

# Integrating particle tracking models into a GIS for analysis and display of environmental phenomena

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## ABSTRACT

Particle tracking models can simulate the path of volcanic ash particles that might affect airplane flights, the path of contaminants from a pollution source in the atmosphere or in a water body, and the path of organisms through the either a water or air environment. These models can be used in hazard assessments, environmental planning and biological research. Model outputs include locations of particles in space and time and associated environmental measures such as temperature, wind or current speed and direction, water turbidity, and water salinity. The outputs may include both a fully populated four-dimensional grid of environmental attributes and the x, y, z, t location of the particle(s).

A geographic information system (GIS) can provide tools to display and analyze the results of tracking models. In this paper we report on the development of a tool to display particle tracks in 3-D, to display and analyze the environmental variables along the track of one or more particles and to integrate particle tracks with a variety of spatially-explicit datasets. The tool uses functions native to ESRI's ArcGIS, Java-based statistical and analysis tools, functions from VTK, and display tools from Unidata's Integrated Data Viewer (IDV).

## Categories and Subject Descriptors

J.2 [Computer applications] PHYSICAL SCIENCES AND ENGINEERING

## General Terms

Management, Performance, Design, Experimentation, Human Factors, Languages, Theory

## Keywords

Geographic Information Systems, particle tracking models,

environmental planning and response, emergency management, oceanography, geovisualization, scientific models, 3-D, spatial analysis and integration, spatial information and society, spatial modeling and reasoning, ArcGIS, Java, IDV, VTK

## 1. INTRODUCTION

### 1.1 Background and examples

While geographic information systems more traditionally portray broad spatial patterns, they can also be used to depict and investigate much smaller-scale interactions. Along with the traditional static patterns, they can investigate phenomena with structure in both the spatial *and* temporal domains. Many phenomena, such as the spread of atmospheric or aquatic plumes, the dispersion of the eggs and larvae of a variety of organisms, and the paths followed by drifting vessels, wreckage or individuals can be shown using a particle tracking model. The particle tracking model is run on top of a dynamical model that calculates the currents and other variables that might affect the drift of particles. The underlying hydrodynamic or atmospheric model can be run in advance using a supercomputer or other large computer resources. The particle tracking model can be run in real time during a disaster or can be used as a part of a scientific study or field research project. The results of the circulation model are stored in a fully four-dimensional grid of speeds, directions and associated physical variables. The result of the particle model is another four-dimensional dataset of particle locations in space and time. Gridded model output lends itself to display and analysis using a combination of traditional GIS tools and tools for volumetric visualization and analysis.

Particle tracking models can display the paths of particles in the atmosphere, the hydrosphere and in groundwater. The particles can be passive – either non-living particles or living particles that are so young as to be unable to propel themselves – or active, in which case they may exhibit swimming or flying abilities, the tendency to avoid predators, a tendency to cluster together or a host of other biological and chemical behaviors.

A recent review of the literature on particle tracking models for fisheries science [2] has shown that these models have been adapted from engineering/laboratory models to a more applied environmental and coupled model approach. The modeling framework has been adapted by other disciplines. Below are a

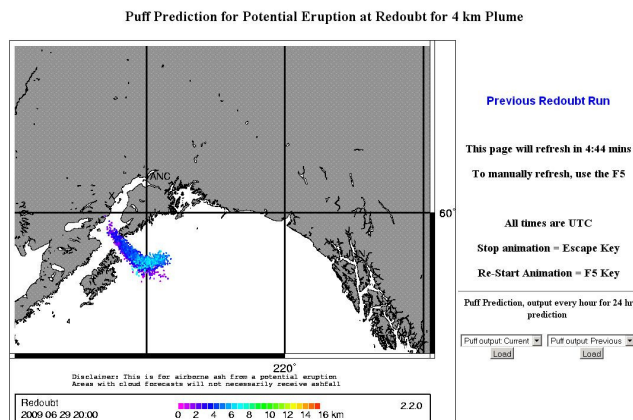
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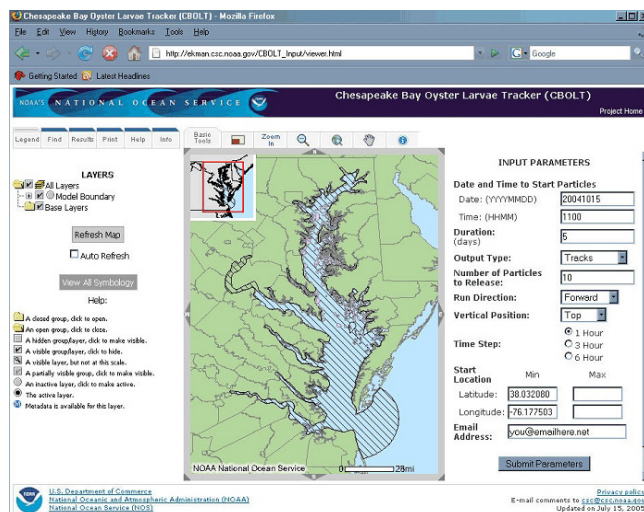
few examples that demonstrate the strength and usefulness of this type of modeling in applied research and real time operations.

