

Continental Shelf Embayments of the Eastern Margin of the Philippines; Lamon Bay Stratification & Circulation

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LONG-TERM GOALS

To investigate the circulation, stratification and the Shelf-Slope interaction within Lamon Bay of the eastern margin of the Philippines, marking the 'birth' of the Kuroshio, before its encounter with Luzon Strait.

OBJECTIVES

The objectives of the Lamon Bay program are to quantify the spatial and temporal characteristics of the ocean processes governing the stratification & circulation within Lamon Bay, including shelf / slope exchange, and their relationship to regional marine ecosystems, as well as to investigate linkage of Lamon Bay oceanography to the larger scale, such as the development of the Kuroshio. The objectives are attained utilizing the observations obtained during the R/V Revelle in May/June 2011 and April/May 2012 research cruises; time series from moorings spanning the cruises; as well as satellite derived data and other observations collected as part of the OKMC program,

APPROACH

The Lamon Bay observational program of 2011-12, provides significant insights into the workings of the embayment environment of the eastern coast of Luzon, the Philippines. The proposed data analysis fall under 3 categories:

1. Circulation & stratification and physical processes within Lamon Bay: Quantitative study of the patterns, dynamics and water mass components of the Kuroshio 'feeder' current and of the anticyclonic and cyclonic dipoles, which bracket the Kuroshio 'feeder' current; the development of a western boundary Kuroshio near $\sim 17^\circ\text{N}$. The ship-based observations are linked by a mooring array time series, as well as satellite and OKMC observations. Comparison to model output to be developed as observational results evolve.
2. Linking the physical processes to the marine ecosystems of Lamon Bay, in collaboration with Philippine colleagues: Satellite ocean color regional time series coupled to ship based observations of CTD Fluorometer LSS and Transmissometer and Plankton Sampling, will be used

to delineate the circulation patterns in the southwest corner of Lamon Bay and the associated marine ecosystems.

3. Relating Lamon Bay oceanography to the larger regional scale, including the relationship to the NEC Bifurcation and Kuroshio generation and characteristics of the flow into Luzon Strait and of the Indonesian throughflow.

The research is carried out with Pierre Flament of the University of Hawaii, and the Philippine research team; Lamon Bay program is a component of the OKMC DRI.

WORK COMPLETED

Background: The Lamon Bay program provides significant insights into the workings of the embayment environment of the eastern coast of Luzon, the Philippines. Reports of Lamon Bay cruise 1 (LB01, May/June 2011) and Lamon Bay cruise 2 (LB02, April/May 2012) provide an overview of the observations and basic insights to Lamon Bay oceanography and its place in the larger scale regional ocean. The reports are available at:

Lamon Bay 1 Report: http://www.ldeo.columbia.edu/~agordon/Reports/LamonBay2011_Report.pdf

Lamon Bay 2 Report: http://www.ldeo.columbia.edu/~agordon/Reports/LamonBay2_rept.pdf

The research objectives of the 2011-2012 Lamon Bay observational program (Figure 1) was to quantify the spatial and temporal characteristics of the ocean processes governing the stratification & circulation within Lamon Bay and their relationship to marine productivity and ecosystems and to investigate possible linkage of Lamon Bay dynamics to the development of the Kuroshio.

