Study of Kuroshio Intrusion and Transport Using Moorings, HPIES, and EM-APEX Floats in the QPEU Experiment

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LONG-TERM GOALS

Our long-term scientific goals are to understand the dynamics and identify mechanisms of small-scale processes—i.e., internal tides, inertial waves, nonlinear internal waves (NLIWs), and turbulence mixing—in the ocean and thereby help develop improved parameterizations of mixing for ocean models. Mixing within the stratified ocean is a particular focus as the complex interplay of internal waves from a variety of sources and turbulence makes this a current locus of uncertainty. For this study, our focus is on small-scale processes (NLIWs and inertial waves), internal tides, and cold-water intrusions generated as the Kuroshio and barotropic tides interact with the continental shelf of the East China Sea (ECS) and with one prominent submarine ridge (I-Lan Ridge). These small-scale processes modulate the temporal, horizontal, and vertical spatial structures of water properties in the ocean, and therefore may significantly modify oceanic acoustics and introduce uncertainty to sonar performance and acoustic propagation. Our ultimate goal is to collaborate with acousticians to identify oceanic processes that alter acoustic properties. The properties, mechanisms, and dynamics of these oceanic processes will help quantify and assess uncertainty in acoustic prediction.

OBJECTIVES

The primary objectives of this observational program are 1) to quantify and to understand the dynamics of the Kuroshio intrusion and its migration into the southern East China Sea (SECS), 2) to identify the generation mechanisms of the Cold Dome often found in the SECS, 3) to quantify the internal tidal energy flux and budgets on the SECS and study the effects of the Kuroshio front on the internal tidal energy flux, 4) to quantify NLIWs and provide statistical properties of NLIWs in the SECS , and 5) to provide our results to acoustic investigators to assess uncertainty in acoustic prediction.

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APPROACH

An at-sea field observational program was conducted. It included two components: an array of six subsurface moorings and an array of six EM-APEX profiling floats. For the 1.5-month extended observational program, we deployed an array of six subsurface moorings with 75-kHz Long Rangers and a series of temperature/conductivity sensors, one at I-Lan Ridge, and five on the continental slope of the SECS. These observations are used to quantify the Kuroshio intrusion and migration, internal tidal energy and energy flux, NLIWs, and the Cold Dome. For the ~1/2-month intensive observational program on the continental slope, overlapping the extended observations, we deployed six EM-APEX floats in the North Mien-Hua Canyon. These EM-APEX floats provide near real-time observations of velocity, temperature, and salinity. The location of moorings and trajectory of EM-APEX floats are shown in Fig. 1.

