

## GeoModeler--Linking GIS and Oceanographic Models

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### *Abstract*

In responding to crises, researchers need to gather data, define interactions, and model systems. Two important tools are the use of decision support models and geographic information systems. These two tools have not been well integrated for scientific uses. GIS packages are starting to expose code and objects to allow coupling of core GIS functionality and analytical/modeling tools. Through the use of Java-based APIs, a GIS is directly linked with models. ArcGIS Engine and ArcObjects are used to communicate with an ArcGIS software-based front end. The front end provides both setup--allowing the user to specify the datasets to be used, the weights for elements of the model and the output desired--and for display--showing the results of the model run in a map or other spatial output.

### *Introduction*

Models provide a way to understand and predict the behavior of natural and human systems. Ideally models would be easily linked to a geographic information system (GIS). In the past, these two have not been well integrated for scientific uses. This lack of true integration hinders the ability of managers and scientists to create interactive, GIS-based models for management and research. However, GIS packages are starting to expose code and objects to allow closer coupling of core GIS functionality and analytical/modeling tools.

In creating GeoModeler, we have provided a prototype of how one might integrate a GIS with a number of oceanographic and decision-support models. Through the use of Java-based application programming interfaces and connectors, a GIS is directly linked with the Regional Ocean Modeling System (ROMS) model and with the Method of Splitting Tsunami (MOST) model. Scientists and managers are able to use a graphical interface to display datasets, select the data to be used in a scenario, set the weights for factors in the model and run the model. The results are returned to the GIS for display and spatial analysis. The project creates a framework for linking to other types of back-end models written in a variety of programming languages.

Ocean-atmosphere models such as ROMS are intended to provide a multi-purpose, multi-disciplinary oceanic modeling tool. A basin-scale ROMS has been developed over the Pacific Ocean with a spatial resolution of 12.5 km (<http://ouerocean.jpl.nasa.gov/>). The MOST model is a numerical simulation code to simulate the tsunami evolution elements of an earthquake, transoceanic propagation and inundation of dry land (<http://nctr.pmel.noaa.gov/research.html>). ROMS and MOST implementations in GeoModeler are used to introduce oceanographic modelers to GIS techniques.

For smaller areas, decision-support models provide ways to create and test scenarios during natural or manmade crises. A model might allow emergency managers to specify the location, magnitude and time of day for an earthquake and the model would return the number of

people who might be in areas affected. Similarly, a model might look at the effects of climate-change on a fishery and return results based upon a number of different change scenarios.

### *Software components*

GIS packages are starting to expose software code and objects to allow closer coupling of core GIS functionality and analytical/modeling tools. GeoModeler prototypes the direct integration of GIS and modeling capabilities in support of management and decision making. Through the use of Java-based application programming interfaces (APIs) and connectors, a GIS front-end is directly linked with models. Scientists and managers are provided with a GIS-based graphical interface to display datasets, select the data to be used in a scenario, set the weights for factors in the model and run the model. The results are returned to the GIS-based application for display and spatial analysis.

The project creates a Java-based framework for back-end models that incorporate a variety of programming languages. Visualization is performed using Java3D and the Visualization Toolkit (VTK). The Java3D API extension is designed as a high-level, platform independent 3D graphics programming API, and is amenable to very high performance implementations across a range of platforms. To optimize rendering, Java3D implementations are layered to take advantage of the native, low-level graphics API available on a given system. In particular, Java3D API implementations are available that utilize OpenGL, Direct3D, and QuickDraw3D. This means that Java3D rendering will be accelerated across the same wide range of systems that are supported by these low-level APIs.

We also make use of a second 3D API called the Visualization Toolkit (VTK) ([www.kitware.com](http://www.kitware.com)). VTK is a cross-platform 3D application programming interface built upon, and independent of, the native rendering library (OpenGL, etc). It exposes Java bindings (as well as Tcl and Python). It is written in C++ and includes similar scene-graph, lighting models, and graphic primitives as Java3D. VTK performs boolean operations on 3D volumes (intersection, union), volume rendering, filtering, including convolution, FFT, Gaussian, Sobel filters, permutation, high- and low-pass Butterworth filters, and divergence and gradient calculation. The VTK data model allows for fast topology traversal, making these filters very fast, and allows for rapid mesh decimation. VTK also offers powerful 3D probe "widgets" that allow easy interaction with the data, and has methods to utilize parallel architecture through the Message Passing Interface (MPI).

