AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Oceans

RESEARCH ARTICLE

10.1002/2014JC009882

Key Points:
- Distinct Kuroshio develops within Lamon Bay
- The Lamon Bay T/S stratification displays abrupt shift in December 2011
- The Lamon Bay shift induced by shift in NEC bifurcation

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Citation:
Gordon, A. L., P. Flament, C. Villanoy, and L. Centurioni (2014), The nascent Kuroshio of Lamon Bay, *J. Geophys. Res. Oceans*, *119*, 4251–4263, doi:10.1002/2014JC009882.

Received 31 JAN 2014
Accepted 8 JUN 2014
Accepted article online 14 JUN 2014
Published online 10 JUL 2014

The nascent Kuroshio of Lamon Bay

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Abstract A northward flowing current, emanating from the North Equatorial Current (NEC) bifurcation at the Philippine margin, enters Lamon Bay along Luzon's eastern coast. There the NEC tropical water masses merge with subtropical water of the western North Pacific to form the Kuroshio. A northward flowing western boundary current is first observed near 16.5°N, marking the initiation of the Kuroshio. The current feeding into the nascent Kuroshio of Lamon Bay is bracketed by an anticyclonic dipole to its northeast and a cyclonic dipole to its southwest. Ship-based observational programs in the spring seasons of 2011 and 2012 detect a shift of the Lamon Bay thermohaline stratification with marked enrichment of NEC tropical thermocline water in 2012 relative to a dominant western North Pacific subtropical stratification of 2011. Temperature-salinity time series from moorings spanning the two ship-based observations identify the timing of the transition as December 2011. The NEC bifurcation was further south in May 2012 than in May 2011. We suggest that the more southern bifurcation in May 2012 induced increased NEC thermocline water injection into Lamon Bay and nascent Kuroshio, increasing the linkage of the western North Pacific subtropical and tropical thermoclines. This connection was reduced in May 2011 as the NEC bifurcation shifted into a more northerly position and western North Pacific subtropical thermocline dominated Lamon Bay stratification.

1. Introduction

The Kuroshio, with surface currents of over 1 knot, is first detected as a distinct western boundary current near 16.5°N, within Lamon Bay, defined as region west of 124°E, south of 18°N, north of 14°N, along the eastern coast of Luzon, the Philippines [*Nitani*, 1972] (Figure 1). The nascent Kuroshio is fed from the northward flowing limb emanating from the North Equatorial Current (NEC) bifurcation near ~12°N [*Qiu and Chen*, 2010], with additional inflow of western North Pacific subtropical water. North of Lamon Bay the Kuroshio encounters Luzon Strait, shedding on average 4 Sv (Sv = 10^6 m^3/s) into the South China Sea [*Fang et al*., 2009]. The South China Sea inflow depends on season, stronger in the boreal winter [*Rudnick et al*., 2011] and stronger during El Niño [*Hurlburt et al*., 2011]. The Kuroshio strengthens as it continues northward along the eastern coast of Taiwan [*Centurioni et al*., 2004; *Rudnick et al*., 2011] with further inclusion of North Pacific subtropical water.

To investigate the spatial and temporal characteristics of the nascent Kuroshio of Lamon Bay, an observational program was carried out in the spring seasons of 2011 and 2012. The ship-based occupations bracketed a time series gathered at mooring sites (Figure 2).

We first discuss the surface layer circulation pattern and Kuroshio transport within Lamon Bay. We then describe a shift of the thermocline water mass stratification observed by the two research cruises. Using the temperature and salinity time series at two mooring sites, we identify the timing of the water mass regime transition. We then relate the water mass stratification shift to larger regional scale oceanography associated with latitudinal shift of the NEC bifurcation and southward projection of the Kuroshio recirculation gyre into Lamon Bay, and discuss the larger scale implications.

2. Data

The observational components of the two research cruises from the R/V Roger Revelle consisted of ship-based underway oceanographic and meteorological measurements along the ship track (Figure 2, left) and

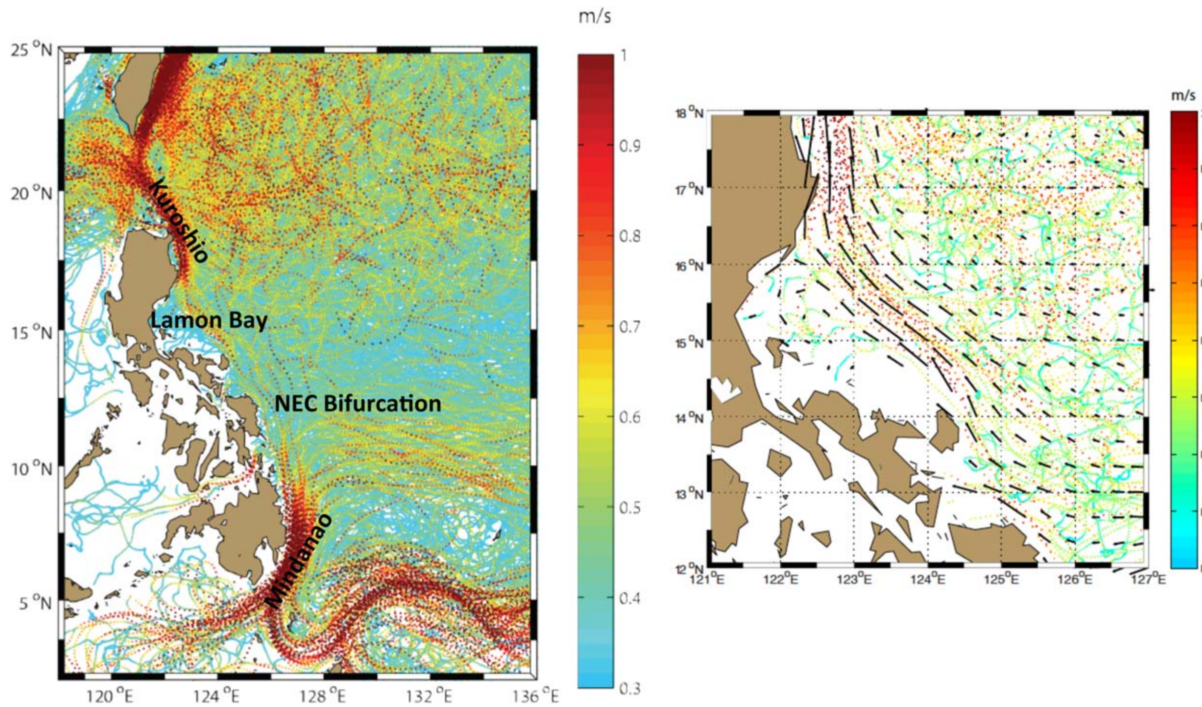

Figure 1. Location of SVP drifters color-coded in accordance with their 6 hourly instantaneous speed. 370,581 locations are shown, collected between 24 November 1986 and 31 December 2013. The drifter data are first quality controlled and a Kriging interpolation scheme is then applied to obtain 6 hourly, regularly spaced, drifter location time series [*Hansen and Poulain*, 1996] from which the drifters' velocities were obtained using 12 h center differences. A wind slip correction is also applied [*Niiler et al*., 1995] to the velocity data. Velocity from drifters that had lost their drogue is also recovered as described in *Pazan and Niiler* [2001]. Tidal and shorter period velocities are filtered out with a 36 h wide boxcar filter of unit amplitude applied along the drifter track centered at the time of the observation. (left) Large-scale view; (right) Lamon Bay, March through June.

water column CTD stations (Figure 2, right), with a 24 bottle rosette, which extended to 1550 m or within 10 m of the seafloor if water depth were shallower than 1550 m. The R/V Revelle underway system included the hull mounted ADCP, a 75 and 150 KHz. The 75 KHz system has a range of up to 800 m, the 150 KHz up to 250 m.

