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Influence of Florida Current frontal eddies on circulation and fish recruitment around the Florida Keys Reef Tract

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Abstract. The coastal seas around the Florida Keys Reef Tract exhibit complex dynamics resulting from the interaction with the Loop Current/Florida Current system and the frontal eddies that interact with the complex reef topography. Nesting to a succession of coarser, regional model and finally to basin-wide and global models allows the downscaling of large scale flows to scales of reef related processes. A high resolution (~900m) of the Hybrid Coordinate Ocean Model has been developed for the Florida Keys (FKEYS-HYCOM).

Florida Current frontal eddies are important mechanisms for the interaction of nearshore and offshore flows. They enable upwelling in the vicinity of the Reef Tract and influence transport and recruitment pathways, as they carry waters of different properties (such as river-borne low salinity/nutrient-rich waters) and waters containing larvae from upstream source, or entrained from nearby spawning grounds. FKEYS-HYCOM simulates both mesoscale and submesoscale eddy passages during a 2-year simulation period (2004-2005), forced with high resolution/high frequency atmospheric forcing. Coupling with the ecological population connectivity BOLTS model (BiOphysical Lagrangian Tracking System) allows simulations of larval transport, taking into account not only the dispersion of active physical larvae, but also the interaction of factors influencing larval survival, habitat selection and condition at settlement.

Key words: Florida Current frontal eddies, larval transport, Reef Tract, FKEYS-HYCOM, upwelling

Introduction

The ocean circulation around South Florida is dominated by the Florida Current, which originates where the Loop Current enters the Straits of Florida from the Gulf of Mexico, subsequently becoming the Gulf Stream as it emerges in the South Atlantic Bight (Fig. 1). The Florida Bay is openly connected to the Southwest Florida Shelf along its wide western boundary, but exchange with the Atlantic coastal zone of the Keys is restricted to a few narrow passages between the Keys island chain. Freshwater runoff occurs along the Ten Thousand Islands area through a series of small rivers (Fig. 1). Loop Current eddies propagate southward along the outer edge of the Southwest Florida Shelf and develop into persistent eddy structures off the Dry Tortugas.

The Keys coastal zone consists of a narrow, curving shelf with complex topography associated with its shallow Reef Tract. The outer shelf region of the Keys is dominated by meanders of the Florida Current and the downstream propagation of eddies.

The Florida Current frequently forms cyclonic, cold-core frontal eddies along the Slope and Shelf. These eddies are formed along the western edge of the Florida Current and travel northward along the continental margin.

Recirculation within mesoscale eddies and their several months' duration in the Keys coastal zone have been proposed as a retention mechanism that may contribute to local recruitment of larvae spawned in the Dry Tortugas or along the outer Reef Tract (Lee et al. 1992). Off the Florida Keys, frontal eddies are associated with cross-shelf larval transports (Sponaugle et al. 2005).

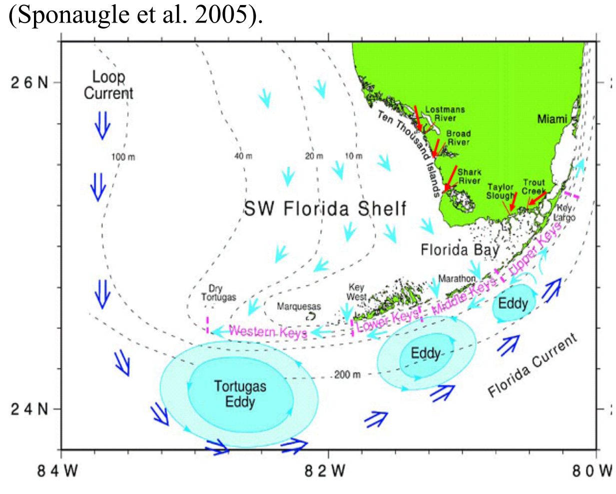

Figure 1. The complex South Florida coastal system, adapted from Lee et.al (2002). Red arrows mark the river sources.

A nested modeling approach has been employed to ensure the proper representation of the complex south Florida coastal system (Fig. 1). A high resolution (~900m) application of the Hybrid Coordinate Ocean

Model has been developed focusing on the circulation around the Florida Keys (FKEYS-HYCOM). Nesting to a succession of coarser, regional models (South Florida SoFLA-HYCOM and Gulf of Mexico GOM-HYCOM) and finally to basin-wide and global models allows the downscaling of large scale flows to scales appropriate for the study of reef related processes.

