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Physical processes impacting passive particle dispersal in the Upper Florida Keys

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ABSTRACT

Physical processes affecting the dispersion of passive particles (e.g., coral larvae, pollutants) in the Upper Florida Keys are investigated through in situ observations (acoustic Doppler current profilers and surface drifters) and numerical ocean circulation modeling (horizontal resolution: 800 m, vertical resolution: 0.1–1 m). During the study period in August 2006 (set to coincide with an annual coral spawning event), Lagrangian trajectories in the vicinity of the reef tract indicate that alongshelf advection was mainly poleward and due to the subtidal flow of the Florida Current, while cross-shelf advection was mainly onshore and due to wind-driven currents. Tidal currents resulted in predominantly alongshelf displacements, but did not contribute significantly to net passive particle transport on a weekly timescale. Typical advection distances were of the order of 10 to 50 km for pelagic durations of 1 week, with significant variability linked to geographical location. In contrast, the direction of transport from the offshore reefs remained essentially constant (i.e., potential dispersion pathways were limited). In addition, Lagrangian trajectories and progressive vector diagrams in the vicinity of the reef tract indicate that alongshelf variations in the cross-shelf velocity gradient associated with the FC are relatively weak on an alongshore scale of ca. 50 km. For August 2006, the highest particle concentrations typically occur inshore of the reef tract, thereby suggesting that onshore transport associated with wind-driven currents contributes significantly to the local retention of passive organisms (and other tracers) in the Upper Florida Keys. Overall, the results illustrate the necessity of conducting targeted in situ observations and numerical model predictions to quantify the physical processes affecting reef-scale advection, especially in an effort to understand local retention and dispersion mechanisms for larval marine organisms.

1. Introduction

With increasing anthropogenic stress on marine populations, especially in nearshore waters, it becomes more urgent to better understand and more efficiently protect living resources in the coastal ocean. Because of the relationship between juvenile and adult populations, characterizing the distribution and abundance of key species (e.g., commercially targeted fishes or reef-building corals) requires knowledge of the larval dispersal rates and recruitment patterns of those organisms (see Cowen et al., 2002 for a review on population connectivity in marine systems). One of the central issues for the connectivity problem is then to quantify the relative importance of alongshore advection and diffusion versus cross-shore advection and diffusion in the coastal boundary layer, as well as possible modulations due to larval behavior (e.g., horizontal and vertical swimming) (Largier, 2003). Characterizing the connectivity patterns between reefs in a specific region would also help address the issues of externally supplied (open) versus self-sustained (closed) populations, recruitment limitation, and population regulation (Armsworth, 2002).

Along the Florida Keys (FK), the motions of mesoscale and submesoscale frontal features associated with the Florida Current (FC) act as mechanisms modulating the cross-shelf exchange of water masses (Shay et al., 1998; Haus et al., 2004), transport of biological material (Lee et al., 1994; Sponaugle et al., 2003), plankton concentration (Lane et al., 2003), and fish larvae abundance (Limouzy-Paris et al., 1997). External (barotropic) and internal (baroclinic) tidal currents, predominantly semi-diurnal in the FK region, are also expected to contribute to local circulation patterns in the vicinity of the Upper FK (UFK) reef tract (Leichter et al., 1996). In addition to tidal and subtidal flows, wind-driven currents also contribute directly to alongshore and

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cross-shore transport, especially for biological organisms concentrated near the ocean surface. The dominant westward wind regime, with a northward component during the summer months, is fairly coherent and homogeneous in the Straits of Florida (SOF) (Peng et al., 1999). Since the orientation of the UFK coastline and reef tract is roughly SW to NE, both Ekman and Stokes drift transports associated with the summer wind conditions will typically have an onshore component.

Previous modeling studies of larval transport in the SOF region have indicated that the interactions between vertical diurnal migration, tidal currents, and salinity gradients may have important effects on the spatial abundance and distribution, as well as the larval dispersal distances, of pink shrimp larvae (Wang et al., 2003; Criales et al., 2005). Larval transport modeling efforts elsewhere have also attempted to predict both short- and long-range larval dispersal/recruitment patterns for diverse marine organisms. For an offshore reef along the Great Barrier Reef, dispersal rates for coral larvae are strongly dependent on reef-scale physical processes (Wolanski et al., 1989), including alongshore currents, tidally driven recirculations, and topographically controlled fronts. In the same region, hydrodynamical models have also been used to investigate the dispersal of reef fish larvae, and to characterize self-recruitment levels and metapopulation connectivity (James et al., 2002; Bode et al., 2006). In particular, the studies illustrate the importance of a few single reefs in maintaining population connectedness and thus allowing transfer of genetic information between subregions of the domain. For Caribbean reef fishes, biophysical modeling studies suggest that the dispersal distances important on ecological time scales are of the order of 10–100 km, and that self-recruitment must be supplemented by outside larval import to sustain most Caribbean fish populations (Cowen et al., 2006).

