HIGH FREQUENCY DOPPLER RADAR SCATTEROMETER (HFDRS) OBSERVATIONS OF A CYCLONIC EDDY IN THE LEE OF PANAY, PHILIPPINES DURING THE NORTHEAST MONSOON

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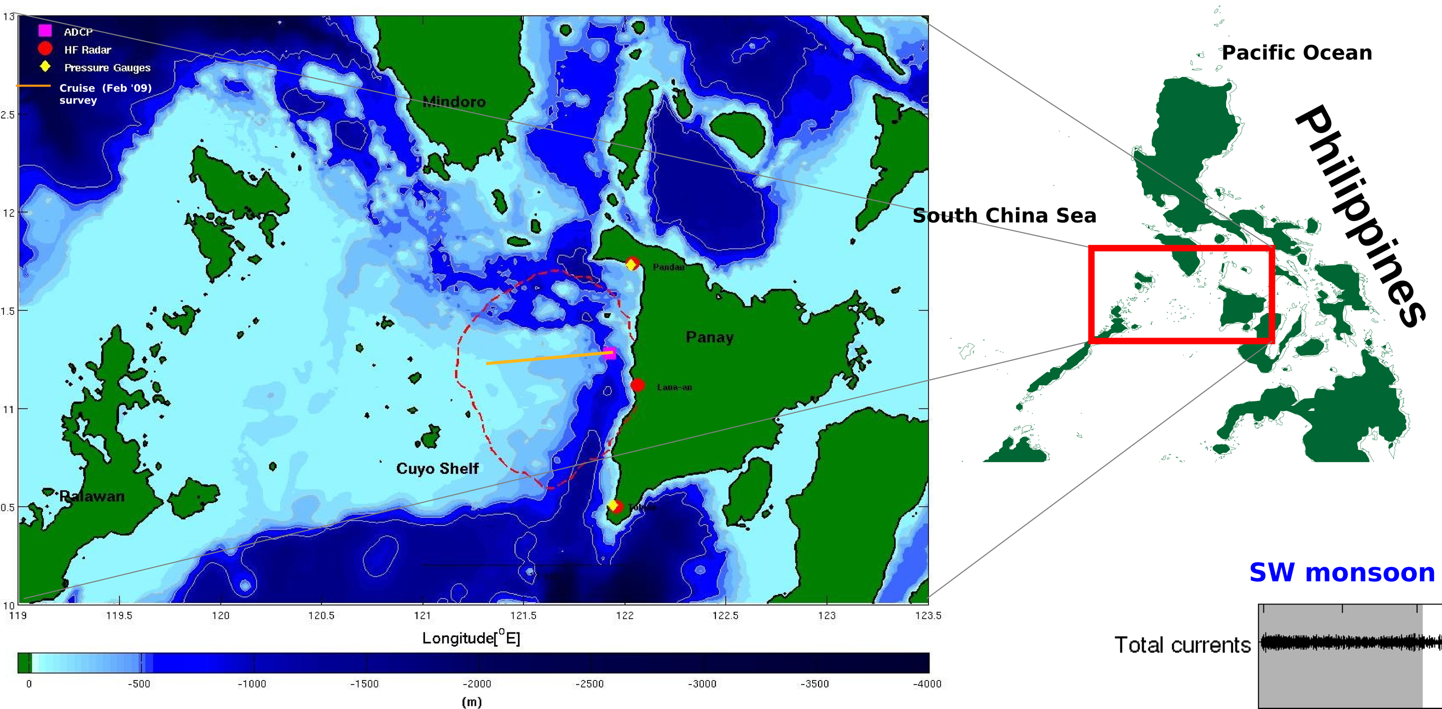
Abstract

Low frequency surface currents inferred from three HFDRS (August 2008 – August 2009), revealed a mesoscale cyclonic eddy west of Panay island during the NE monsoon. This eddy affected the Panay coastal jet formed at its eastern limb. Winds from QuikSCAT and from a nearby airport indicate that these flow structures correlate with the strength and direction of the prevailing local wind. The eddy was surveyed in February 6-23, 2009. Successive cross-shore CTD sections in conjunction with shipboard ADCP measurements showed a well-developed cyclonic eddy characterized by near-surface velocities of ~50 cm/s. These observations suggest that intensification of wind between the Mindoro and Panay islands generates a positive wind stress curl in the lee, which in turn induces divergent surface currents. Water column response showed a pronounced signal of upwelling, indicated by the doming of isotherms and isopycnals. A pressure gradient sets up, resulting in the spin-up of a cyclonic eddy in geostrophic balance. Evolution of the vorticity within the vortex core confirmed wind stress curl as the dominant forcing.