The first of the two research cruises (LB01) from Kaohsiung, Taiwan on 18 May 2011 returned to Kaohsiung on 6 June 2011. There were 45 CTD stations within Lamon Bay. The R/V Roger Revelle diverted from Lamon Bay, reaching 10°N along the eastern coast of the Philippines to escape the passage of Typhoon Songda across Lamon Bay, 23–26 May 2011. This provided opportunity to gather ship-based underway data across the NEC bifurcation. The second research Lamon Bay cruise (LB02) was also from the R/V Roger Revelle, from Legaspi, the Philippines, 24 April 2012 to Kaohsiung, Taiwan, 14 May 2012. In April 2012, just prior to LB02, the NEC bifurcation was observed during the R/V Roger Revelle transit from Freemantle to Legaspi. There were 78 CTD stations during LB02, mostly to 1550 m.

During LB01 an array of moorings were deployed (Figure 2, right), which were then recovered the following year during LB02. In this report, we identify the timing of a water mass shift as revealed by the CTD data from the two R/V Roger Revelle cruises, using the temperature/salinity time series obtained by Sea-Bird Electronics SBE37 recorder, at 170 m from the mooring at 15.7540°N and 124.2274°E and at the seafloor 178 m, outer shelf at Trawl Resistant Bottom Mooring (TRBM) at 15.8186°N, 121.7415°E.

3. Circulation and Stratification

3.1. Circulation and Transport

The circulation within Lamon Bay is vigorous, with surface layer currents reaching 1–2 knots (Figure 3). The Kuroshio at 18.35°N (northeastern tip of Luzon) reached nearly 3 knots at the sea surface, with speeds of approximately 1 knot to ~350 m. At 16.5°N the surface current was close to 2 knots, extending to ~250 m.

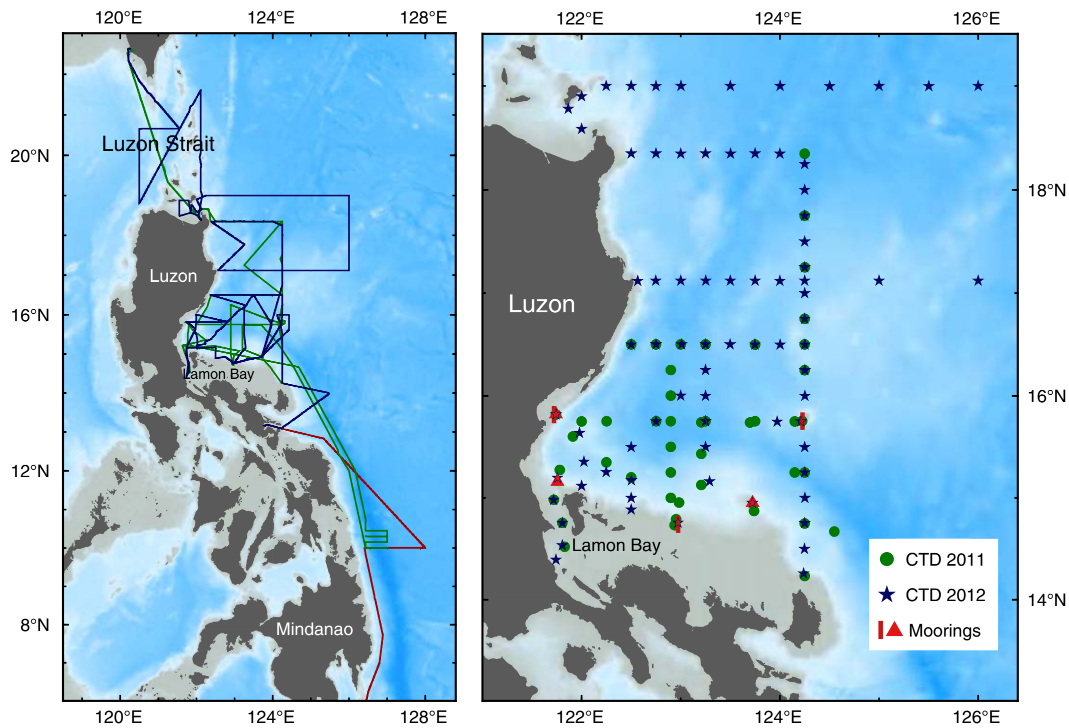

Figure 2. (left) Ship track and (right) the sites of CTD stations and moorings within Lamon Bay. The ship-based observations were from the R/V Revelle in 18 May 2011 to 4 June 2011 (blue ship track) and 24 April 2012 to 13 May 2012 (green track). The 2011 CTD stations are shown as blue stars for the 2011 cruise and as green discs for the 2012 cruise. The mooring sites are shown by red symbols. The red bars are moorings with instrumentation attached to a cable (three such moorings); the red triangles are instruments at the seafloor within Trawl Resistant Bottom Mooring installation.

The transport across both 16.50° and 18.35°N were higher, by about ~50% during the 2012 cruise (Figure 4), as the northward flow extends to deeper levels, spanning a great longitude range. Of course, with only two realizations the transport change is not necessarily indicative of a long-term trend, as the transport is likely affected by westward propagating eddies. *Lien et al*. [2014] report on a six mooring array during June 2012 to June 2013, along 18.75°N off the northeastern point of Luzon, finding a annual transport of 15 Sv (Sverdrup = 10^6 m^3/s). The transport of affected by impinging westward propagating eddies, which produce >10 Sv transport anomalies. However, the eddy effect is mainly at latitudes of the northern tip of Luzon and to the north, as shown in the drifter tracks (Figure 1) [*Maximenko et al*., 2009].

Within Lamon Bay, the ship-based ADCP reveals two energetic dipoles that bracket a northwestward flowing stream into the Kuroshio, which we refer to as the Kuroshio "feeder current" (Figure 4). The dipole features, reaching to 150–200 m, set up a bifurcation along the western boundary of Lamon Bay, near 16°N, marking the first occurrence of the northward flowing western boundary, the nascent Kuroshio at 16.5°N.

The cyclonic dipole, which is also captured by the drifter trajectories (Figure 1, right), occupies the southern tier of Lamon Bay, with characteristic surface layer speeds of <1 knot, and low sea surface salinity, a consequence of accumulative terrestrial runoff, during the residence time within the cyclonic pattern, estimated as 2.5 months (discussed below). The southward flowing western boundary branch of the cyclonic dipole spreads onto the continental shelf entering into Polillo Strait between Luzon and Polillo Island, returning to the deep ocean east of Polillo Island.