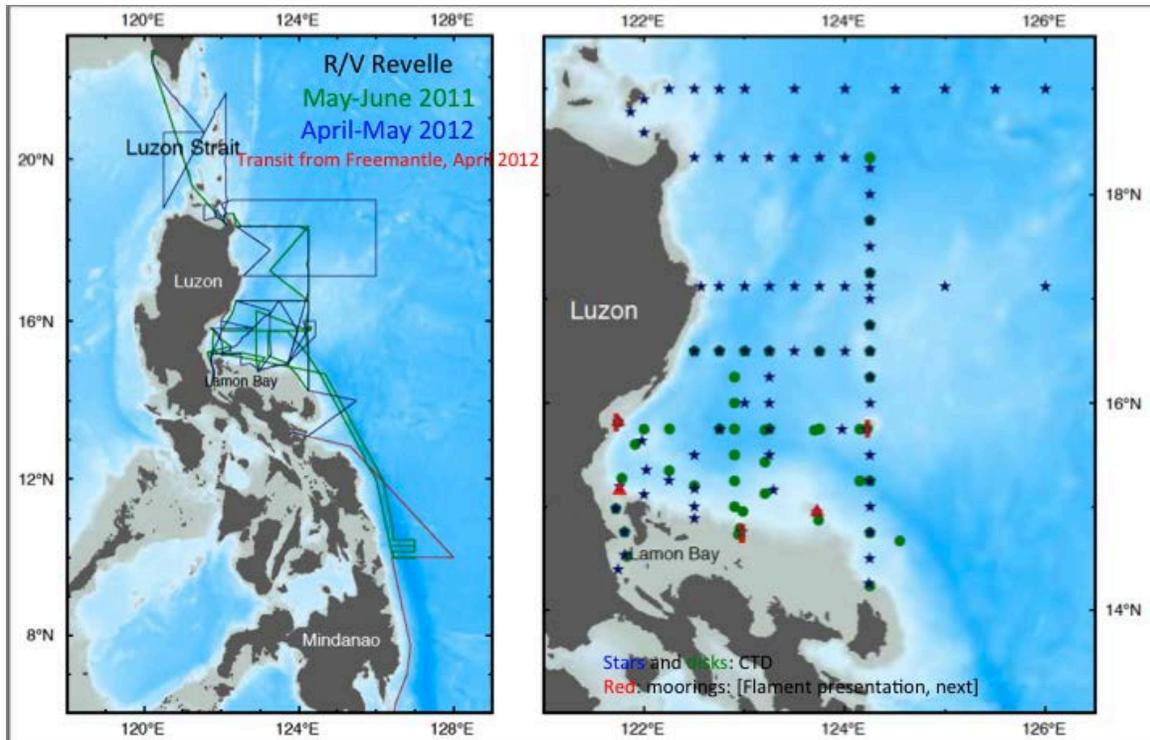


Figure 1: Track (left panel) and CTD stations (right panel) obtained from the two cruises aboard the R/V Revelle: Lamon Bay 1 (green track lines and green station symbols): 18 May – 4 June, 2011; Lamon Bay 2: 24 April – 13 May, 2012 (blue track lines and station symbols). The transit from Freemantle Australia in April 2012 is shown as a red line in the left panel. The position of the moorings in the right panel, spanning the 2 ship based occupations are shown as red symbols: triangles are upward looking ADCP from the sea floor; red columns are moorings with instruments attached to a mooring line.

The initial analysis of the Lamon Bay data was presented at the IAPSO meeting (Gothenburg Sweden) in July 2013. An Abstract has been submitted to the February 2014 AGU Ocean Science meeting and by the end of 2013 submitted to a peer review journal.

Joint study with the Philippine researchers (*Villanoy CL, Cabrera OC, David LT, Yniguez AT, Jacinto GS, San Diego-McGlone ML, Siringan FP, Alabia ID, Fernandez IQ, Solera LA, Bollozos IS, Escobar MT, Saban RC, Quevedo JD*

Marine Science Institute, University of the Philippines) is developing.

The research focus is shelf/slope interaction along the southern tier of Lamont Bay (Figure 2)

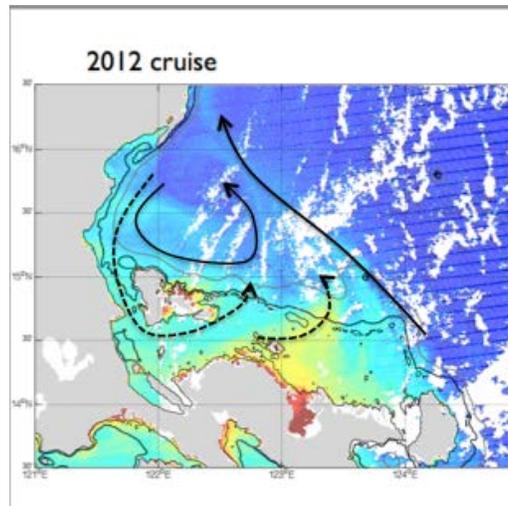


Figure 2: Ocean color and circulation pattern along the southern tier of Lamon Bay.

RESULTS

The AGU abstract provides an overview of the analysis results derived from our 2013 research:

LAMON BAY: KUROSHIO BIRTH AND THE NEC BIFURCATION, by Arnold L. Gordon, Pierre Flament, Cesar L. Villanoy

The Kuroshio forms within Lamon Bay (Luzon eastern margin). A shift of the Lamon Bay circulation and stratification is observed between the May 2011 and May 2012 (Figure 1), with a significant enrichment in tropical water in 2012 relative to the subtropical water regime of 2011 (Figure 3).

