Case Study on Visualizing Gulf Stream Eddies from ROMS

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Figure 1. As the Gulf Stream (blue) meanders northeastward (left figure), vortices spin off to the north and south forming anticyclonic (pink) and cyclonic eddies (orange), respectively. Here we track the eddies' daily motion across the ocean for long-lived (≥50 days) eddies in the ocean basin and extract four examples (middle figures). An individual eddy changes daily in size, shape, and temperature distributions. Two selected isosurfaces (right figures) show the scale and temperature distributions of typical eddies.

ABSTRACT

Visualization of Gulf Stream eddies produced in a regional ocean model simulation has improved understanding of eddy kinetics and structure. In this work, we extract and track eddies over three successive years (2005, 2006, and 2007) of daily frames. The tracking metadata permits the generation of a series of long-lived (≥two weeks) eddy evolution paths which reflect the life-cycle of individual eddies. Important geometric and physical properties of the eddies lead to three types of visualizations. First, a regional three-dimensional eddy distribution map shows eddy occurrence over time in the context of the ocean basin. Second, illustrative visualization of eddy evolution paths demonstrates the kinetics of eddies. Third, a vorticity isosurface, color-coded for ocean temperature and salinity, illustrates internal structure and vertical transport. We provide GUI-based tools to permit scientists to easily browse back and forth exploring eddy characteristics at different levels. This is the first time that the three-dimensional evolution of eddies has been observed directly from Regional Ocean Modeling System (ROMS) data.

Keywords: ocean model, oceanic eddies, feature tracking, illustrative visualization, GUI.

1 INTRODUCTION

As the Gulf Stream crosses the Atlantic Ocean, it develops kinks, which spin off to form high-vorticity features called eddies. Eddies are important sources of transport for nutrients and heat. Three-dimensional ocean model simulations are used to study the development of such eddies, but publications in oceanography typically show only simple two-dimensional plots of eddy variables on the surface and in vertical sections. While two-dimensional representations efficiently and simply illustrate the dominantly horizontal dynamics in the ocean, eddies are places of vertical transport. The structure of such eddies and their internal variation in temperature and salinity are fundamentally three-dimensional. This motivates the development of fully three-
dimensional visualization and analysis methodologies appropriate to the analysis of eddies in the ocean.

In [1], Williams et al. computed geometric information for extracted eddies to provide a summarized global view. They then created detailed but static regional two- and three-dimensional maps to learn how eddy properties are related to each other and to the overall structure of the ocean. However, tracking eddies over time is vital to investigate kinematic changes and understand their transport capacity.

In this work, we apply feature tracking techniques to track eddies to determine the kinematics of long-lived eddies and investigate their structure. Our visualizations of eddies include (a) a three-dimensional eddy distribution map with a GUI to display it as a function of time; (b) illustrative visualization of eddy evolution paths; and (c) color-coded three-dimensional isosurfaces of single eddies. The novelty of our visualizations is applying feature extraction and tracking to the ROMS data for the first time, such that the eddies can be treated as independent objects. In particular, the eddy evolution paths extract the selected eddy from a series of time steps.

2 DATA AND METHOD

Our study uses a numerical simulation of the northwest Atlantic Ocean off the coast of North America [2] generated by the ROMS. The chosen dataset in our study covers the most recent three years (2005, 2006, and 2007) with 1095 daily-average NetCDF files. Each data frame has 762×362 grid points (average spacing of 7 km) for each of 40 terrain-following levels.

Our method computes the Okubo-Weiss (OW) parameter [2] at each data grid point to estimate the relative importance of rotation. We apply a region-growing algorithm [3] with a threshold equal to -0.2 times the standard deviation of OW for the current daily data frame. Connected components of points with Okubo-Weiss values below the threshold are extracted as vorticity-dominated features which are potential eddies. To filter out non- eddy features, we require an eddy to contain velocity vectors pointing in all four geographic directions [1]. The identified eddy features are tracked over time with a volume-based feature tracking algorithm [3] to determine evolution. During the “evolution” process, an eddy can split, propagate or merge. From the tracking results and feature attributes, we compute important properties for each eddy (i.e. volume, depth, duration etc.) and generate several visualizations.

3 VISUALIZATION

We present three applications of existing visualizations to improve the understanding of and illustration of eddy evolution in the Atlantic Ocean. However, our methods are applicable to results of any ROMS model regardless of location. Three-dimensional eddies are placed in the context of the ocean basin and coastline to indicate more clearly the transport potential of these eddies (Figure 2). A standalone GUI has been developed to allow the user scientists to view the temporal evolution of eddies in the context of the ocean basin (Figure 2). Basic techniques of illustrative visualization [4] are combined with isosurfaces of an eddy at each day in its life to illustrate the physical and kinematic changes in the eddy over its life cycle (Figure 3). In this case, the eddy shrinks and warms over time. Previously studies of eddies have extracted limited information on the three-dimensional structure of eddies (e.g. depths of penetration [1] or single cross-sections). Here we show the ocean temperature variation on the surface of a three-dimensional eddy illustrating both the physical tapering of the eddy and the penetration of the thermocline by the eddy (Figure 4).

Figure 2. Evolution paths longer than 14 days are shown within the ocean basin for cyclonic (orange) and anti-cyclonic (pink) eddies. The GUI facilitates stepping through time, selecting paths (insets), and adjusting visualization viewpoint on pre-processed ROMS data.

Figure 3. This eddy evolution path shows changes in temperature, size, and penetration depth over time for an anti-cyclonic eddy.

Figure 4. These isosurfaces (temperature on left; salinity on right) show the first time step of the anti-cyclonic eddy in Figure 3 as a shell of high vorticity surrounding a core of cold water.

4 CONCLUSION

This study improves illustration of eddies and understanding of their structure by applying feature tracking and illustrative visualization techniques to three-dimensional ocean modeling results. The basin provides oceanographic context while the eddy evolution paths and temperature or salinity isosurfaces illustrate newly discovered details of eddy life cycles and three-dimensional structure. This is the first time that the three-dimensional evolution of eddies has been observed directly from ROMS data.

REFERENCES


