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STUDY TITLE: A Modeling Study of Gulf of Mexico Deep Water Circulation, Ventilation, and Transport

REPORT TITLE: Lagrangian Study of Circulation, Transport, and Vertical Exchange in the Gulf of Mexico

CONTRACTING NUMBER(S): 14-35-0001-30660-19952

SPONSORING OCS REGION: Gulf of Mexico

APPLICABLE PLANNING AREA(S): Northern Gulf of Mexico

FISCAL YEARS(S) OF PROJECT FUNDING: 1997, 1998, 1999, 2000, 2001, 2002.

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COST(S): FY1997: $10,504; FY 1998: $47,022; FY 1999: $36,649; FY 2000: $98,761; CUMULATIVE PROJECT COST: $135,410

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KEY WORDS: Gulf of Mexico; Loop Current rings; deep circulation; ventilation; vertical exchange

BACKGROUND: Increased activity associated with offshore oil and gas exploration and production in the outer continental shelf and slope regions of the northern Gulf of Mexico calls for a better understanding of the ocean circulation in these regions and the potential environmental effects of those activities. Moving into deep water places the oil and gas operations closer to strong surface-intensified currents associated with the Loop Current and Loop Current eddies. Sub-surface current measurements over the northern continental slope provide evidence of vigorous currents and Topographic Rossby Waves. Along the continental slope there is an abundance of benthic communities associated with numerous hydro-carbon seeps. Understanding how deep energetic currents and eddies interact with the bottom topography is important to ensure that deepwater activities are safe and environmentally sound. The deep water of the Gulf of Mexico below the deepest sill depth is completely isolated from outside, but it is well-ventilated. The renewal of deep water should take place only via vertical exchange of water with the water above the sill depth.

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OBJECTIVES: (1) To characterize the deep circulation in the Gulf of Mexico which appears to be dominated by vertically homogeneous eddies associated with the surface anticyclones; (2) To investigate transport, mixing, and ventilation processes in the deep water using Lagrangian techniques; (3) To estimate the residence time of deep water in the Gulf of Mexico; (4) To examine vertical exchanges over the outer shelf and slope in the northern and western Gulf of Mexico where Loop Current rings interact with the bathymetry and eventually decay.

DESCRIPTION: The study area featured the entire Gulf of Mexico, although the model domain extends into the western Caribbean and the western North Atlantic Ocean to facilitate forcing inflow and outflow. The project was conducted in three parts: (1) numerical model development and verification; (2) tracer particle experiments at various depth levels; and (3) examination of the model mean fields and energetics. The Modular Ocean Model version 1.1, a three-dimensional, primitive-equation, numerical model was chosen for this study. The model grid has a horizontal resolution of 0.1º by 0.1º and the boundaries of the model domain are 98.0°W to 72.0°W and 15.0°N to 31.0°N. There are 20 levels in the vertical with a minimum depth of 12.5 m and a maximum depth of 3850 m. NODC global mean hydrographic data is used to initialize the model temperature and salinity. The model is forced at the surface with seasonal averages of temperature, salinity, and wind stress. A target value of 28 Sv is chosen to represent the annual-mean volume transport through the southern Straits of Florida. The Lagrangian technique of seeding and tracking tracer particles is used to examine detailed transport and mixing processes. Several different experiments were designed that feature different starting positions of the tracer particles depending on the region or process of interest. The positions of the tracers were analyzed to identify characteristic patterns in the particle paths and correlate the particle paths with physical processes or circulation features. The model temperature and horizontal velocity were saved at intervals of 1, 3, or 10 days for 15 years at selected levels and all prognostic variables are saved at every grid point every 30 days. Animations were created of the particle positions superimposed on the model flow fields for model verification and analysis.

SIGNIFICANT CONCLUSIONS: The vertical exchange of particles in the deep water below 1000 m occurs over the steep slopes in the eastern basin of the Gulf of Mexico where the Loop Current is constrained by the bathymetry. Vertical motion of particles is observed as the Loop Current moves back and forth off the Campeche Bank, producing a net upward motion as particles are swept back toward the slope. Pronounced vertical motion of tracer particles also occurs over the steep slopes of the central and western Gulf as a result of deep eddies interacting with the bathymetry. In the upper layer above 800 m, the most active region of vertical migration of particles is in the northwest portion of the Gulf where Loop Current rings spin-down. The gradual upward motion of particles in the relict rings is likely due to the shoaling of the isotherms as the rings decay. There is limited communication between the eastern and central basins across approximately 88ºW in the deep water. During a 15-year simulation in which the waters below 2200 m were seeded with nearly 20,000 particles, fewer than 10% of particles were transported across 88ºW in either direction. The deep motions appear to 'feel' the bottom, and the advective properties of deep eddies may change as they squeeze through the deep channel.

