

GeoFish – visualization and analysis of particle tracking model output for fish and shellfish larvae

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Abstract

The spatial and temporal patterns of larval dispersion provide insights into the interplay between physical and biological processes in the ocean. These insights can guide the understanding of the early life history of a species and can become part of plans to manage and preserve the habitat of a fishery. Tracks for the dispersion of larvae are calculated by running a particle-tracking model on top of an ocean circulation model. The resulting spatial (x, y and z) and temporal (t) data for tens to thousands of larvae are a rich and complex dataset. Visualizing these data interactively in three-dimensions allows scientists to see patterns in the transport, and to explore the vertical and horizontal dispersion of organisms. The tracks of the organisms can be integrated with supporting datasets including water temperatures and salinity or nutrients. A geographic information system (GIS) is an excellent tool for displaying and analyzing these disparate datasets. A GIS allows the viewer to integrate datasets and to rotate the view through three dimensions. GeoFish is a tool for specifying model parameters, running the particle tracking model and analyzing and displaying results. It combines many essential functions into one powerful application making it easier for both sophisticated and novice modelers to rapidly generate and analyze model results

Keywords: larval fish, GIS, visualization, particle tracking, circulation model, Bering Sea

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Introduction

Models provide a way to understand the complex interactions of biological and physical processes. Models can also describe and link two physical processes. The motion of particles, or organisms too small to swim, can be calculated by using a combination of general circulation models and particle tracking models to describe the physics and biology of the particles being studied. These linked models use an underlying circulation model to describe motion in one or more dimensions, and an overlying particle-tracking or individual-based model to describe the behavior of the organism or particle in a fluid or gaseous medium. Entering the parameters for these model runs is a complex process, and the output can be voluminous and complicated. Graphical techniques for both the input of model parameters and the output of visualizations can make it much easier to use these models, and to understand the results of model runs.

Models can be computed in one-, two-, three-, or four-dimensions. One-dimensional particle-tracking models describe the motion of particles at a point in an imaginary stream or other linear feature. Adding a second dimension allows the model to show the evolution of patterns in arbitrary vertical or horizontal slices of space or planes. Creating animations with these would provide a third dimension, time. Spatially three-dimensional models show snapshots of the positions of particles in space and a series of these snapshots can provide a rough animation to show the evolution of trajectories and patterns through time. Four-dimensional models provide both spatial and temporal understanding, and can be used to study the evolution of patterns with time.

Particle-tracking models are used to study the dispersion and survival of a variety of species. Ribergaard et al. (2004) have used individual-based models based on finite element circulation models to study the transport of shrimp larvae west of Greenland. The particle-tracking model uses Lagrangian advection and diffusion to represent the effects of small-scale turbulence. The Quoddy circulation model drives the particle tracker. Brickman et al. (2007) used the METACOD circulation model and an advective and random displacement particle-tracking algorithm to study the dispersion of cod larvae near Iceland. While the particle tracks were mapped, there was no spatial analysis of the results. Opdal et al. (2008) used a particle-tracking model to study the early life and thermal history of cod larvae in Norway using a Regional Ocean Model System

(ROMS) model. Proctor et al. (1998) studied the transport of sandeel larvae using a model developed for tracking oil spills and Sentchev and Korotenko (2004) looked at the concentrations of flounder larvae and compared Lagrangian model results with field sampling. In the north Pacific models have been used to study the transport of Walleye pollock in Shelikof Strait (Hermann et al., 1996) and Lanksbury et al. (2007) looked at the dispersion and transport of rock sole larvae. Particle-tracking can also be used to study the dispersion of introduced and nuisance species. Pedersen et al. (2005) used a Lagrangian model to study the spread of the non-indigenous red king crab to the Barents Sea, while Gillibrand and Willis (2007) looked at the spread of sea louse larvae from salmon farms in a Scottish inlet.

