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**STUDY TITLE:** Dynamics of the Loop Current in U.S. Waters

**REPORT TITLE:** Observations and Dynamics of the Loop Current

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KEY WORDS: Eastern Gulf of Mexico; Straits of Florida; Yucatan Channel; Campeche Bank; West Florida Slope; Mississippi Fan; Loop Current; Eddies; Observations; Currents; Temperature; Salinity; Pressure; Travel Time; Moorings; Pressure Equipped Inverted Echo Sounders (PIES); Numerical Modeling; Circulation; Dynamics; Instabilities; Meanders; Frontal Eddies; Eddy Separation; Inertial Oscillations; Satellite Oceanography; Sea Surface Height; Inter-Annual; Intra-Annual; Statistics.

**BACKGROUND:** The Loop Current (LC) is a branch of the major western boundary current system of the North Atlantic that includes the Florida Current and the Gulf Stream. It enters the Gulf of Mexico through the Yucatan Channel, makes a clockwise Loop through the eastern basin, and exits through the Straits of Florida between Cuba and Key West. This energetic and variable current is the major source of upper layer (surface to ~ 1000 m) eddies, and lower layer (below 1000 m) eddies and planetary waves throughout the deep waters of the Gulf. The LC, on an irregular cycle averaging 9 to 11 months, extends to the northwest towards the Mississippi delta, and sheds a large warm, clockwise rotating eddy of ~ 200 to 400 km in diameter. A detached eddy may reattach to the LC several times, but eventually will separate and move into the western Gulf where it dominates circulation processes. These types of events are well known and have been studied using remote sensing and circulation models. However, there had been no previous attempts to directly observe the three-dimensional velocity and density structure of LC variability, eddy detachments and separations using in-situ measurements, with the goal of investigating these processes in detail. A deeper understanding of LC circulation processes is important for the assessment of numerical circulation models that are used for predictions, investigations of dynamics, and oil spill research.

**OBJECTIVES:** (1) To increase understanding of LC incursions into the Gulf; (2) To describe circulation processes that lead to detachments, reattachments, and separations during eddy shedding; (3) To understand how the LC interacts with and forces the lower-layer circulation; and (4) To incorporate observations from the Mexican sector of the Eastern Gulf into the investigation of circulation and dynamics.

**DESCRIPTION:** A moored array of nine full-depth and seven near-bottom moorings, and 25 bottom-mounted, pressure-equipped inverted echo sounders (PIES) was deployed in an array in the deep basin of the eastern Gulf for 30 months beginning in April 2009. The Mexican complementary study deployed nine full-depth moorings in two transects across the western Campeche Bank slope for 24 months beginning in June 2009. The near-bottom moorings were equipped with one current meter 100 m above bottom. The full-depth moorings were equipped with a variety of instrumentation, including ADCPs, current meters, and temperature, salinity and pressure (T/S/P) instruments, distributed so as to adequately capture the velocity and T/S vertical structure of the strongly sheared and nearly depth-independent upper and lower layers, respectively. PIES measure bottom pressure, temperature and the acoustic travel time from bottom to the surface and back. The latter are converted to water column T/S profiles using the historical database of CTD casts that included calibration CTDs taken during the field operations. Additionally, historical remote sensing data, including altimeter measurements of sea-surface height (SSH), sea-surface temperature (SST) and ocean color were acquired through the period of the field studies. Finally, a numerical circulation model was used to investigate the dynamics using observations. A high rate of data return was obtained from the moored instruments in both the U.S and Mexican sectors, and data were made available to PIs from both studies for analysis and interpretation.

**SIGNIFICANT CONCLUSIONS:** The three observed LC eddy detachments in the records followed consistent scenarios with the northwestward extensions of the LC that developed large amplitude, southward-propagating meanders, with crest to crest distances of ~ 300 km, and periodicities of 40 to 60 days on the northern and eastern sides of the southeastward flowing arm of the current that is over deep water (> 2500 m). Growth of these meanders was fed by baroclinic instabilities that involved interactions between a depth-independent (surface to bottom, i.e., barotropic), and a surface intensified velocity components. Initiation of baroclinic instability was triggered by lower-layer eddies propagating into the LC from the north-northeast part of the eastern basin. The growing barotropic eddies that dominated the lower layer, were steered by the topography of the Mississippi Fan and propagated southwestward across the neck of the LC to effect an eddy detachment. The east side meanders were not generated by LC frontal eddies propagating clockwise along the front from the Campeche Bank slope into deep water, as previous studies have suggested. These short ~ 10 day period frontal eddies appear to decay over deep water or are absorbed in to larger-scale meander troughs.

A new history of LC eddy separations was constructed for 1978 to 1992 using pre-altimeter datasets, and was combined with the 1993 to 2012 altimeter defined separations to give the longest time series yet available. Mean annual variability was examined and it was found that there is a significant higher probability of separations occurring around the spring equinox than in other months. LC growth and wane is a predominantly annual process with LC area being relatively large from January through July, and low in late fall and December. Mean annual variance of the LC area was found to co-vary with the dominant mode of monthly SSH anomalies along the southeast Atlantic coast of the U.S., through southward propagating coastal-trapped waves.

**STUDY RESULTS:** Three LC eddy formations and separations occurred during the field study. The three eddies were named Ekman, Franklin and Hadal with first detachment dates of July 6, 2009, June 8, 2010, and August 15, 2011, respectively. Ekman and Franklin were large eddies that behaved initially very similarly with detachment points in the southwest of the basin that followed the scenario given above. Ekman eventually separated after two reattachments to the LC when the detachment point moved to the northwest of the Campeche Bank. Franklin reattached four times after the initial detachment, and at each reattachment the LC drained area and energy from the eddy, so that after the final separation, Franklin was not a significant western Gulf LC eddy. Hadal extended much farther to the northwest than the other two eddies with three growth spurts with decreases in east-side meander activity between spurts. It separated on first detachment, and a free-running numerical model was able to hindcast the detachment date within about two weeks. For each eddy, lower-layer currents had large increases in variance over background, one to two months just prior to, or during the first detachments, which was accounted for by the baroclinic instability mechanism that drew on the large potential energy of the mean LC upper-layer flows. The propagation of short-period frontal eddies around the periphery of the LC was found to have very little influence on near bottom flows. There was significant growth of frontal eddies on the western side of the LC between the Yucatan northwards along the Campeche Bank slope, with decay occurring over deep water.

Strong inertial oscillations in the observed velocity field occurred during winter, and for hurricane Ida in November 2009. The inertial response to the northward transit of Ida was reasonably simulated using a regional numerical model and confirmed that the horizontal velocity shear of the LC front suppressed the inertial response of the upper water column compared with more quiescent waters.

**STUDY PRODUCT:** Hamilton, P., K. Donohue, C. Hall, R. R. Leben, H. Quian, J. Sheinbaum, and D. R. Watts. 2015. Observations and dynamics of the Loop Current. US Dept. of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEM 2015-006. 490 pp.

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