Model domain and set-up

The Florida Keys HYCOM model domain covers 79.0°W to 83.4°W and 22.8°N to 26.1°N (Fig. 2) with very high resolution of about 900m in horizontal and twenty-six hybrid-layers in vertical. It is being nested within the 1/25° SoFLA-HYCOM (Kourafalou et al. 2008) with daily updating for barotropic and baroclinic boundary conditions. Time integration steps are 30 sec for the baroclinic mode and 1 sec for the barotropic mode.

The topography is derived from the 2-minute NRL DBDB2 global dataset with a minimum depth of 2m. The FKEYS-HYCOM is forced with three-hourly wind stress, air temperature, atmospheric humidity, heat fluxes and precipitation from the 27-km horizontal resolution Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS, Hodur 1997; Hodur et. al 2002) for the year 2004 and 2005.

River runoff from the Shark River in the domain is the important source of low salinity which can impact the water property inside/around Florida Bay and along the Florida Keys through the neighboring Keys passages. It was prescribed as a line source of fresh water input along the Ten Thousand Islands starting from the Shark River. Low salinity waters from the SW Florida Shelf reach the AFKS through the Keys passages, influencing water properties along the Reef Tract.

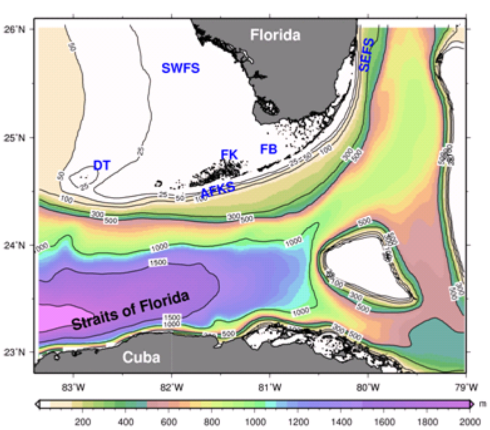

Figure 2. The Florida Keys (FKEYS) model domain and bathymetry (contours in m). It covers the Southwest Florida Shelf (SWFS), the Southeast Florida Shelf (SEFS), the Atlantic Florida Keys Shelf (AFKS) and the Strait of Florida, extending from Cuba to the Biscayne Bay. (FB: Florida Bay, FK: Florida Keys National Marine Sanctuary, DT: Dry Tortugas Ecological Reserve).

Evolution of eddies in the Straits of Florida

The Okubo-Weiss parameter is employed to quantify eddies and their propagation along the Florida Current front. This parameter represents a balance between the magnitudes of vorticity and deformation (Veneziani et al. 2005). Since the Okubo-Weiss parameter typically assumes highly negative values inside coherent vortex cores, while it becomes highly positive in the area immediately surrounding the vortex cores, it is very useful in identifying vortices and rotating structures, like eddies in the ocean. It measures the relative contribution of deformation and vorticity in a velocity field. Taking into account the characteristics of two-dimensional flow fields, eddy cores can be identified as the simply connected regions with high negative values of the Okubo-Weiss parameter. This parameter was used to identify and track eddies from altimeter data (Isern-Fontanet et al. 2003 and Cruz Gomez and Bulgakov 2007).

It is given by $Q = d^2 - \zeta^2$, where ζ is the relative vorticity field which is defined as

$$\zeta = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

and d is the deformation rate whose squared value is defined as

$$d^2 = \left(\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}\right)^2$$

A series of 6-hourly maps of Okubo-Weiss parameter for 2004 has been prepared to identify and track eddies in the domain. One eddy (known as the Tortugas Eddy) appears on May 29 and becomes well organized as it moves along the shelf (Fig. 3). Its evolution is shown along with isobaths of 100m and 200m in black lines. Green lines mark 20°C isothermal lines at 150m to capture the Florida Current frontal boundaries (inner and outer). Variability of eddy strength and shape happens within these boundaries. As the eddy moves, it becomes elongated with smaller eddies embedded.