Models and GIS

The recent international emphasis on an ecosystem approach to management of commercial fisheries leads to increasing dependence on models and modeling. Models can provide simplified understanding of complicated systems and can be used to study the effects of alternate management scenarios. As models become more complex and increased computational resources allow for the routine use of three-dimensional models, interpreting the ever larger and more complex output becomes a greater challenge. The objective of this project is to demonstrate how ecological models and a geographic information system (GIS) can be tightly coupled to provide easier manipulation of the model parameters, rapid interaction with the model, and enhanced analysis and 3-D visualization of the results. To do this we take advantage of two existing GIS-based architectures - a particle-tracking model in the Chesapeake Bay Oyster Larvae Tracker (CBOLT) and a visualization tool called GeoModeler. Additionally, a variety of Java-based tools provide other parts of the functionality needed for truly four-dimensional displays and analyses of model output.

GIS provide tools for handling disparate types of data, have strong 2-D analytical tools and provide excellent 2- and 3-D visualizations and displays. They also include new capabilities to handle netCDF files, a standard for model output, natively within the GIS. However, they are not powerful enough to run true ecosystem models and have limited abilities to analyze and display data in three-dimensions. This can be a problem

as models such as ROMS are fully three-dimensional and much potential information is lost when the results are shown in 2-D. Visualization tools such as Java3D, Visualization ToolKit (VTK) and GeoModeler provide 3-D visualization and analysis and allow scientists to add analyze patterns in model results.

CBOLT (Figure 1) is an integrated system of components written in a variety of languages [<http://gis.esri.com/library/userconf/proc06/papers/abstracts/a2095.html>] that allow users to control a particle tracking model, and then examine the output as geospatial features in a Web-based map interface. CBOLT uses a web interface to allow users to input model parameters for particle tracking, sends these parameters off to computational engine, returns results to a database, and then plots them in 2-D in a web map. While CBOLT is currently a specialized system for showing oyster larvae tracking results, it was written in such a way that it could be broken into reusable components. We use these components in GeoFish 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 file-based geodatabase.

GeoModeler (Vance et al., 2007) is used for visualization and analysis of oceanographic and fisheries model results in 2- and 3-D. GeoModeler uses Java and a GUI to set up model display parameters, allows for 3-D display/manipulation, and provides analytical tools via Java-based utilities. GeoModeler is modular and can be expanded to read and analyze the output of a variety of models. It was developed to exploit the fact that ESRI ArcEngine exposes code and objects to allow closer coupling of core GIS functionality and analytical/modeling tools. The GeoModeler interface and display use graphical objects to provide functionality related to the type of data being displayed. As a data layer is added, the relevant tools for analyses are exposed for use. Data can be read directly from an OPeNDAP server by the Java code in GeoModeler. GeoModeler has been used for displaying results from the ROMS circulation model. As with CBOLT, GeoModeler was designed in components. We use the GeoModeler Java-based components for I/O with oceanic models such as ROMS, and for 3-D display and analysis. Analysis tools include path on volume and volume on volume intersections. Display components include pan, zoom, slice, and adding and removing data layers.

GeoFish: integrating CBOLT and GeoModeler

In GeoFish (Figure 2), we provide a fully-functional prototype of how one might integrate a GIS with a number of oceanographic and fisheries models. Current prototype applications include two examples - one for fish larvae and the other for shellfish larvae. The first models the distribution and transport patterns of larval northern rock sole, *Lepidopsetta polyxystra*, in the southeastern Bering Sea (Lanksbury et al., 2007). This application uses a ROMS model, runs an associated particle tracking model and displays results draped over a three-dimensional globe. The second implementation allows the setting of sources for dispersion of oyster larvae in Chesapeake Bay using the triangular grid C3PO model [<http://nauticalcharts.noaa.gov/csdl/op/c3po.html>] and displays the resulting dispersion tracks in two and three-dimensions.

