

STUDY TITLE: Northeastern Gulf of Mexico Physical Oceanography Program: Eddy Monitoring and Remote Sensing

REPORT TITLE: Surface Circulation and the Transport of the Loop Current into the Northeastern Gulf of Mexico

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BACKGROUND: To properly manage shelf resources, we need to better understand processes in the ocean and be able to assess oceanic variability over large space and time scales. In particular, it is critical to understand the motion of waters within a region to assess the potential consequences of possible spills derived from oceanic, shelf, and coastal mining industries. This Cooperative Agreement between the University of South Florida (USF) and the Minerals Management Service (MMS) was established to jointly assess the value of merged satellite data and specific oceanographic field data in determining the circulation and biological productivity of waters within the Northeast Gulf of Mexico (NEGOM). The effort centered around collecting, processing, and merging historical and concurrent Infrared, Radar-Altimetry, and Ocean Color satellite data as well as selected *in situ* information. We used various national and international sensors based upon availability of the data, honoring restrictions in the use and distribution of such data.

OBJECTIVES: The primary goal of this work was to assess the utility of merging specific satellite and field data sets in quantifying the magnitude and variability of water movement in the Northeastern Gulf of Mexico. Specifically, we sought to document and to better understand the behavior of the Loop Current, eddies shed by the Loop Current, the circulation of waters over the shelf and along the coast of the NEGOM, and the interaction between offshore and shelf waters. We have developed a strategy to derive new products useful to MMS and other interested parties for monitoring the circulation of the region by combining several different data sets. With these, we updated historical statistics on major oceanographic features observed in the region. We published part of the results of these analyses in the peer-reviewed literature, and additional manuscripts were being prepared upon completion of this summary.

DESCRIPTION: Satellite data used for this study were Advanced Very High Resolution Radiometer (AVHRR) Sea Surface Temperature (SST) distribution fields, Sea-Viewing Wide-Field-of-View Sensor (SeaWiFS) ocean color-derived pigment concentrations, and TOPEX and ERS Radar Altimetry Sea Surface Height (SSH) fields. The first two datasets were collected locally using an antenna located at the College of Marine Science, USF, in St. Petersburg, Florida. The product for the NEGOM area was mapped to $1 \times 1 \text{ km}^2$ and $2.8 \times 4 \text{ km}^2$ pixel resolution. Meanwhile, TOPEX and ERS data were collected and processed at the University of Colorado, Boulder. To quantify the magnitude and variability of water movement in the NEGOM, we merged Sea Surface Height fields, Sea Surface Temperature fields, and Ocean Color Pigment Products. We also merged satellite and field data products from companion operational projects sponsored by the MMS, specifically concurrent buoy track, and hydrographic and wind velocity data.

SIGNIFICANT CONCLUSIONS: The AVHRR SST data provided substantial information on circulation patterns during the winter (October-May), when temperature gradients were strong. However, during summer (June-September), AVHRR data for the most part showed uniform sea surface temperature patterns over the NEGOM. We confirmed that the AVHRR provided information on the position of the Loop Current during summers after images were contrast-stretched. Also, significant upwelling events were seen during summer along the periphery of the NEGOM, specifically in coasts of the Big Bend region and in the region off Pinellas and Manatee Counties (near the mouth of Tampa Bay). During the period of May-July 1998, we observed unusual upwelling along the coasts of the Florida Panhandle in the northeastern Gulf of Mexico that led to 3-6 °C lower SST than normal. We also observed strong upwelling near the shelf break in the northeastern Gulf of Mexico after hurricanes Earl (September 2-4, 1998) and Georges (September 25- October 1, 1998) suggesting that the shelf and slope may have enhanced upwelling associated with hurricanes. Using monthly mean AVHRR SST images, TOPEX/ERS SSH data, and current data derived from surface drifters deployed in 1996, the mean flow at the shelf break in the DeSoto Canyon region from January through July was from west to east, and in the west Florida Shelf region from north to south. An anticyclonic jet followed the curvature of the shelf off the Florida Panhandle shelf break. In August, flow reversed and the mean surface currents at the shelf break were from south to north-northwest off the west Florida Shelf, east to west in

