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Simulations of the Influence of the West Caribbean Sea Circulation and Eddies on the Meso-American Barrier Reef System

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ABSTRACT

The Meso-American Barrier Reef System (MBRS) along the coasts of Mexico, Belize, Guatemala, and Honduras is an ecologically and biologically sensitive region. It provides for example, major spawning aggregation sites for various species of fish; these activities may be influenced by variations of the flow near the reef and the transports between the MBRS and the Caribbean Sea circulation. Caribbean eddies, which may play an important role in flow variability, have been studied in the past by observations and models (Carton and Chao, 1999; Murphy et al., 1999; Andrade and Barton, 2000; Oey et al., 2003), but knowledge of their influence on the MBRS is still not complete. With limited availability of long-term observations near the reef and coast, as well as in the open Caribbean Sea, hydrodynamic numerical ocean models may provide important means to study this region.

A three-dimensional, terrain-following (sigma) coordinate ocean model, based on the Princeton Ocean Model, POM (Blumberg and Mellor, 1987), is set up for the West Caribbean Sea (WCS) region (15°N–22°N, 76°W–87°W). A curvilinear orthogonal grid with variable resolution of 3-8 km (with a finer grid near the MBRS) is used. Special attention was put on manually modifying the inaccurate global topography data to include more details near the coast, including for example, the Meso-American Lagoon (MAL) between the reef and the coast of Belize. Lateral boundary conditions include an input transport in the south of 25 Sv (1 Sverdrup = 10^6 m^3 s^{-1}) that exits the model in the Yucatan Channel in the north (Ezer et al., 2003). More details about the model setting can be found in Thattai (2003) who also describes experiments to evaluate the sensitivity of the model to various factors such as wind, eddies and tides. In this short paper we only describe experiments aim to demonstrate the effect of eddies on the coastal area near Belize and along the MBRS.

Sea surface height (SSH) anomaly fields are obtained from a composite of the Topex/Poseidon and ERS satellite altimeters data and are available at 10 days intervals (Ducet et al., 2000). For example, a negative SSH anomaly near the MBRS is seen in January 29, 1999 (Fig. 1a), and a positive anomaly is seen in April 19, 1999 (Fig. 1b); these anomalies will support more cyclonic and more anticyclonic flows, respectively. In order to introduce eddies into the model, surface to subsurface correlations are used to convert the SSH fields into subsurface temperature fields, following the data assimilation approach of Ezer and Mellor (1997). The three-dimensional ocean model is then used to infer the flow field associated with these anomalies (or eddies) using the diagnostic-prognostic approach of Ezer and Mellor (1994). A 20 day diagnostic run (holding the initial density unchanged) is used to compute the SSH associated with the density field, and then a prognostic run (with relaxation of model temperature and salinity to the surface observed fields) is used until the velocity field is dynamically adjusted (after additional 30 days). Monthly averaged wind stress is used as surface forcing.

After the diagnostic calculations the model produces SSH anomaly fields (Fig. 1c and Fig. 1d) that capture the observed anomalies (Fig. 1a and Fig. 1b) very well; this indicates that the data assimilation scheme is able to capture the subsurface baroclinic structure associated with the surface data.