I. Introduction

The surface wind is an important forcing mechanism particularly evident in the circulation patterns in and around the Philippine Archipelago. Spatially variable wind stress modulated by the seasonal Asian monsoon produces sub-mesoscale ocean features in the lee of the islands that induces divergent and convergent surface currents, which in turn lift or depress the thermocline, forming cyclonic and anticyclonic eddies (Chavanne, et al., 2002). In Panay Strait, an improve understanding of strait circulation and dynamics was carried over using high-resolution both in time and space HFDRS inferred surface current in conjunction with time-series data from observations and satellites. In-situ data during the Philippine Straits Dynamics Experiment regional Intensive Observational Period cruises in the winters of February 2009 (IOP-09) confirmed the mechanisms of the dominant flow features.

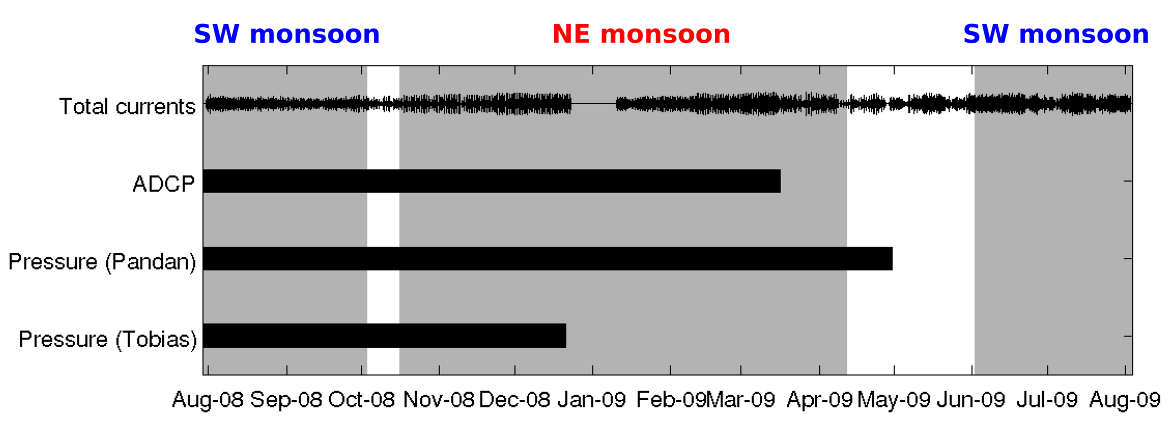


The Panay Strait (red inset) in Philippines is one of the major pathways from the South China Sea to the Indonesian seas.

Marked are locations of instruments deployed. The red broken line indicate 75% coverage of HFDRS. Successive cross-sections were surveyed during the Philippine Straits Dynamics Experiment (PhilEx) Intensive Observational period in February 2009 (IOP-09) cruise.

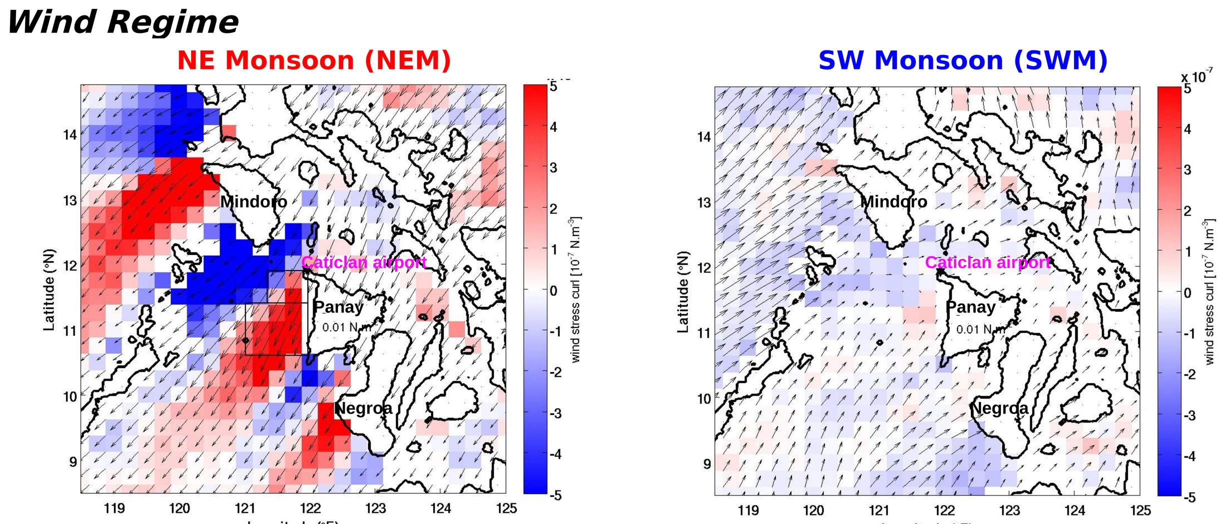
II. Data

Temporal coverages of the data span over a year, covering the Asian monsoon reversal. All data were detided and subject to 6-day running median to obtain the low frequency signal.