The PUFF volcanic ash tracking model [6][17], developed at the University of Alaska, is an example of an atmospheric model that tracks inert volcanic particles and predicts their path and location based upon wind speeds and directions. Particles originate at the chosen volcano and advect, diffuse and settle based upon standard physical laws. Parameters such as the height of the erupted cloud, the size of the particles, the settling rate of the particles, and dispersion rates can have default or specified values. Output is a map of the particles coded by height (Figure 1). The model is intended to support emergency managers, aircraft operators and weather forecasters.



**Figure 1** PUFF prediction for an eruption cloud from Mt. Redoubt. The colored symbols show the location and height of the particles. <http://puff.images.alaska.edu/index.shtml>

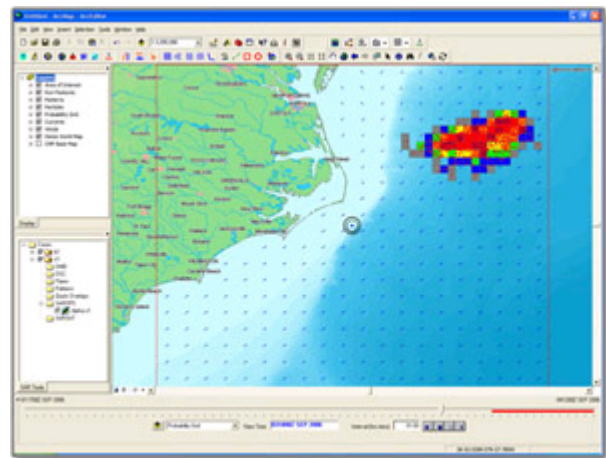
The Chesapeake Bay Oyster Larvae Tracker (CBOLT) [3] is an example of a particle tracking model developed for marine larvae.



**Figure 2** Web page to set starting parameters for the CBOLT model. <http://www.csc.noaa.gov/cbolt/>

The oyster larvae are animate, but unable to swim or maneuver themselves. The model uses parameters such as tidal and wind forcing, water temperature, and salinity. It runs on top of a circulation model for the Bay and the user can specify the starting location for the oyster larvae, the number of larvae released and whether the model will run forwards or backwards in time (Figure 2). The model runs through a web interface and a two-dimensional representation of the path of the larvae is returned to a web page. The model is intended to serve as a decision support tool for scientists considering the introduction of new oyster species in the Bay.

The Search and Rescue Optimal Planning System (SAROPS) [5] uses particle tracking to simulate the path of drifting vessels or individuals to assist with rescue operations. SAROPS includes three main subsystems - a C/JMTK/ArcGIS GIS-based user interface, the Environmental Data Server (EDS) to store hydrodynamic and environmental data, and a Search Planning Simulator and Optimal Search Planning Tools (Figure 3). The system allows the search planner to define the scenario; to access environmental data (winds and currents) via web services from a central data server; and to develop near optimal search plans given the amount of searching effort available. The system was deployed throughout the U.S Coast Guard in 2007, and has successfully been used to find missing vessels and to save lives.