Both applications implement an ArcIMS and VTK-based interface to a Lagrangian particle tracking model. The user "seeds" a region or area with larvae and watches how they disperse based upon a hydrodynamic circulation model. The user sets parameters for the model run including the release location for the larvae, the release data and time, the run duration and direction, the number of larvae to release and the type of spatial output. A particle-tracking model is run and the results are returned as a netCDF file, which is translated and stored as geospatial features. The output is a three-dimensional grid of the trajectories of the larvae over time. The features can be shown as a two-dimensional map in an ArcIMS (Figure 3), and as a three-dimensional visualization in GeoFish (Figure 4 and Figure 5). The ArcIMS renderer provides analyses such as spatial queries and buffering. 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.

Conclusions

Particle tracking models are used in a variety of disciplines. Atmospheric applications include tracking volcanic plumes and the release of contaminants. Marine applications include tracking of inanimate (sediment particles) and animate (plankton, larval and juvenile fish) objects. While the output of these models can be complicated and voluminous, GIS provides simple ways to analyze and visualize the output. GeoFish

is a prototype of an application to set the parameters for running the models and an application to analyze the results in three- and four-dimensions. Using a GIS also allows the user to add other geospatial data, such as water temperatures, the boundaries of hypoxic or marine protected regions, and infrastructure such as bridges and jetties. The visualizations allow users to explore relationships in the data, and to better present the results to non-modelers, scientists and resource managers. In this way, particle-tracking models can be better integrated into decision support and resource management systems.

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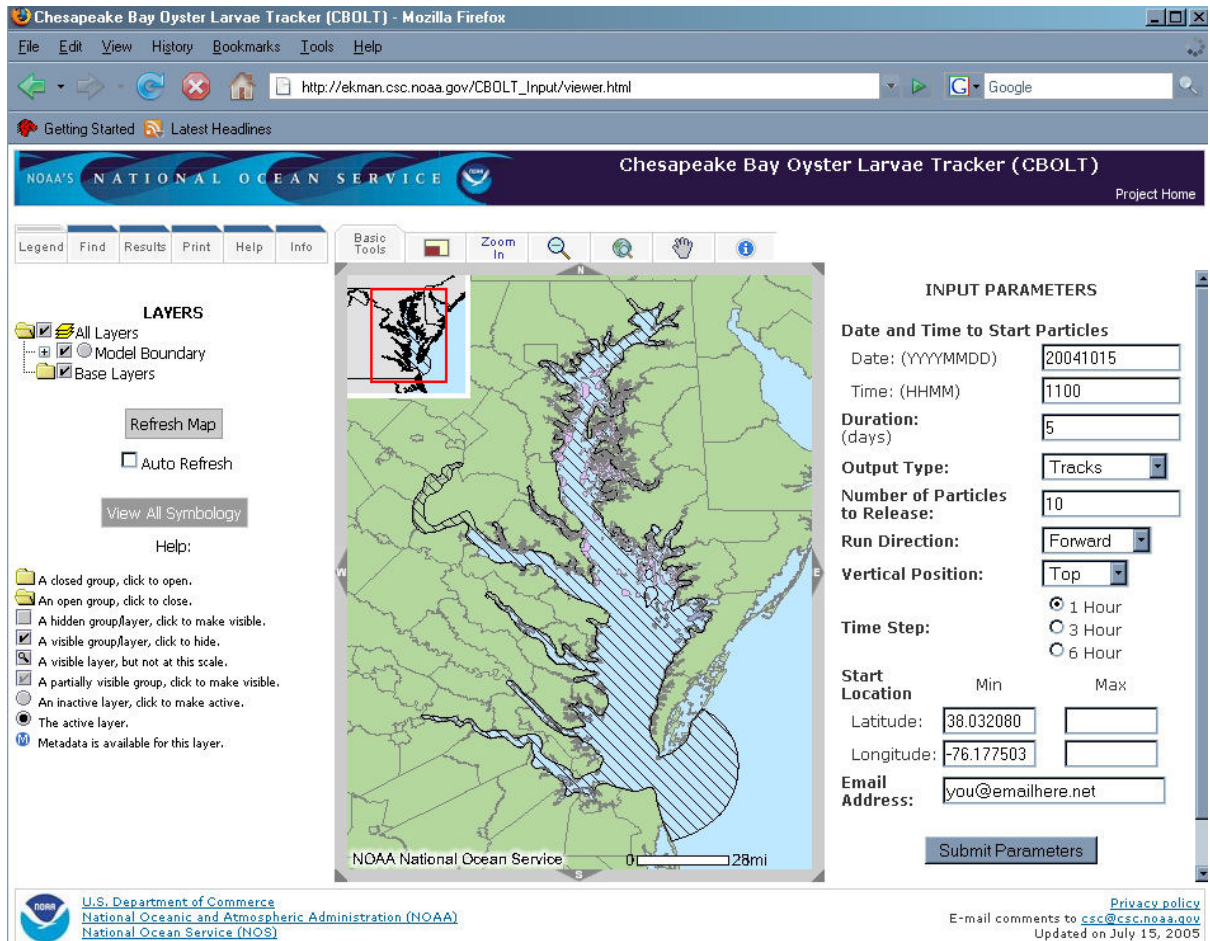


