Eddy-Mean Interaction during Loop Current Formation

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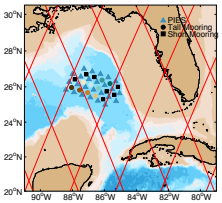
1. Dynamics of the Loop Current Experiment



The array was placed where historical analysis indicated eddy separation was most likely to occur and designed to encompass the Loop Current from east to west.

Goals: Increase dynamical understanding of the Loop Current, eddy-shedding mechanisms, and genesis of lower-layer flows.

Elements: Moored arrays of current and temperature and bottom-mounted pressure equipped inverted echo sounders (PIES) together with remote-sensing and numerical-modeling approaches.

Field Program: April 2009 -- November 2011
30 months

Three Loop Current Eddies formed during the experiment: Ekman, Franklin, and Hadal.

2. PIES Methodology

PIES τ are converted to profiles of temperature and specific volume anomaly through a gravest empirical mode, GEM, look-up table using historical hydrography.

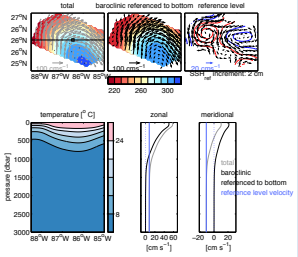
Deep pressure and currents combined with estimated horizontal density gradients yield referenced geostrophic velocities.

Sea Surface Height: $SSH = SSH_{bcb} + SSH_{ref}$

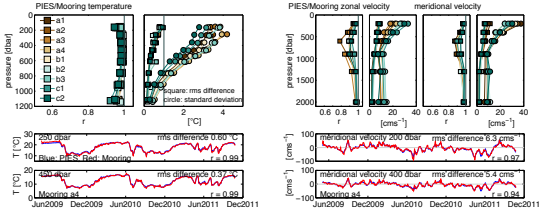
SSH_{ref}: bottom pressure converted to height equivalent (pressure divided by gravity and density)

SSH_{bcb}: surface geopotentials referenced to 3000 dbar converted to height equivalent (geopotential divided by gravity).

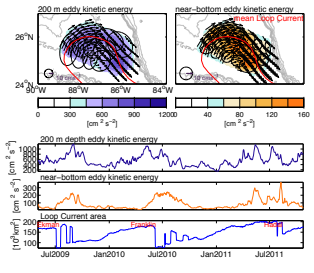
Several views of current and temperature structure in the region for May 5, 2009.



Excellent agreement between mooring measurements and PIES-derived temperature and velocity.



3. Upper and Deep Statistics



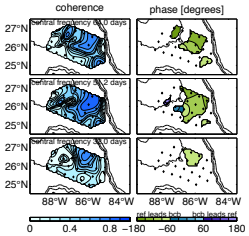
In the lower layer, mean circulation shows a west-east pattern of anticyclone-cyclone pair.

Deep mean currents and their principal axes of the standard deviation ellipses are not aligned with those of the upper layer.

Deep eddy kinetic energy is high along the northeastern periphery of the mean Loop Current position.

During Loop Current Eddy detachment and formation events, a marked increase in lower-layer eddy kinetic energy occurs.

4. Evidence for Baroclinic Instability

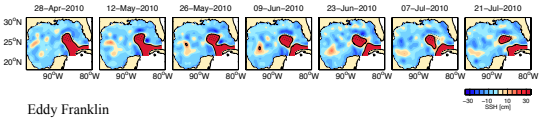


Upper and deep are coherent over large portions of the array only for frequencies between 1/64 d^{-1} and 1/32 d^{-1}

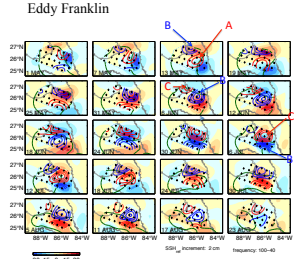
A tongue of high coherence extends from the northeast trending south-southeast.

Where statistically coherent, the phase offset is such that deep leads upper-- consistent with baroclinic instability.

5. Upper-Deep Case Studies



Eddy Franklin



Early May: A large-scale Loop Current meander develops.

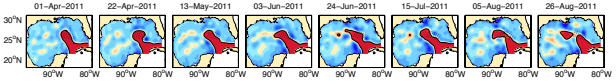
May 13: Deep anticyclone A resides downstream of the upper crest. Deep cyclone B resides upstream of that crest.