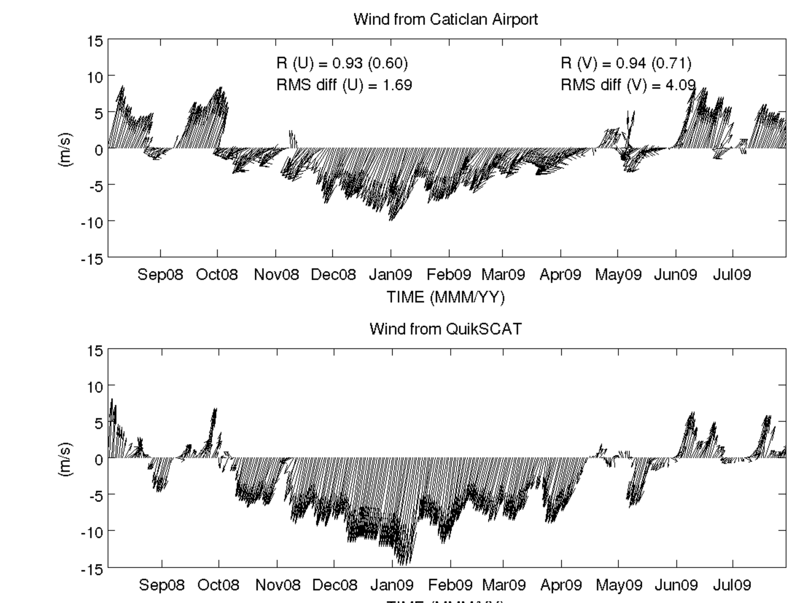


III. Observations

A. Wind Regime

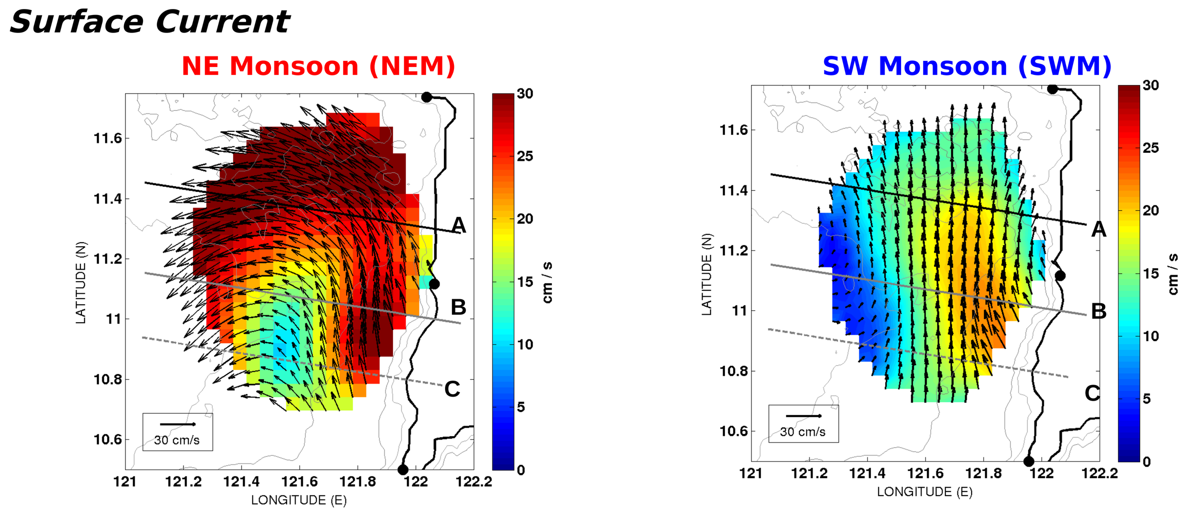


Wind stress overlaid with wind stress curl contour from QuikSCAT shows pronounced seasonal variations between NEM and SWM periods. Spatially variable winds interact with the rugged terrain of the islands generating spatial pattern of alternating band of positive and negative wind stress curl at the lee of the islands during NEM. Consequently, positive wind stress curl prevails in the lee of Panay which presents a favorable condition leading to the formation of mesoscale eddy.