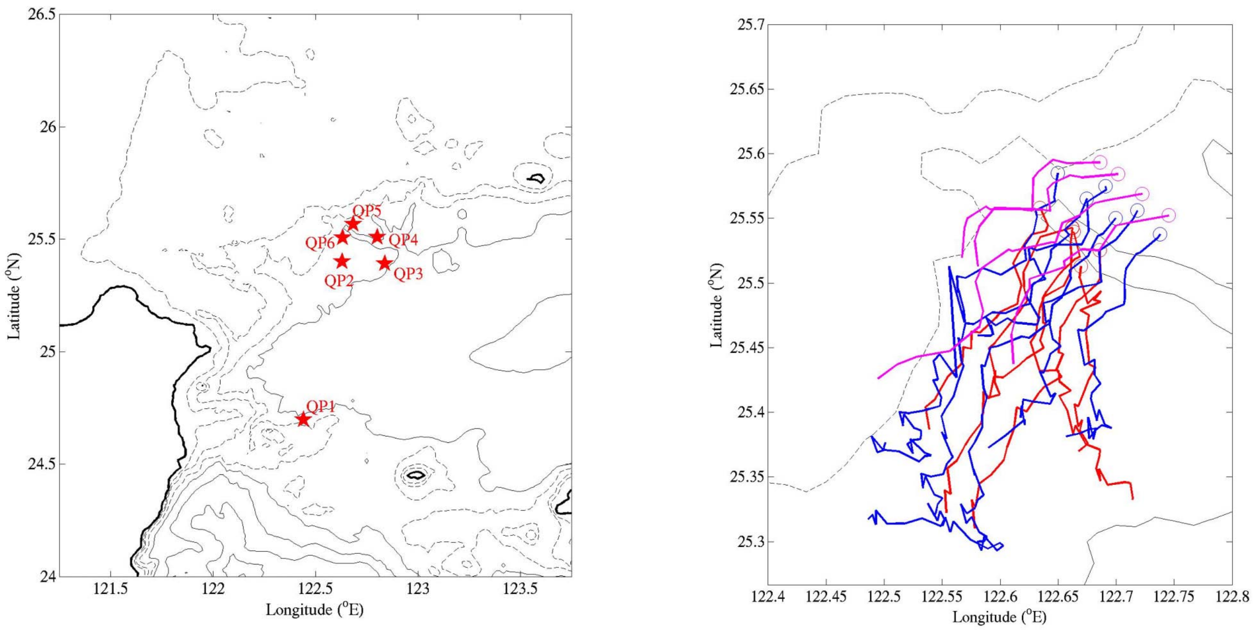

Figure 1. Bathymetry map of the southern East China Sea and mooring locations (left) and trajectory of six EM-APEX floats (right). The dashed contour lines on the left are isobaths of 100 m, 200 m, and 500 m. The solid contour lines are isobaths of 1000 m, 2000 m, 3000 m, and 4000 m. Positions of six moorings, QP1–6, are labeled.

WORK COMPLETED

In 2010 we have focused on data processing and analysis of mooring observations and EM-APEX float observations.

RESULTS

<u>Internal Tides</u>

Strong internal tides are observed at all six moorings and by EM-APEX floats. Semidiurnal tides dominate the diurnal tides. The vertical displacement often exceeds 100 m, and the velocity reaches 1 m s^{-1}. An example of internal tides observed on the QP2 mooring is shown in Fig. 2. Measurements from EM-APEX floats reveal the spatial structure of internal tides. An example of float mission 4437b is shown in Fig. 3.

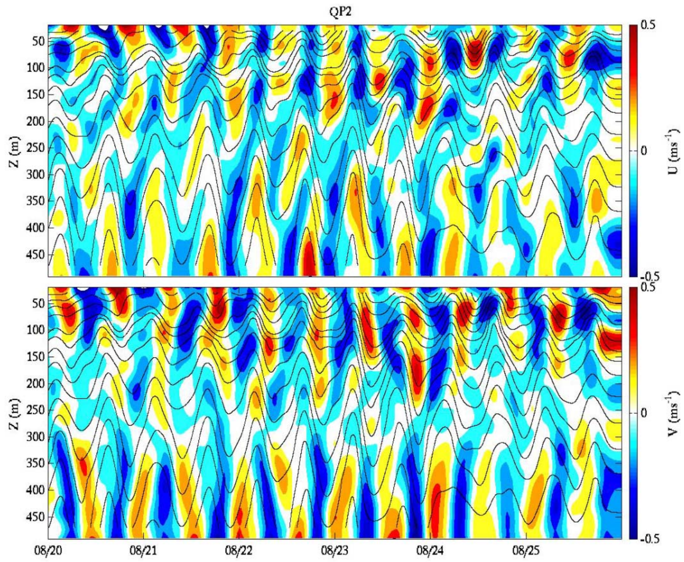

Figure 2. Contours of zonal and meridional velocity observed at QP2. Observations are band-pass filtered at semidiurnal tidal frequency.

