

STUDY TITLE: Cross-Shelf Exchange Processes and the Deep-water Circulation of the Gulf of Mexico: Dynamical Effects of Submarine Canyons and Interactions of Loop Current Eddies with Topography

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BACKGROUND: Deep-water exploration and development is expected to progress rapidly under stimuli of high flow rates, high volume, and technological advances. In response to this expectation the U.S. Department of the Interior sponsored a multi-part numerical modeling study designed to improve our understanding of physical mechanisms controlling the ocean circulation in deep-water regions of the Gulf of Mexico. This report contains results of a 4-year process-oriented numerical study focused on investigating the interaction of deep ocean circulation features, e.g. Loop Current Eddies (LCEs), with continental shelf and slope.

OBJECTIVES: (1) To adapt eddy resolving numerical models to the rise, slope, and adjacent shelf of the northern Gulf of Mexico; (2) To reproduce the three-dimensional currents associated with eddy-slope, eddy-eddy, and Loop Current-eddy interactions as well as other known physical phenomena in the area; (3) To determine the optimal sampling scheme to modify ongoing field observations in the area.

DESCRIPTION: The overall methodology adopted for this study is based upon a numerical experiment strategy of building model configurations with gradually increasing realism: start with relatively less complex models, which we hypothesize to represent the essential physics of the phenomenon, then gradually transition into a more complete set of physics while still retaining

the simplified setting of the problem as much as possible. A hierarchy of numerical experiments was constructed. The hierarchy is based upon the level of approximation used to derive the differential equations describing the fluid motion in each experiment and upon the degree of realism involved in the experiment design. The hierarchy consisted of four classes of experiments: intermediate equations (IE) experiments, extended intermediate equations experiments (IE+), idealized primitive equations (PE) experiments, and realistic PE experiments. The intermediate equations are a class of approximations to the system of primitive equations, which is similar but generally more accurate than the traditional quasi-geostrophic approximation and remains valid for moderate Rossby and Froude numbers. The principal goal of the IE experiments was to develop an initial understanding and intuition of the system's principal dynamics. Another important goal of IE experiments was the development of initialization techniques for more sophisticated primitive equations models. IE models are capable of isolating the balanced component of the flow providing a very useful tool for initialization. The IE+ experiments extend the results of the IE experiments into domain configurations with bottom topography that penetrates the lower layer density interface. In many cases the IE+ model allows a significant increase in the realism of numerical experiments, e.g. by including realistic coastal topography, while at the same time retaining the computational efficiency and the clarity of the dynamical analysis of the IE model. The idealized PE experiments further increase the realism of the numerical simulations by including a realistic continuous stratification and a more complete set physics. The PE model used in this class of experiments was the Princeton Ocean Model (POM) configured with high (better than 5 km) horizontal and vertical (50 levels) resolutions. The final step in the hierarchy of numerical experiments was running the fully realistic PE model simulations. These simulations were designed primarily to verify the results of previous idealized experiments by enabling a direct comparison with observations.

SIGNIFICANT CONCLUSIONS: It was demonstrated that deep eddies can form during LCE interaction with the western shelf, particularly in the region around 25W. The deep eddies are characterized by relatively strong currents (up to 20 cm/s) and large size (200-300 km in diameter) and have significant impact on the deep local environment. Deep eddies were also shown to significantly affect the evolution of LCEs interacting with the western shelf. It was also demonstrated that LCE interacting with a thermocline-penetrating shelf can form small to intermediate-scale cyclones as a result of water advection from the shelf. The cyclones generated by this process can reach considerable strength depending upon the exact shape of the bathymetry and the motion of the LCE. The intermediate layer, i.e., the density layer defined with moderate to weak stratification extending from approximately 400 to 1,200 meters, was found to play a central role in the process of LCE-topography interaction.

STUDY RESULTS: LCE interactions with topography were studied in four regions: the central GOM, the northern GOM, the north-east corner of the GOM, and the western GOM. Several new dynamical mechanisms controlling the LCE-topography interactions were identified, and other more familiar mechanisms were clarified. Potential scenarios describing the evolution of an isolated LCE interacting with bottom topography in various regions of the GOM were identified. A real event of an LCE interacting with coastal topography was simulated in a realistic setting and the results were compared directly with observations. The previously developed understanding of dynamical processes involved in LCE-topography interactions obtained from more process-oriented experiments enabled a much clearer dynamical interpretation of the observed events.

The investigation of physical processes within, and in the vicinity of, the DeSoto Canyon focused on the conceptual models of DeSoto Canyon circulation based on observational data

collected during the DeSoto Canyon Eddy Intrusion Study (1997-1999). In particular, three conceptual models were analyzed: 1) the direct interaction of an anticyclone with the canyon; 2) remotely generated eastward jets west of the canyon; and 3) the interaction with Loop Current frontal eddies. As the result of the analysis conclusions about the dynamical feasibility of the conceptual models were made and some of the physical mechanisms involved were identified. For each of the conceptual models the corresponding observed events were simulated, and the results compared with observations.

STUDY PRODUCT(S): Frolov, S.A., G.D. Rowe, L.M. Rothstein, and I. Ginis, 2003. Cross-shelf exchange processes and the deep-water circulation of the Gulf of Mexico: Dynamical effects of submarine canyons and the interactions of Loop Current eddies with topography; final report. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2004-017. Contract No. 14-35-01-99-CT-31029. 164 pp.