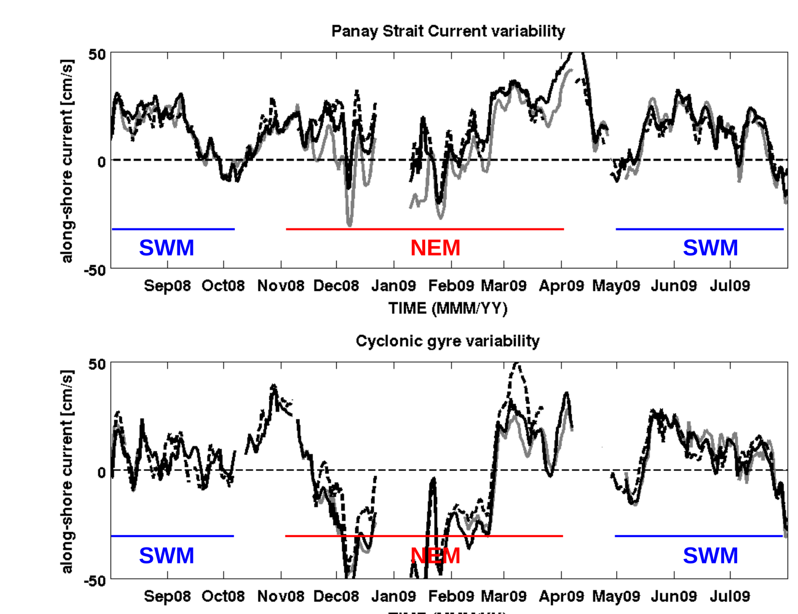


Wind vectors from nearby Caticlan airport and QuikSCAT from the closest grid points are well correlated. Monsoon and transition periods are well-define. Persistent NEM wind from Oct-Apr and SWM wind from May-Sept with pronounce sub-seasonal breaks.

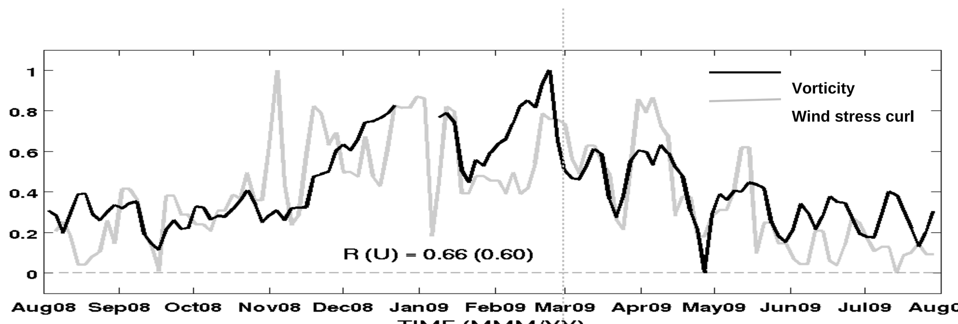
B. Surface Current



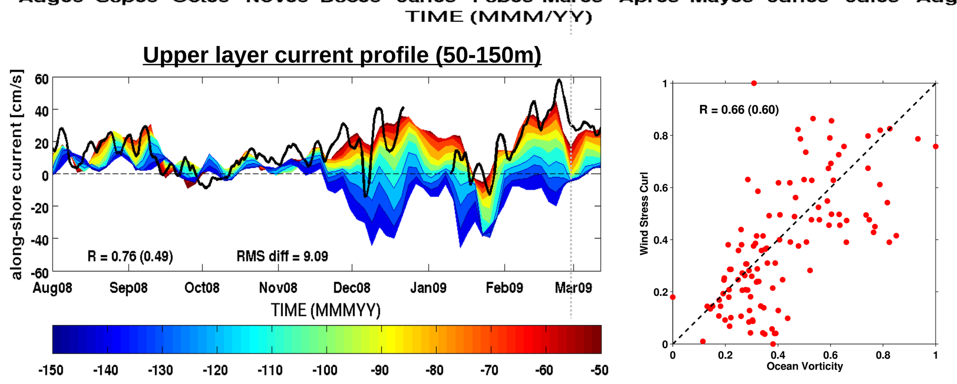
Subject to pronounced Asian monsoon reversal, data was separated into two monsoon periods. Dominant flows are the northward Panay coastal jet and southwestward return flow to the west forming the cyclonic circulation.



Panay coastal jet (top) defined as flow from the coast to the center of the gyre is intraseasonal while cyclonic gyre (bottom) defined as flow from the center of the gyre to the west is highly seasonal. Positive values indicate flow towards the northwest.