Figure 1 The CBOLT interface showing how it is used to enter parameters for a model run.

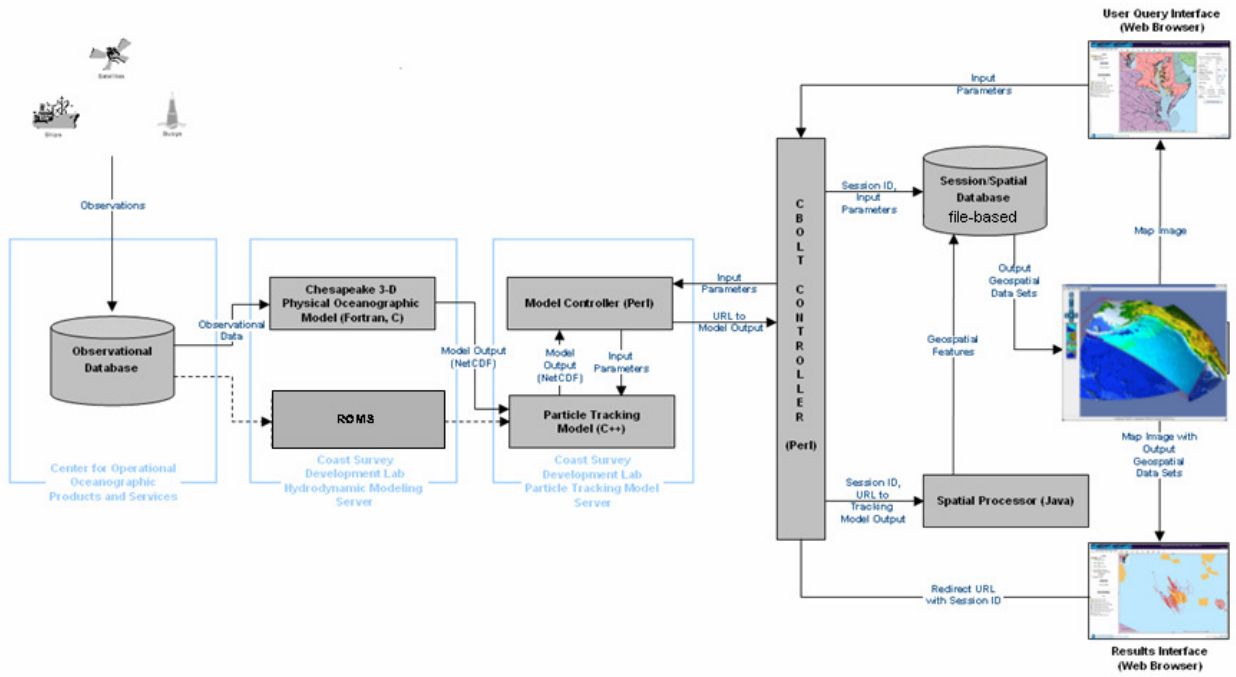


Figure 2 GeoFish architecture.