The shift is a response to ENSO/PDO induced changes of circulation of the western tropical Pacific, specifically of the North Equatorial Current Bifurcation latitude (Figure 4). The May 2012 flow pattern within Lamon Bay is similar to that observed in May 2011, though ~50% greater Kuroshio transport, from 10 to 16 Sv (Figure 5a, b).

Temperature/salinity time series from moorings identify the timing of the transition as December 2011 in the Kuroshio 'feeder-current' in the southeastern Lamon Bay, and February 2012 within the cyclonic circulation dipole of the southwestern Lamon Bay (Figure 6).

During May 2011 (neutral ENSO) the nascent Kuroshio marked the southern tip of the Kuroshio recirculation gyre, with the telltale subtropical thermocline (S-max) and North Pacific Intermediate Water (S-min); in May 2012 (La Niña ENSO) it is composed of tropical water, with a more intense S-max and weaker S-min .

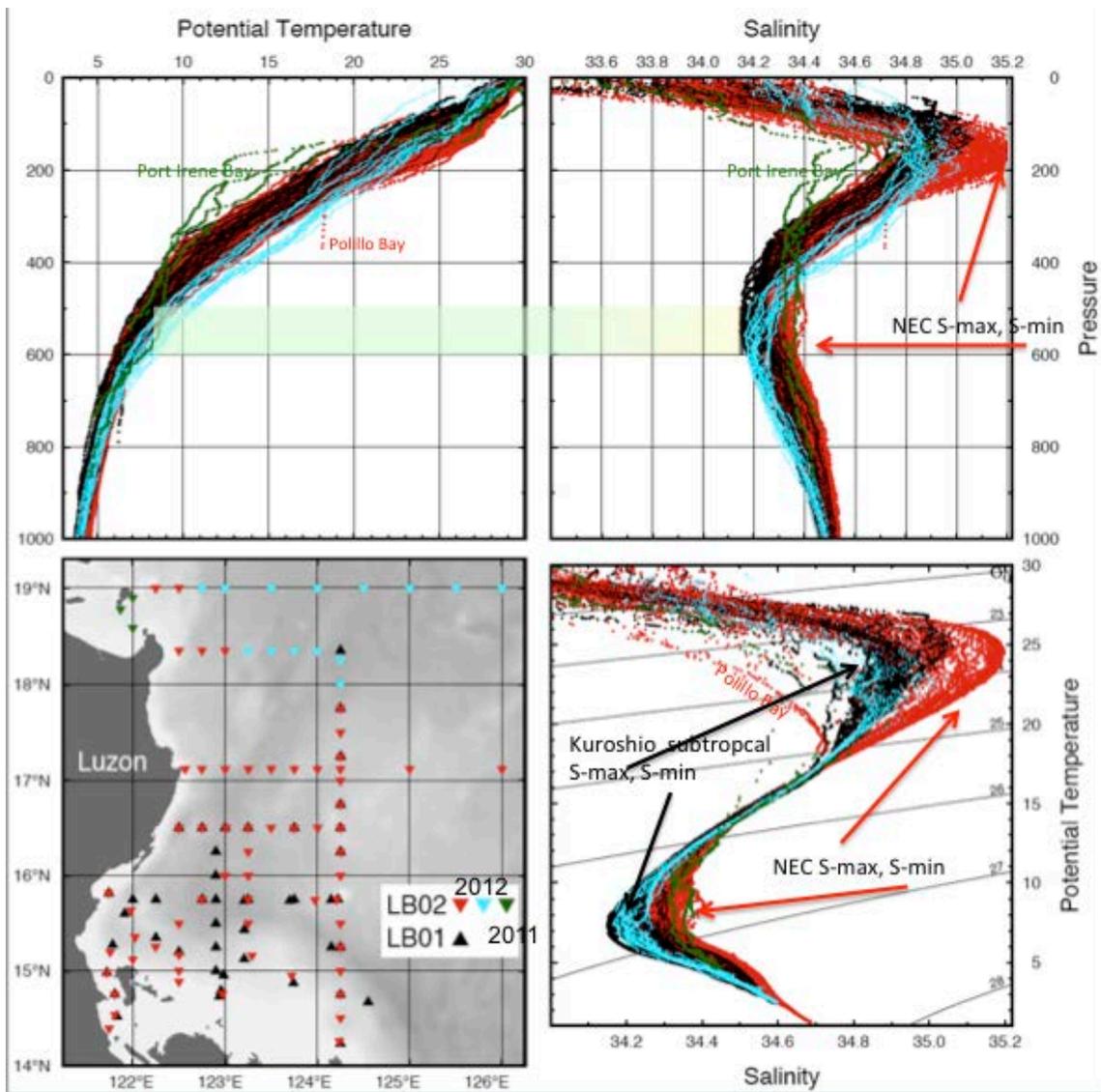