The descent of particles is observed near the entrance to the Straits of Florida along the northern side of Cuba. From the 12-year mean temperature and salinity fields, it appears that relatively cold water flowing over the sill of the Yucatan Channel, hugs the eastern side of the channel and then flows northward along the eastern side of the basin. The cold water follow the topography back to the west at progressively greater depths. Relatively warm water appears to upwell over the northern Campeche Bank at the same depths. The Loop Current flows over the sill at a depth of 1400 m into waters depths greater than 3000m. The upwelling may be caused by the Loop Current entraining water just below sill depth on the northern side of the sill as the Loop Current moves over deeper water. A cyclonic current that follows the 3000-m isobath is present in the 12-year mean velocity fields . A conceptual model for ventilation of the deep water has developed from this study that features downwelling in the far eastern basin, a deep mean cyclonic current, and upwelling over the Campeche Bank.

STUDY RESULTS: The numerical ocean model is able to realistically reproduce observed upper-layer circulation features, with special attention given to the 3-D structure of the Loop Current and Loop Current rings. Two important aspects of the model forcing are the temporal and spatial structure of the inflow through the Yucatan Channel. These aspects were handled with care in order to realistically simulate the vertical structure of the Yucatan/Loop Current system, as well as the variability in the shedding of Loop Current Rings. The implementation of a high resolution grid was also essential in the simulation of vertical motion, which is primarily a product of current-topographic interaction. Lagrangian analysis of the tracer particles has indicated that the greatest vertical exchange below the surface layer is occurring in the eastern basin due to the bathymetric constraints on the Loop Current. Rapid vertical motion of particles is observed where deep currents impinge directly on steep topography, such as in the northern Gulf. Slow ascent of particles is observed in the northwestern Gulf as Loop Current rings decay. The model eddy kinetic energy fields provide evidence of Topographic Rossby Wave propagation along the slope in the northern Gulf of Mexico.

STUDY PRODUCTS: Welsh, S. and M. Inoue, 2002. Langrangian Study of Circulation, Transport, and Vertical Exchange in the Gulf of Mexico. OCS Study MMS 2002-064 Contract 14-35-001-30660-19952. U.S. Dept. of the Interior, Minerals Management Service, New Orleans, LA, 61pp.

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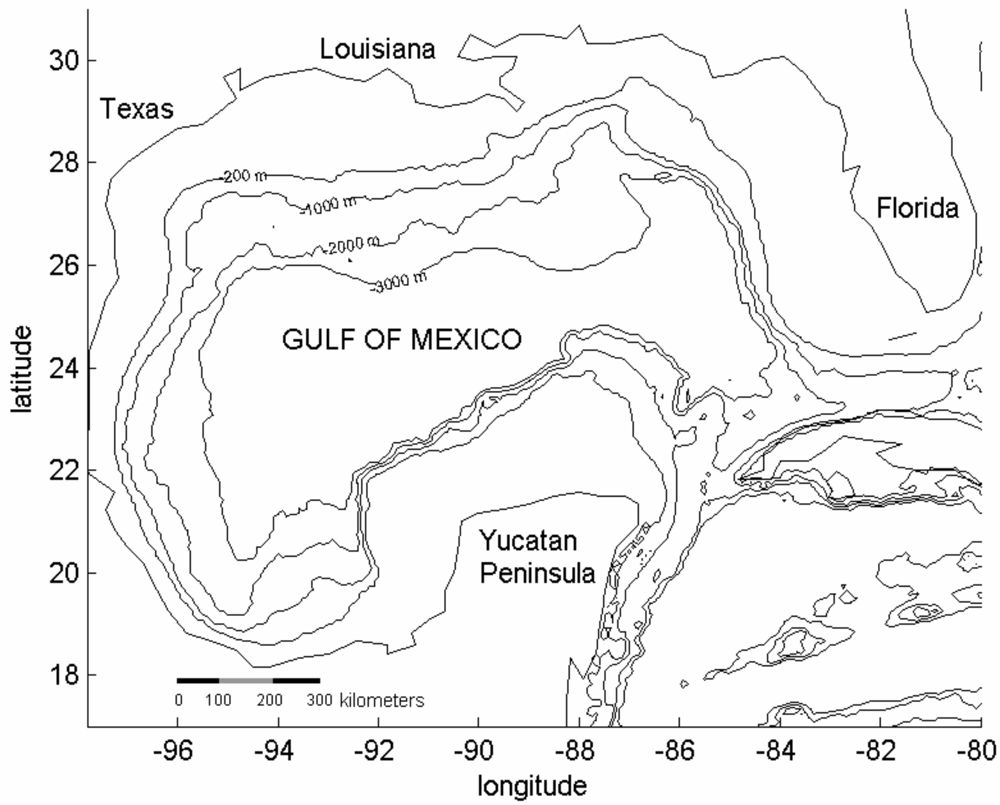

NUMERICAL MODEL DOMAIN FOR LAGRANGIAN STUDY OF CIRCULATION, TRANSPORT, AND VERTICAL EXCHANGE IN THE GULF OF MEXICO.