Kuroshio Transport East of Taiwan and the Effect of Mesoscale Eddies

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LONG-TERM GOALS

The long-term goal of this project is to improve understanding and predictability of the regional circulation in the western North Pacific.

OBJECTIVES

The objective of this project is to characterize variability in the Kuroshio east of Taiwan and to understand (1) how this variability is related to variability in the upstream region, where the North Equatorial Current bifurcates forming the northward-flowing Kuroshio and the southward-flowing Mindanao Current and (2) how westward-propagating mesoscale eddies that arrive east of Taiwan from the ocean interior affect Kuroshio variability. This will establish the advective versus the eddy-driven contributions to Kuroshio variability east of Taiwan.

APPROACH

To determine the time-varying Kuroshio tranpsort and velocity structure east of Taiwan, in situ measurements are being collected with moorings deployed for 2 years. This work is being carried out in collaboration with Dr. Sen Jan from the National Taiwan University (NTU) and Dr. Ming-Huei Chang from the National Taiwan Ocean Univeristy (NTOU), whose companion projects are funded by the Taiwanese National Science Council.

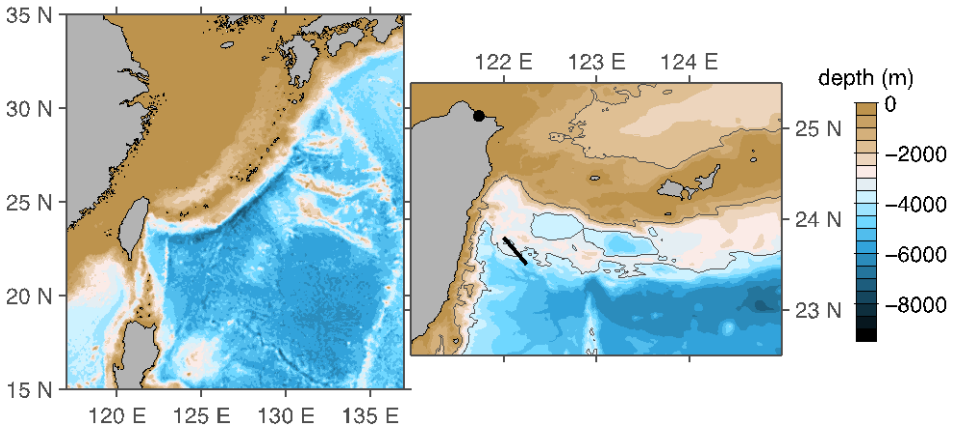

Figure 1. Map of the western North Pacific. Grey contours in the right panel show the 3500 m and 1500 m isobaths.

The field work is being carried out along the Yaeyama Ridge (***Figure 1***) which is is about 100 km south of the Ilan Ridge, which separates the Philippine Basin from the East China Sea. The field experiment includes shipboard and time series measurements. Mooring were deployed November 2012 and will be recovered fall 2014 to provide 2-year long timeseries.

Instruments are deployed on the KTV1-line (along the Yaeyama Ridge) and along a meridional section which stretches southward from the KTV-1 line. The array includes 6 bottom-moored pressure-sensor-equipped inverted echo sounders (PIES) one of which has an added current-sensor (CPIES). Making concurrent measurements are 3 tall moorings (Dr. Chang, NTOU) deployed along KTV-1. Each is instrumented with an upward-looking ADCP at 500 m depth and a deep RCM-8 current sensor (***Figure 2***). This combination of instruments is providing excellent horizontal and temporal resolution of the Kuroshio's time-varying position (including resolving a double-core structure when it is present) and will allow us to determine the full-water column transport time series without having to assume a level of no motion.

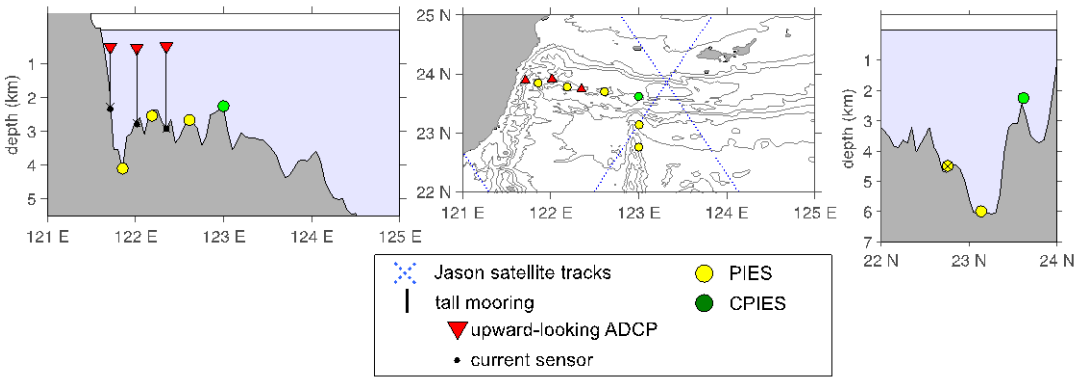

Figure 2. Map and cross-sections showing the instrumentation east of Taiwan.

