Origins of the Kuroshio and Mindanao Currents

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LONG-TERM GOALS

The long-term goal of this project is to quantify the processes leading to the bifurcation of the NEC into the northward flowing Kuroshio and the southward Mindanao Current. As these are the dominant currents of the region, the improved dynamical understanding should lead directly to better predictions.

OBJECTIVES

The four objectives are (a) to clarify the dynamic state of the NEC-Kuroshio-Mindanao Current system, (b) to quantify the temporal evolution of the upper ocean temperature and salinity fields, the seasonal mixed layer above the pycnocline, and the deeper mode and intermediate waters, (c) to evaluate the upper ocean heat, salt and potential vorticity budget in the OMKC region, and (d) to improve the predictability of the oceanic circulation variability on various timescales in the OKMC region by incorporating in-situ data, including those from the profiling float measurements.

APPROACH

Profiling floats will be deployed during the duration of the OKMC project. In conjunction, high-quality satellite altimeter sea surface height (SSH) information will be analyzed. By combining the SSH information and profiling float T/S data, we plan to infer the strengths and locations (through dynamic height difference and maximum gradient) of the incoming NEC and the bifurcated Kuroshio and Mindanao Currents. Dynamic height maps from the SSH and float T/S data will be used to put in perspective the temporal and spatial variability of the regional circulation detected by other observational instruments. The broad-scale SSH information will also be used to explore the dynamics for regional variability that is forced remotely in the interior ocean.

WORK COMPLETED

In collaboration with the Japanese scientists from JAMSTEC, we have in the preceding two years deployed 10 SOLO-II profiling floats in the OKMC domain along ~140°E from 8°N to 18°N between 23-25 August 2011 and another set of 17 SOLO-II profiling floats near the same region between March 15-23, 2013. Twenty four of the 27 deployed floats are functioning normally and are returning high-resolution temperature/salinity data on a 5-day repeat cycle. Analyses of the OKMC float data have been conducted in combination with the coarse-resolution float data from the International Argo Program.

In addition to the float data analyses, we have furthered our investigation into the temporal changes of the North Equatorial Current (NEC) bifurcation and the Kuroshio variability both east of the Luzon Island and Taiwan with the use of satellite altimeter sea surface height (SSH) data from the past 20 years. We have clarified the intraseasonal Kuroshio variability and its connection to the mesoscale eddies generated in the interior North Pacific Ocean.

I have co-convened a special session "Ocean Circulation Variability and Air-Sea Interactions in the Western Pacific and Eastern Indian Ocean" at the 2014 Ocean Sciences Meeting with Drs. K. Ando and C. Maes. At the session, many OKMC and OKTV PIs have made timely oral and poster presentations, raising the visibility of the OKMC DRI project and the OKTV project.

Three peer-reviewed papers are published in Journal of Geophysical Research and Journal of Physical Oceanography, respectively, in 2013 and 2014.

RESULTS

Subthermocline circulation in the tropical North Pacific Ocean of 2°-30°N was investigated using profiling float temperature-salinity data from the International Argo and the OKMC projects. Three well-defined eastward jets are detected beneath the wind-driven, westward-flowing North Equatorial Current. Dubbed the North Equatorial Undercurrent (NEUC) jets, these subthermocline jets have a typical core velocity of 2-5 cm/s and are spatially coherent from the western boundary to about 120°W across the North Pacific basin. Centered around 9°N, 13°N, and 18°N in the western basin, the NEUC jet cores tend to migrate northward by ~ 4° in the eastern basin. Vertically, the cores of the southern, central, and northern NEUC jets reside on the 26.9, 27.2, and 27.3 $\sigma\theta$ surfaces, respectively, and they tend to shoal to lighter density surfaces, by about 0.2 $\sigma\theta$, as the jets progress eastward (Qiu et al. 2013a).