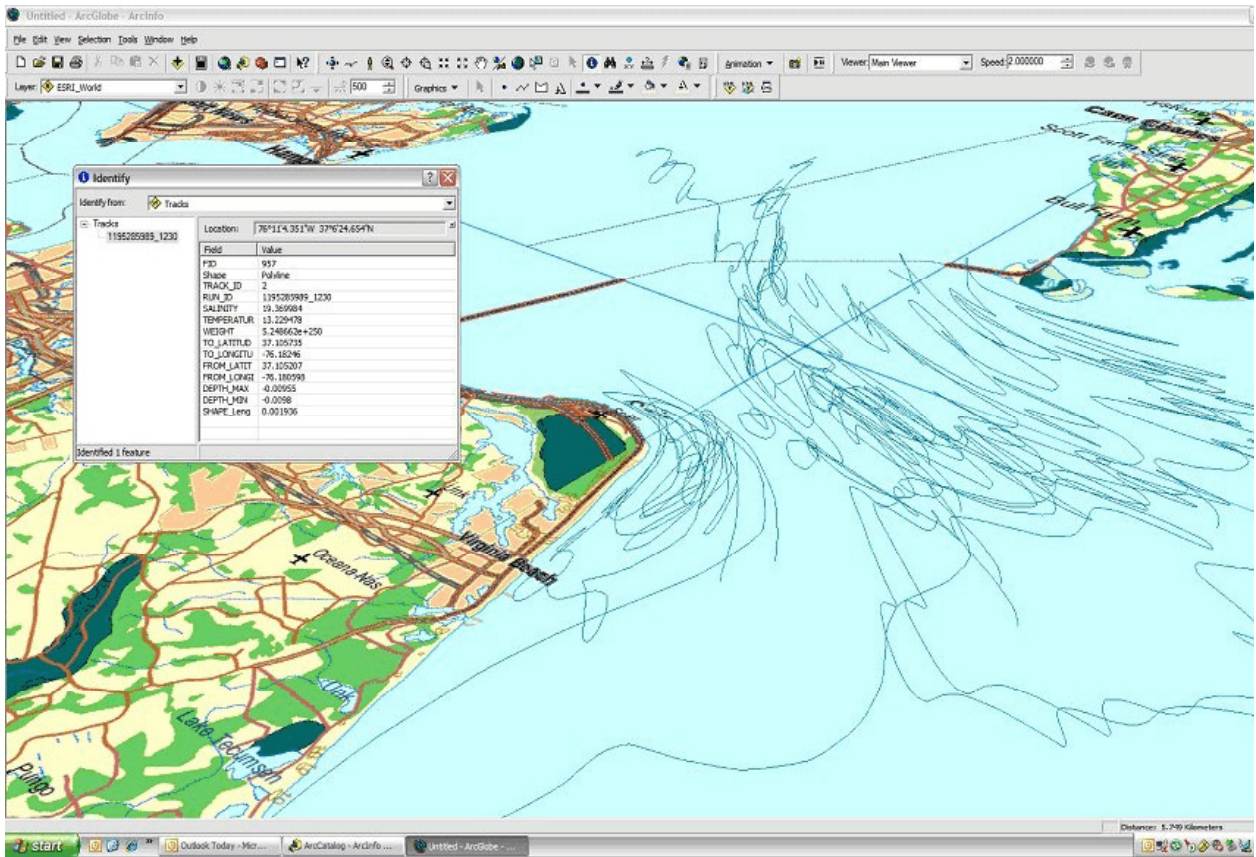


Figure 3 2.5-dimensional output of oyster larvae tracks from GeoFish. Larvae are released at the entrance to Chesapeake Bay and they mainly drift out through the mouth of the Bay.