WORK COMPLETED

In preparation for the field program, Vegan Mensah, a Ph.D. student from NTU, visited the Woods Hole Oceaongraphic Institution (WHOI) for two weeks in March 2012. M. Andres trained V. Mensah in the interpretation of acoustic travel time data collected by PIES. Using historical hydrogrpahy from the region, gravest empirical mode (GEM) lookup tables were constructed. These relate synthetic acoustic travel time, calculated from an equation for the speed of sound in seawater (Del Grosso, 1974), to vertical profiles of temperature, salinity and density (Meinen, 2001).

The PIES and CPIES were built by the University of Rhode Island. The NTU instruments (3 PIES) and WHOI instruments (2 PIES, 1 CPIES) were shipped to Taiwan and M. Andres and Erran Sousa, an engineer from the University of Rhodes Island, traveled to Taipie, Taiwan to provide PIES training for the NTU collaborators and technicians. PIES were deployed from the OR1 in November 2012 and a telemetry cruise in June 2013 retreived 8 months of processed data from the PIES/CPIES. Recovery is planned from fall 2014. Preliminary analysis of the telemetred data (3-day low pass filtered acoustic-travel-time and bottom pressure) is ongoing.

RESULTS

The analysis of histrocal hydrography established that acoustic-travel-time can be used as a proxy for the vertical profiles of specific volume anomaly and temperature in the region east of Taiwan. The GEM lookup tables constructed from these data are critical for making use of acoustic travel time data to calculate vertical velocity shear. This will enable calculation of a timeseries of the Kuroshio's absolute geopstrohic velocity along the KTV-1 line (Donohue et al., 2010) once the mooring data have been collected.

Initial analysis of the telemetered data shows that the instruments are working properly: all of the instruments are returning pressure and acoustic-travel-time measurements and the values are within the ranges expected for this region. Comparison of acoustic-travel-time with concurrent satelite altimetry suggests that the instrumetns are capturing changes in the sub-surface structure of the Kuroshio that arises due to the impact of mesoscale eddies that propagate into the region from the ocean interior (***Figure 3***). Qualitative results suggest that cycloncic eddies lead to a more barotorpic (less vertical shear) Kuroshio by elevating the offshore edge of the pynocline and depressing the on-shore edge of the pycnocline across the Kuroshio.

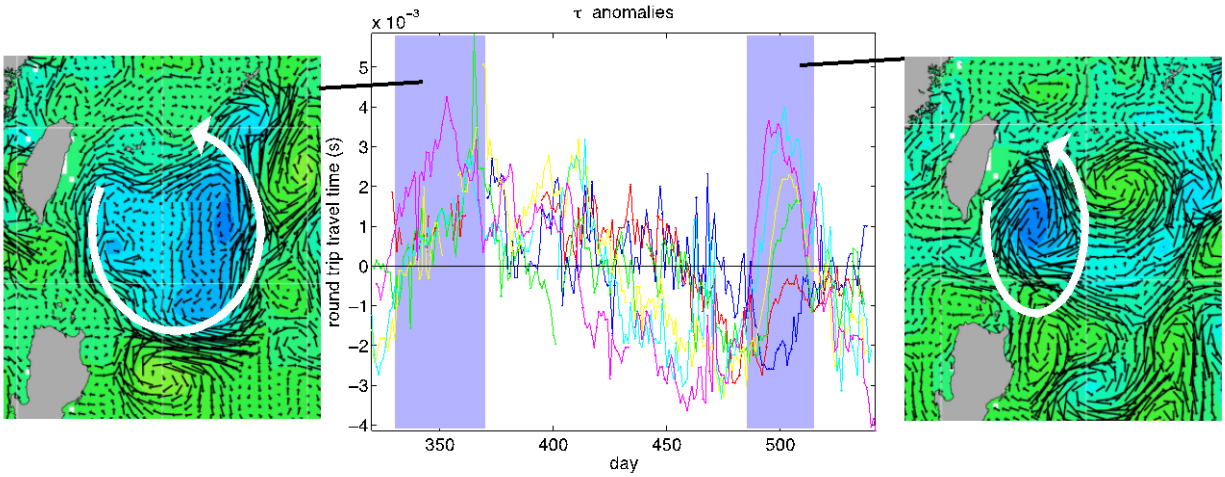

Figure 3. Time series of acoustic-travel-time (means removed) retrieved from the CPIES/PIES in June 2013 via acoustic telemetry. Highlighted periods show times when acoustic-travel times are anomalously long due to a shallower than average thermocline. These times correspond to arrivals of cyclonic eddies (sea surface lows).