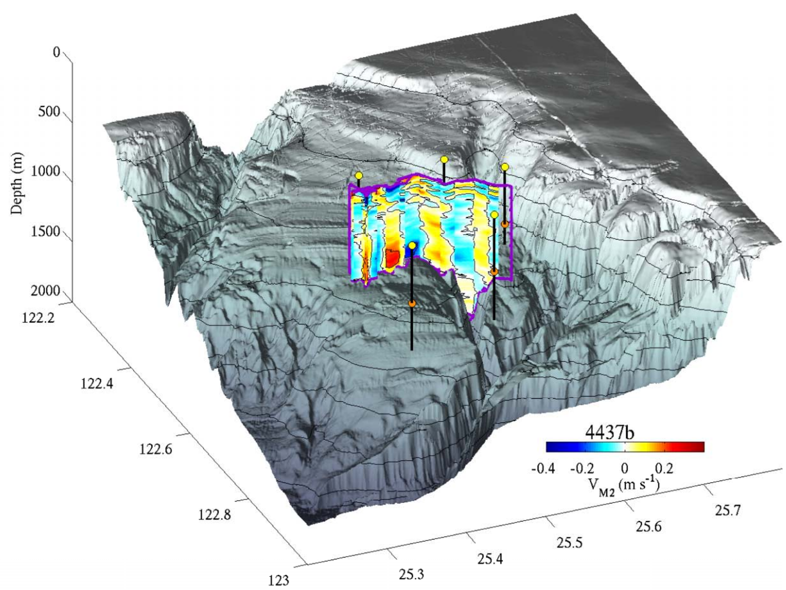

Figure 3. Semidiurnal band-pass filtered meridional velocity measured by the EM-APEX float mission 4437b. Five moorings are marked as vertical lines with yellow and orange dots, representing the two subsurface floats.

Velocity measurements taken by the EM-APEX float #4437b and six moorings are compared in Fig. 4. The float trajectory is shown in Fig. 3. The float was deployed north of North Mien-Hua Canyon, and was recovered close to the mooring QP2. The velocity profile of the EM-APEX float measurements agrees very well with that at mooring QP2 in the upper 500 m on and about 1 September 2009 when the float passed the mooring (see Fig. 3). Both show upward phase propagation suggesting downward energy propagation of semidiurnal internal tides.

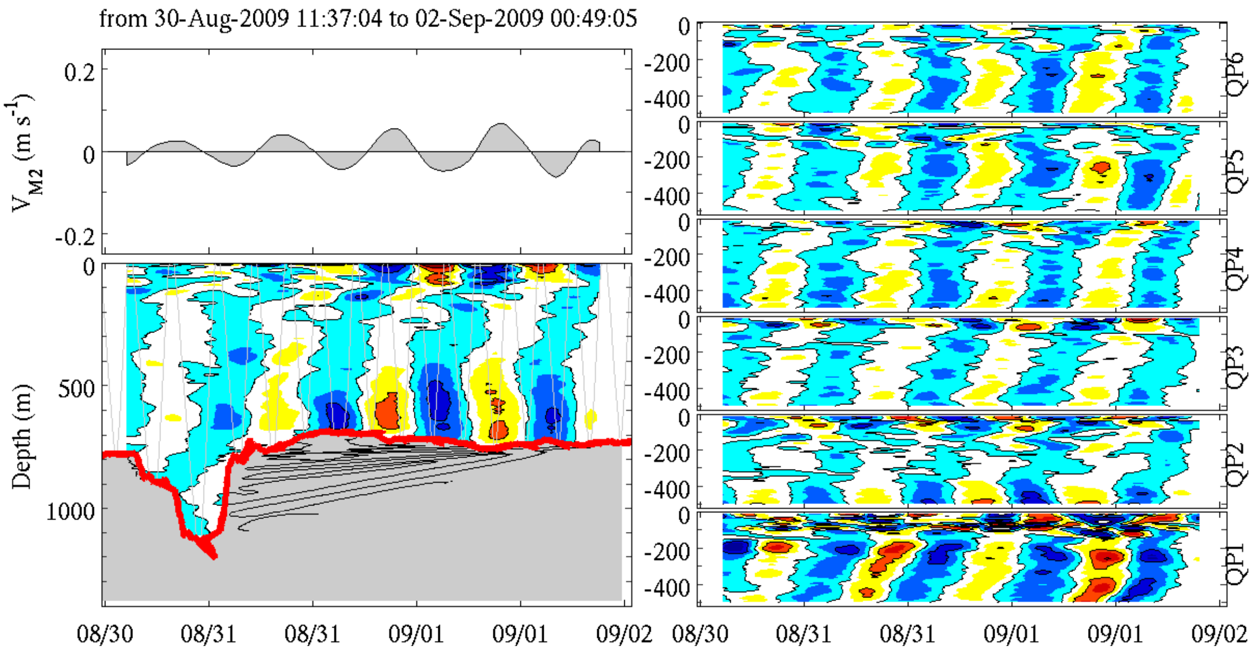

Figure 4. Meridional velocity measured by EM-APEX float #4437b and by six moorings. The velocity color scale is shown in Fig. 3. The top left panel shows the barotropic velocity, and the bottom left panel shows the meridional velocity measured by the EM-APEX float. The thin grey line indicates the EM-APEX float profile. The right panels show the meridional velocity measured by six moorings during the same time period of the EM-APEX float mission.

