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**STUDY TITLE:** Deepwater Physical Oceanography Reanalysis and Synthesis of Historical Data

**REPORT TITLE:** Deepwater Physical Oceanography Reanalysis and Synthesis of Historical Data: Synthesis Report

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**BACKGROUND:** The Minerals Management Service (MMS) Gulf of Mexico Outer Continental Shelf Region sponsored a workshop on 22-24 April 1997 in New Orleans, LA, to identify issues related to the expansion of oil and gas operations into the deepwater Gulf of Mexico and to provide recommendations on studies needed to fill gaps in knowledge. One recommendation was that a synthesis of historical physical oceanographic data be completed prior to implementation of any major observational study of the deepwater physical oceanography. Based on that recommendation, MMS funded the Deepwater Physical Oceanography Reanalysis and Synthesis of Historical Data Study in the Gulf of Mexico.

**OBJECTIVES:** (1) To create an inventory of physical oceanographic data and compile it into a single database on a CD-ROM. (2) To conduct analyses and interpretations of

the physical oceanographic data to identify physical processes and phenomena. (3) To produce a climatology of the processes from available data and analyses and to prioritize the processes in terms of importance to improved understanding, simulation, and prediction of deepwater circulation. (4) To provide criteria and constraints useful in design of future field observations and numerical modeling efforts.

**DESCRIPTION:** The study area is bounded by the northern Gulf shelf edge (approximately the 200-m isobath) and the 25°N latitude line and extends from sea surface to sea floor. The three project components were: assembly of physical oceanographic data from the deepwater Gulf of Mexico; identification and prioritization of physical processes and phenomena operating in the deepwater Gulf; and development of recommendations for experimental designs for future field studies. An inventory of data sets was compiled. Data included were current measurements from moored single-point current meters and acoustic Doppler current profilers; hydrographic observations from bottles, conductivity-temperature-depth sensors, mechanical bathythermographs, and expendable bathythermographs; and drifting buoy trajectories. As many of these data sets as possible were obtained from MMS, the National Oceanographic Data Center, other federal and state agencies, national laboratories, universities, Mexican institutions, and the private sector, particularly the oil and gas industry. Data were quality controlled. Data provided without restrictions on use were compiled into a database and put on a CD-ROM with a descriptive technical report. A high resolution numerical model of Gulf circulation provided output for 1993-1999. Ten processes were identified and prioritized as requiring additional study. They are discussed in Significant Results below. Specific measurement programs, systematic monitoring operations, and numerical model enhancements were recommended to improve our understanding of priority processes. These are discussed in Significant Conclusions below.

**SIGNIFICANT CONCLUSIONS:** General conclusions are: (1) The general surface Gulf circulation is rather well described and understood in terms of forcing and response. (2) There appear to be adequate data to characterize surface features, such as the Loop Current and anticyclonic eddies, but not to understand the processes of eddy evolution and decay. Moreover, models and their inflow conditions are not yet adequate to hindcast or forecast them with the needed degree of skill. (3) There are inadequate data to fully characterize the deep subsurface processes, which include barotropic deep events in the form of topographic Rossby waves or deep eddies, or to determine the influence of surface processes, such as Loop Current Eddy separation events, on such deep processes. (4) Verification of mid-water jets remains problematical; a few events have been documented, but data quality remains in doubt. (5) There is no convincing evidence of topographically generated near-inertial motion in the Gulf. (6) Knowledge of the general deep Gulf circulation is based principally on model output and physical speculation. However, the sparse, existing data sets tend to confirm the speculation and model results. (7) Processes responsible for mega-furrows near the Sigsbee Escarpment in the north-central Gulf are not understood.

Three types of recommendations are made: specific measurement programs, systematic monitoring operations, and model improvements. Specific measurement programs are: a moored array near the Sigsbee Escarpment in the north-central Gulf designed to measure barotropic deep motions propagated along this boundary; a thin array of current moorings over the abyssal plain to detect and describe deep eddy pairs and surface-intensified eddies propagating across the Gulf; a Lagrangian float experiment in the deep basin designed to obtain statistics regarding the deep circulation and its variability and to give indications of deep flow through the Yucatan Channel; and an experiment to characterize currents and determine processes responsible for the mega-furrows in the north-central Gulf. Systematic monitoring operations are: to enhance the environmental observations obtained on drill vessels and production platforms of the petroleum industry; to monitor surface currents with pairs of high frequency radars; to use automated sea level and meteorological stations on both sides of the Yucatan Channel and between Cuba and Key West to monitor the transport of the inflow and outflow; and to obtain regular surface estimates of velocity and temperature and subsurface measurements of temperature and salinity by inclusion of the Gulf of Mexico in operational surface drifter, ship-of-opportunity XBT, and Argos profiling float deployment programs. To enhance the capabilities of numerical models for providing needed environmental information, periodic, careful comparisons should be made between results from the many available models and improvements should be made to Gulf of Mexico circulation models, including notably better boundary conditions for regional models and improved data assimilation capabilities.

**STUDY RESULTS:** General hydrography and circulation of deepwater Gulf. The circulation within the Gulf of Mexico is driven principally by two sources of energy. The main source consists of the Yucatan Current and other circulation features that enter the Gulf from the Caribbean Sea through the Yucatan Channel. Effects are seen as a Loop Current, current rings that detach from the Loop Current and their subsequent distribution of energy throughout the Gulf, and effects on the deep circulation within the basin of ring separation from the Loop Current. Transport estimates for the Loop Current system are approximately 30 Sverdrups with seasonal fluctuations of about 10%. The second major energy source is wind stress forcing. Effects are seen as low-frequency regional circulation patterns forced by low-frequency regional wind patterns and as episodic currents forced by high frequency atmospheric events including tropical cyclones and extratropical cyclones. Although thermohaline forcing is known to be important over the Gulf shelves, no thermohaline forcing of consequence or significant water mass formation are known to occur in the deepwater Gulf.