The anticyclonic dipole lies to the north of the Kuroshio feeder current (Figure 4). The surface water is relatively salty in comparison to the nascent Kuroshio (attesting to its subtropical origin, as supported by the thermocline stratification), with surface layer speeds of ~1 knot. As the region offshore of the Kuroshio at these latitudes and at more northern latitudes displays high level of eddy kinetic energy [*Maximenko et al*., 2009], the form of the anticyclonic feature as expected is highly variable. However, what is more significant in terms of the subject of this paper is that the thermohaline stratification within the entire anticyclonic dipole is

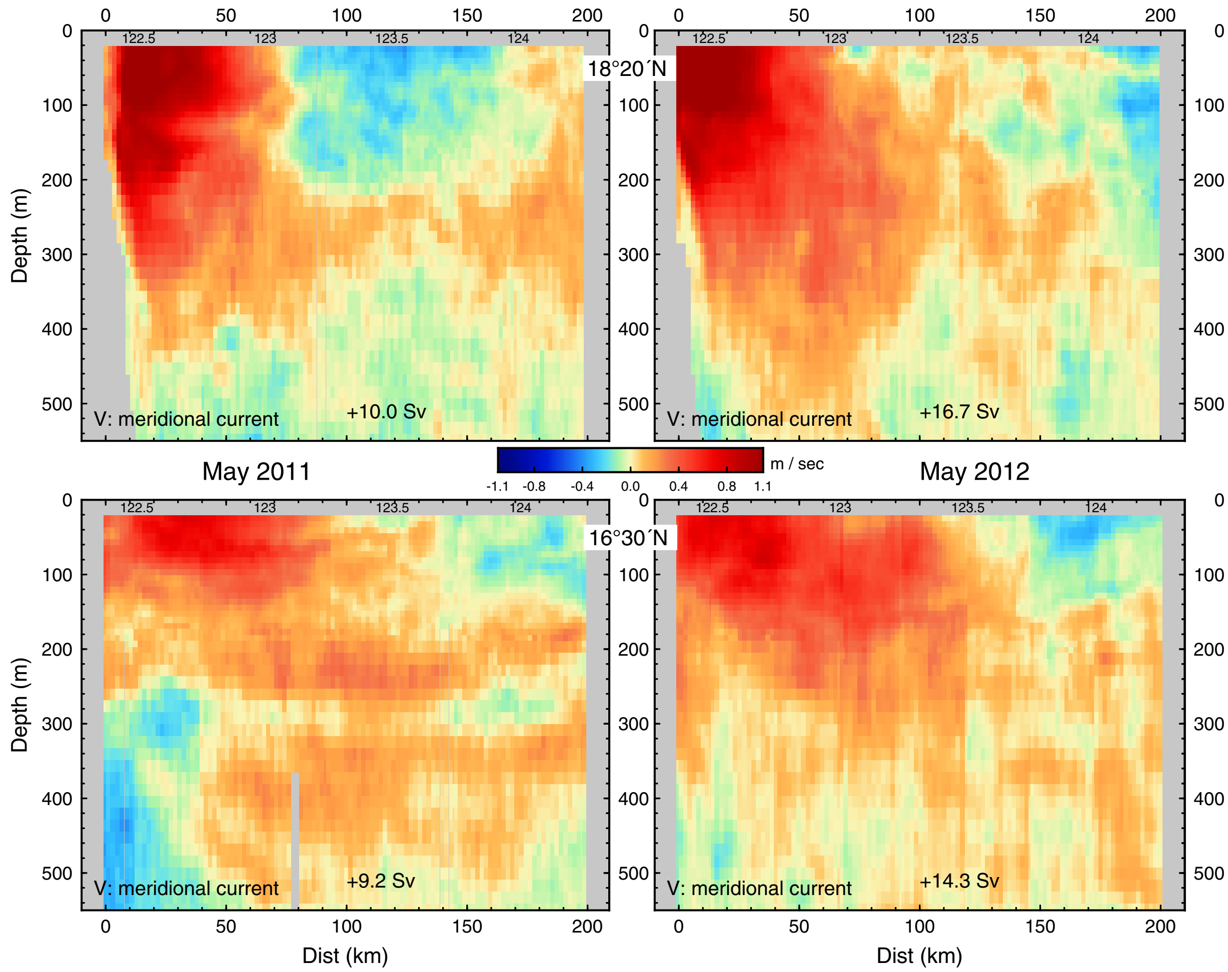

Figure 3. Meridional speed (cm/s), as measured by the RV Revelle ship mounted 75 KHz ADCP, across two sections: (top) 18°20′N and (bottom) 16°30′N for the two Lamon Bay cruises: (left) 2011 and (right) 2012. The transports in Sv (10^6 m^3/s) within the 0–600 db interval are shown in bold on each figure.

distinctly that of the subtropical region of the western North Pacific, associated with the Kuroshio recirculation gyre (discussed in section 3.2). The composite drifter trajectories (Figure 1, right) do not capture the anticyclonic gyre, which is likely due to the time variably eddy field, though the low surface current speeds near 17°N, 125°E may mark the climatic center of the anticyclonic dipole.

3.2. Thermohaline Stratification

The upper thermocline S-max is a product of subtropical evaporation, which spreads toward the equator as part of the shallow meridional overturning circulation [*McCreary and Lu*, 1994], enriching the tropical regime of the NEC in upper thermocline salt. Lamon Bay falls at the boundary between subtropical and tropical thermohaline stratification, with the NEC injecting waters of the equatorial limb of the subtropical gyre, while the Kuroshio recirculation gyre contributes subtropical stratification of the western North Pacific. The subtropical regime displays weaker upper thermocline salinity maximum (S-max), often referred to as subtropical underwater [*O'Connor et al*., 2005] or North Pacific Tropical Water (NPTW) [*Fine et al*., 1994; *Kashino et al*., 1996; *Li and Wang*, 2012], and fresher lower thermocline salinity minimum (S-min) relative to that within the NEC stratification. Saltier NPTW is carried westward toward the Philippines within the NEC [*Li and Wang*, 2012] (see WOCE section P08 along 130°E and P09 along 137°E, WOCE Pacific Atlas [*Talley*, 2007]) near 150 m depth, 24.0 neutral density surface, along a trajectory that meets the Philippine coast near 12°N (WOCE Pacific Atlas [*Talley*, 2007; *Talley et al*, 2011, Figure 10.30]).

The lower thermocline S-min, the North Pacific Intermediate Water (NPIW), is derived from the northwest Pacific, Sea of Okhotsk [*Talley et al*., 2011]. It spreads toward Lamon Bay from the northeast near 500 m, on