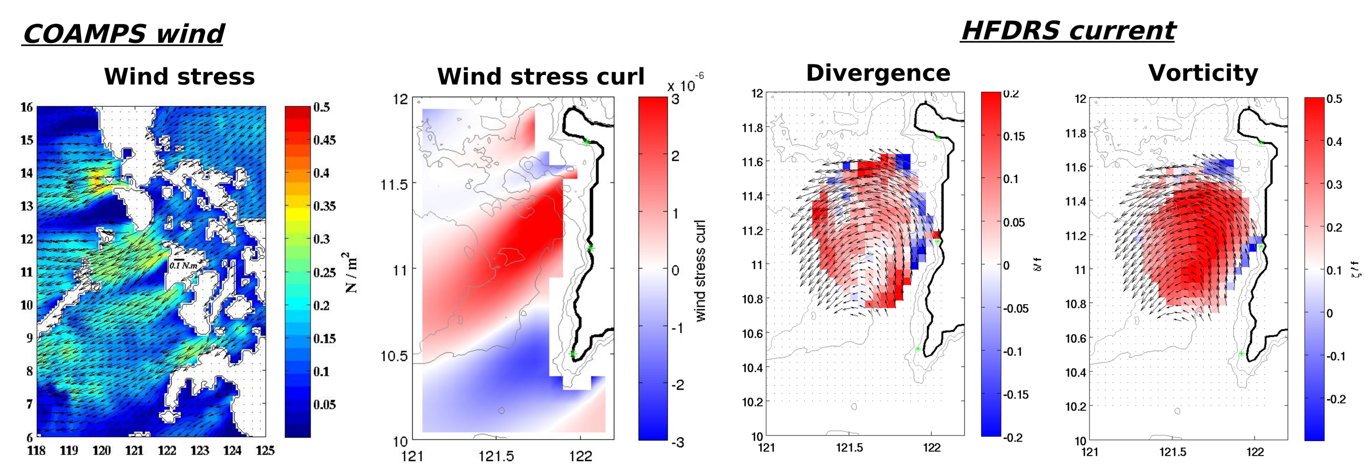


Vorticity input to the ocean from the overlying wind stress curl appears responsible for the eddy generation and propagation during NEM. Variability of the surface ocean vorticity from HFDRS (think black line) and wind stress curl (thick gray line) from QuikSCAT over the shelf (marked on wind stress map above) has correlation coefficient of $R=0.66$. Both are predominantly high during NEM period.

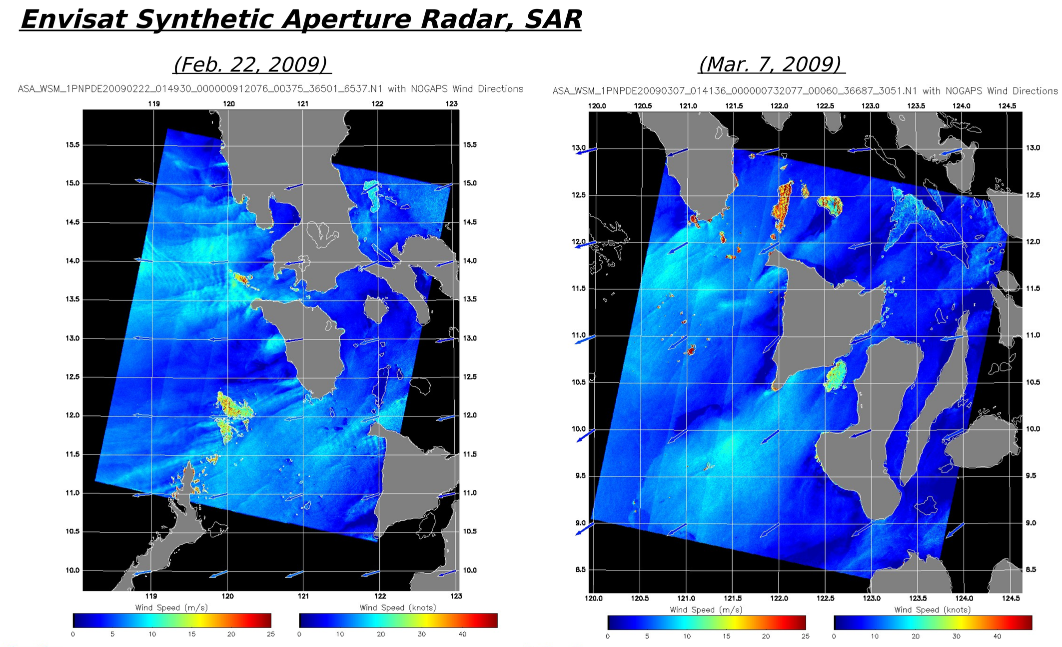


The relative importance of the curl and its role in generating the Panay coastal jet are confirmed by the current profile obtained from ADCP. Along-shore current from ADCP (thick black line) overlaid with along-shore surface current from the closest HF Radio data (think gray line) indicate dominant northward flow for both season. During NEM, the coastal jet intensifies with notable flow shear at intermediate layer (below 130m).

