

# REPORT DOCUMENTATION PAGE

*Form Approved*  
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.  
**PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.**

<b>1. REPORT DATE (DD-MM-YYYY)</b> 08/23/2012	<b>2. REPORT TYPE</b> FINAL	<b>3. DATES COVERED (From - To)</b> 01/01/2007 - 12/31/2011		
<b>4. TITLE AND SUBTITLE</b> High-Resolution Hydrographic Surveys Near the Shelfbreak in the East China Sea: Joint Studies with National Taiwan University		<b>5a. CONTRACT NUMBER</b>		
		<b>5b. GRANT NUMBER</b> N00014-07-1-0482		
		<b>5c. PROGRAM ELEMENT NUMBER</b>		
<b>5. AUTHOR(S)</b> Glen Gawarkiewicz		<b>5d. PROJECT NUMBER</b> WHOI 147482SP		
		<b>5e. TASK NUMBER</b>		
		<b>5f. WORK UNIT NUMBER</b>		
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b> Woods Hole Oceanographic Institution Mail Stop 21 Department of Physical Oceanography Woods Hole, MA 02543		<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b> FINAL		
<b>9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b> Office of Naval Research 875 North Randolph Street Arlington, VA 22203-1995 ONR 321		<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b> ONR		
		<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>		
<b>12. DISTRIBUTION/AVAILABILITY STATEMENT</b> UNLIMITED / UNCLASSIFIED				
<b>13. SUPPLEMENTARY NOTES</b>				
<b>14. ABSTRACT</b> For this project, we jointly planned and executed a major field program in the East China Sea northeast of Taiwan. We along with our Taiwanese collaborators performed high-resolution hydrographic surveys over the outer continental shelf and upper continental slope during August/September 2009. The field work was in close collaboration with numerical modelers from MIT who were assimilating the high-resolution hydrographic data into their model and producing ocean circulation forecasts including uncertainty forecasts. During the field experiment, we measured a major fresh water pulse from the runoff from Typhoon Morakot, which caused the most typhoon-related rainfall over Taiwan in 50 years. Our results show strong alongshelf gradients of freshwater at the shelfbreak associated with this freshwater pulse. Our data has been used by the modelers to verify the uncertainty forecasts and the predicted error distribution compares very well with the actual error distribution.				
<b>15. SUBJECT TERMS</b> East China Sea, High-Resolution Hydrographic Surveys, Shelfbreak, Ocean Circulation Forecasts, Typhoon Morakot				
<b>16. SECURITY CLASSIFICATION OF:</b>		<b>17. LIMITATION OF ABSTRACT</b> UNLIMITED UNCLASSIFIED	<b>18. NUMBER OF PAGES</b> 6	<b>19a. NAME OF RESPONSIBLE PERSON</b> Glen Gawarkiewicz
<b>a. REPORT</b> UNCLASSIFIED	<b>b. ABSTRACT</b> UNCLASSIFIED			<b>c. THIS PAGE</b> UNCLASSIFIED

# High-Resolution Hydrographic Surveys near the shelfbreak in the East China Sea: Joint Studies with National Taiwan University

Glen Gawarkiewicz

Senior Scientist, Physical Oceanography Department

Mail Stop 21, Woods Hole Oceanographic Institution

Woods Hole, MA 02543

Phone: (508) 289-2913 Fax: (508) 457-2181 email: [ggawarkiewicz@whoi.edu](mailto:ggawarkiewicz@whoi.edu)

Award Number N00014-07-1-0482

## LONG-TERM GOALS

The long-term goal of this project is to understand how the physical oceanographic processes within the region northeast of Taiwan in the East China Sea affect uncertainty predictions of both the ocean fields (temperature, salinity, density, velocity) as well as acoustic propagation (transmission loss, ambient noise, azimuthal variability of transmission loss).

## OBJECTIVES

The primary objective of this project was to obtain high-resolution hydrographic observations over the outer continental shelf and upper continental slope in order to obtain error estimates for comparison with numerical model forecasts of the ocean circulation. This work involved close collaboration with Dr. Sen Jan of National Taiwan University for overall planning and execution of the Quantifying, Predicting, and Exploiting Uncertainty DRI as well as Dr. Joe Wang of National Taiwan University for the field work using the National Taiwan University SeaSoar. During both a pilot cruise in September, 2008 and the main field work in August/September, 2009, we did field work in close collaboration with Dr. Pierre Lermusiaux of MIT, who was running a data-assimilative regional ocean model and producing forecasts of both the ocean fields as well as uncertainty of the ocean fields. We have also been working with acousticians from the U.S. and Taiwan to determine how the shelfbreak processes we observed affected acoustic propagation and uncertainty during the field experiments.