**Figure 3** SAROPS tool using particle tracking to estimate the location of a missing vessel

All of these particle tracking tools can be made more useful by adding supporting data and making it easy to visualize and analyze the results. Integrating the model with a GIS provides a straightforward route for data integration and the use of geostatistical analyses. Integration with advanced visualization tools can provide both volumetric depictions and tools for volumetric analysis.

## 1.2 Motivation and aims

The motivation behind our project, referred to as GeoFish, is a desire to make it as simple as possible for non-modelers to set up

the parameters for a particle tracking model, run the model and analyze and visualize the results. This is not intended to replace formal modeling conducted by specialists to test hypotheses and the functioning of the model. Rather, we wish to make it easy for fisheries biologists to create a scenario, run the model to test their assumptions and revise and rerun the model based upon the results. In cases where they have limited *in situ* data, the model results could also be used to enhance the datasets.

We aim to simplify the setting of parameters and to make the output available in a variety of visualizations. One of our goals is replace the expert user interface often used with biophysical model parameterization/set up with a streamlined GUI for setting up user defined preferences and displaying the of results. We also aim to make it easy to integrate the results with supporting environmental data such as fish catch data, meteorological data and values for other biological parameters that affect particle survival. We provide graphics such as a plot of the salinity along the track of a particle or a statistical measure of the variability of water temperature during an organism's life history.

The project also tests various technical aspects of the integration of particle tracking models, written in C++ and Fortran, with a GIS. The Visualization Toolkit (VTK) [20] and the Integrated Data Viewer (IDV) [12] were tested as tools for visualizing three-dimensional features such as volumes of cold water and clouds of possible habitat. While a traditional GIS can visualize and analyze 2.5-dimensional features, we wanted to be able to imagine the marine environment as a fully three-dimensional landscape for the particles.

## 2. SOFTWARE COMPONENTS

The GeoFish architecture (Figure 4) has components for storing and manipulating the output from circulation models, for computing particle tracks, and for visualizing and analyzing results in both GIS and non-GIS environments. We have thus far worked with two ocean circulation models, namely ROMS (Regional Ocean Modeling System) [15] and NCOM (the Navy Coastal Ocean Model)[11]. The circulation models are run independently in advance of the particle tracking and the results stored as netCDF [7] files. Particle trackers are run using the modeled current velocities, and the resulting tracks are stored in a THREDDS [19] data server. The environmental and track data are also stored in an ArcGIS file-based geodatabase. The following sections describe some of the software components used for GeoFish

### CBOLT framework and utilities

CBOLT is an integrated system of components that allow users to control a particle tracking model, and then examine the output as geospatial features in a Web-based map interface [3]. CBOLT uses an ArcIMS interface to allow users to input model parameters for a particle tracking model, sends these parameters off to computational engine, returns the results to a database, and then plots them in 2-D. While CBOLT is currently a specialized system for showing larvae tracking results, it was written in such a way that it can be divided into reusable components. We utilize some of these components for the initial setting of model parameters, the passing of parameters to the model and the storage of the results of model runs in a spatial database.