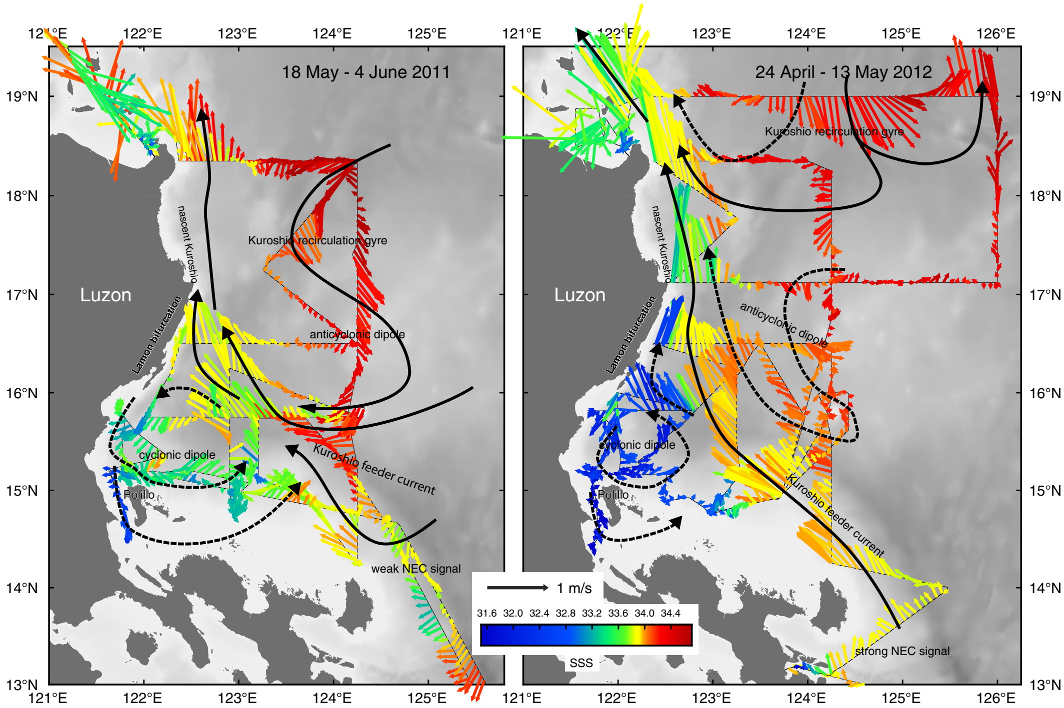

Figure 4. Ocean current vectors color-coded for sea surface salinity (SSS): (left) LB01 and (right) LB02. The currents are from the 21–53 m bins of the R/V Revelle ship mounted ADCP (75 KHz). The SSS are recorded by the temperature, salinity underway system.

the 26.75 neutral density surface (WOCE Pacific Atlas [*Talley*, 2007; *Talley et al*., 2011, Figure 10.33]). Lamon Bay stratification affected by waters from the western subtropical Pacific would have weaker S-max, stronger S-min than waters injected from the NEC tropic regime.

The two ship observations of 2011 and 2012 reveal a shift between subtropical and tropical stratification regimes (Figure 5). We find that the Lamon Bay temperature/salinity (T/S) stratification in 2012 is predominately composed of NEC tropical thermocline water, whereas 2011 T/S is composed of the western subtropical stratification of the North Pacific. Water mass distribution are a consequence of the circulation within the residence time of the region and so provide indicators of circulation over longer period of ocean processes than does the surface data collection along the ship track, e.g., ADCP (Figure 4), prone to eddy "noise." The distinct difference of the April/May 2012 stratification from the May/June 2011 stratification is best seen at the S-max and S-min core layers (Figure 5).

Lamon Bay stratification in LB01, 2011 shows a lower salinity S-max, by approximately 0.2, than observed during LB02, 2012 (Figure 5), signifying weaker presence of NEC tropical upper thermocline water, with enrichment of subtropical stratification. At the S-min the salinity of LB01 is less by approximately 0.1 than that observed during LB02, indicating a stronger presence of western North Pacific subtropical stratification, less of the NEC stratification, in the spring 2011. It is apparent from the thermohaline stratification that the NEC thermocline has a stronger presence in Lamon Bay in LB02, 2012 than it had in LB01, 2011. Only in the northeastern part of the station array does the 2012 stratification depict the subtropical regime that was evident throughflow Lamon Bay in 2011. The mooring T/S time series, discussed in the next section, captures the timing of the shift.

Mean chlorophyll-a profiles from the two cruises (Figure 6) are consistent with the observed T/S stratification shift, with higher chlorophyll-a maximum in the 100–120 m interval, marking the upper thermocline and S-max core layer, during LB01 relative to LB02. During LB01 the NEC input was weaker, with a stronger western subtropical Pacific presence in Lamon Bay. *Furuya* [1990] finds that in the western Pacific there is higher subsurface chl-a north of 20°N compared to stations between 10 and 20°N. The increased NEC input of LB02 was accompanied by reduced chl-a within the upper thermocline.

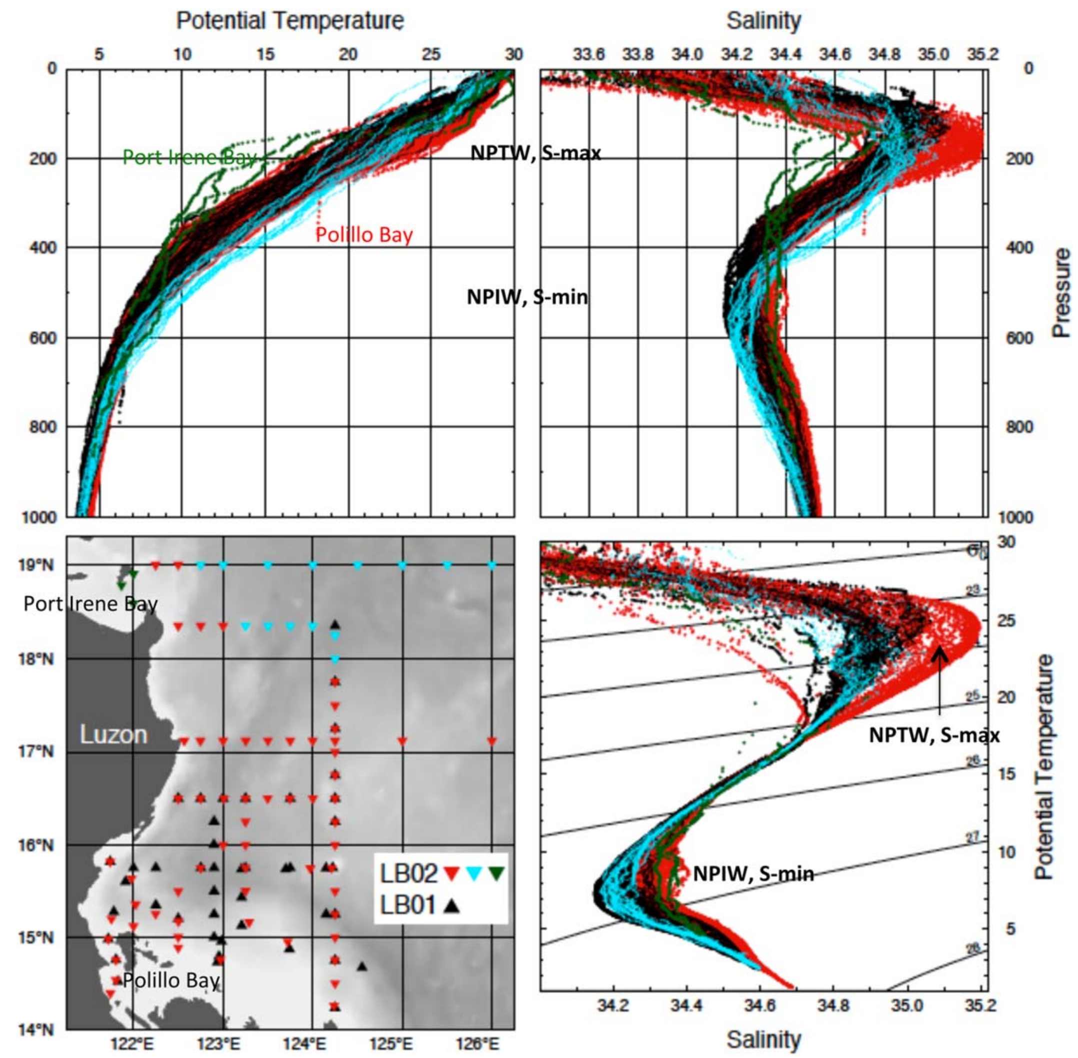

Figure 5. Lamon Bay ship-based stratification. (top) Potential temperature (T) and salinity profiles versus pressure. (bottom right) *T*/S for the two cruises. (bottom left) Station map with different symbols denoting cruise. In 2012, the reduced subtropical S-max and more intense S-min are found only in the north/northeastern stations; and the profiles reveal a deeper thermocline. The cyan 2012 northeastern stations display Kuroshio T/S. NPTW = North Pacific Tropical Water; NPIW = North Pacific Intermediate Water.