June 6 to June 30: Deep cyclone B intensifies as it leads a developing upper trough.

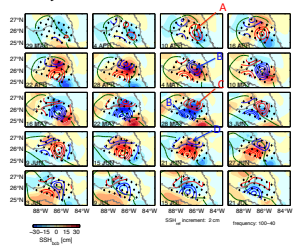
June 6: Deep anticyclone C arrives with an upper crest close behind. B and C eddies and their trailing upper meander trough and crest propagate downstream around the Loop.

July 6: The trough and deep eddy B jointly intensify and the Loop Current neck pinches off into a momentary detachment.

The recurrent structure observed in these sequences is that as deep eddies propagate through the array they lead their upper counterpart.



Eddy Hadal



April 10: deep anticyclone A sits just downstream of an upper and during the subsequent 15 days the upper and deep highs jointly intensify.

May 4: deep cyclone B leads an upper trough and both intensify during the subsequent 20 days.

May 22: deep anticyclone C leads an upper crest downstream, intensifying during the next 20-30 days

June 12: Deep cyclone D follows this train of upper-deep coupling interactions.

June 21 to July 21: Deep cyclone D leads and jointly develops with an upper low and trough, constricting the Loop Current neck greatly, Eddy Hadal separates.

6. Mean Eddy Potential Energy Budget

In peak conversion regions there is a near balance between horizontal down-gradient eddy heat flux (BC) and vertical down-gradient eddy heat fluxes (PKC).

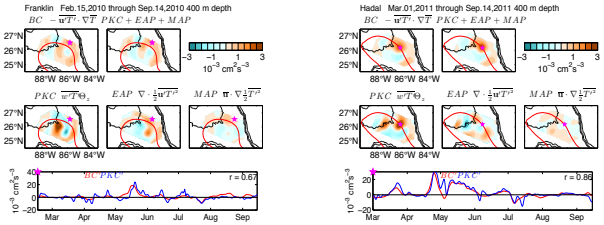
Baroclinic energy conversion term (BC) is largest along the eastern side of the Loop Current.

Eddies extract available potential energy from the mean baroclinic field and further convert that eddy potential energy to eddy kinetic energy.

The magnitude of eddy advection of eddy potential energy EAP is of the same order as the BC and PKC term, mean advection of eddy potential energy MAP is small.

The spatial pattern and magnitude of the combined PKC+EAP +MAP terms is very similar to the BC term.

At any particular location, the time series that contribute to the terms in the eddy energy budget are event-line, often only a few events dominate the mean.



7. Discussion and Conclusions

•In all three Loop Current Eddy formations, along the eastern side of an extended Loop Current, large amplitude meanders (~300 km wavelength, 40-60 day period) develop and propagate southward toward Florida Straits.

•A simultaneous increase in deep eddy kinetic energy occurs. Deep eddies develop with signature vertical phase tilts between upper and deep characteristic of baroclinic instability.

•Joint intensification is intermittent, lasting only tens of days while the vertical phase tilt is optimal for baroclinic growth.

•Strongest upper-deep interaction and the most energetic deep eddies can occur well in advance of the final eddy separation. Each separation is preceded by a train of upper-deep eddy interactions.

•Due to the limited spatial domain of the array, we cannot unambiguously distinguish between locally generated deep eddies and external deep eddies that may enter and intensify when they encounter favorable phasing with the upper thermocline waters.

•Possible sources for the external deep eddies may be deep cyclones generated by the flow of the Loop Current over the Mississippi Fan as suggested by Le Hénaff et al. 2012.

•Interpretation of remotely sensed SST and SSH data note a merging and stalling of Loop Current Frontal Eddies that produce a large `supercyclone' (e.g. Walker et al. 2011). This work suggests that the large northern cyclone development is due to the generation of a large meander trough through the baroclinic instability process.

References

Le Hénaff et al, 2012, Simulating the dynamics and intensification of cyclonic Loop Current frontal eddies in the Gulf of Mexico, JGR 117, 2034

Walker et al. 2011, Impacts of Loop Current frontal cyclonic eddies and wind forcing on the 2010 GOM oil spill. Geophys. Monogr. 195, AGU pp. 103-116.

See related posters:

2896 Hamilton, P., Ekman, Franklin and Hadal: Loop Current Eddy separation and statistics from observations.

2902 Rosburg, K., Comparison of the 1/25° assimilated Gulf of Mexico HYCOM with observation in the Loop Current Eddy formation region.

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