Temperature and Salinity Property

TS analysis is performed using mooring and EM-APEX measurements. An example of TS observations from 1 September 2009, 12–15Z is shown in Fig. 5. The observed TS from mooring measurements (blue dots) and EM-APEX measurements (black dots) are compared with the TS of the Kuroshio (magenta curve) and the South China Sea (brown curve). Mooring and EM-APEX float measurements agree with each other. The observed TS is similar to that of the SCS, but differs from that of the Kuroshio.

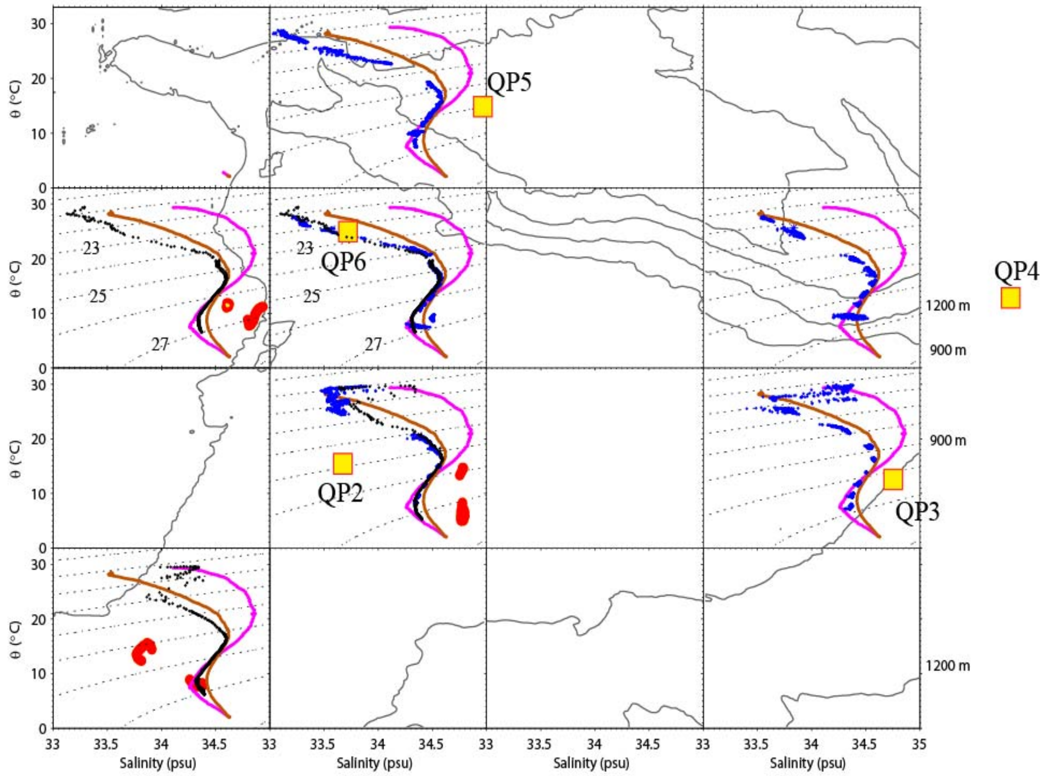

Figure 5. Temperature and salinity measurements by EM-APEX floats in 1 September 2009, 12–15Z. The magenta and brown curves represent the water properties of the Kuroshio and the South China Sea, respectively. The blue dots and black dots are TS measured by the mooring and by the EM-APEX floats, respectively, in the grid area. The dashed curves are isopycnal contours at 1 kg m^{-3} interval. The grey contours are bathymetry at 300-m depth interval. The yellow squares represent the positions of moorings and are labeled. The red circles represent EM-APEX float positions. During this period, there was no EM-APEX float in the area surrounding mooring QP6. The TS measurements from EM-APEX float west of the mooring QP6 were used to compare with those at the mooring.