The initial implementation of GeoModeler was done using a VTK interface to the Regional Ocean Modeling System (ROMS). The test application, OceanGIS (written in java) used an interface that allowed the user to modify any of the C-preprocessor directives that ROMS uses in its build-script to enable various physical and numerical options. The initialization file can also be modified to reflect changes in timestep, tiling, and initial conditions. The Method of Splitting Tsunami (MOST) implementation uses a similar process.

In a future development, we plan to use ArcGIS Engine and implementations of ArcObjects to communicate with an ArcGIS based front end to support decision support models. As with the current framework, the front end would provide both setup - allowing the user to specify the datasets to be used, the weights for elements of the model and the outputs desired, and for display - showing the results of the model run in a map or other spatial output. With the use of the Java connector to ArcIMS, the results may also be displayed in an ArcIMS or other

map server.

ArcEngine is an ESRI developer product for creating and deploying ArcGIS solutions. It is a simple API-neutral cross-platform development environment for ArcObjects - the C++ component technology framework used to build ArcGIS. ArcObjects are the core of the ArcGIS functionality and include tools such as overlay - union, intersect; proximity - buffer, point distance; surface analysis - aspect, hillshade, slope; and data conversion - shapefile, coverage and DEM to geodatabase. ArcEngine's object library makes full GIS functionality available through fine and coarse-grained components that can be implemented in Java and other environments. Using ArcEngine, solutions can be built and deployed to users without requiring the ArcGIS Desktop applications (ArcMap, ArcCatalog) to be present on the same machine. It supports all the standard development environments, including Java, and C++, and all the major operating systems. In addition, some of the functionality available in the ArcGIS extensions can be embedded. This product is a developer kit as well a deployment package for ArcObjects technology.

## Results

### OceanGIS

The GeoModeler interface and display use graphical objects to provide functionality