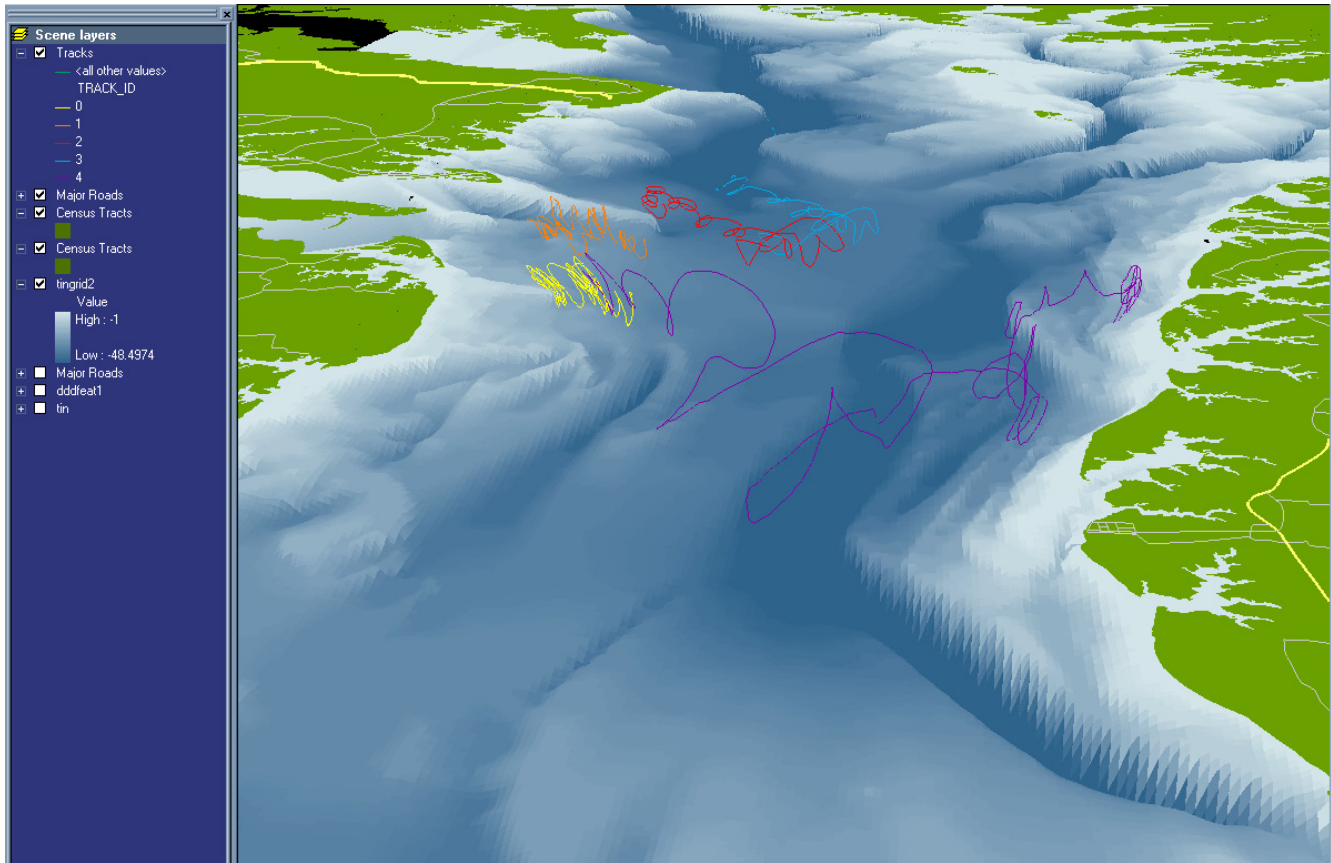


Figure 4 GeoFish three-dimensional view of larval paths in Chesapeake Bay. The larvae were seeded near the shore on the left-hand side of the visualization. Most stayed near the shore but one was carried across the channel to settle on the far shore.