## APPROACH

We used the National Taiwan University SeaSoar as the primary tool for our hydrographic surveys. In September, 2008, we tested the instrument over the steep bathymetry over the shelfbreak and canyons in the area and worked out procedures to operate safely in the presence of strong currents, a strong commercial fishing presence, and weather constraints in the typhoon season. We also tested the communications via satellite transmission with the modeling group at MIT.

20120828198

In August/September, 2009, we did three weeks of sampling which included ten days of SeaSoar operations. We successfully operated between the upper continental slope and mid-shelf regions. During the main experiment, we adjusted our hydrographic sampling based on the results of the MIT regional model as well as the Taiwanese broad scale hydrographic surveys. Our sampling was coordinated with research cruises led by researchers from the University of Washington and Scripps Institution of Oceanography. Our data was subsequently shared with the physical oceanographers and acousticians associated with the QPE program.

## **TASKS COMPLETED**

We successfully completed the field observations and have been analyzing the data. An overview of the circulation in the region appeared in Sen et al. (2011) and an overview of the physical oceanographic processes including a description of the uncertainty forecasts appeared in Gawarkiewicz et al. (2012). A manuscript describing the characteristics of the internal waves and tides has been submitted (Duda et al., 2012) as well as a manuscript on the impact of the fresh water outflows resulting from Typhoon Morakot (Sen et al., 2012). Several other manuscripts are in preparation and will be submitted in the near future.

## **RESULTS**

The study area north of Taiwan appears in Figure 1. The hydrographic surveys were in the region between Mien-Hua and North Mien-Hua Canyons, in close proximity to the Kuroshio current. The most dramatic variability in the thermohaline (and soundspeed) fields was the passage of a fresh water pulse associated with the large rainfall over Taiwan from Typhoon Morakot. Salinity fields from three separate days before, during, and after the fresh water pulse appears in Figure 2. During this pulse, the average salinity along the 130 m isobath, just shoreward of the shelfbreak, dropped by 0.7 g/kg and the average density over the upper 60 m of the water column dropped by  $1 \text{ kg/m}^3$ . Observations over mid-shelf showed that this pulse extended shoreward at least 40 km. Associated with the fresh water pulse was a significant deepening of the thermocline with maximum vertical gradients lowered by roughly 40 m in the water column (Figure 3). After the passage of the fresh water pulse, a cyclonic eddy appeared on the upper continental slope which resulted in significant cross-shelf velocities in moored ADCP records.

The SeaSoar fields have been shared with the modeling group at MIT for calculating the error distributions between the ocean model forecasts and the SeaSoar data. In general, the uncertainty forecasts from the model were accurate, with standard deviations for model-data misfits which were comparable to the predicted standard deviations of errors from the uncertainty forecasts. A manuscript on the verification of the uncertainty forecasts will be submitted in the near future.

We are presently collaborating with acousticians from the U.S. and Taiwan to quantify the impacts of the oceanographic variability on the propagation of sound in the west branch of North Mien-Hua Canyon, and azimuthal dependence of transmission loss at two sites.

## **IMPACT FOR SCIENCE**

The integrated international efforts on this project and the QPE field program provide the first field verification of uncertainty predictions for ocean model forecasts. The field program involved a number of different components including ship-based and autonomous sampling that enabled the regional ocean model to be initialized and updated to provide high quality forecasts for several days in a complex oceanographic environment. The internal wave and internal tide field in this region has been characterized and compared to other regions with more comprehensive measurements such as the South China Sea. The suite of observations also provides the first comprehensive measurements of the coastal ocean response in the East China Sea to the input of flooding from a major typhoon.

This project also provides new insights into acoustic propagation in a complex oceanographic environment, the shelfbreak in the East China Sea.

## **RELATIONSHIP TO OTHER PROGRAMS**

Techniques developed on this project have been used in the ONR program Quantifying Acoustic Uncertainty due to Marine Mammals and Fish near the Shelfbreak Front off Cape Hatteras.

## FIGURES

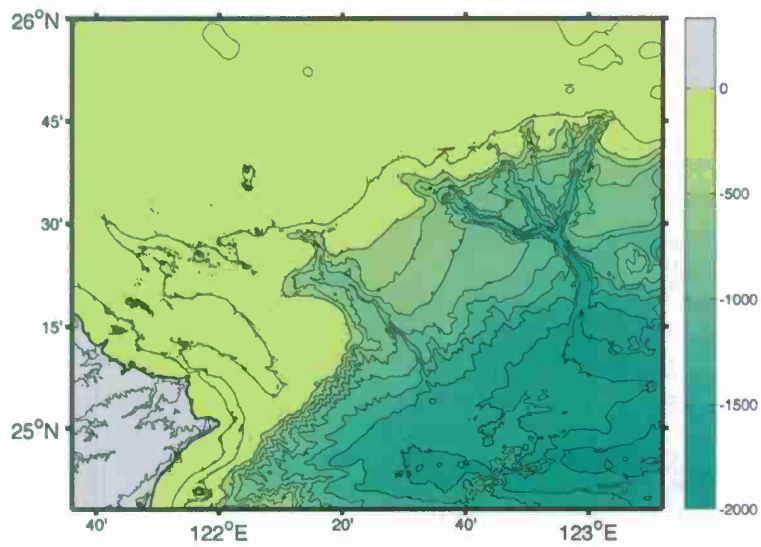


Figure 1- The study area for the field work for this project, northeast of Taiwan in the East China Sea. The eastern, branched canyon is North Mien-Hua Canyon, and the western canyon is Mien-Hua Canyon. Taiwan is in the lower left portion of the figure.