Figure 3: 2012 T/S stratification reflects dominance of North Equatorial Current (NEC) water; whereas 2011 T/S reflects Kuroshio ‘subtropical’ recirculation gyre regime. The cyan 2012 northeastern stations, display Kuroshio (subtropical) T/S characteristics.

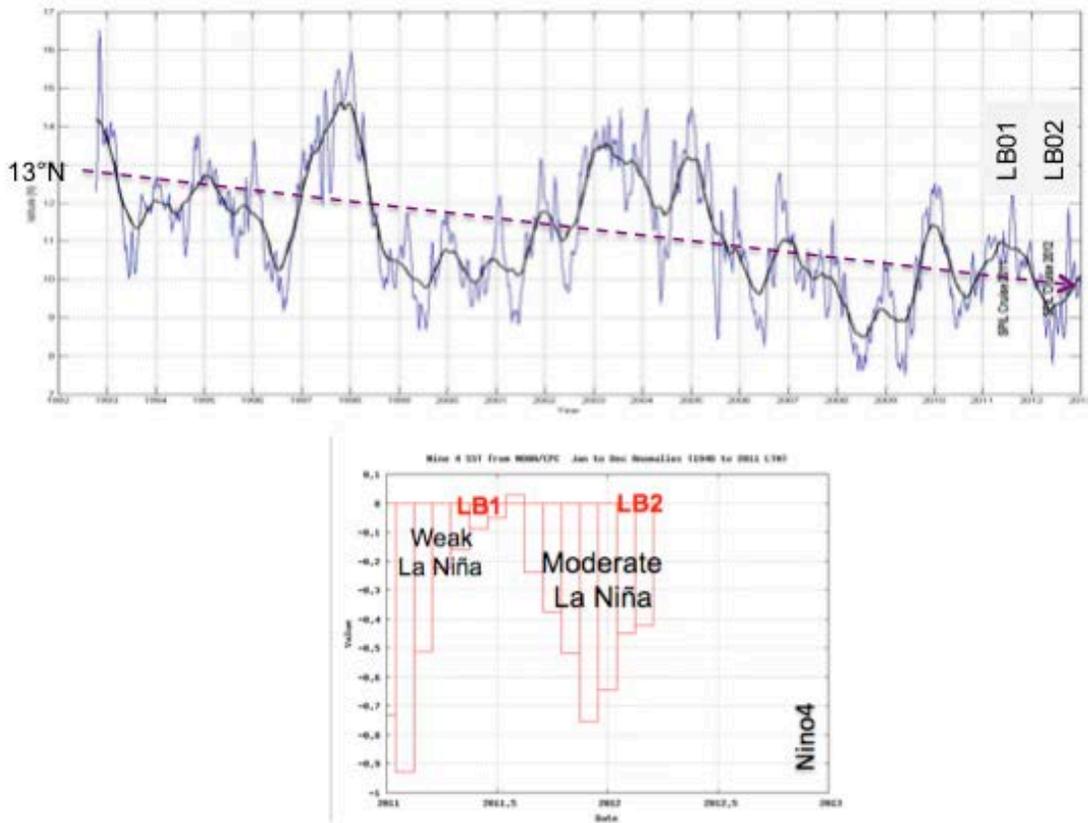


Figure 4: Latitudinal shifts of the North Equatorial Current Bifurcation following the procedure of Qiu and Chen (2010). The linear trend in NEC bifurcation latitude is $-1.16^\circ/\text{decade}$. Bo Qiu: *pc* (July 2012), finds the trend after regressing out PDO index is $-0.52^\circ/\text{decade}$; Trend after regressing out nino3.4 index is $-0.92^\circ/\text{decade}$

Hypothesis: the more southern NEC bifurcation position induces a stronger (Lamon Bay) Kuroshio. It is noted that the NEC bifurcation is a dynamic feature and likely displays independence of shifts in the tropical temperature / salinity water mass field.