The continental shelf along western boundary of Lamon Bay is quite narrow, but along the southern tier of Lamon Bay as well as in Port Irene Bay of the northern coast of Luzon, the shelf is broad. Both of these regions reveal anomalies relative to the larger scale regional thermohaline stratification (Figure 5). Polillo Bay to the southwest of Polillo Island is a relatively deep isolated basin, up to 850 m at 14.5°N, 121.75°E. It is filled with relatively warm/saline water, which from the T/S relationship can be shown to fill from 200 m within Polillo Strait, west of Polillo Island. The deep basin water have a distinct oxygen minimum (3 mL/L, not shown in Figure 5) flows northward in 150–200 m layer of Polillo Strait, which, on reaching into Lamon Bay, is advected eastward by the southern limb of the Lamon Bay cyclonic dipole. Port Irene displays a different profile to a depth of ~350 m than does Lamon Bay, with a cooler thermocline and near absence of the S-max and S-min core layers. The similarity with the South China Sea thermohaline stratification [see *Gordon et al*., 2012, Figure 4] suggests an eastward flowing current from the South China Sea along the northern coast of Luzon.

4. Lamon Bay Mooring Time Series

The mooring at 15.7540°N, 124.2274°E (Figure 2) falls within the Kuroshio feeder current. The temperature and salinity time series recorded by a SBE-37 sensor at 170 m (Figure 7a) provides information as to the

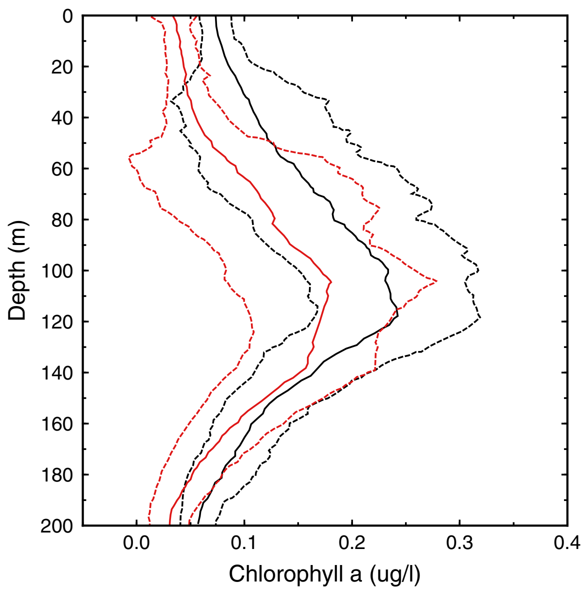

Figure 6. Mean chlorophyll-a profiles of LB01 (black) and LB02 (red). The solid line denotes the mean of all stations, with the dashed line showing the standard deviation.

timing of the change of water mass regimes observed by LB01 and LB02. The T/S scatter plot (Figure 7a, left) of the 170 m SBE-37 data depicts two fields, a low salinity scatter (black dots) and a higher salinity field (red dots). The red dots are on average 0.12 saltier than the black dots in the temperature range of 21°–24°C, marking the upper thermocline near the S-max core (Figure 5). Plotting the T and S time series (Figure 7a, right), keeping the T/S color-coding, reveals a shift from the subtropical to tropical stratification in December 2011. The cooler/lower salinity water period of September through November 2011 interval marks the transition from subtropical to tropical NEC dominance, as the anticyclonic Kuroshio recirculation gyre retreated northward resulting in lifting of the deeper isopycnal with cooler/lower salinity water, before the warmer/saltier upper thermocline of the NEC (Figure 5) advected into Lamon Bay.

Repeating this procedure at the SBE-37 set at seafloor near 178 m at the TRBM 3, deployed at 121.7415°N, 15.8186°E (Figure 7b) on the western shelf to Lamon Bay, within the cyclonic dipole, indicates the transition from subtropical to tropical water occurred in February 2012, ~2.5 months after the transition within the Kuroshio feeder current (Figure 7a), which may be an indicator of the isolation (residence time) of the cyclonic dipole from the Kuroshio feeder current.

The water mass transition shown in Figures 7a and 7b is better portrayed with a histogram representation (Figure 7c): the transition to NEC thermohaline stratification occurs in December 2011 within the Kuroshio feeder current and February 2012 in the southwest Lamon Bay.

5. Discussion

We find that in May 2011, Lamon Bay is dominated by western North Pacific subtropical water: weak S-max within the upper thermocline and strong S-min within the lower thermocline, whereas in May 2012 there is a greater presence of NEC thermocline: strong S-max of the upper thermocline and weak S-min of the lower thermocline. The mooring T/S time series indicate that the source water transition occurred in December 2011 within the Kuroshio feeder current, delayed to February before flooding the cyclonic dipole of the southern tier of Lamon Bay.

Coincidental with the T/S stratification change is a transport change of the nascent Kuroshio (Figure 3). Although transport changes based on ship-based snapshot views may reflect the mesoscale, it is noted that surveys of the western boundary region off the Philippines in December 2006 and January 2008 report similar results of the Lamon Bay surveys reported here [*Kashino et al*., 2009]. They find that the Kuroshio crossing the latitude of the northern tip of Luzon was stronger in a 2008 survey under La Niña conditions, and weaker in the El Niño phase of the 2006 survey. *Kashino et al*. [2009] also find that the Mindanao Current follows the opposite relationship, in late 2006 under El Niño conditions it was stronger than measured during in 2008 under La Niña conditions. They relate these findings to an increase in dynamic height around 8°N, 130°E from December 2006 to January 2008, similar to the sea surface height anomaly used to track the latitude of the NEC bifurcation (based on *Qiu and Chen* [2010, equation (2)]) used below.

We now explore the relationship of the observed water mass shift within Lamon Bay to the larger scale regional oceanography associated with latitude shifts of the NEC bifurcation. The bifurcation shifts