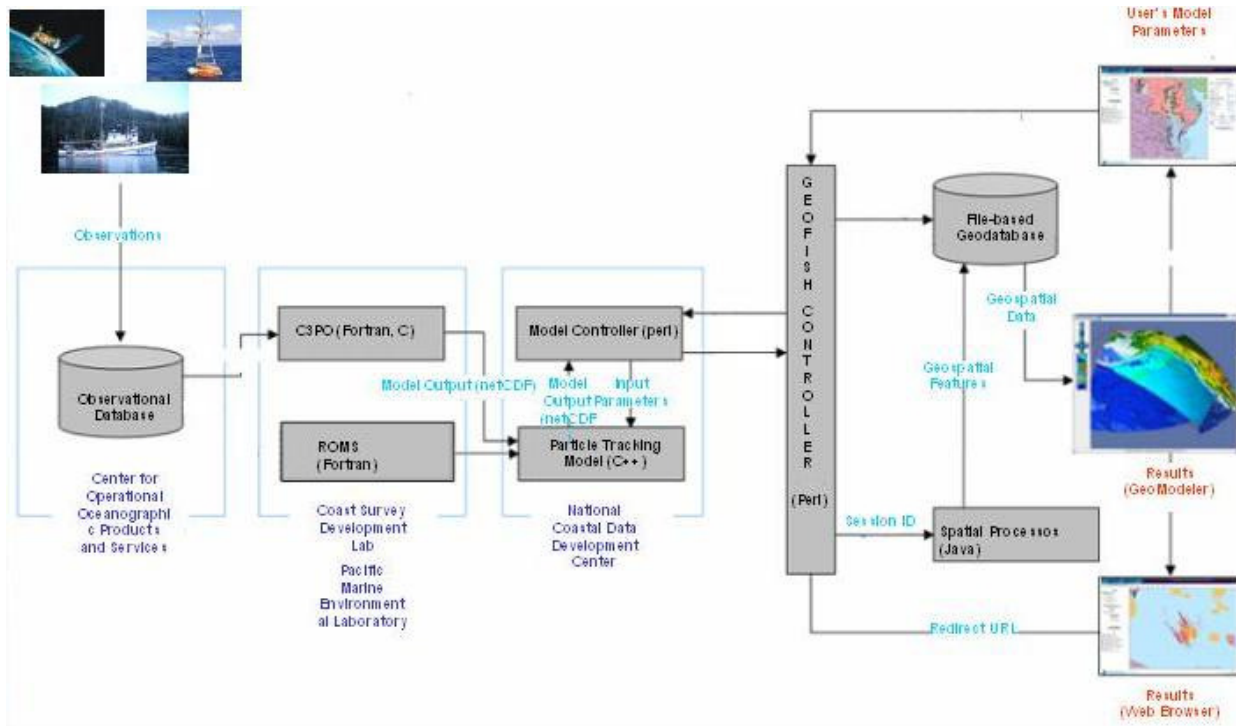


Figure 4 GeoFish architecture

## ArcGIS/ArcEngine

In implementing analysis of the particle tracks, we use a proprietary package from Environmental Systems Research Institute (ESRI) called ArcGIS Engine and implementations of ArcObjects [www.esri.com] to provide spatial analytical tools.

ArcEngine is a simple API-neutral cross-platform development environment for ESRI 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, advanced modeling 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.

## Visualization and analysis utilities

VTK and IDV are used for visualization and analysis of the tracks and the environmental data. VTK provides visualization tools and spatial statistics for this project. The GeoFish renderer allows for color-coding of the tracks, overlays of other parameters stored in shapefiles and netCDF files, and zoom, pan and rotation of the visualization for user exploration. We are exploring the use of IDV as a visualization tool due to its ease of implementation; the ability to modify the user interface to provide specific tools; and the ease of installing IDV on the user's system. IDV can be customized using Java plugins.

Java is used to tie the elements together and for various utilities and supporting routines. Python is used for programming statistical analyses of the output. Particle tracks and environmental data can also be viewed and analyzed in ArcGIS using the standard ESRI file geodatabase.