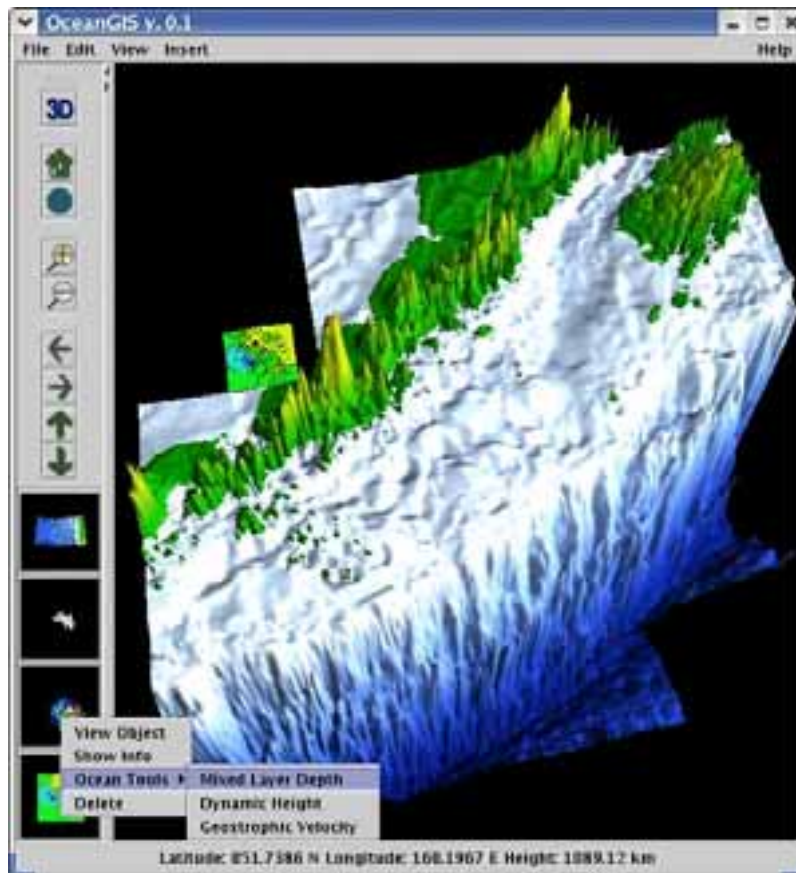


Figure 1 OceanGIS interface for CTD data

related to the type of data being displayed. The tools are intended to be familiar both to GIS users and to users of scientific graphics packages. GeoModeler builds upon an earlier tool called OceanGIS (Vance et al., 2005). OceanGIS was initially designed to allow 3D oceanographic calculations on *in-situ* data, and to overlay the results. As such, tools were developed to calculate some basic properties of conductivity-temperature-depth measurements, such as mixed-layer depth, geostrophic velocity, and dynamic height. As a data layer is added, the relevant tools for analyses are exposed for use. In the example shown in Figure 1, the addition of a layer of conductivity-temperature-depth (CTD) data causes tools for calculating mixed layer depth and other appropriate oceanographic parameters to become available. Data can be read directly from an OPeNDAP (Open-source Project for a Network Data Access Protocol) server by the Java code in GeoModeler.

### Running a ROMS model

The model is configured, compiled and launched through the GeoModeler interface (Figure 2), and model results are output to an OPeNDAP ([www.opendap.org](http://www.opendap.org)) server directory, allowing either viewing in OceanGIS or sharing results with remote colleagues.

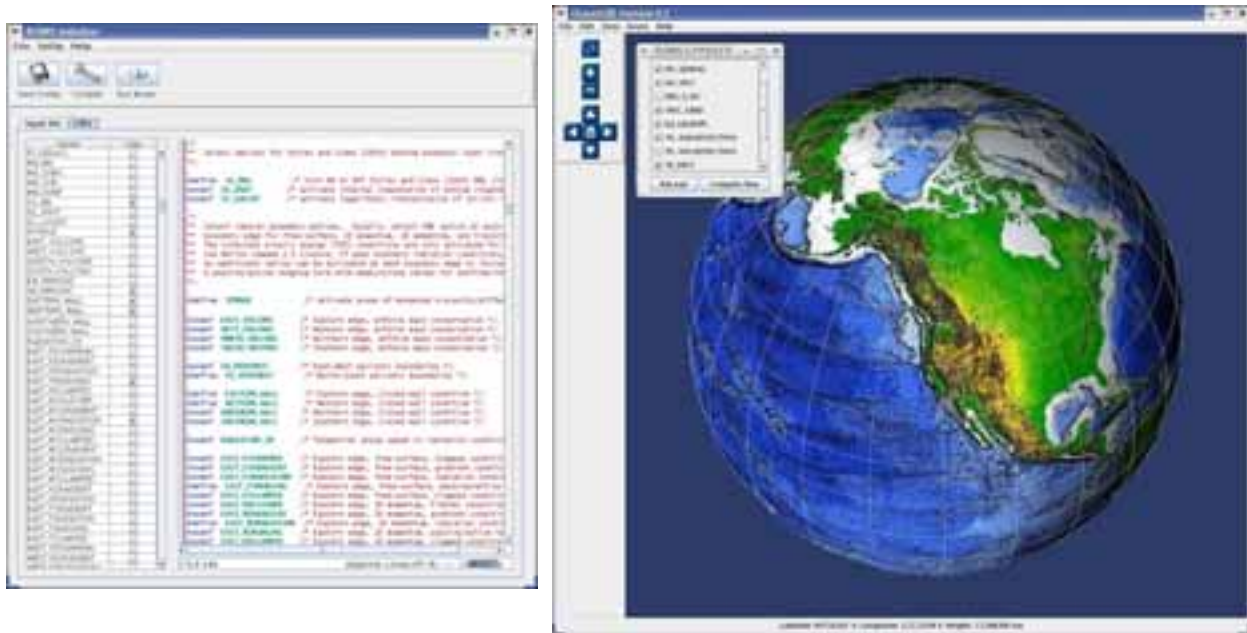


Figure 2 - ROMS parameter setup

The OceanGIS ROMS Data Reader is a GUI class that reads netCDF output of ROMS model data, and allows 3-D renderings to be created and animated in a geo-referenced framework. Since OceanGIS utilizes the Geotools ([www.geotools.org](http://www.geotools.org)) library, shapefiles of data using standard projections can be rendered simultaneously (as opposed to simply overlaying). The ROMS model output is loaded through the ROMS Data Reader, and the user selects the variable of interest, contour levels, color maps, etc., and animates the resulting rendering (Figure 3).