Some of the simulated eddies are captured by SeaWiFS chlorophyll-a images distribution. A big eddy south of Key West is present both in the SeaWiFS chlorophyll-a distribution and the FKEYS simulation. Also a chain of sub-mesoscale eddies along the Keys bounded by the 100m isobath line are shown (Fig. 4).

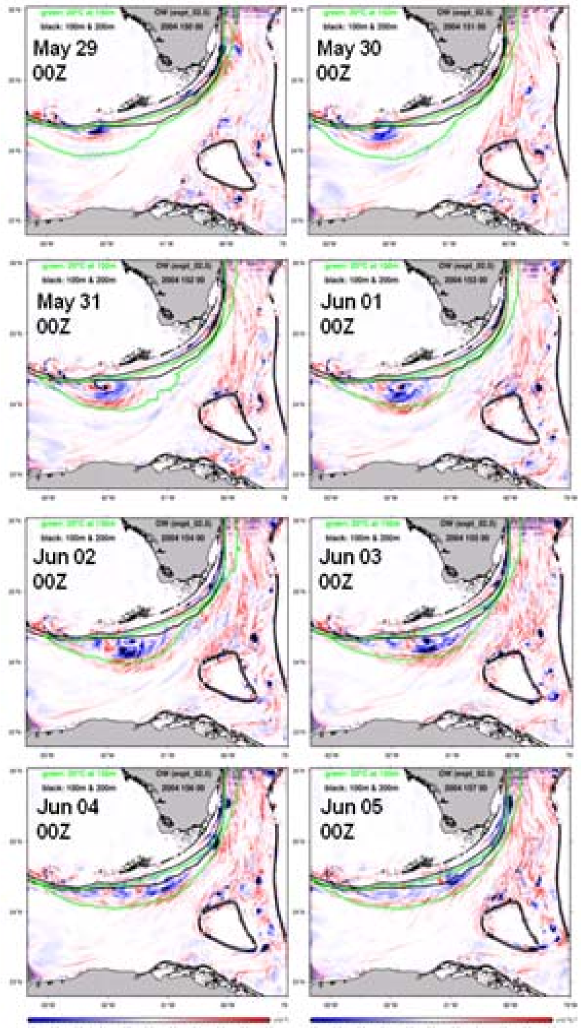

Figure 3. A series of daily Okubo-Weiss parameter maps from May 29 to Jun 5, 2004. Black lines are for 100m and 200m isobaths. Green lines are contour lines of 20C at 150m.

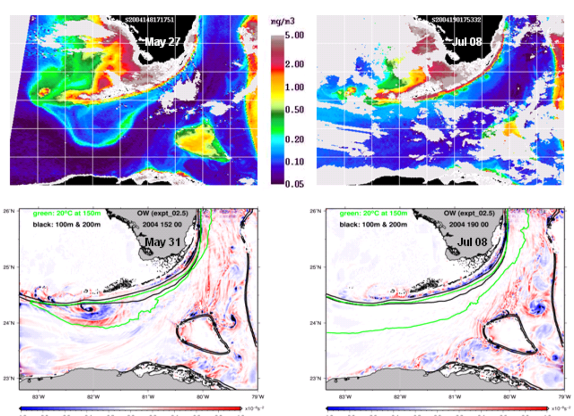

Figure 4. Distributions of Chlorophyll-a on May 27 and Jul 8, 2004 are shown on the upper panels while HYCOM-FKYS simulated Okubo-Weiss parameter maps on May 31 and Jul 8, 2004 on the lower panels.

Eddy induced Upwelling

A mesoscale eddy occurs near the lower part of the Florida Keys Reef Tract (see the top fourth picture in Fig. 5). Cross-sectional distributions of simulated temperature, salinity and along-shore velocity along the western edge of the eddy (82^{o}W) show the upwelling of cool waters, impinging upon the Florida shelf. Strong positive velocities indicate the eastward flowing Florida Current, while velocities turn cyclonically to westward in the vicinity of the eddy.