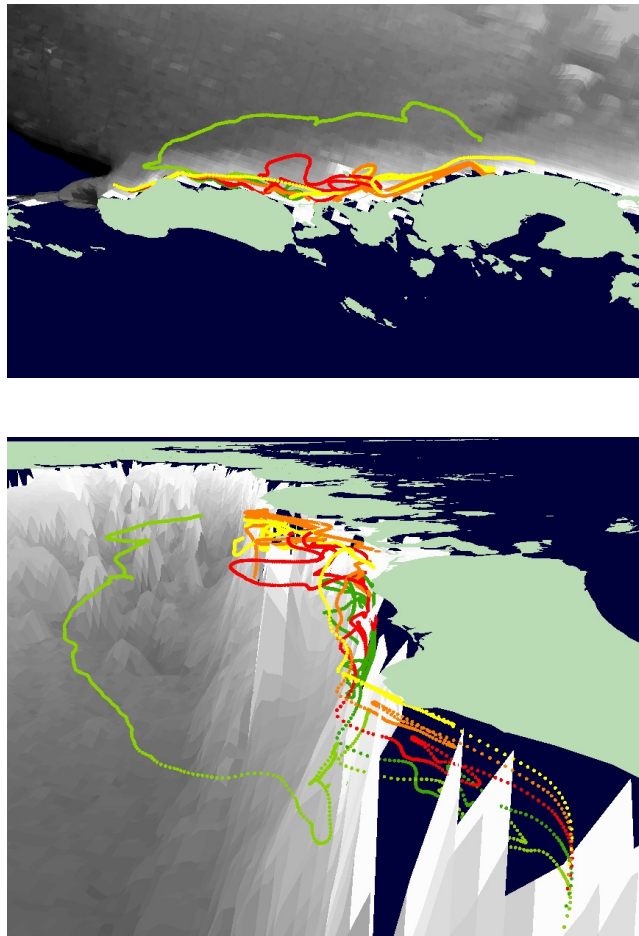
## 3. RESULTS AND CASE STUDIES

Use of GeoFish to display the particle tracks allows scientists to easily visualize the paths, to compare the paths of individual particles, and to look for overall patterns in the paths. It is currently being used to look at the paths of larvae for fish in newly exploited fisheries. It is also proving useful for looking at changes in the spatial patterns of dispersal of fish species in existing fisheries that are showing new patterns due to climate change. With the help of scientific modelers, biologists are using the tools to explore both *in situ* and model datasets.

### 3.1 Visualization of particle tracks generated from ROMS model data - rock sole in the Bering Sea

As climate changes, fish populations subject to fishing migrate and fisheries exploit new populations. Many of these newly

exploited populations are not well studied and the spatial patterns of their life stages are not well understood. Rock sole are a benthic species in the Bering Sea that are increasingly being sought after as a commercially valuable species. While the location of adults is known from fish catch data, the location of spawning and the dispersion of larvae are less well understood. Lanksbury et al. [1] used biophysical models to track the possible paths of larvae after spawning. Figure 5 shows particle tracks for rock sole larvae based upon a particle tracking model run using the ROMS circulation model. Individual tracks are color coded for clarity and two views are shown to place the tracks in perspective.



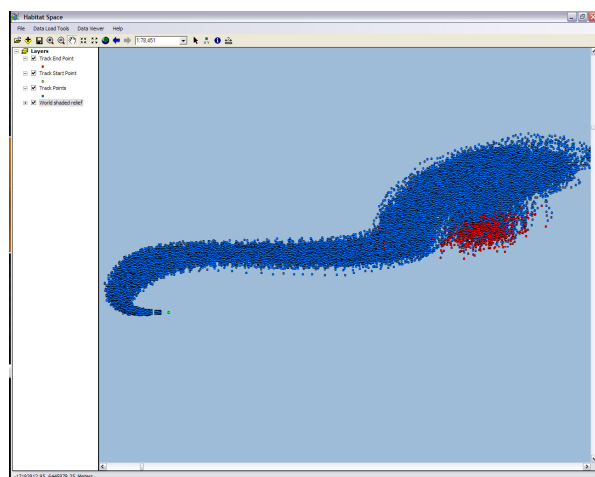
**Figure 5** Plan and oblique views of the theoretical paths of rock sole larvae in the Bering Sea.

### 3.2 Visualization of particle tracks generated using NCOM model forecast data - walleye pollock in Shelikof Strait, Alaska

One of the tools for ensuring that an exploited fishery is not overfished is the creation of accurate predictions of the number of



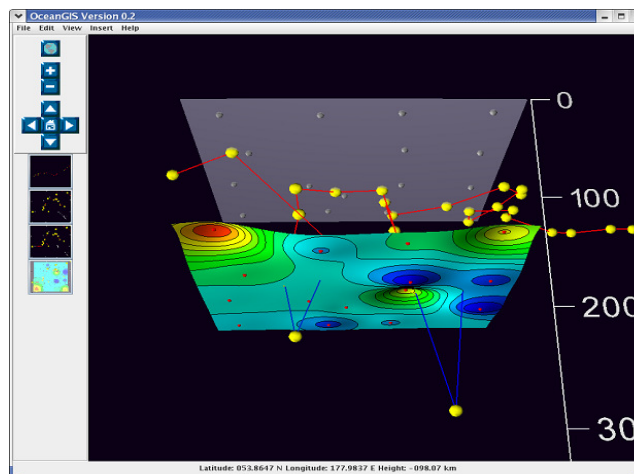
adults that can be harvested without overexploiting the resource. Determining these levels requires accurate assessments of the number of fish being recruited into the fishery (larvae) and the survival of the new fish. While field assessments are used to locate and quantify the spawning biomass, this information can also feed into advanced models that couple the biological resources with environmental factors – both large scale climatologies and observational data collected in tandem with biological data. Slight changes in water temperatures, current patterns and perturbations in the weather can affect the survival of young fish. Circulation models can be used to predict current patterns during critical portions of the larvae's life and particle tracking models can be used to determine if they will be transported to good or poor habitats. The NCOM, developed for the U.S. Navy, provides both hindcasts and forecasts of ocean current patterns. Since it is an operational forecast model, its results are continuously available. NCOM can be used to run particle tracks during research cruises studying the current year's population and can provide early views of where the larvae might end up, and how their location might affect their survival. In this way, it can provide real-time input to fisheries managers and can assist them in setting quota for future years.