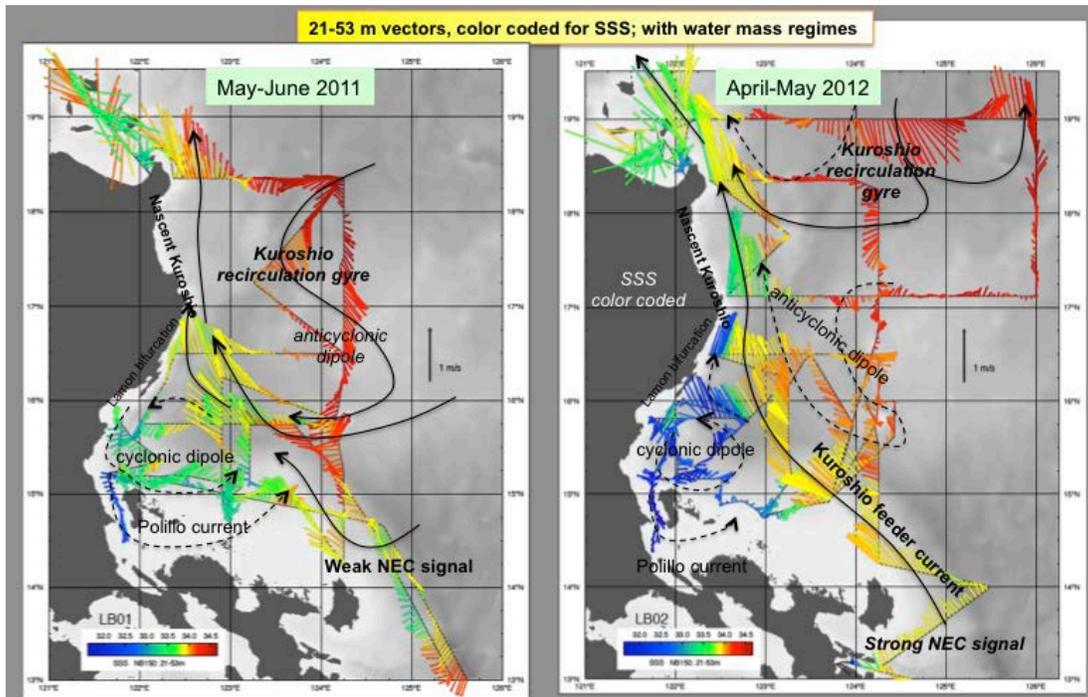


Figure 5a: Sea surface salinity (SSS) color-coded current vectors (21-53 m layer) derived from the R/V *Revelle* underway system, for Lamón Bay 2011 research cruise (left panel) and Lamón Bay 2012 research cruise (right panel). Circulation pattern, constructed from the ADCP data and water mass thermocline T/S stratification, are added to bring out the regional circulation. A anticyclonic dipole circulation cell is separated from a cyclonic dipole of the southwest Lamón Bay by a flow towards the northwest, which feeds into the western boundary current, which is established near 16.7N.