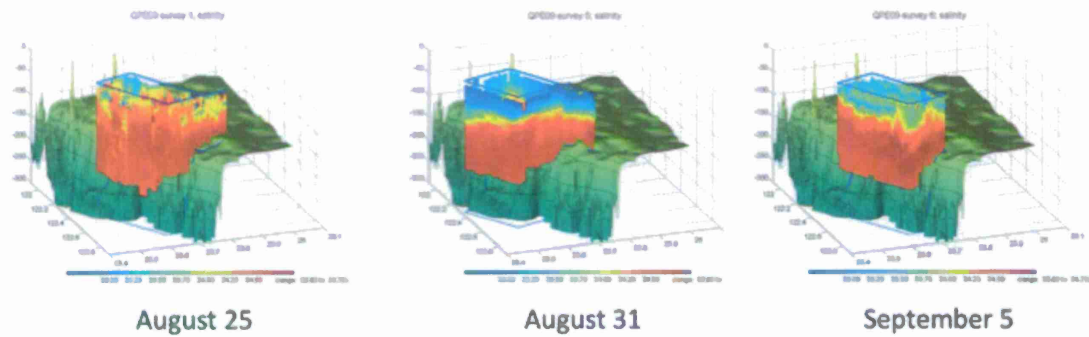


Figure 2- A visualization of the salinity fields from three different surveys over the outer shelf and upper slope in 2009. Note the low salinity surface layer on August 31, 2009, in the middle panel.

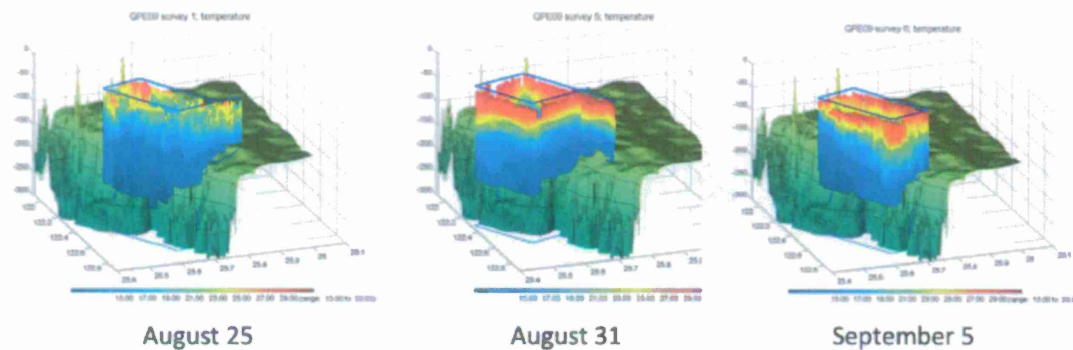


Figure 3- A visualization of three separate surveys showing the temperature structure over the outer shelf and upper slope in 2009. Note the increasing temperature in the surface mixed layer between August 25 and 31 (left and middle panels) as well as the steeply sloping isotherms over the upper slope on September 5, indicative of an eddy over the continental slope.

## REFERENCES

- Duda, T., A. Newhall, G. Gawarkiewicz, M. Caruso, Y.-J. Yang, and S. Jan, 2012. Significant internal waves and internal tides northeast of Taiwan. *J. of Marine Research*, submitted.
- Gawarkiewicz, G., Sen Jan, P. Lermusiaux, J. McClean, L. Centuriani, K. Taylor, B. Cornuelle, T. Duda, J. Wang, Y.-J. Yang, T. Sanford, R.-C. Lien, C. Lee, M.-A. Lee, W. Leslie, P. Haley, Jr., 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, 110-121.
- Sen Jan, C.-C. Chen, Y.-L. Tsai, Y.-J. Yang, J. Wang, C.-S. Chern, G. Gawarkiewicz, R.-C. Lien, and J.-L. Kuo, 2011. Mean structure and variability of the Cold Dome northeast of Taiwan. *Oceanography*, 24, 100-109.
- Sen Jan, Y.-J. Yang, J. Wang, G. Gawarkiewicz, and J.-Y. Kuo, 2012. Observation of 2009 Typhoon Morakot induced excess freshwater pulse in Taiwan surrounding seas. *J. of Marine Research*, submitted.