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STUDY TITLE: New Remote Sensing Methodologies for the Surveillance of Ocean Features and Circulation Processes in the Gulf of Mexico

REPORT TITLE: Loop Current Frontal Eddies Based on Satellite Remote-Sensing and Drifter Data

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BACKGROUND: As industry migrates towards deep water exploration, the need to characterize the deep water environments of the Gulf of Mexico has become increasingly important. This study focused on developing remote sensing tools to study Loop Current Frontal Eddies (LCFEs), which are cyclonic features found along the periphery of the Loop Current (LC) and Warm Core Eddies (WCEs) which separate from it. These features have proven problematic for study as they often move rapidly, they do not always have a distinct thermal signature, and they can be relatively small. They play an integral but not completely understood role in separation of warm core rings from the LC and have been discussed as potential trigger mechanisms for high energy events within that water column and on the bottom along the Sigsbee Escarpment. They are biological oases along the margin of the oligotrophic LC waters.

OBJECTIVES: The over-arching goal of this project was to develop and apply new remote sensing methodologies to improve upon the surveillance of ocean features and the understanding of circulation processes in the Gulf of Mexico (GoM). The more

specific project goal was to apply these new techniques to improve understanding of the basic characteristics of LCFE cyclones, specifically where they develop, how they evolve as they travel around the LC, frequency of occurrence, and their impacts on surface and deeper circulation in areas of oil and gas operations.

DESCRIPTION: This study involved collaboration between researchers from Louisiana State University, University of Colorado, and Horizon Marine, Inc. Each group provided a key data component from which new feature tracking tools were developed. Louisiana State University (Nan Walker) has expertise in remote sensing of sea surface temperature (SST) and ocean color and has developed a unique archive of GOES-8 and GOES-12 night-time "de-clouded" composite imagery (January 1996 to the present) for surveillance of circulation features in the Gulf over short time-scales. The GOES "de-clouded" SST data provides a means of tracking the features on a daily basis. The advantage of GOES data is excellent repeat coverage (every 15-30 minutes) which allows for substantial removal of clouds over short time periods and thus the potential of daily updates for tracking features of interest. University of Colorado (Bob Leben) has expertise in the quantification and analysis of satellite-derived sea surface height (SSH) data in the Gulf dating back to 1993. SSH data from several satellite altimeters enables tracking sea surface highs and lows, revealing the LC, warm- and cold-core eddies with updates of 10-30 days. The main advantages of the SSH data are the facts that it is an all-weather system, unaffected by cloud cover, and it yields dynamical information related to ocean circulation (Leben et al., 2002). Horizon Marine Inc. (Steve Anderson, Jim Feeney, Patrice Coholan) have operated the industry-supported Eddy Watch Program for over two decades and they provide expertise in quantifying near-surface velocities using drifting buoys which they deploy routinely in features of interest. In addition, they provided Eddy Watch reports, which summarize circulation of the LC and eddies in the GoM on a weekly basis. The main time period covered by this project was January 2001 through May 2004.

SIGNIFICANT CONCLUSIONS:

LCFE effects on Surface and Bottom Currents

- Our results clearly show that velocities within the surface upper layer (50 m depth) are largest when drifters move in the frontal zone between the LC and a LCFE cyclone. Typical velocities at 50 m water depth ranged from 100 to 175 cm/s.
- LSU mooring data showed that the most energetic currents at mid- and lower-layers of the water column occurred when LC intrusions and rapid movement and growth of LCFEs occurred along the Sigsbee Escarpment to the east of the mooring.

LC Intrusions

- The February 2001 "full water column" current event measured at the LSU mooring in ~2250 m water revealed the interaction of LCFEs, detached cyclones and the LC to produce strong currents near the surface (seen in drifter data) as well as abnormally strong currents from 400 m to 2250 m. Vertical motion associated with enhancement of upwelling and downwelling along the LC margin or interaction of the LC with the Sigsbee Escarpment provide likely trigger mechanisms for the abnormal current accelerations at depth. Topographic Rossby waves may have been initiated east of LSU's mooring, propagating westward along the Escarpment.

- The January to May 2002 period showcased an abnormal westward intrusion of the LC to 96°W. During this intrusion, seven LCFEs were positioned along the LC margin. This intrusion was associated with large and intense LCFEs, especially on the southwest margin. SSH data revealed a maximum LCFE dimension of 175 km and SSH of -40 cm. The maximum LCFE phase velocity observed in this study was measured at the height of this intrusion. The mean phase velocity of this LCFE was 83 cm/s over a 5 day period.

