obtain fish stocks dynamics, spawning grounds, seasonal habitats and to discern the impact of the climate change on these vital resources. To exploit water column data, an efficient means of reading, processing and analyzing the data is required, including time-dependent 3D analysis (weeks/days/hours/minutes/ seconds).

4.3 Development of more tools that facilitate collaborative decision-making through authenticated access to data. This should better enable consensus-driven decisions about ocean management, protection, and commerce. Ocean issues are often opaque to one or more segments of a user base.

4.4 Development of more database workflows that can be successful in the absence of real-time Internet connections. This is especially as ships often do not have high-bandwidth access to the Internet at sea, and restrict transmissions of email and digital data during periods when they connect to a satellite or port for transmission and reception of these files.

4.5 Improve marine science applications of GIS&T to better support ocean numerical models. In the ocean, one of the most widely-used models is the Regional Ocean Modeling System or ROMS (Shchepetkin and McWilliams, 2003 and 2005). Its algorithms are used for understanding a wide array of processes, including vertical mixing and biogeochemical processes in the open ocean, sediment transport and storm-surge inundation of coastal areas and sea ice movement. And yet models such as ROMS pose great challenges for GIS&T, as they are often not uniformly spaced, and may be comprised of either unstructured triangles or structured curvilinear grids. There is a great need for tools to handle these grids in a more standardized way, allowing for the possibility of standard access to data on the model’s native grid. In addition to providing better support for netCDF4 (Network Common Data Form) and HDF5 (Hierarchical Data Format), the use of netCDF Markup Language (NcML), an XML representation of netCDF metadata, should be investigated, as it contains attributes that work effectively with the third-dimension.

Marine science continues to provide interesting and challenging applications for GIS&T, applications that will advance the body of knowledge in GIS design and architecture, as well as the body of knowledge in the broader field of marine science. The future is bright for the continued evolution of applications that will effectively plan the exploration and discovery of the undiscovered parts of our planet, to ensure safety on the oceans from hazards and storms, to sustainably extract energy, food, and other services, and to geodesign ocean space among its multiple and simultaneous uses.

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1 The source of many of these facts is the World Bank's Global Partnership for the Oceans, which in turn draws on a number of published studies. Included also are economic factors of ocean usage as summarized by the Committee on the Marine Transportation System and the Environmental Science Division of the Argonne National Laboratory.