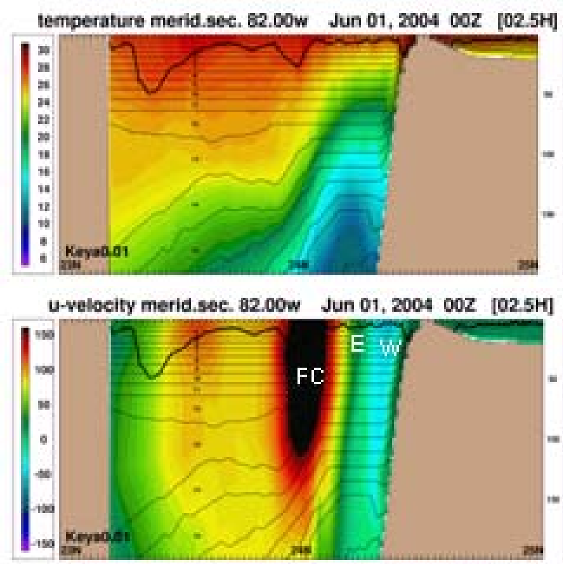

Figure 5. Cross-sectional distributions of simulated Temperature (upper) and along-shore Velocity (lower) during an eddy passage along 82.0^{o}W on June 1, 2004.

Biophysical Lagrangian Tracking System (BOLTS) coupled with FKEYS-HYCOM

Coupling with the ecological population connectivity BOLTS model allows simulations of larval transport, taking into account not only the dispersion of active physical larvae, but also the interaction of factors influencing larval survival, habitat selection and condition at settlement (Paris et al. 2007). This probabilistic modeling system is composed of multiple standalone code units (i.e. biological seascape, ocean general circulation modules) coupled in a single Lagrangian stochastic unit. Of particular interest is the flexibility of the biological module in integrating any type of organism's life history traits, stochastic and spatially explicit larval mortality, larval vertical migration, and larval settlement behavior through the perception of suitable settlement habitat via coupling of the seascape module. In addition, BOLTS runs very efficiently in parallel processing within a LINUX PC Cluster environment and generates various types of output files, including individual larval trajectories and probability transition matrices of individual larvae migrating from a source to a receiving population.

Passive 30-day near surface advection of larvae released at a single location in the Dry Tortugas computed with the BOLTS model is shown in Fig. 6, where random walk has been added on the FKEYS hydrodynamic model velocity fields. Trajectories and particle distribution integrated over the 30-day period show looping trajectories and accumulation of particles into small eddies (see orange-red particles). This result shows that eddies are an important mechanism of larval transport and delivery.

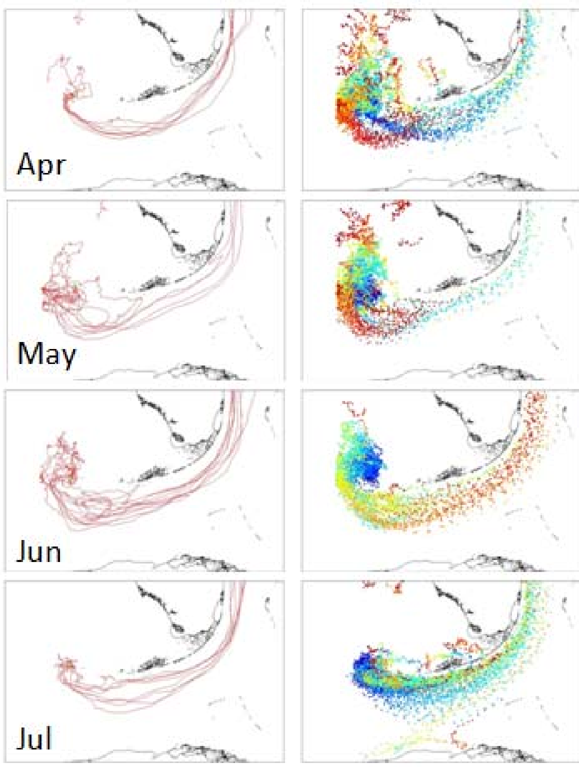

Figure 6. Passive scenario using 6-hour output of the FKEYS-HYCOM 2004: Monthly 30-day trajectories (left – a maximum of 10 trajectories are shown for clarity) and transport of 100 individual particles integrated over 30 days (right) released in the upper 5 m at a single location in the Dry Tortugas Ecological Reserve (green start). Color-code of the particles indicate their age from day 1 (blue) to day 30 (red). Areas with blue and cyan particles indicate strong advection, while areas with concentration of red particles represent retentive flow and/or the end of the 30-day advection.

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