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STUDY TITLE: Current Measurements in the Yucatan-Campeche Area in Support of Dynamics of Loop Currents Study

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BACKGROUND: The flow through Yucatan Channel (upper 1000 m) is known as the Yucatan Current; it is considered the principal forcing agent of the circulation in the Gulf of Mexico (GoM) and its variability has significant implications for the dynamics within the GoM and the circulation in the Western Subtropical Atlantic. The Yucatan Current, characterized by a strong jet on the western side of the channel, becomes the Loop Current within the GoM and exits through the Straits of Florida over its 700 m sill. Below 700 m, there is flow into the Caribbean over the Yucatan slope. On the eastern side of channel (east of 86.5ºW), there are flows into the Caribbean, particularly an intermittent near-surface flow close to Cuba, known as the Cuban Countercurrent, and a deeper flow below it.

Transport variability through Yucatan Channel has important implications downstream, affecting in particular the Loop Current. A characteristic feature of the Loop Current is the detachment of large anti-cyclonic eddies (LCEs) at irregular intervals. Two years of continuous measurements of the Yucatan Current (Sep., 1999 to May, 2001) revealed a mean transport of ~23 Sv that is 20% smaller than the 28 Sv previously estimated for this current. The 23 Sv also differ substantially from the 32 Sv estimated from long-term cable measurements monitoring transports at the Florida Straits. The new Yucatan Channel measurements reported here together with current observations over the Campeche Bank where the Yucatan-Loop Current is usually located, document several aspects of the Yucatan Current variability and its downstream connection with the Loop Current; particularly some aspects of the anticyclonic eddy releases and their relation to vorticity fluxes from the Northwestern Caribbean into the GoM.

OBJECTIVES: (1) Determine the connections of the flows in the western Yucatan Channel and Yucatan slope with the Loop Current growth and the eddy detachment process. (2) Expand our understanding about the three-dimensional flow fields of the Yucatan and Loop Currents, as well as the basic statistics of the flow to characterize their long-term variability. (3) Determine the spatial structure and temporal variability of the modes that explain most of the variance of the Yucatan Current, Loop Current and currents north of Campeche Bank. (4) Produce new continuous-measurements of transport on the western Yucatan Channel and compare them with previous observations. (5) Expand understanding of the Loop Current behavior during the eddy releases and the possible upstream connection with the Yucatan Current. (6) Examine the seasonal cycle of the transport through Yucatan Channel and its connection with the wind stress curl.

DESCRIPTION: Three transects of mooring arrays were deployed nearly perpendicular to the western edge of Yucatan and Loop Currents. A set of seven moorings were deployed at the western Yucatan Channel (WYC, west of 86.5ºW), each designed to adequately sample the distribution of currents from the near-surface to the bottom. Moorings were equipped with Acoustic Doppler Current Profilers (ADCP), looking toward the surface measuring from the bottom or 500 m depth up to 30–60 m near the surface. Deeper moorings installed in the center of the channel had an additional ADCP sampling downward at 500 m depth; below 700–750 m down to the bottom current measurements were taken by 5 or 6 single depth current meters, with the deepest instrument measuring at 10 m off the bottom. The measurements at WYC lasted over 24 months, from June 2009 to May 2011, with a one-month gap due to service and redeployment of the moorings. Additional 14-months (March 2008 to May 2009) of data covering the entire Yucatan Channel were used to complement the analysis.

Two mooring transects north of Yucatan Channel crossing from the shelf break to depths between 2,000-3,500 m were deployed on the Campeche bank: near 23ºN transect PE (“Plataforma Este” [“Eastern shelf” in Spanish]), consisting of five moorings and near 24.3ºN transect PN (“Platforma Norte” [“Northern shelf” in Spanish]) with four moorings. These mooring’s design was similar to those deployed in the Yucatan Channel. The PE and PN measurements lasted over 22 months (June 2009 to April 2011).

Objective mapping of the velocity data was carried out to interpolate the velocity into a regular grid, considering all functional instruments at each time-step including those with short time series. Additionally, maps of absolute dynamic topography and geostrophic velocities derived from it were used to observe the evolution of the Loop Current and identify the eddy releases by tracking the SSH's 50-cm contour. The altimeter data are produced by Ssalto/Duacs and distributed by AVISO, with a 1/3 of a degree spatial resolution, and seven days temporal resolution. From these data, we determined that four LCEs were released during the time our instruments were deployed and serve to illustrate the behavior of currents and eddies as they separate from the Loop Current.

SIGNIFICANT CONCLUSIONS: In the western Yucatan Channel, current structure is characterized by the intense flow of Yucatan Current with mean velocities of about 1 m/s in its core, whose position varied mainly between 86.4°W and 86°W and mean current values larger than their standard deviation. Current decreases considerably from the surface to 1,000 m depth, where mean speeds and velocities standard deviation are of the same order below 0.1 m/s. Further north, the position of the current core is constrained by the topography following the shelf break and slope near the 1000m isobath for sections PE (~ 23°N) and PN (~24.3°N). Here, the mean current near the surface is lower than through Yucatan Channel (0.75 m/s). The variability at the PE transect is of the same order as the mean current, and at transect PN variability exceeds the magnitude of the mean currents. According to an empirical orthogonal function analysis (EOF) of the data, the first EOF mode, which explains about 75% of the variance, has large spatial variability along the Yucatan Channel and along the topography for the northern transects over the shelf. The second mode, which explains between 7 to 25% of the variance (depending on the section) basically, has more structure across Yucatan Channel and perpendicular to the topography at PE and PN, showing intense pulses propagating from the shelf to the deep slope.