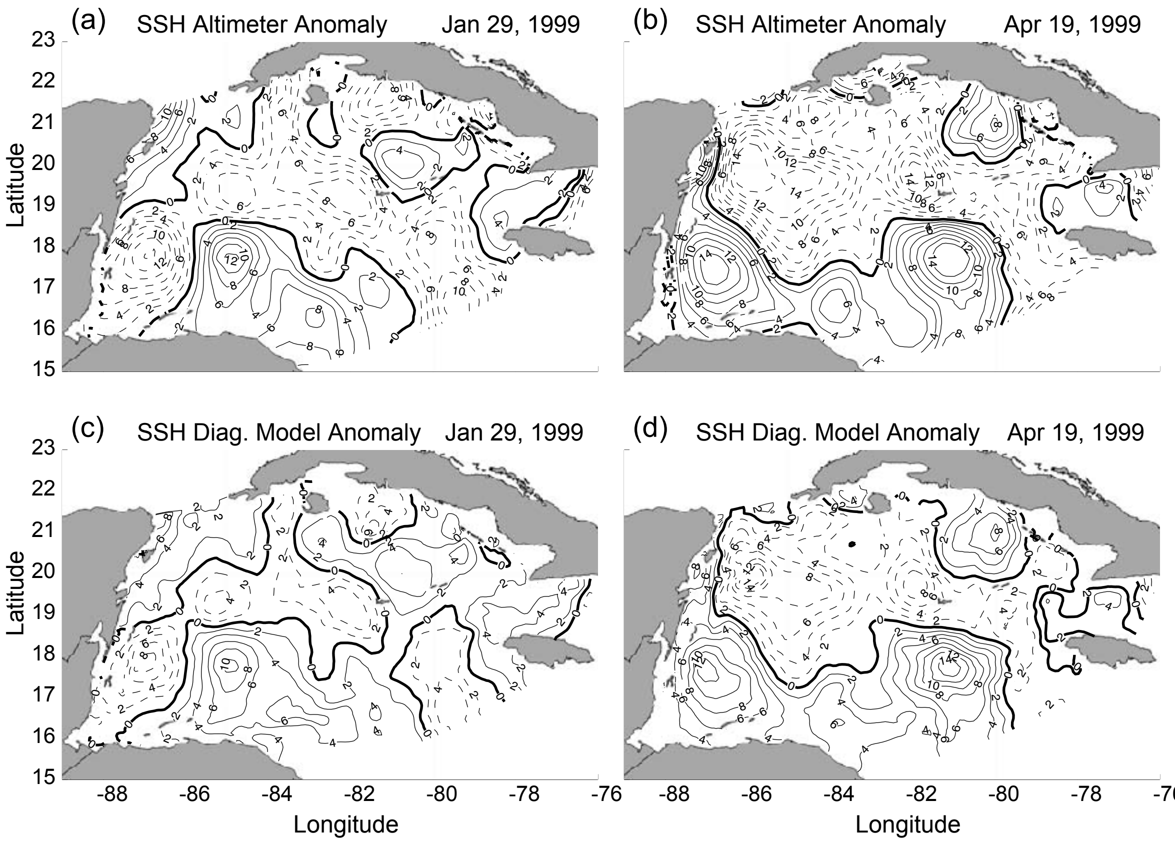

Figure 1. Sea surface height anomaly in cm (relative to the long-term mean) over the model domain. Top panels are from altimeter data and bottom panels are from diagnostic model calculations when initializing the model with assimilated density field representing the observed eddies. Left panels are for January 29, 1999, when a cyclonic eddy was observed near the coast of Belize (the south-west corner of the model), and right panels are for April 19, 1999, when an anticyclonic eddy was observed at the same location. Solid/dashed contours represent positive/negative anomalies.