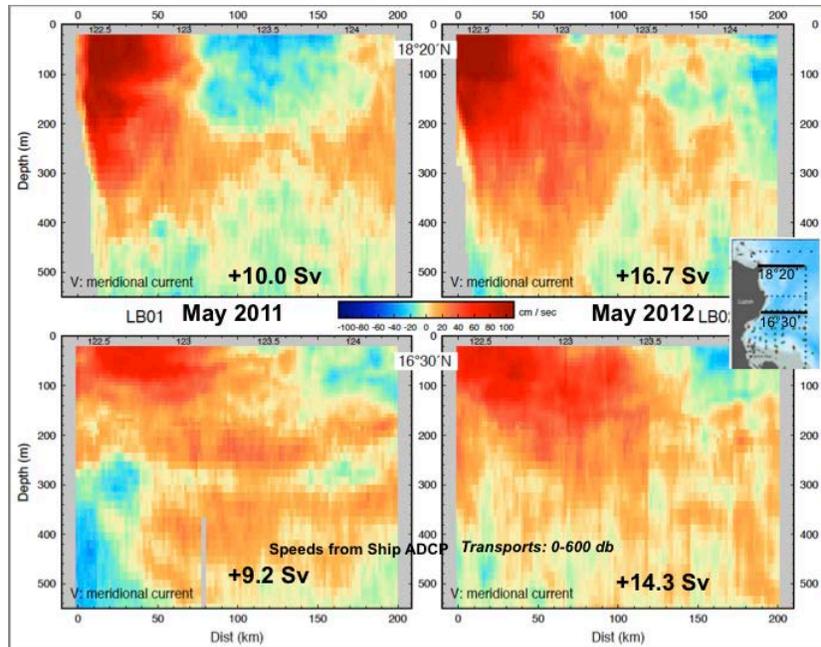


Figure 5b: *The meridional current component as recorded by the R/V Revelle hull mounted ADCP for 16.5N (lower panels) and 18.3N (upper panels) for Lamón Bay 2011 research cruise (left panel) and Lamón Bay 2012 research cruise (right panel). Transport values are determined from the meridional speed for the sections shown. That the higher transport values of 2012 are associated with tropical Pacific water drawn from the North Equatorial Current argues that the transport differences are associated with the NEC Bifurcation shift, and not transient eddies impinging on the western boundary from the east.*

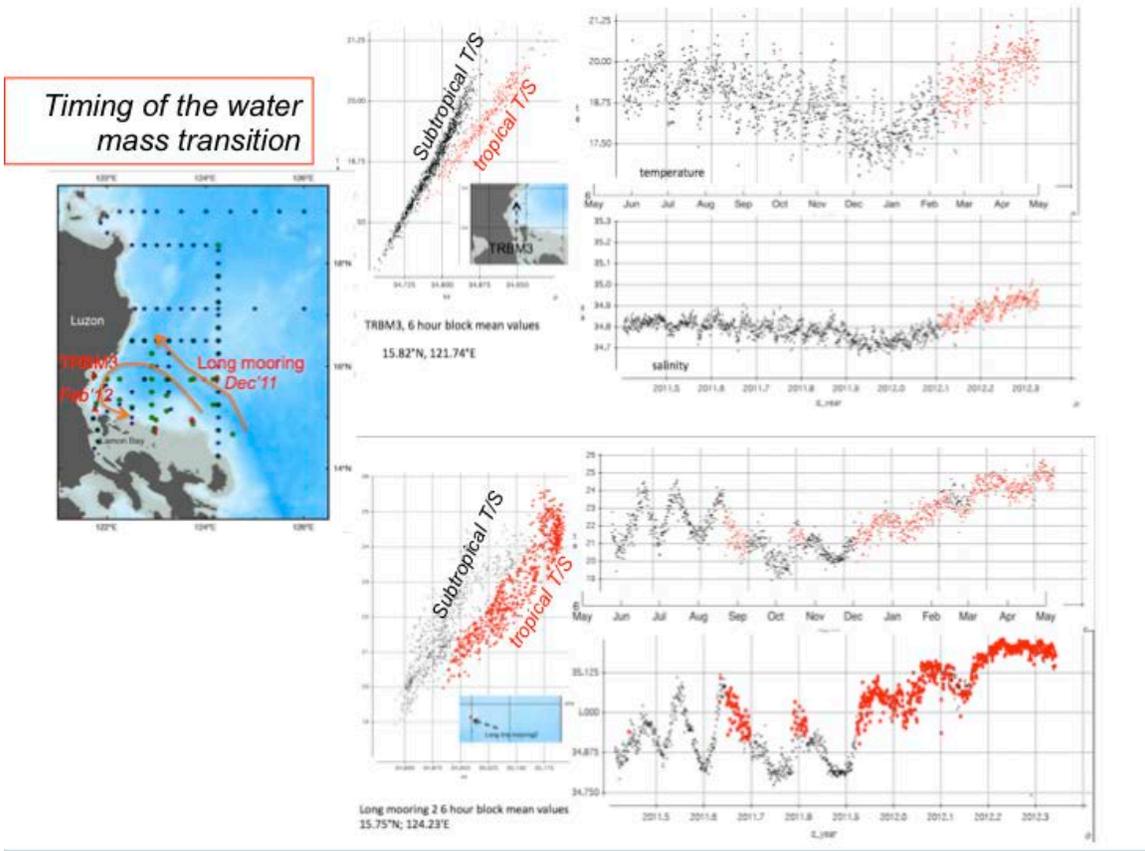


Figure 6a: Time series of temperature and salinity of the Long Mooring within the Kuroshio 'feeder-current' (lower right panel; 15.75N, 124.23E) and southwestern shelf of Lamon Bay (upper right panel; 15.82N 121.74E). The red dots denote Pacific tropical water; the black dots denote North Pacific subtropical water.