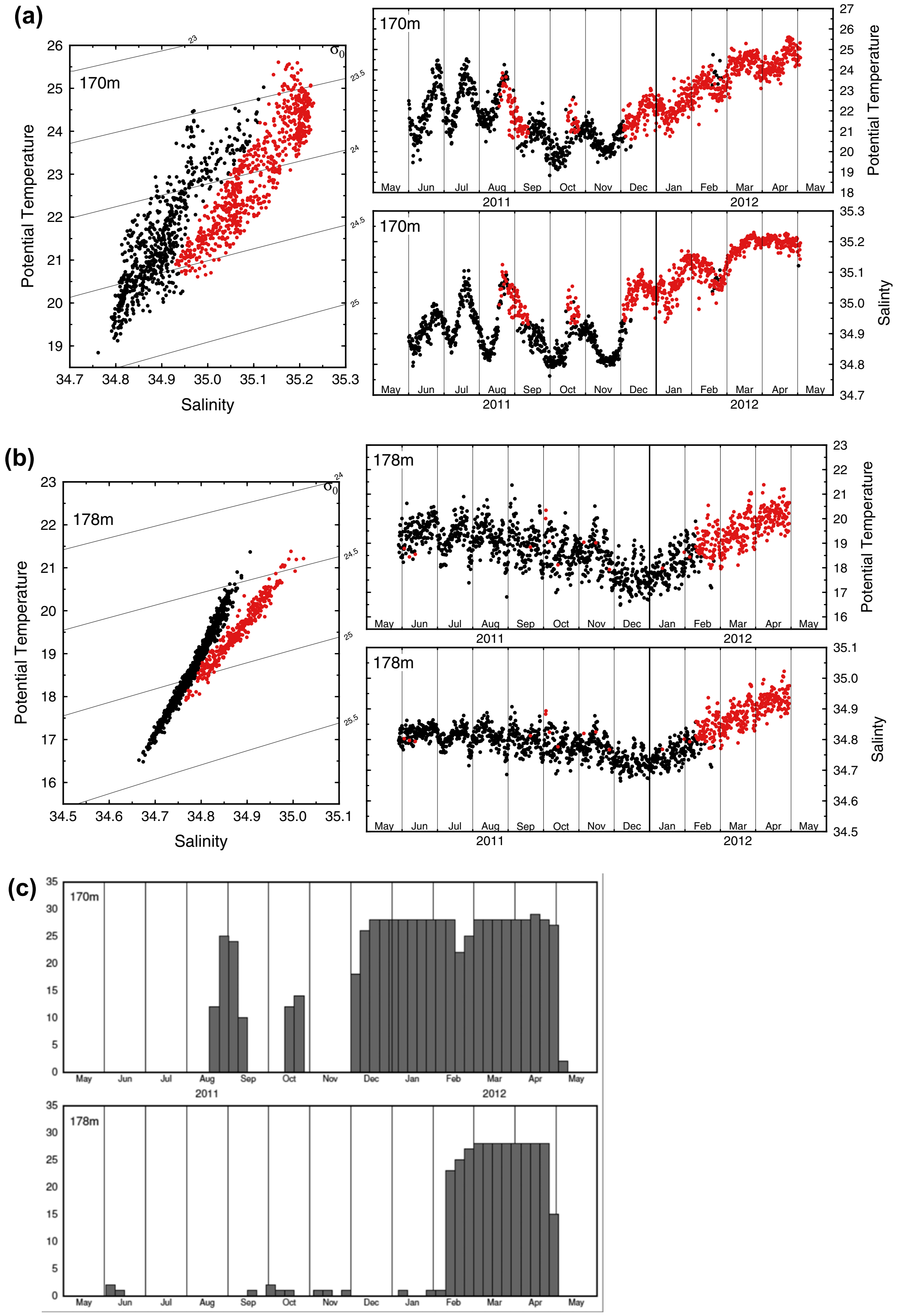

Figure 7. (a) Time series of potential temperature and salinity measured at the mooring 124.2274°N, 15.7540°E, at the southwest flank of Benham Bank, deployed 31 May 2011; recovered 4 May 2012. The red dots denote a saltier S-max, characteristic of the NEC tropical stratification. (b) Time series of potential temperature and salinity at TRBM 3, 121.7415°N, 15.8186°E, deployed 28 May 2011; recovered 30 April 2012. The red dots denote a saltier S-max, characteristic of the NEC tropical stratification. (c) Histogram of the number of red dots (marking the saltier NEC S-max) in 6 h block mean, for (top) the mooring at 124.2274°N, 15.7540°E and (bottom) the TRBM at 121.7415°N, 15.8186°E.

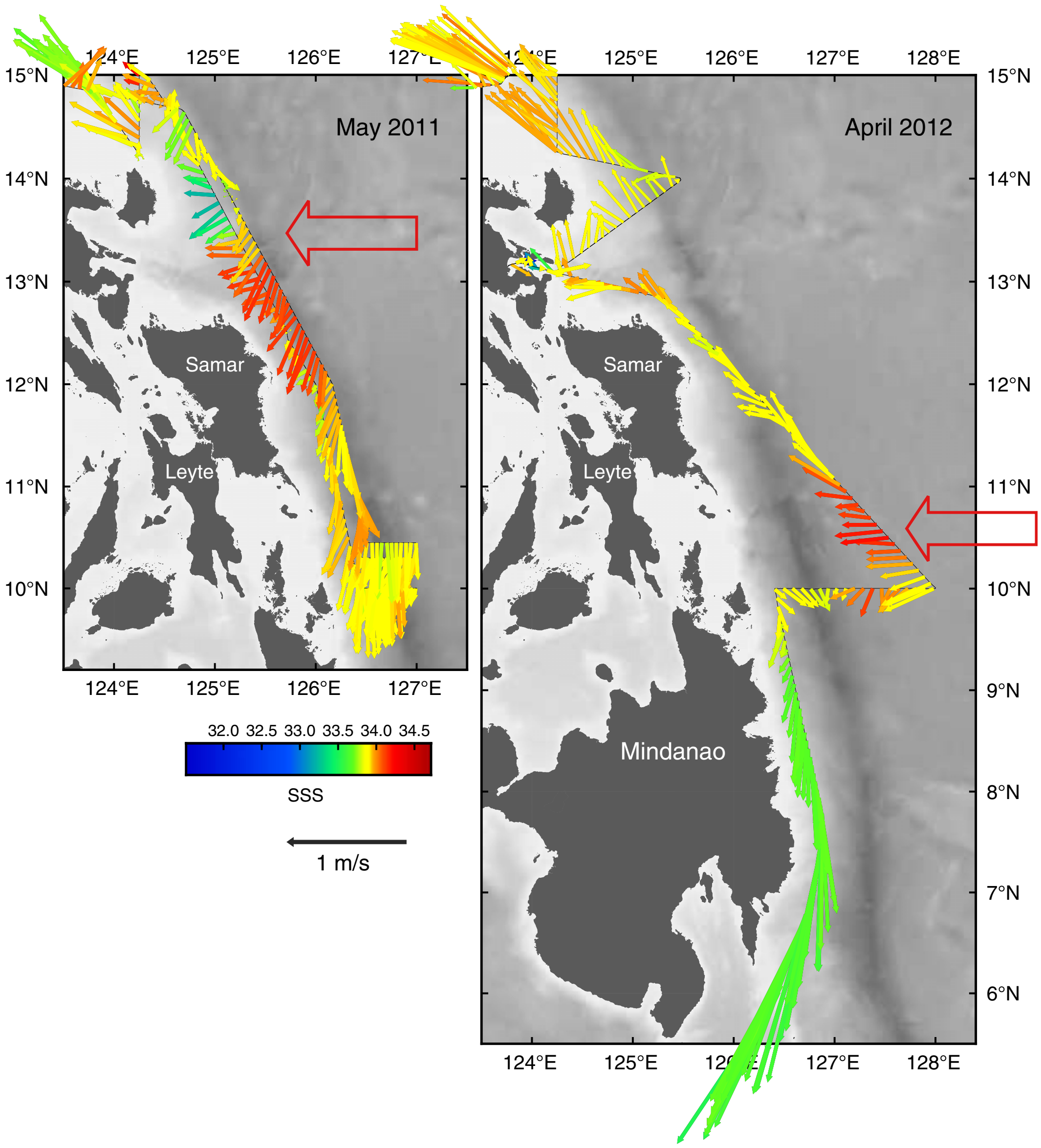

Figure 8. (left) NEC bifurcation, May 2011, during R/V Revelle transit to south to avoid typhoon Songda. The bifurcation based on the ship ADCP data of the currents in the 21–53 m interval is between 13° and 14°N. (right) NEC bifurcation, late April 2012, observed during the R/V Roger Revelle transit, Freemantle, Australia to Legaspi, Philippines. The bifurcation is found between 10° and 11°N, about 300 km south of the position in May 2011.