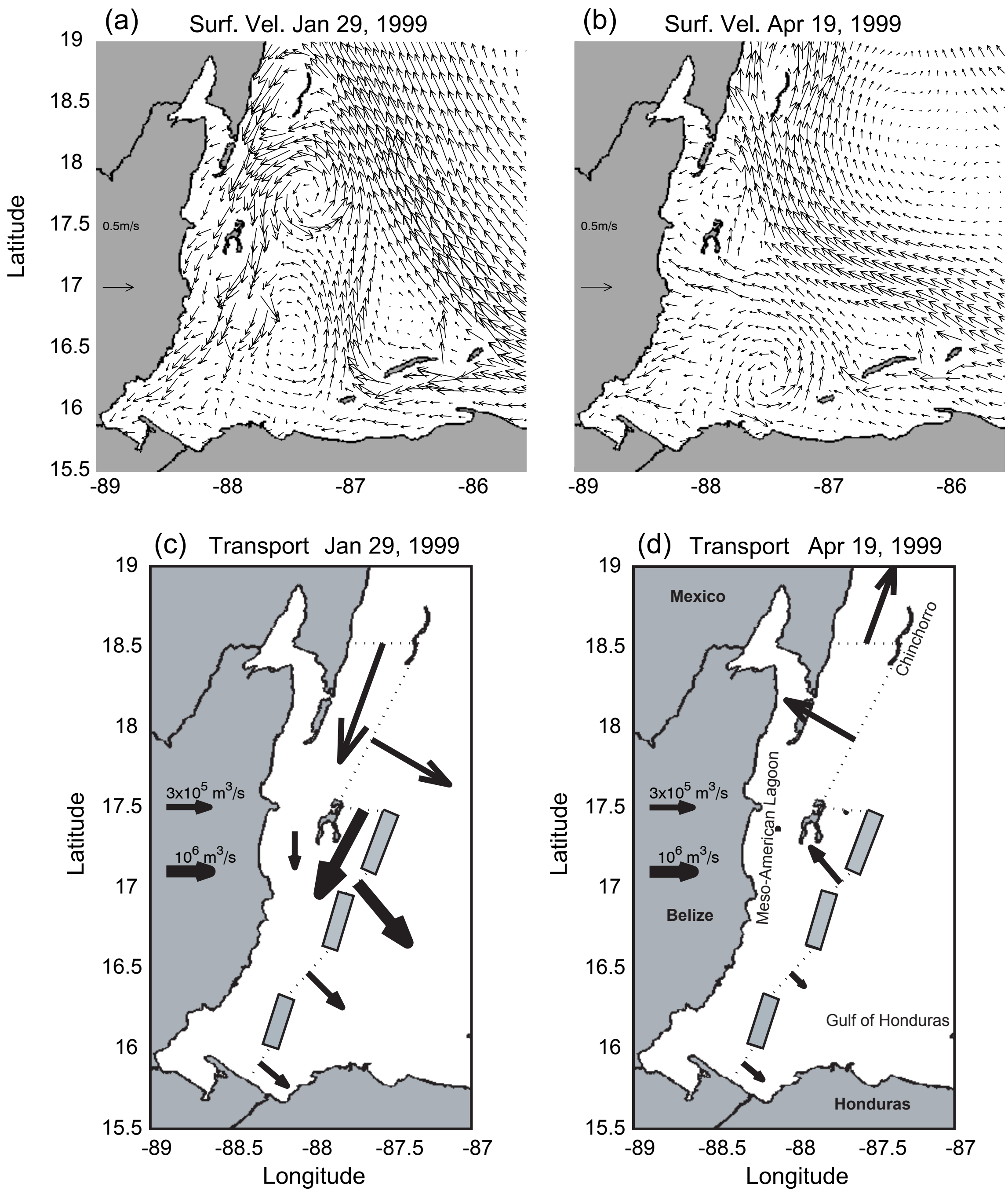

Figure 2. Simulated velocities near the Meso-American Barrier Reef using the diagnostic-prognostic model calculations with data from January 29, 1999 (left panels) and April 19, 1999 (right panels). Top panels are the surface velocity vectors at every other model grid point. Bottom panels are the vertically integrated transports across the major passages between islands. Heavy arrows represent transports larger than 10^6 m^3 s^{-1}.

The flow field after the velocities are adjusted is strongly affected by eddies and the flow near the coast is very different during the two periods (Fig. 2a and Fig. 2b). During the first period (January 29, Fig. 2a) the negative SSH anomaly pushes the Caribean Current (CC) offshore and intensifies the cyclonic circulation in the Gulf of Honduras. The result is a strong southward flow along the MBRS and in the lagoon. On the other hand, during the second period (April 19, Fig. 2b) the positive SSH anomaly pushes the CC closer to the reef, limiting the extent of the cyclonic circulation and reversing the flow near Chinchorro. However, comparisons with similar calculations using the monthly climatology of January and April without eddies (not shown) reveals that the reversing of the circulation near Chinchorro is due to the change in climatology and not due to eddies; the other changes of flow across the MBRS are all due to the eddies, with negligible dependency on which climatology is being used.

Analysis of the total transports through several passages across the MBRS (Fig. 2c and Fig. 2d) reveals how the water mass exchange between the lagoon and the WCS is affected by eddies. The cyclonic eddy produces a strong transport into the lagoon from the north, with return eastward outflows across the reef (Fig. 2c), while the anticyclonic eddy causes almost no net flow in the upper part of the lagoon and only weak transports across the MBRS (Fig. 2d). These significant changes in circulation and transports near the reef and lagoon may have important biological consequences for fish population and behavior and need further research.

In additional to the above example of the influence of eddies on the MBRS, additional research on other aspects such as seasonal changes, high frequency wind variations, tides, and fresh water inflows are now underway.

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