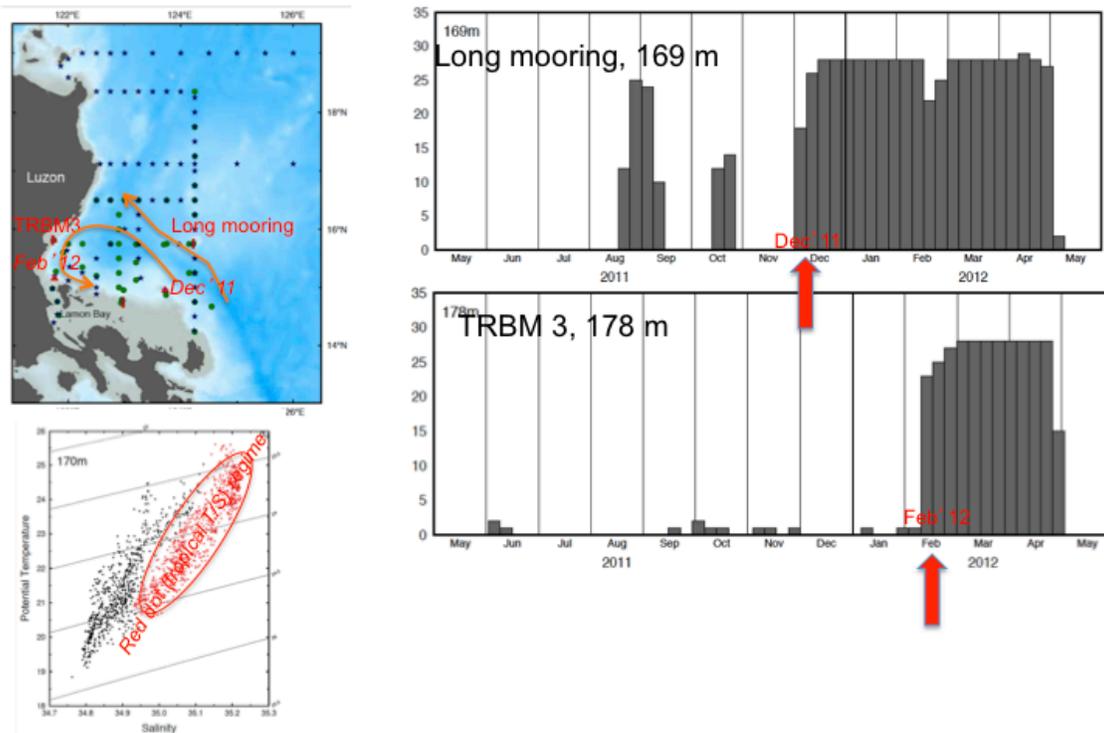


Figure 6b: Time series obtained from moorings, identify the timing of the transition of water mass regimes as late December 2011 in the eastern Lamón Bay, to early February 2012 within the southwestern Lamón Bay. In 6b: shows the histogram of red dots, marking transition to tropical Pacific water.

Summary of the Research results to date (Figure 7):

§ A sharp contrast of the Lamón Bay circulation and stratification (water mass composition) is observed between the May/June 2011 (*LB01, neutral ENSO*) and April/May 2012 (*LB02, La Niña ENSO*), with a stronger ‘nascent’ (pre-Luzon Straits) Kuroshio, enriched in equatorial water types in 2012, relative to 2011.

§ The Kuroshio subtropical recirculation gyre, which had a dominant presence within Lamón Bay in 2011, retreated to the north in 2012.

§ The shift is a western boundary response to ENSO/PDO induced changes of circulation of the western tropical Pacific, specifically to latitude of the North Equatorial Current Bifurcation (further south in 2012).

§ Time series obtained from moorings, identify the timing of the transition of water mass regimes as late December 2011 in the eastern Lamón Bay, to early February 2012 within the southwestern Lamón Bay.

§ There are significant larger scale implications of our findings, related to North Pacific meridional fluxes and to the Indonesian Throughflow.