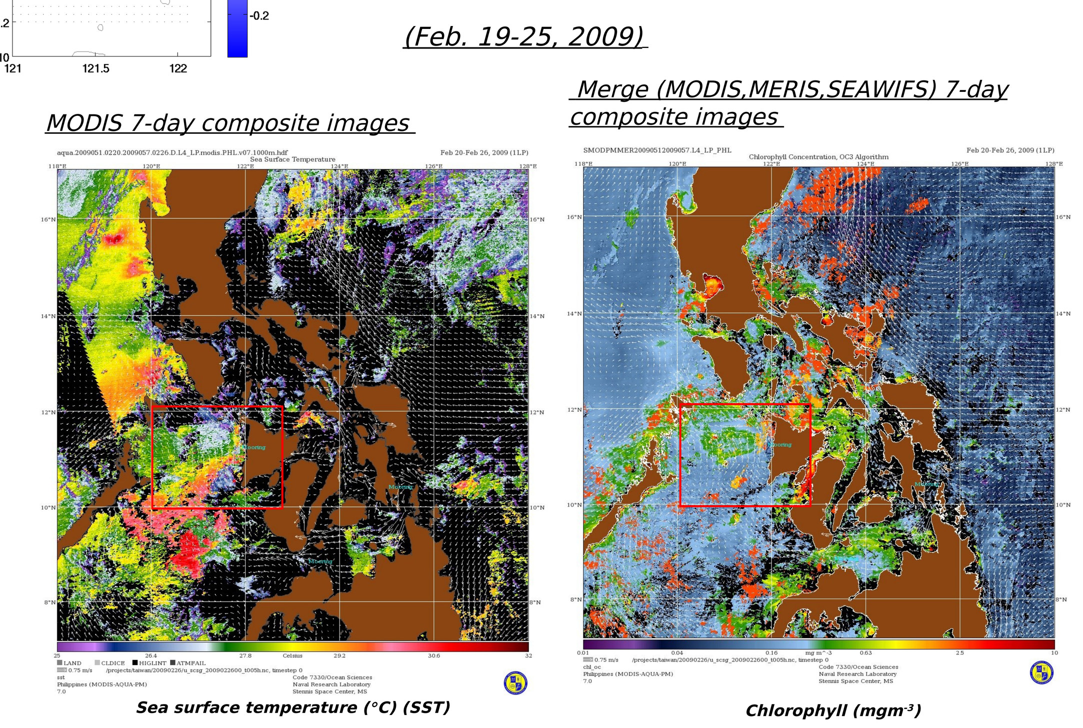
C. Real Time Data Support to IOP-09 Cruise Feb - Mar 2009



Wind intensifies in between Mindoro and Panay islands.
It generates positive wind stress curl at the lee of Panay island.
HFDRS inferred current shows divergent surface currents and positive vorticity as eddy spins-up in geostrophic balance to pressure gradient generated.

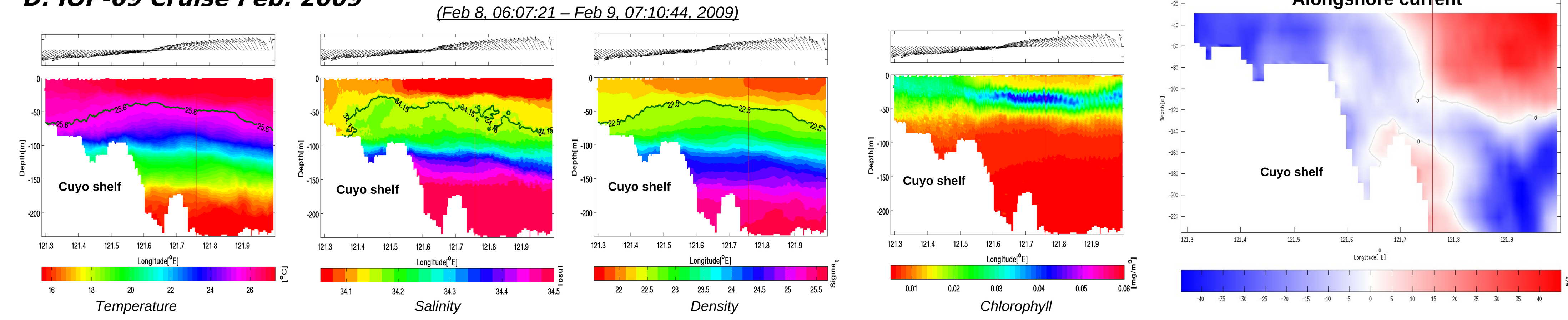


SAR images shows the prevailing NEM wind during the cruise. The wind blow through Tablas Strait, forming a wind jet in between Mindoro and Panay Island,



From satellite images, the channel yield cooler SST while warmer in the calm lee. Enhanced chlorophyll concentration over the Cuyo shelf is collocated with the center of the cyclonic eddy, an indicative of active upwelling of subsurface, nutrient-rich waters in its core in response to divergent surface currents.

D. IOP-09 Cruise Feb. 2009



Water column response to divergent currents shows a pronounced signal of upwelling indicated by doming of the thermocline, halocline and isopycnal that corresponds well within the center of the gyre shown as a return flow in the near-surface current flow from shipboard ADCP. Collocated with the doming is an elevated chlorophyll concentration while outcropping of isolines over the shallow shelf are visible.