**Figure 6** Theoretical paths of pollock larvae released at the lower left of the image. The red dots show the final location of the larvae based upon NCOM circulation patterns.

### 3.3 Tracking animate particles – marine mammals

The analysis and display tools of GeoFish are not limited to model output. The paths of instrumented marine mammals [4], such as fur seals, can be visualized using the same tools. The path of instrumented animals can be shown. The relationship of an animal's path to factors such as water temperature can be shown if model or in situ data are available.

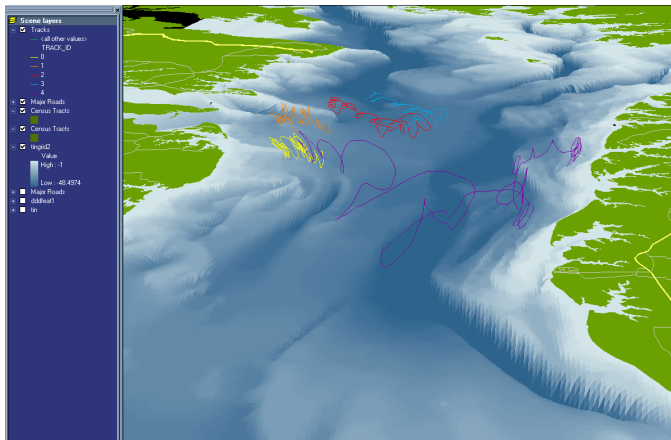


**Figure 7** Path of a theoretical animal and a contoured temperature surface

The same techniques could be used to display the path of any sort of instrumented individual or object. Combining flight data with radar or other images of the storm system could show the path of an airplane through a weather system. Telemetered locations and acoustic data could show the path of an autonomous undersea vehicle (AUV) through the water column. Paths of instrumented fish such as tuna could be combined with basin-wide oceanographic model data to show how the fish might be drawn to, or avoid, waters of certain temperatures.

### 3.4 Displaying data for resource managers in 3-D – CBOLT

While the original CBOLT application only shows the larval tracks in a map view, GeoFish can be used to show the tracks in three dimensions. The data are stored as ESRI shapefiles and are displayed using the ArcGIS implementation of GeoFish. These displays can be used by managers to better display the results of larval seeding operations and to easily visualize complicated relations between topography and larval paths. With the recent development of KML output from ArcGIS, the results can also be displayed for the public in a familiar GoogleEarth view.



**Figure 8** CBOLT tracks for oyster larvae shown in 3-D using GeoFish.

## 4. CONCLUSIONS

GeoFish and its integration of particle tracking models and GIS has proved to be a useful tool for biologists. It is intuitive to implement and the resulting displays and analyses make it faster and easier to understand complicated four-dimensional datasets. Using components from a variety of existing applications speeded development. The use of Java as a connector between elements proved invaluable. The greatest challenge has been the implementation of new hydrodynamic models and their associated particle trackers. The original framework used a triangular mesh hydrodynamic model. Adapting this tool for rectangular coordinate systems proved problematic. The particle trackers developed for these later models are very customized and cannot be easily integrated in the CBOLT framework. To extend the existing tool, we are going to use a more generalized package developed for search and rescue and other activities. It makes use of the Environmental Data Server and ncml to integrate a variety of models via standardized data formats and data translators.

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