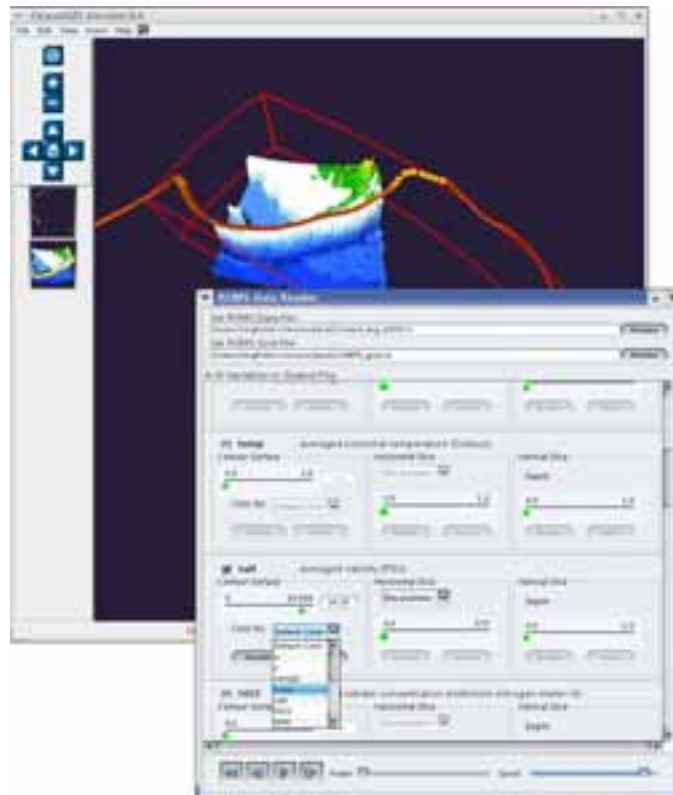


Figure 3 ROMS output display parameters

#### Running a tsunami model

A second test for GeoModeler was the implementation of an interface to launch tsunami models and allow the integration of results into a GIS framework. The initial results for this implementation are shown in Figure 4. The model output renderer/ animator reads results of the MOST model, and surface height is rendered at each of 1440 timesteps. This model run includes “runup”, or the adjusting of the model boundary condition to simulate inundation (Titov and

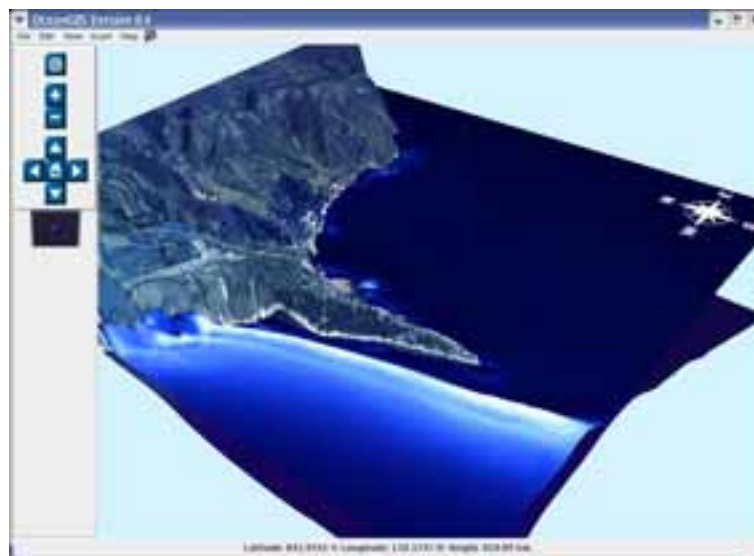


Figure 4 Tsunami model output

Gonzalez, 1997). Rendering this surface over high-resolution topography, overlaid with an aerial photograph produces a fairly realistic view of the event. A complete description of this event can be found in Titov and Synolakis (1997).