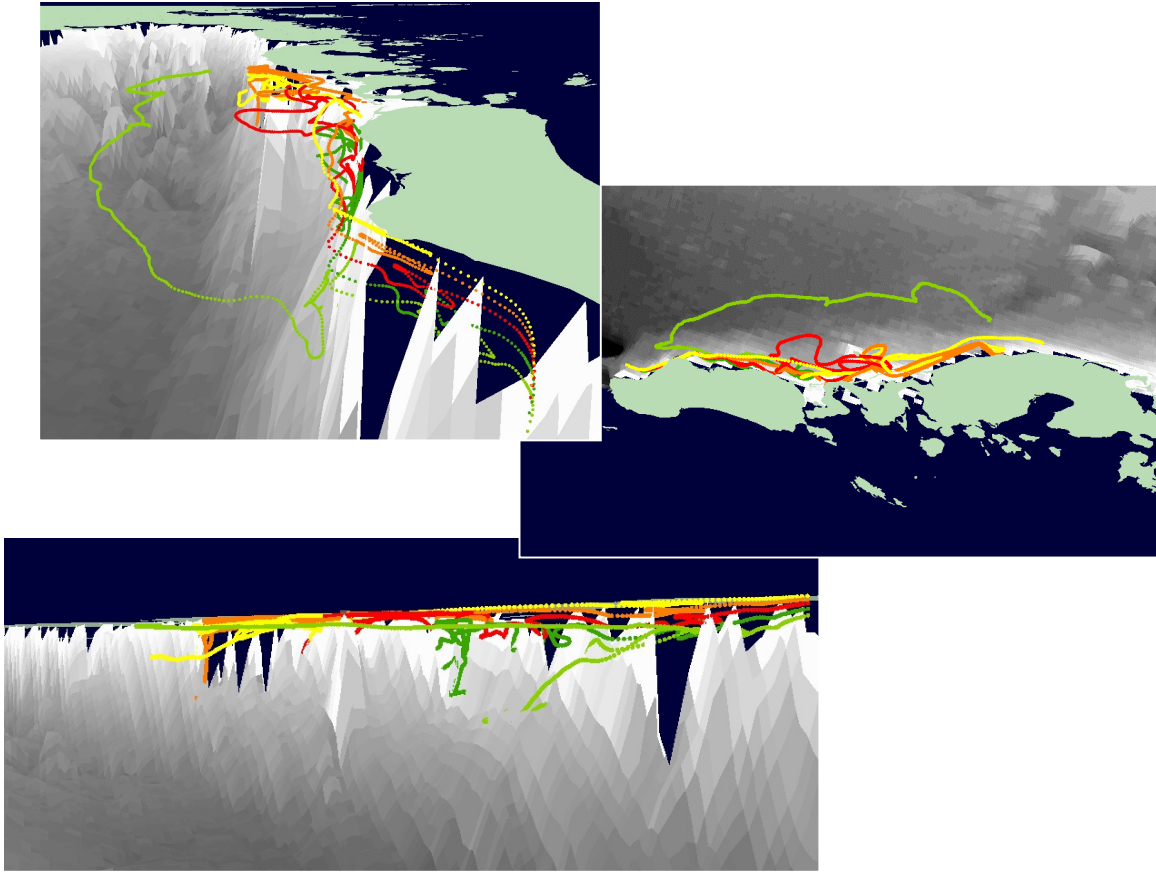


Figure 5 GeoFish visualization of rock sole larval trajectories. The larvae were seeded in a vertical column near the shore. Most drift along shore close to the shoreline but, one is carried offshore into deeper water.