Detachment of WCEs from the LC

- WCE separations were observed to occur when the Loop Current length scale on the Hovmoller diagram exceeded 2000 km. Examples include Eddy O in September 2001, Eddy P in February 2002, Eddy Q in March 2002 and Eddy T in December 2003. The number of LCFEs along the LC margin during these events ranged from 4 to 7.
- Uncharacteristically large LCFEs along the Campeche Bank were associated with the separation of Eddy Q. SST/SSH data for February 24, 2002 and March 3, 2002 revealed SSH of -40 cm and length scales of ~ 130 km. This cyclone moved along the northern margin of the LC; further separating Eddy Q from the LC.

LCFE and Hurricanes

- A detailed investigation was made of ocean and atmosphere interactions and changes associated with Hurricane Ivan (see Walker et al., 2005). The research clearly showed that the “cool wake” typical of hurricanes was maximized within two LCFEs where hurricane winds enhanced cyclonic upwelling affecting SST dramatically. SSTs dropped well below the minimum threshold of 26º C and the hurricane’s intensity decreased, despite moving over a WCE, which typically increases hurricane intensity. LCFE intensification may have caused the WCE to separate from the LC.

STUDY RESULTS: The new techniques provided the means to determine metrics on LCFE motion, size, frequency and intensity. Extensive use was made of Hovmoller

time/distance graphs comprised of daily “de-clouded” SST composite data for tracking the LCFEs around the entire perimeter of the LC. The 17 cm SSH contour was used as a reference for the location of the LC on a daily basis. The main time periods studied were September – May of 2001/02, 2002/03 and 2003/04. The metrics were determined directly from the Hovmoller graphs and also by manually tracking features using interactive software which combined Hovmoller graphs and the component GOES SST images. Case study analyses of selected events provided important additional information on LCFE variability during extreme events and their affects on circulation through the water column.

LCFEs along the Campeche Bank averaged 49 km, based on alongtrack SSH data and -21 cm in intensity. As features moved northward, they typically experienced an increase in size to 120 km and in intensity to -27 cm. However, not all LCFEs developed into larger features as coalescence of features and change in the meander structure altered the spatial scales of these features. The most robust statistics were obtained for LCFEs moving along the eastern margin of the CB as the sample size was largest there. Mean speeds were 23-32 cm/s and frequencies varied from 3/month to 4.4/month. Frequencies were much more variable but lower along the northern and eastern margins of the LC. One of the outstanding results was the observation of intense (-30 to -40 cm) LCFEs with large spatial scales (~150 km) proximate to the CB near 22 N. In particular, several features were observed to move along the northern margin of the LC, playing a role in the separation of WCRs from the LC.

In addition to the study of LCFE metrics, case study analyses were used to investigate current characteristics for selected events. Drifter data revealed that maximum upper layer velocities (~50 m) occurred within the frontal zone between the LC and LCFEs, where flow was found to range from 100-175 cm/s. LCFEs were found to be closely associated with meanders of the LC; with larger meanders producing large LCFEs. The abnormal westward intrusion of the LC in January/February 2002 was closely studied. During this event, LC water reached 97° W and seven LCFEs were observed along the LC margin. The most typical configuration is 3-4 LCFEs. The features along the southern margin were observed to enhance westward flow, to coalesce and one feature was tracked with a phase velocity of 83 cm/s over a 5 day period. During the extension, LCFEs moved rapidly on the south side but were essentially stalled on the northern side as the energy was trapped by the LC extension. During the highest energy events studied; February 2001 and February/March 2002 when the LC was deeply intruded into the northern Gulf, LCFEs exhibited width scales of 140-175 km and SSH values of -30 to -40 cm. The fastest phase speeds were repeatedly observed along the western/northwestern margin of the LC. Increases in LCFE speed were observed during periods of rapid growth in LCFEs as well as downstream meanders.

STUDY PRODUCTS: Walker, Nan D., Robert Leben, Steve Anderson, James Feeney, Patrice Coholan, Neha Sharma. 2009. Loop Current frontal eddies based on satellite remote-sensing and drifter data. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2008-023 88 pp.

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P.I.’s affiliation may be different than that listed for Project Manager.