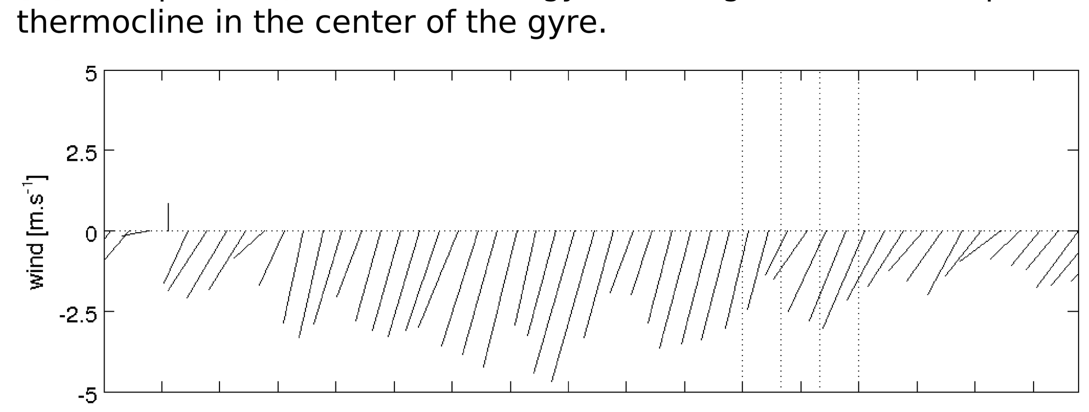
Depth of cyclonic circulation reached the depth of ~ 130 m.