The MOST model parameters include a series of uniform-sized seismic faults, called “unit sources”, shown in Figure 5. These sources are initially set using an interface that allows the user to set the magnitude for each source, as well as the vertical distance the fault moves (the



Figure 5 MOST model with source units

slip). An initial condition for running the inundation model is built up of a linear combination of model runs for each unit source. This initial condition is passed to the inundation model, with default parameters pre-set to give a rapid estimate of inundation in time for emergency managers to view results well before the approaching wave strikes populated areas. Future work includes getting all the parameters for MOST model runs into the interface so the GeoModeler tool can be used for research.

### *Future Developments*

We plan to expand the capabilities of the current GeoModeler. The expansion will include capabilities for handling three-dimensional analyses, such as the intersection of two volumes or the intersection of a three-dimensional path with a volume. This will require implementation of complex algorithms for volume on volume calculations. We are also going to take advantage of new developments in ArcGIS to include netCDF as a native GIS data format for GeoModeler. In addition, we plan to generalize the existing interface for the ROMS model so that a variety of oceanographic and atmospheric models might be used. GeoModeler's capabilities for scenario testing and decision support will be expanded. We also hope to provide a simple method for allowing new analytical modules, especially those utilizing parts of the ArcObjects library, to be inserted into the tool. This would allow us to implement enhanced

geostatistical and other capabilities.

These new capabilities will be demonstrated by using GeoModeler to prototype three applications. The first would involve making the tsunami models outputs shown above available for scenario testing. Users would be able to choose a source region, the intensity of triggering event, the time of day and area of study. The tool would take these parameters, choose model output from a compendium of model results and return the inundation model results. The results would be combined with social data, such as population, to calculate populations at risk. The user could create any number of scenarios by changing the input parameters for the test. As the model results are pre-calculated, the response time is quick and the tsunami modelers are able to ensure that correct tsunami model parameters are chosen.

The second demonstration would be an application to visualize and analyze the results of two models; a model for mammal-prey interactions and a model to look at the effects of climate change on the recruitment of economically important fish species. The first model is an Individual-Based Model (IBM) that models the fate of individuals using characteristics such as age, size and prey consumption. As such, it is a typical example of the models used for ecosystem interactions and studying the consequences of changing environmental conditions. The second model is a Nutrient-Phytoplankton-Zooplankton (NPZ) model looking at the effects of climate change on young fish. The adults of these species studied are the target of major fisheries. This part of the project would take advantage of the new direct reading of netCDF data and the multi-dimensional analysis techniques described above.

For the third demonstration we will be exploring decision support modeling. Two NOAA activities that have identified a need for such decision support tools are the joint NMFS-states Southeast Area Monitoring and Assessment Program (SEAMAP)[<http://www.gsmfc.org/seamap.html>], and the NOS National Marine Sanctuaries (NMS) West Coast Observing System (WCOS) [[http://www.mbnms-simon.org/sections/obs/nms\\_wco.php](http://www.mbnms-simon.org/sections/obs/nms_wco.php)]. Modeling of NMS Monitoring Program data with the display capabilities developed through this project will enable Sanctuary scientists to integrate observed physical and biological data into predictions of the effects of environmental and anthropogenic variables on marine sanctuaries. For the prototype of linking a decision support model with a GIS, we will use ArcGIS Engine to create a front end linked to back end ArcObjects based modeling tools.

## *Conclusions*

GeoModeler provides a fully functional prototype of closely linking scientific models and a GIS. The results have been applied to two types of models - ROMS ocean models and the MOST tsunami model. The ease with which these models have been implemented suggest that the implementation of further models should be straightforward. The ease with which modelers have been able to integrate new GIS-based functionality has made them more open to implementing GeoModeler. The enhanced visualization capabilities and the ability to easily include GIS-based socioeconomic data will enhance the results of the existing scientific models. GeoModeler has enhanced OceanGIS so that it can be used as a front end for the ROMS circulation model and the MOST model. This type of integration, where parameters are passed to a model and the results are returned for display, can now be applied to many types of

models.

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ROMS web page, <http://ouocean.jpl.nasa.gov/>

Southeast Area Monitoring and Assessment Program (SEAMAP), <http://www.gsmfc.org/seamap.html>



VTK web page, [www.kitware.com](http://www.kitware.com)

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