Large scale circulation and its variability. Large scale circulation was examined using geostrophic shear fields from hydrography, statistics from the near-surface drifter velocity field, the Gulf model circulation, and altimeter sea surface height fields. Current data, model output, and prior hydrographic studies indicate 800-1000 m is a reasonable depth estimate for separation of surface-intensified upper ocean currents from nearly barotropic deep currents within the Gulf. The dominant feature in the mean fields of the upper layer is the Loop Current. A closed anticyclonic feature is often present within the

Loop Current. In addition to the strong inflow on the west side of the Yucatan Channel, the drifter field shows an outflow just west of Cuba. The largest variability is in the region of the Loop Current and eddy separations in the northeastern Gulf. Variance ellipses generally are aligned parallel with the inflow and outflow limbs of the Loop Current. Both the sea surface height field and surface dynamic topography have a slight lowering of sea level around the margins relative to the center, suggesting slight anticyclonic circulation. The fields exhibit evidence of anticyclonic circulation in the west central Gulf, centered about 24°N 95°W, that is consistent with the forcing of the surface circulation by the annual cycle of wind stress curl. The fields also indicate cyclonic circulation in the Bay of Campeche. The dynamic topography indicates there is a cyclone beneath the Loop Current and that the circulation in the western Gulf is cyclonic at depth. Model results also show a cyclone beneath the Loop Current, most predominantly on the 1000-m and 2000-m surfaces. They also indicate cyclonic flow around the basin near the 2000-m to 3000-m isobaths. The strong effect of the bathymetry on the directionality of the variability is seen in the orientation of the model variance ellipses along isobaths at the margins.

Identification of energetic current events. The inventory of identified processes and phenomena was conducted in three steps: identification of energetic currents, identification of possible processes/phenomena, and categorization of currents by class. Each time series of currents was examined for the occurrence of energetic currents. Energetic current events were considered to have occurred when the magnitudes of currents over the period of an event were considerably greater than the background currents for the region and/or for situations where the currents had characteristics known to be associated with particular classes of events. The possible processes and phenomena were identified from the literature and from the character of the energetic currents observed. Five broad classes of energetic current events were identified: Loop Current and surface-intensified eddies; deep barotropic and bottom-trapped motions; atmospheric storm generated motions; internal waves generated by topographic influence; and mid-water current jets. Current records were compared and, where appropriate, matched in time and space to known occurrences of the Loop Current, Loop Current Eddies, other anticyclonic or cyclonic rings, tropical storms, hurricanes, extratropical (winter) cyclones, frontal passages, and other energetic wind events. The energetic portions of each record were then inventoried according to type of phenomena or process.

Climatology of processes and phenomena. The climatology of processes and phenomena consisted of general current statistics, current roses and persistence tables, current speed versus depth by region, record-length velocities and variances, eddy kinetic energy distributions, energy spectra, vertical empirical orthogonal functions, and a detailed examination of the statistics for each event type. The categories of physical processes and phenomena identified for prioritization and their priorities are: (1) deep barotropic & bottom-intensified motions, (2) general circulation—deep currents, (3) currents associated with furrows, (4) eddy induced currents, (5) Loop Current, (6) general circulation—surface currents, (7) subsurface, mid-water column motions, (8)

hurricane/tropical storm-induced motions, (9) other energetic wind event induced motions, and (10) topographically generated near-inertial motion. Prioritization was based on the need for additional data to improve understanding, simulation, and prediction of slope and subsurface circulation. Three major criteria were selected for use in determining the priority. These were: improved level of understanding, improved ability to simulate and predict, and ability to observe.

Measurement system design criteria. The primary region of interest for gathering more data to characterize energetic phenomena and processes in the Gulf is the north-central slope and rise and northwest corner of the deepwater Gulf. The highest priority phenomena/processes are considered to be the currents in deep water. These include: (1) deep anticyclonic-cyclonic eddy pairs and topographic Rossby waves; (2) the deep general circulation; and (3) currents associated with furrows. Current and hydrographic data and model output were examined for the presence of the top three processes. Characteristics of these processes, in terms of spatial and temporal scales, were estimated. Deep eddies and topographic Rossby waves have time scales of 10 to 100 days and spatial scales of hundreds of kilometers. The deep circulation has spatial scales ranging from eddy size (200-400 km) to basin scale, with time scales that are long but uncertain. Furrow fields have cross-isobath scales of ~35 km and along-isobath scales of over 100 km; time scales of currents associated with these fields are unknown. Measurement arrays were developed for each priority process using, among other factors, the characteristic scales to determine optimal spatial locations and temporal duration.

**STUDY PRODUCT(S):** Nowlin, W. D., Jr., A. E. Jochens, S. F. DiMarco, R. O. Reid, and M. K. Howard. 2001. Deepwater Physical Oceanography Reanalysis and Synthesis of Historical Data: Synthesis Report. OCS Study MMS 2001-064, U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. 537 pp.

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CD-ROM, Deepwater Physical Oceanographic Data Base for the Gulf of Mexico, 2001. Deepwater Physical Oceanography Reanalysis and Synthesis of Historical Data. OCS Study MMS 2001-064, U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA.

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