the DeSoto Canyon region, and offshore in the Mississippi Delta region. This gave the flow a cyclonic curvature. The flow reversal seen in 1996 occurred as a major eddy separated from the Loop Current, and it persisted into the fall. The combined AVHRR, altimeter, and drifter-derived monthly velocities indicate that there is a seasonal cycle in the flow over the west Florida shelf, with southward flow during the spring and northward flow during late summer. While some very strong currents were also observed in the northern and western part of the NEGOM, currents here in general were more erratic. The historical ocean color data obtained from the CZCS shows that the pigment concentration patterns are an effective tool for tracing small scale as well as large scale circulation patterns in the GOM. These patterns were very clearly outlined during summer months, and therefore the combination of AVHRR and CZCS/SeaWiFS was very useful for outlining the position of the Loop Current, eddies, and various instability waves visible along fronts in the region. The SeaWiFS ocean color data and *in situ* data collected during a series of 9 cruises showed that freshwater from the Mississippi River spread eastward in the summers of 1998, 1999, and 2000. In Spring and Winter, however, there was no significant eastward entrainment of the Mississippi River water. Upon merging the AVHRR SST data with the altimeter fields, we found good correlation between warm areas and elevated dynamic heights, and cool areas and low dynamic heights. Using AVHRR SST, CZCS, SeaWiFS, TOPEX/ERS SSH and in-situ data for 24-year period 1976-1999, we found that the Loop Current and associated warm water penetrated as far as 27.5 °N about 10 % of the time (i.e., about 2 events every 3 years), and 28 °N about 5% of the time (i.e., 2 events every 5 years). No penetration to 29 °N was detected.

STUDY RESULTS: For the period covered under this study (April 1997-December 2000), approximately 10,560 AVHRR SST images of the Gulf of Mexico (GOM) were collected by the USF station. These images were stored in high (1x1 km²) and low (2.8x4.1 km²) pixel resolution. Monthly mean SST for the Gulf of Mexico was computed for the period of 1993-2000. Approximately 2,400 SeaWiFS images (September 1997-December 2000) were collected over the Gulf of Mexico and monthly means of chlorophyll-a concentration computed. In addition, the historical Coastal Zone Color Scanner (CZCS) data were processed to pigment products and then averaged to derive a series of 92 monthly pigment concentration means. Near-real time and monthly mean SST and SeaWiFS images for the Gulf of Mexico can be accessed at:

<http://imars.marine.usf.edu> (some areas of this site are password protected).

A CD-ROM containing all of the historical altimetry data for the Gulf of Mexico from 1993 through the end of 1999 was produced at the University of Colorado (Dr. R. Leben). The final version of the processed data included both sea surface anomaly relative to the 1993-1999 time period and an estimate of the total dynamic topography. A model mean was added to the sea surface height anomaly to produce an estimate of the total dynamic topography. The 1993-1999 mean from the GOM model hindcast simulation performed for the MMS Deepwater Reanalysis and Synthesis Project was used. These data are also available on line. Dr. Leben has developed a Loop Current Intrusion (LCI) index based on altimetry data, which was analogous to the El Niño-Southern Oscillation (ENSO) indices. Several integral measures of Loop Current

properties including estimates of Loop Current area, volume and circulation have been produced from the statistics of the historical data set. The Loop Current circulation, which was estimated by a line integral of the velocity along the 17-cm sea surface height contour, was a proposed index for continuous monitoring of the Loop Current penetration and shedding. The 17-cm contour was chosen by experience and success tracking the Loop Current and its eddies in altimetry and with a data assimilative model. Dr. Leben also developed software for automatic tracking of Loop Current Eddy centers, as well as for tracing the perimeter of an eddy by using the 17-cm contour of SSH anomaly.

This effort included extensive collaboration and participation in NEGOM cruises conducted by Texas A&M University. Flow-through data confirmed that freshwater from the Mississippi River spread eastward in the summers of 1998, 1999, and 2000. Mississippi water was seen near 27°N and 87°W, as indicated by low salinity (~23 psu), high Chlor-a (~2 mg/m³, compared with <0.1 mg/m³ for the adjacent oligotrophic ocean), and high colored dissolved organic matter (CDOM absorption at 400 nm is ~0.3 m⁻¹, compared with <0.05 m⁻¹ for the oligotrophic ocean). The ocean color satellite imagery (SeaWiFS) showed that the spatial patterns of eastward entrainment of this river plume were similar in the three summers. In some instances, the eastward entrainment was facilitated by an anticyclonic eddy located south of the Desoto Canyon area. In Spring and Winter, however, there was no significant eastward entrainment of the Mississippi River water. Correlation between CDOM and salinity was higher ($r^2 = -0.85$ or higher) than the correlation between CDOM and chlorophyll-a ($r^2 = 0.783$ or less), suggesting that CDOM is a better tracer of low salinity associated with river plume waters.

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