$$F_w = \frac{1}{\rho H_E} curl_z \tau \quad (2)$$

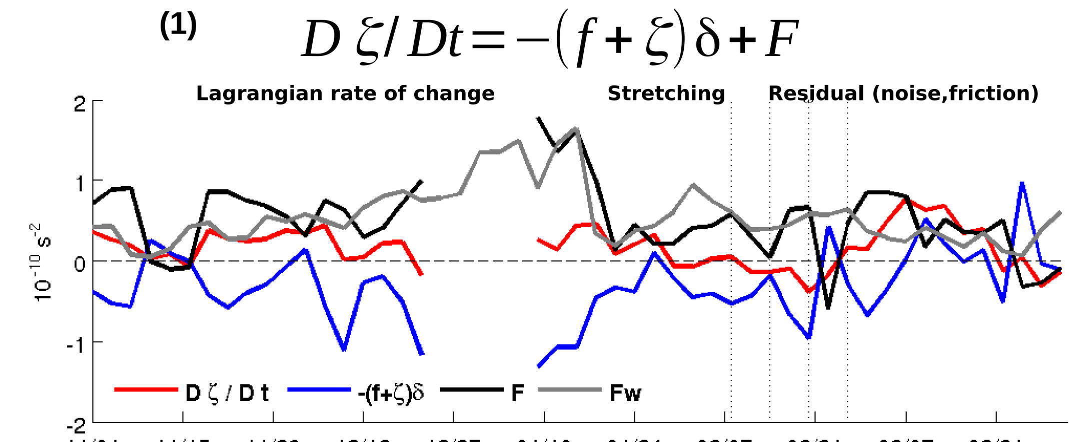
Friction due to wind stress

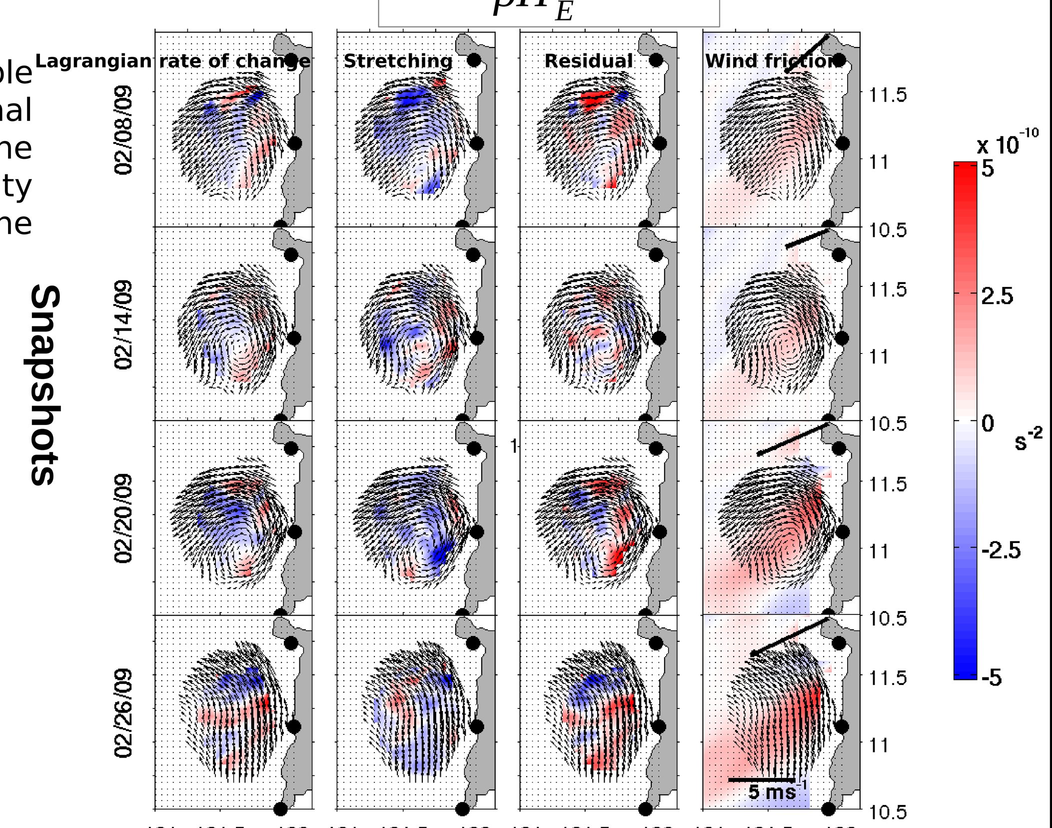
E. Vorticity Balance

By estimating the surface vorticity balance **(1)**, mechanisms responsible for growth and decay of the vortex was determined to be the frictional force induced by the wind. Vortex formation corresponds well with the eastward progressing component of the wind . Ekman pumping velocity **(3)** is upward (+) over the gyre that generates an uplist of the thermocline in the center of the gyre.



$$D\zeta / Dt = -(f+\zeta)\delta + F \quad (1)$$

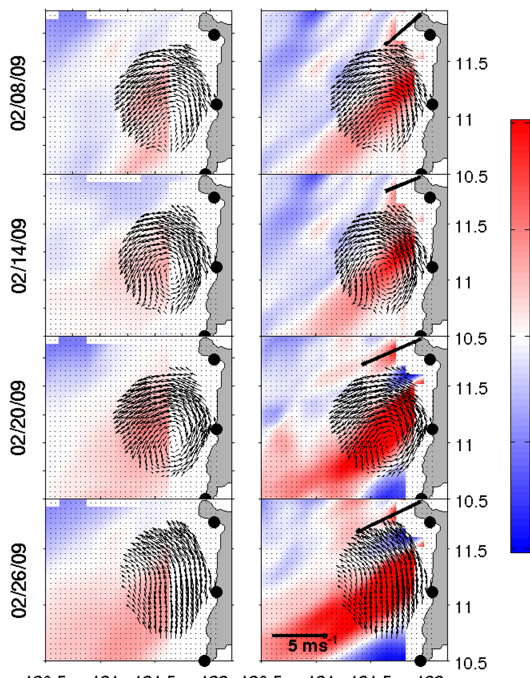




$$w_E = curl \frac{\tau}{\rho f} \quad (3)$$

Ekman pumping velocity

QuikSCAT vs. COAMPS

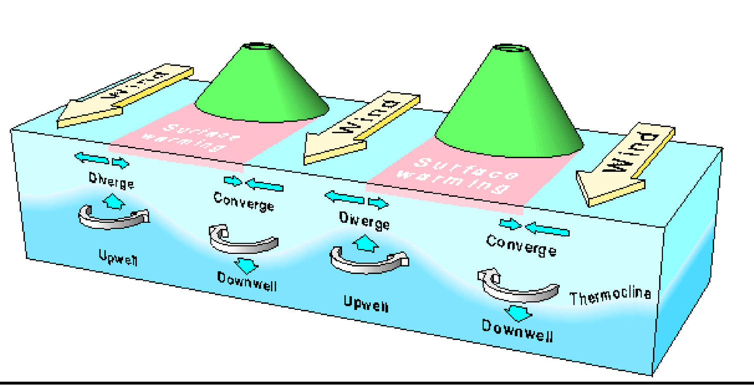


III. Summary and Conclusion

Observations show that the main generation mechanism of the cyclonic gyre is wind stress curl.

Conceptual diagram showing Ekman pumping at the lee of the Panay island

1. **wind intensify between islands**
2. **wind speed variations forms positive wind stress curl at the lee of the island.**
3. **then induce a divergent surface currents**
4. **upwell the thermocline**
5. **spins-up eddy in geostrophic balance with pressure gradient**



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Pullen, J., J. D. Doyle, P. May, C. Chavanne, P. Flament, and R. A. Arnone. 2008. Monsoon surges trigger oceanic eddy formation and propagation in the lee of the Philippine Islands. Geophys. Res. Letters, Vol. 35, L07604.

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