northward in winter and southward in summer [*Qiu and Lukas*, 1996, 2003; *Wang and Hu*, 2006], accompanied by a change in the partition of the NEC transport between the Kuroshio and the Mindanao Current. *Yaremchuk and Qu* [2004] report that nearly equal transport partitioning between the Kuroshio and Mindanao, though in the February to July periods, the Kuroshio is slightly stronger. *Yang et al*. [2013] find that Kuroshio weakens and Mindanao strengthens as the bifurcation shifts northward and that the westward flow into the South China Sea via Luzon Strait increases. On the interannual time scale, results both from high-resolution general circulation models [*Kim et al*., 2004] and from satellite altimetry analysis [*Wang and Hu*, 2006; *Qiu and Chen*, 2010] have consistently indicated that the bifurcation latitude of the NEC moves northward during El Niño years, resulting in a minimum transport of the Kuroshio east of Luzon [e.g., *Kim et al*., 2004; *Qu and Lukas*, 2003]. The situation reverses during La Niña years. This interannual change is due to the positive wind stress curl anomaly over the North Pacific tropical gyre prior to the El Niño years that works to shift the NEC bifurcation northward through the interior ocean's baroclinic adjustment [*Qiu and Lukas*, 1996; *Zhang et al*., 2012].

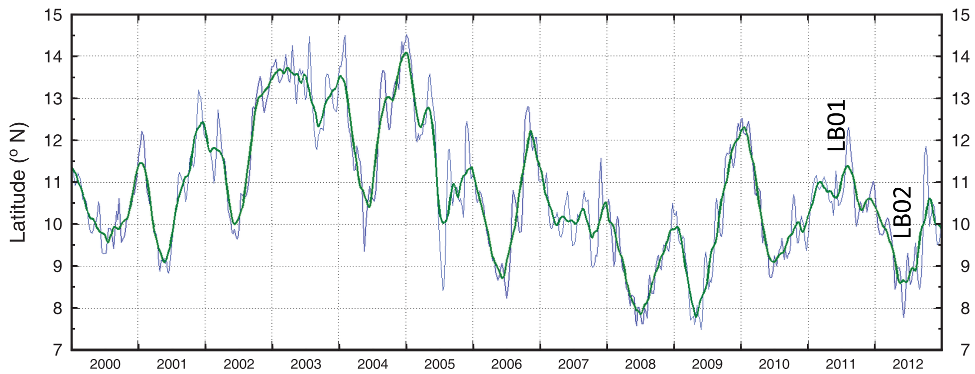

Figure 9. Latitude of the NEC bifurcation based on sea surface height at 12°–14°N, 127°–130°E [*Qiu and Chen*, 2010, equation (2)]. The blue line shows monthly values, the green line is a 3 month running mean. The timing of the two R/V Revelle Lamon Bay research cruises are shown as LB01 and LB02.

Model studies indicate that nino3.4 index leads the NEC bifurcation latitude; e.g., *Qiu and Chen* [2010] find that nino3.4 leads the bifurcation latitude by 2 months, whereas the earlier study of *Qiu and Lukas* [1996] suggests a 5 month lead time. These studies find that the wind stress curl also leads the NEC bifurcation latitude: 6 months [*Qiu and Chen*, 2010] and 12 months [*Qiu and Lukas*, 1996]. *Qiu and Chen* [2010] caution: "the exact NEC bifurcation latitude depends on the surface wind forcing over the western tropical North Pacific Ocean containing variability not fully represented by the commonly used ENSO indices."

Further insight is gained by including the Pacific Decadal Oscillation (PDO) along with ENSO indices. PDO and ENSO are linked, with PDO "considered as a reddened response to both atmospheric noise and ENSO..." [*Newman et al*., 2003] and are not independent climate indices. *Schneider and Cornuelle* [2005] find that "PDO is not governed by a single physical process that defines a climate mode, akin to ENSO, but results from at least three different processes.," sea level pressure of the Aleutian low, ocean circulation within the Kuroshio-Oyashio extension, and ENSO. *Qiu and Chen* [2010] find linear trend in NEC bifurcation of −1.16°/decade. The trend after regressing out PDO index = −0.52°/decade and after regressing out nino3.4 index = −0.92°/decade (Bo Qiu: pc, July 2012).

During LB01, Typhoon Songda forced the R/V Roger Revelle to move out of Lamon Bay toward the south into the NEC bifurcation region. The bifurcation was observed to be within the 13°–14°N (Figure 8). In April 2012, just prior to LB02, the bifurcation was observed during the R/V Roger Revelle transit from Freemantle to Legaspi, to be further south, 10°–11°N. The latitude of the NEC bifurcation following the procedure given by *Qiu and Chen* [2010] (Figure 9) finds that the calculated LB01 latitude is 11°N, and 9°N during LB02,

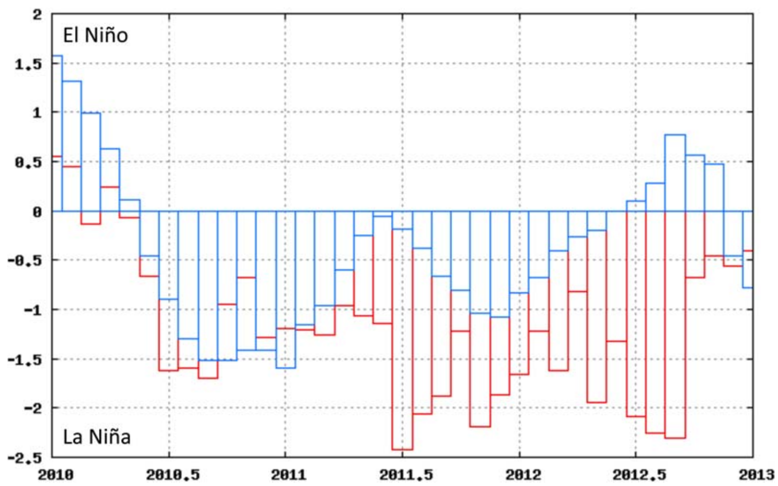

Figure 10. Pacific Decadal Oscillation (PDO; red) and Niño3.4 (blue) (both begin with 0 anomaly) from http://www.esrl.noaa.gov/psd/data/climateindices/.