IMPACT/APPLICATIONS

Understanding the variability of the Kuroshio east of Taiwan has implications for predictability in the downstream region where the Kuroshio sometimes intrudes onto the East China Sea shelf northeast of Taiwan. There is evidence that a weak Kuroshio corresponds with strong intrusions of the Kuroshio onto the East China Sea shelf (Gawarkiewicz et al., 2011). Understanding the Kuroshio interactions with the continental shelf is very important for forecasting acoustic propagation conditions in this region (Lermusiaux et al., 2011).

Determining the advective versus the eddy-driven contributions to Kuroshio variability east of Taiwan is relevant to understanding acoustic propagation in the Philippine Sea. Furthermore, this is an area where typhoons frequently pass, and the data collected here should provide some very interesting case studies for determining how the Kuroshio reacts to the passage of typhoons.

RELATED PROJECTS

This project is part of the Origins of the Kuroshio and Mindanao Currents (OKMC) program (http://kirin.apl.washington.edu/okmc/), funded by the Office of Naval Research and the Observations of Kuroshio Transports and Variabilities (OKTV) program (***Figure 4***), funded by the Taiwanese National Science Council. Instrumentation along the KTV-1 line is funded in part by this ONR proposal and in part by the OKTV program (Sen Jan, PI). Shiptime for instrument deployments and recoveries is provided through OKTV. Training for PIES deployments and recoveries is provided through this proposal. Data processing and analysis are being carried out collaboratively between NTU and WHOI.

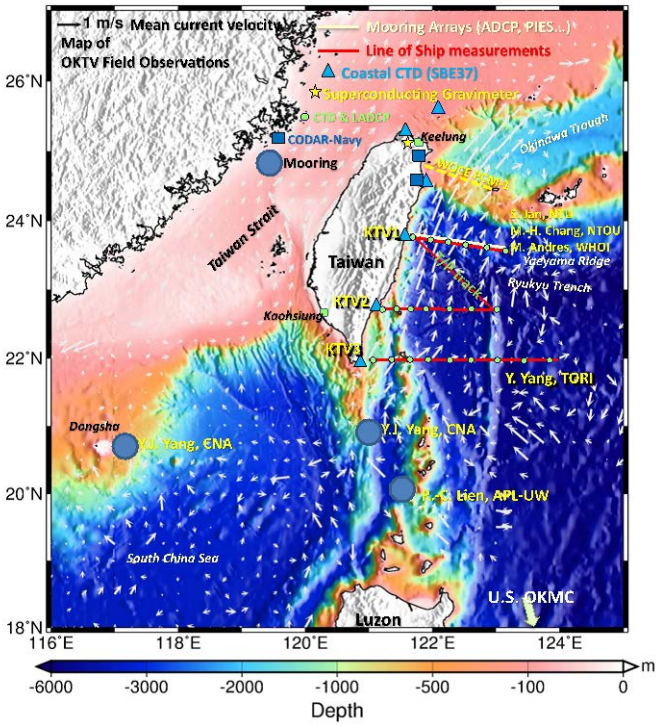

Figure 4. Map summarizing the elements of the Taiwanese OKTV field program. The ONR-funded efforts described in this annual report complement the OKTV measurements near the KTV1-line. (Figure courtesy of Sen Jan.)

REFERENCES

Del Grosso, V. A., 1974. New equation for the speed of sound in natural waters (with comparisons to other equations). *J. Acoust. Soc. Am*. **56**(4), 1084-1091.

Donohue, K. A., D. R. Watts, K. L. Tracey, A. D. Greene and M. Kennelly, 2010. Mapping circulation in the Kuroshio Extension with an array of Current and Pressure recording Inverted Echo Sounders. *Journal of Atmospheric Oceanic Technology,* doi:10.1175/2009JTECHO686.1.

Gawarkiewicz, G., S. Jan, P.F.J. Lermusiaux, J.L. McClean, L. Centurioni, K. Taylor, B. Cornuelle, T.F. Duda, J. Wang, Y.J. Yang, T. Sanford, R.-C. Lien, C. Lee, M.-A. Lee, W. Leslie, P.J. Haley Jr., P.P. Niiler, G. Gopalakrishnan, P. Velez-Belchi, D.-K. Lee, and Y.Y. Kim, 2011: Circulation and intrusions northeast of Taiwan: Chasing and predicting uncertainty in the cold dome, *Oceanography,* **24**(4):110–121, http://dx.doi.org/10.5670/oceanog.2011.99.

Lermusiaux, P.F.J., J. Xu, C.F. Chen, S. Jan, L.Y. Chiu, and Y.-J. Yang, 2010: Coupled ocean-acoustic prediction of transmission loss in a continental shelfbreak region: Predictive skill, uncertainty quantification and dynamical sensitivities. *IEEE Journal of Oceanic Engineering,* **35**:895–916, http://dx.doi.org/ 10.1109/JOE.2010.2068611.

Meinen, C.S., 2001. Structure of the North Atlantic Current in stream-coordinates and the circulation in the Newfoundland Basin. *Deep Sea Res*., **4**8(7), 1553– 1580, doi:10.1016/S0967-0637(00)00103-5.