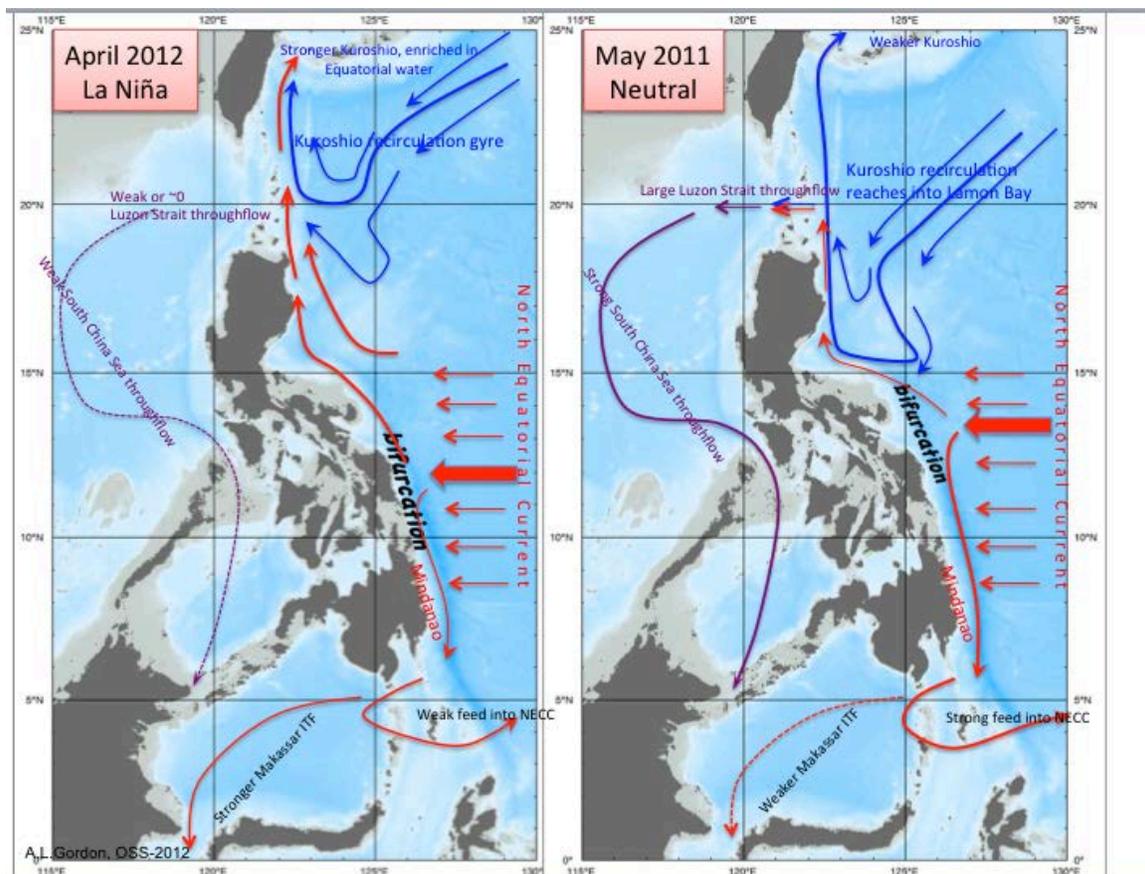


Figure 7. This schematic is based on the CTD (T/S stratification) and ship-based ADCP currents of the upper ~600 m obtained by the Lamon Bay research cruises of May/June 2011 and April/May 2012, which covered the area south of ~19°N west of ~126°E and the NEC bifurcation region [typhoon detour in 2011 and transit from Fremantle in 2012].

IMPACT/APPLICATIONS

The spatial and temporal shelf/slope interactions processes within and at the boundaries of Lamon Bay may be instrumental in the origin and dynamics of the Kuroshio Current including the links of the Kuroshio to the North Pacific subtropical gyre and Pacific North Equatorial Current Bifurcation. The cyclonic dipole circulation of the southwest Lamon Bay is likely closely linked to the active marine ecosystem characteristic, and shelf/slope interaction.

RELATED PROJECTS

OKMC (Origin of the Kuroshio and Mindanao Current).

HONORS/AWARDS/PRIZES

IAPSO Prince Albert I Medal awarded to Arnold L. Gordon, 2013.