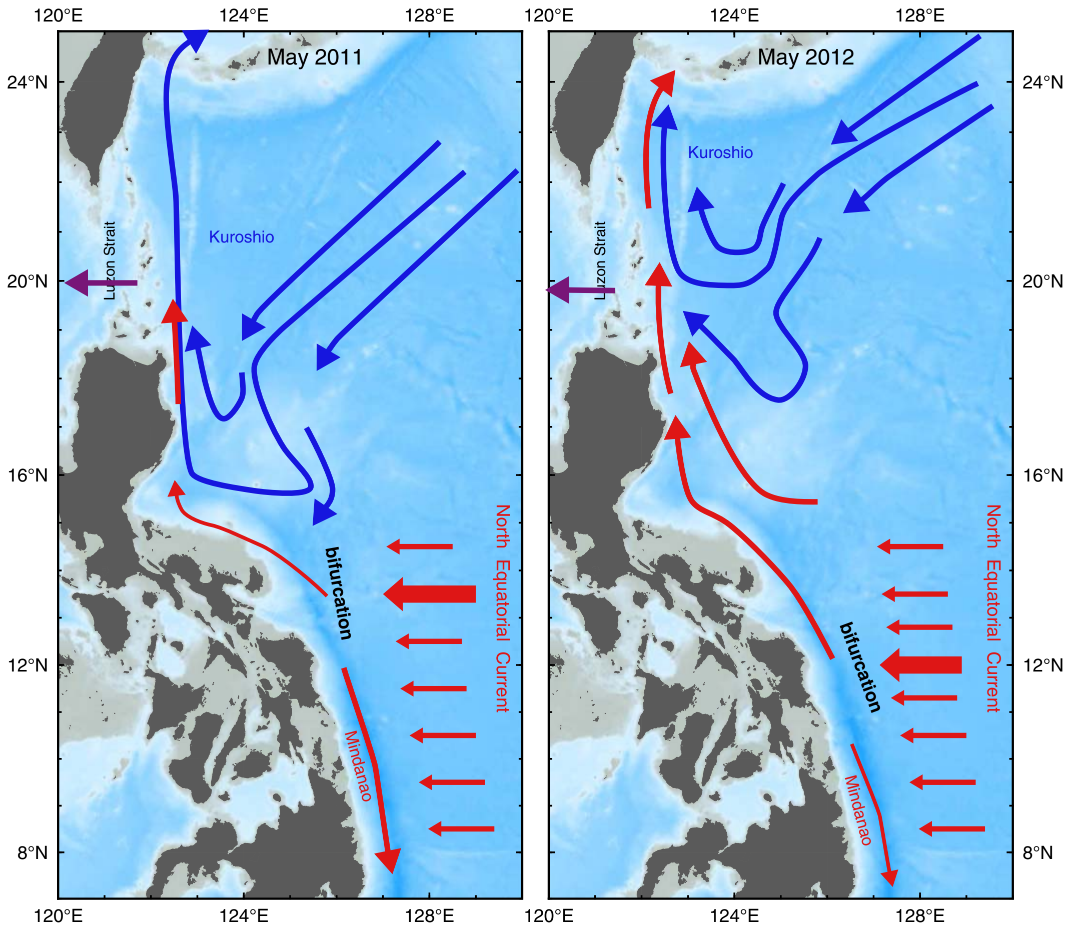

Figure 11. Schematic of the circulation pattern based on the water mass stratification observed by two Lamon Bay research cruises, May/June 2011 and April/May 2012. In 2011, the subtropical thermocline stratification dominated Lamon Bay, whereas in 2012 that regime retreaded northward, replaced by the tropical stratification of the North Equatorial Current (NEC). The NEC bifurcation shifted latitude between the two cruises: more southern position in 2012.

about the same latitude shift, though 2° of latitude further south than observed surface layer pattern (Figure 8). On a longer time line, *Qiu and Chen* [2012] find southward migration and strengthening of the NEC, as well as the North Equatorial Counter Current, reflecting the southward migration of the bifurcation of 2° of latitude from 1993 to 2009.

The combined state of PDO and Niño3.4 are substantially more negative in the 12 months prior to the LB02 cruise than in the 12 months prior to the LB01 cruise (Figure 10), which is consist with the PDO and ENSO role in the NEC bifurcation latitude as defined by *Qiu and Chen* [2010], with the La Niña condition, coupled with a negative PDO inducing a more southern NEC bifurcation. We propose that this induces increased inject of NEC stratification, including reduced subsurface chl-a maximum, into the nascent Kuroshio of Lamon Bay, as the southern tip of the Kuroshio recirculation gyre of the western subtropical North Pacific retreats northward. The shifting in the Kuroshio recirculation gyre and bifurcation latitude are responses to large-scale wind forcing of the North Pacific, and we do not imply a cause and effect relationship between these two circulation shifts, but rather joint response to large-scale forcing.

6. Summary

We find markedly different thermohaline stratification within Lamon Bay between two research cruses in the spring 2011 and 2012 (summarized in schematic form in Figure 11). The 2011 the thermohaline stratification within Lamon Bay was composed of western North Pacific subtropical thermocline and North Pacific Intermediate Water. In 2012 we find that thermohaline stratification is composed of mainly of NEC tropical thermocline water, with its characteristic a more intense S-max and weaker S-min than that of the western North Pacific subtropical stratification. The Lamon Bay observations suggest that the Kuroshio recirculation gyre of the western North Pacific subtropical regime retreated to the north as the NEC bifurcation shifted southward, resulting in increased NEC thermocline water within Lamon Bay. A less robust result is that while the 2012 flow pattern is about the same as that observed in 2011, the nascent Kuroshio detected in 2012 displays higher speeds and ~50% higher transport than during 2011.

Qiu and Lukas [1996] state: "Understanding the NMK (NEC/Mindanao/Kuroshio) current system is important for an accurate estimation of the heat and fresh water transport away from the tropical Pacific. It is also important because it directly connects the tropical and subtropical ocean circulations." We concur that changing water mass stratification of the nascent Kuroshio within Lamon Bay is a function of the NEC bifurcation latitude, which responds to wind stress curl anomaly over the tropical North Pacific [*Qiu and Lukas*, 1996; *Zhang et al*., 2012; *Yang et al*., 2013] as well as the shifting in the Kuroshio recirculation gyre, which may be expected to be a response to large-scale wind forcing of the North Pacific. *Yaremchuk and Qu* [2004] conclude that the Asian monsoon is the primary mechanism governing seasonal variation in the distribution of waters between the tropics and subtropics. *Yang et al*. [2013] theoretical study using a one-layer nonlinear and reduced gravity model find that northward shift of the NEC bifurcation during El Niño weakens the Kuroshio off Luzon and is associated with increased throughflow within Luzon Strait into the South China Sea. The change of tropical water injection into the Kuroshio may have implications on meridional heat flux in the North Pacific and subtropical marine ecosystems. *Li and Wang* [2012] state: "... low-frequency variations of NPTW may have a profound impact on the Indo-Pacific oceans, including not only oceanic/climatic physics but also biogeochemistry and fishery in marginal seas." We add reduced South China Sea throughflow during La Niña has the effect allowing more surface layer water from the Mindanao Current to enter into the Indonesian seas [*Hurlburt et al*., 2011; *Gordon et al*., 2012]; thus, NEC bifurcation latitudinal shift also impacts the Indonesian Throughflow.

Acknowledgments

We thank the Philippine research team in aiding in the collection of the broad suite of data within Lamon Bay as well as the officers and crew of the R/V Roger Revelle for support in the our 2011 and 2012 Lamon Bay field program. We acknowledge Olivia Cabrera, Phil Mele, and Paul Lethaby in assisting in the collection and processing of the CTD, water sample, and mooring time series data. We thank Bo Qiu, University of Hawai'i, for discussions of the NEC bifurcation; William Large and Billy Kessler for constructive suggestions concerning the role of the NEC bifurcation and Kuroshio recirculation gyre in governing the water mass stratification with Lamon Bay; as well as the anonymous reviewers for their constructive comments. Funding source for this research is as follows: ALG: Office of Naval Research, ONR N00014-10-1-0426; PF: ONR N00014-11-1-0775, N00014-11-1-0430, and N00014-11-1-0478; CV: ONR N62909-10-1-7126; LC: NOAA NA10OAR4320156 and ONR N00014-10-1–0273. The drifter data are available from AOML at http://www.aoml.noaa.gov/phod/dac/dacdata.php. The ship-based underway data, CTD station data, and mooring time series used in the paper are available upon request to A.L. Gordon. Lamont-Doherty Earth Observatory contribution number is 7807. The School of Ocean and Earth Science and Technology, University of Hawaii, contribution number is 9116.

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