Following the data analysis results summarized above, we explored the formation processes responsible for the NEUC jets that appear across the tropical North Pacific Ocean both theoretically and using numerical models with different complexities (Qiu et al. 2013b). Analyses of an eddy-resolving global ocean general circulation model output reveal that the NEUC jets have a mode-1 baroclinic vertical structure and are spatially persistent on the interannual and longer time scales. This OGCM-simulated vertical structure prompts us to adopt the simpler, nonlinear 1.5-layer reduced-gravity model, as well as the baroclinic Rossby wave triad interaction theory, to unravel the essential processes underlying the NEUC jets. The seed for the NEUC jets originates in annual baroclinic Rossby waves driven by the large-scale surface wind stress forcing. Emanating from the ocean basin's eastern boundary, these wind-forced "primary" waves are subject to nonlinear triad interactions and break down offshore where the e-folding timescale of the most unstable triad instability matches the advective timescale of the primary waves. The break-down boundary of the wind-forced primary waves tends to tilt northeast-southwestward and, west of this boundary, finite-amplitude eddies emerge, whose meridional scales are set by the most unstable short secondary waves participating in the triad interactions along the break-down boundary. With their meridional scales set similarly by the short secondary waves, the time-mean zonal jets of characteristics resembling the observed NEUC jets are formed by the converging potential vorticity fluxes of these finite-amplitude eddies.

In collaboration with Dr. Ren-Chieh Lien of APL/University of Washington, we examined the Kuroshio Current velocity at the entrance to Luzon Strait along 18.75N with an array of six moorings during June 2012 to June 2013 (Lien et al. 2014). Strong positive relative vorticity of the order of the planetary vorticity f was observed on the western flank of the Kuroshio in the upper 150 m. On the eastern flank, the negative vorticity observed was about an order of magnitude smaller than f. Kuroshio transport near its origin is computed from direct measurements for the first time. Kuroshio transport has an annual mean of 15 Sv with a standard deviation of 3 Sv. It is modulated strongly by impinging westward propagating eddies, which are identified by an improved eddy detection method and tracked back to the interior ocean. Eight Kuroshio transport anomalies > 5 Sv are identified; seven are explained by the westward propagating eddies. Cyclonic (anticyclonic) eddies decrease (increase) the zonal sea level anomaly (SLA) slope and reduce (enhance) Kuroshio transport. Large transport anomalies of > 10 Sv within O(10 days) are associated with the pairs of cyclonic and anticyclonic eddies. The observed Kuroshio transport was strongly correlated with the SLA slope (correlation = 0.9). Analysis of SLA slope data at the entrance to Luzon Strait over the period 1992–2013 reveals a seasonal cycle with a positive anomaly (i.e., an enhanced Kuroshio transport) in winter and spring and a negative anomaly in summer and fall. Eddy induced vorticity near the Kuroshio has a similar seasonal cycle, suggesting that seasonal variation of the Kuroshio transport near its origin is modulated by the seasonal variation of the impinging mesoscale eddies.

In collaboration with Dr. Y-Chia Hsin of Research Center for Environmental Changes in Taiwan, we investigated seasonal and interannual changes of surface Kuroshio intensity and central position east of Taiwan during 1993–2012 by quantitatively analyzing the satellite altimetry product (Hsin et al. 2013). The Kuroshio moves inshore (offshore) off northeast of Taiwan in winter (summer), whereas it has an offshore (inshore) path off southeast of Taiwan in winter (summer). The seasonal change of heat flux over the East China Sea shelf is found to cause the seasonality of the Kuroshio central position off northeast of Taiwan, whereas the seasonal Kuroshio movement off southeast of Taiwan is found to be induced by the combined effect of the Kuroshio changes through the Luzon Strait and the eastern Luzon Island. In contrast to this y-dependent path changes, the Kuroshio becomes weaker (stronger) as a whole east of Taiwan in winter (summer). On the interannual time scales, the Kuroshio throughout the eastern coast of Taiwan intensifies and has a concurrent offshore path during the periods of 1995–1997 and 2004–2007. The relative intensity of cyclonic eddies to anticyclonic eddies off eastern Taiwan are found to contribute to these interannual Kuroshio changes.

IMPACT/APPLICATIONS

The detection of the North Equatorial Undercurrent (NEUC) jets is unexpected. Such jets are likely to be important for shear instability in the NEC and are crucial for better understanding of the short-term variability of the NEC.

Short-term Kuroshio variability east of the Luzon Strait is also unexpected. The upstream Kuroshio east of the Philippine coast has been regarded heretofore weak and laminarly behaved. The finding that it is under strong influences of impinging mesoscale eddies generated along the Subtropical Countercurrent has important implications for how the Kuroshio behaves inside the Luzon Strait and how it affects the circulation inside the South China Sea.

RELATED PROJECTS

NONE

PUBLICATIONS

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