In the present study, a combination of in situ observations and ocean circulation modeling is used to investigate the complex interactions between the reef tract topography and the FC subtidal, tidal, and local wind-driven currents, as well as their potential impact on Lagrangian transport and larval dispersal pathways in the UFK. Specific interest resides in quantifying alongshelf and cross-shelf transport in relation to larval dispersion following an annual spawning event of *Montastrea faveolata*, one of the major reef-building coral species in the UFK, in August 2006. *M. faveolata* larvae are positively buoyant and located near the surface for 2–3 days after being spawned, then acquire a weak vertical swimming ability and gradually migrate downward during their typical pelagic larval duration (PLD) of ca. 1 week (Szmant and Meadows, 2006). Due to the offshore presence of the FC, larval advection distances along the UFK reef tract could potentially range from hundreds of meters to hundreds of kilometers. The specific reef targeted in the present study, Key Largo Dry Rocks, is located ca. 7 km offshore of the UFK coastline (Fig. 1). Dry Rocks is within the jurisdiction of the Florida Keys National Marine Sanctuary, as well as a designated Sanctuary Preservation Area (SPA). The annual *M. faveolata* spawning event was observed by divers at Dry Rocks on 16 August 2006 at ca. 03:00 UTC.

2. In situ observations

Acquiring high-resolution in situ observations is critical for understanding larval transport mechanisms in a shallow-water environment, and for providing a basis for model-data comparisons in the vicinity of the reef tract. For this purpose, a combination of bottom-mounted acoustic Doppler current profilers (ADPs) and surface drifters is used to characterize the physical environment directly inshore and offshore of Dry Rocks.

2.1. Acoustic Doppler current profilers

Two Sontek 1500 kHz autonomous ADPs were deployed on bottom mounts ca. 1.5 km inshore and offshore of Dry Rocks in water depths of ca. 5 and 7 m, respectively (see Fig. 1). This deployment strategy allowed capturing both reef-scale physical processes and offshore mesoscale variability, as well as identifying the dominant cross-shelf and alongshelf transport mechanisms on each side of the reef tract. In the relatively oligotrophic waters along the UFK, these units have been successfully deployed for up to two months without any adverse effects from biological fouling. The use of high frequency acoustics in shallow water allowed ADP measurements to be made within ca. 1 m of the surface and bottom boundaries. A bin size of 0.25 m was used to maximize vertical resolution and obtain measurements as close as

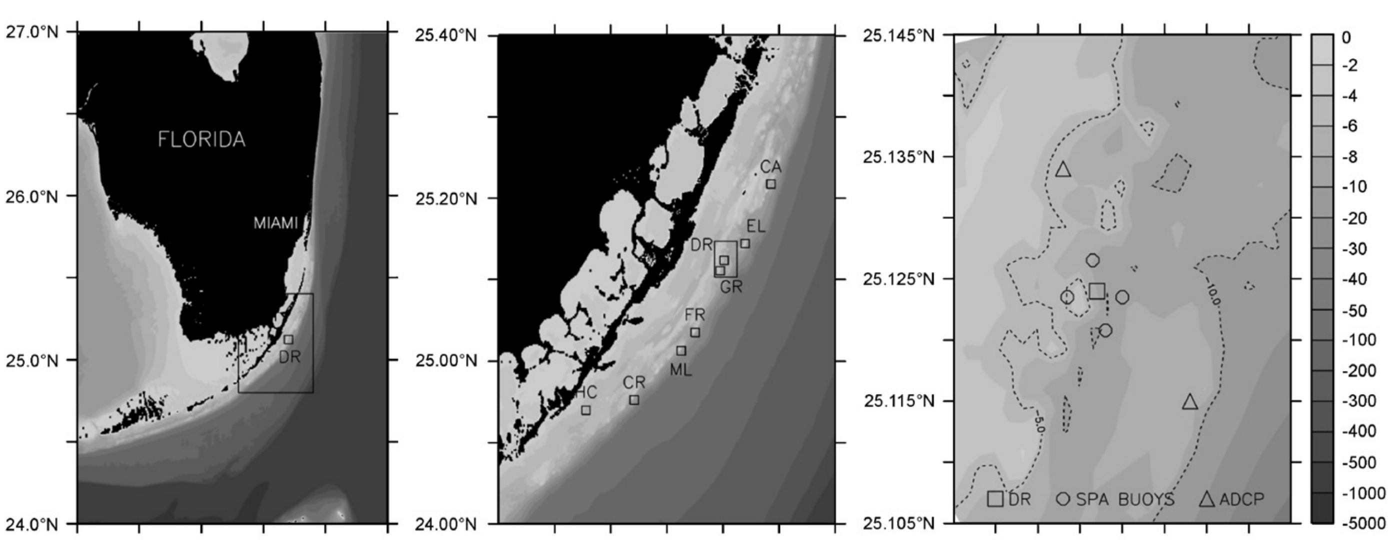

Fig. 1. Geographical map of the Upper Florida Keys reef tract and in situ observations. Left: location of the Upper Florida Keys and Key Largo Dry Rocks (DR). Center: locations of the eight SPA reefs in the Upper Florida Keys (Hen and Chickens (HC), Conch Reef (CR), Molasses Reef (ML), French Reef (FR), Grecian Rocks (GR), Key Largo Dry Rocks (DR), Elbow Reef (EL), and Carysfort Reef (CA)). Right: locations of Key Largo Dry Rocks (DR; square), SPA buoys (circles), and inshore and offshore ADPs (triangles). Gray shades indicate bottom topography (m).