The vertical structure below 1,000 m depth, where the minimum of velocity is observed, is characterized by a minimum of the ratio of sub-inertial velocity variance to total variance, which diminishes below 40% at this depth. On all the deepest moorings at the Yucatan, PE and PN transects, this value increases again over 70% and is also associated with a slight increase of current velocity at depth. The increase near the bottom at the central Yucatan Channel are due to deeper flows entering and exiting the GoM near the bottom, which have been proved to be connected with the Loop Current dynamics. Southward bottom-intensified along-slope flows observed in deep moorings of sections PE and PN, suggest the presence of eddies or topographic Rossby waves seen in other areas of the GoM along the slope.

An important result of this work is that current meanders are related to the LCE releases. The measurements prove that an intense positive pulse in along-channel velocity at the western Yucatan Channel, as well as an eddy kinetic energy pulse in the Loop Current (PE transect), preceded four LCE releases observed between 2008 and 2011. Furthermore, LCEs' releases are simultaneous with the eastward shift of the Yucatan Current, together with periods of positive horizontal shear (cyclonic vorticity) along the Yucatan Channel and PE transects. This relation is very clear in three of the four LCE releases in summer (July 2008, August 2009, and August 2010). The analysis shows that the increase of cyclonic vorticity is related in turn, with the arrival of a cyclone to the Northwestern Caribbean preceding the eastward shift of the Yucatan Current and just before the LCE detachment. Moreover, SSH data from AVISO confirms the propagation of SSH anomalies along the Yucatan shelf from the Caribbean into the GoM, with negative anomalies of SSH (indicating cyclonic anomalies) just before each LCE release.

Although not part of this project, we use transport time series of the entire Yucatan Channel to investigate its seasonality. We find a remarkable compensation between the variability at western and eastern sides of the channel (west and east of 85.6°W). Transport anomalies at both sides of the channel are of similar amplitude (4–5 Sv) and show a compensating behavior (negative correlation around 0.7 to 0.8); consequently, significant changes in the total transport variability with respect to the transport only at the west (Yucatan Current transport) are observed. Even if the mean transport in the WYC represents about 90% of the total mean transport (with 24.4 Sv at the WYC and 2.8 Sv at the eastern side); full transport variability cannot be accounted by considering only the western side since it is modified at both high frequency and seasonal time-scales, by the contribution from the eastern side. The seasonal cycle of the WYC transport shows an asymmetric behavior with maxima in winter-spring and to a lesser extent in summer. This semi-annual behavior is absent in the total Yucatan Channel transport series, which depicts a clear maximum only in summer. The wind stress curl over the Cayman Sea has higher correlation with the WYC transport than the total transport. However, even with the WYC transport there are periods when such connection is lost suggesting that inter-annual variability and forcing at other locations can change conditions enough to break the correlation.

Between May 2010 and May 2011, the Yucatan Channel transport estimated form the moorings was 27 Sv, which is 4 Sv higher than transport measured between 1999 and 2001. Between 2008 and 2011, considering only the western side of the channel, the yearly-mean transports were rather constant (~24 Sv), with a standard deviation of 3.5 Sv. This western transport alone is 2 Sv higher than in 1999-2001. This suggests significant interannual variability of currents through this channel.

STUDY RESULTS: Three years of data (2008–2011) were used to investigate the flow over the WYC and Campeche Bank and its role in the Loop Current dynamics and eddy detachment. This array composed by more than sixteen moorings, provides valuable information in support of the high-density array of observations deployed by our colleagues from the Loop Current Dynamics Experiment whose main focus is over the area where LCE detachments usually occur. Data recovered from our array document several aspects of the Yucatan Current variability and its downstream connection with the Loop Current. In particular, analysis of data from transect PE (across the Loop Current) clarifies some aspects of the anticyclonic eddy releases and their relation to vorticity fluxes from the Northwestern Caribbean into the GoM.

The mooring array installed at WYC (west of 85.6ºW) between March 2008 and May 2011 revealed a high degree of consistency in the yearly-averaged current structure, when compared with the first detailed current measurements at Yucatan Channel during August 1999–June 2001. Regarding volume transport, the comparison between the mean velocity profiles measured previously by the Canek project and recent data of 2010-2011 provides unique information about its seasonality as well as the importance of interannual variability in the system.

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STUDY PRODUCTS: Athie, G., J. Sheinbaum, A. Romero, J. Candela, and J. Ochoa. 2014. Measurements in the Yucatan-Campeche area in support of dynamics of Loop Current study. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study BOEM 2014-669. 191 pp.

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