STUDY TITLE: Model Studies of the Circulation in the Gulf of Mexico

REPORT TITLE: A Numerical Modeling and Observational Effort to Develop the Capability to Predict the Currents in the Gulf of Mexico for Use in Pollutant Trajectory Computation: A Guide to a General Circulation Model of the Gulf of Mexico

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BACKGROUND: Increasing levels of offshore oil and gas development have subsequently increased the probabilities for accidental releases of oil. Such spills can have significant environmental effects. In order to anticipate and mitigate the effects of such spills, it is necessary to be able to predict the trajectory and possible landfalls of released oil. Since such trajectories are largely a function of ocean surface currents, predictive capabilities can be developed through the use of numerical models which simulate currents in the vicinity of a spill. This predictive capability, which may be applied further to a modeling of the movement of an oil spill, was determined to be of particular concern within the Gulf of Mexico, a region of historic and future oil and gas development activity.

OBJECTIVES: (1) To modify an existing numerical model for application to the Gulf of Mexico; (2) to evaluate the ability of the model to adequately simulate the circulation of the Gulf of Mexico using various types and distributions of data; and (3) to describe the Gulf of Mexico circulation using the results of the model.

DESCRIPTION: In order to model or predict circulation patterns within the Gulf of Mexico, a mathematical model was developed using a series of approximations. First, the ocean was assumed to be a Boussinesq fluid (i.e., the density of the ocean differs only slightly from a reference state in which entropy and salinity are constant and there is no motion). Secondly, the ocean was assumed to be in hydrostatic balance. By definition, this means that the vertical balance of forces differs only slightly from a reference state of no motion. The third approximation was based on the fact that the surface of the ocean does not coincide with the geoid even if wind waves and tidal fluctuations are neglected. Fourthly, the equations which were used governed only large scale motion. Finally, the model assumed that the frictional drag of flow on the bottom was negligible over most of the basin. It was recognized that this assumption was not applicable (i.e., was incorrect) in those situations where strong currents extend to the bottom. In these cases, a simple bottom drag coefficient was included. The actual computer program was a modification of a previously developed model.

The interior and boundary conditions for the model were derived from data provided by the National Oceanographic Data Center and from cruises conducted as part of the present study. Monthly circulation of the Gulf of Mexico was simulated using a broad range of input and boundary conditions. Specifically, test calculations were performed on a grid with seven vertical layers (70, 151, 297, 500, 703, 849, and 930 m) and a horizontal resolution of 0.5 degree of longitude and latitude. Time step was kept constant at 0.5 hours and the vertical coefficient of eddy viscosity was 1 cm^2/s. Variable parameters included transport, horizontal coefficient of viscosity, boundary conditions, wind stress, and wide shelf. The ability of the model to simulate the observed circulation was demonstrated through a series of comparisons of circulation model solutions with results from a geostrophic model.

This report is a companion to the final report entitled "A Numerical Modelling and Observational Effort to Develop the Capability to Predict the Currents in the Gulf of Mexico for Use in Pollutant Trajectory Computation: Model Studies of the Circulation in the Gulf of Mexico," also prepared under this contract.

SIGNIFICANT CONCLUSIONS: A numerical model was developed to characterize general circulation patterns within the Gulf of Mexico. Results of simulations compared favorably with results obtained from a geostrophic model. Sensitivity of the models to transport, horizontal coefficient of viscosity, boundary conditions, wind stress, and a wide shelf were tested. Changing boundary conditions in the model had only a minor effect on model results. Among the most important results noted was the fact that large changes in the applied wind stress and in the transport through the Straits of Yucatan and Florida had relatively little effect on interior circulation of the Gulf of Mexico basin. At the same time, a 17% reduction of transport through the Straits of Yucatan and Florida caused significant changes in the transport only near the Cuban coast, suggesting that the interior balance remains unchanged and adjustment to the transport boundary conditions occurs only in a narrow boundary layer along the Cuban coast.

Increasing the vertical viscosity had a significant effect in decreasing transport in the Gulf and changing the characteristics of the Loop Current. Improbable currents were predicted when the model was extended onto the shallow shelf which led to the expanded grid being rejected from the model. Instead, a small amount of bottom friction is added to the model whenever the grid is only one layer thick.

STUDY RESULTS: Under varying boundary conditions, only minor differences were seen between zero gradient and geostrophic boundary conditions. In another experiment, flow through the Straits of Yucatan and Florida was tested under two conditions. The results were essentially the same in the western Gulf and remarkably similar in the eastern Gulf. It was determined that the main effect of under-specifying the transport by 17% was to cause a recirculation of water within the Loop Current and a northwestern flow of water along the northwestern coast of Cuba. Away from the Cuban coast, the circulation is affected only slightly. This led to the conclusion that small errors in transport specified at the boundary does not radically affect the interior circulation in a diagnostic experiment.

Under conditions with and without wind stress, close similarity between the two simulations was obtained. For the most part, wind stress had a negligible effect. The differences were mainly in regions where circulation was weakest. Differences in velocities for the surface and deeper layers were negligible. Several small differences were also noted in the current on the Campeche Bank where wind stress caused some enhancement in flow.

Several experiments were run to test the sensitivity of the model to viscosity changes. Increasing viscosity by a factor of five reduced transport in the central western gyre by 35% and the transport in the Loop Current by 28%. Mean kinetic energy was decreased by 29%. Changing viscosity also caused the Loop Current to become smoother and broader, coupled with reduction in the stream function gradients.

In another experiment, the effect of extending the shallow shelves on the model was tested. To do this, the top layer of the model simulation was extended shoreward to the 15 m isobath. In the expanded grid, a strong current appeared flowing from the Mississippi Delta southward across the west Florida Shelf. This flow replaced a much weaker southward flow in a test without the expanded shelf. The strong Delta current, with velocities as large as those in the Loop Current, were determined to be unrealistic. In both tests, strong currents were defined along the Campeche Bank west of 88°W Long. Although predicted current speeds were probably too large, current direction was consistent with the interior flow. Based on these results, the expanded grid was rejected.

STUDY PRODUCT: Behringer, D. W., R. L. Molinari, and J. F. Festa. 1976. A Numerical Modelling and Observational Effort to Develop the Capability to Predict the Currents in the Gulf of Mexico for Use in Pollutant Trajectory Computation: A Guide to a General Circulation Model of the Gulf of Mexico. A final report by the Atlantic Oceanographic and Meteorological Laboratory, National Oceanic and Atmospheric

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