Isopycnal Analysis

One of the primary goals of this project is to identify the Kuroshio intrusion and the origin of the Cold Dome in the East China Sea. We perform isopycnal analysis of the temperature anomaly to identify the intrusion. We observe propagation of temperature anomalies across the experiment site. One example is shown in Fig. 6. A cold anomaly exists near the head of North Mien-Hua Canyon and a warm anomaly exists near the offshore edge of the continental slope. We are in the process of comparing these observations with modeling results to understand the dynamics of the anomaly.

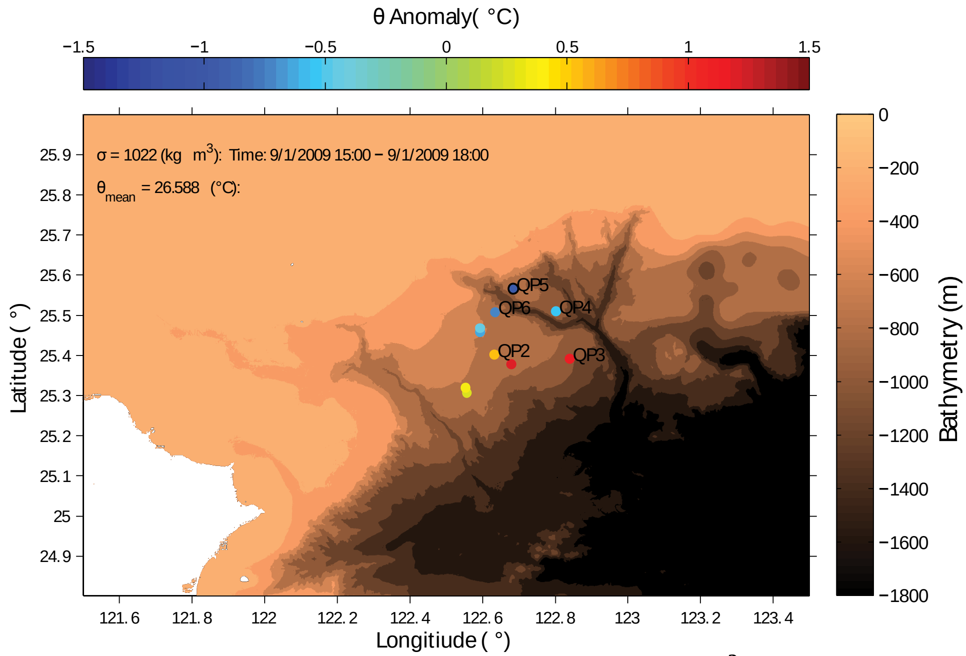

Figure 6. Temperature anomaly on an isopycnal surface 1022 kg m^{-3} measured by the moorings and by EM-APEX floats. A cold anomaly exists at the head of North Mien-Hua Canyon on moorings QP5 and QP6, and a warm anomaly exists on the offshore edge of the continental slope, at moorings QP2 and QP3.

IMPACT/APPLICATION

Our in-situ observations conclude that strong internal tides and NLIWs exist on the continental slope of the East China Sea. In the lower layer, strong salinity anomaly events are present during the spring tides. These small-scale processes may cause strong sound speed anomalies. To quantify, predict, and exploit the uncertainty of acoustic propagation and sonar performance, we need to understand the dynamics of these oceanic processes and their effects on the sound speed. This is the main goal of this experiment.

RELATED PROJECTS

Energy Budget of Nonlinear Internal Waves near Dongsha (N00014-05-1-0284) as a part of NLIWI DRI: In this project, we study the dynamics and quantify the energy budget of nonlinear internal waves (NLIWs) in the South China Sea using observations taken from two intensive shipboard experiments in 2005 and 2007 and a set of nearly one-year velocity-profile measurements taken in 2006–2007 from four bottom-mounted ADCPs across the continental slope east of Dongsha Plateau in the South China Sea. Results of NLIWI DRI will help improve our understanding of the dynamics of NLIWs and apply to the present project.

Process Study of Oceanic Responses to Typhoons Using Arrays of EM-APEX Floats and Moorings (N00014-08-1-0560) as a part of ITOP DRI: We study the dynamics of the oceanic response to and recovery from tropical cyclones in the western Pacific using long-term mooring observations and an array of EM-APEX floats. Pacific typhoons may cause cold pools on the continental shelf of the East China Sea. The cold pool dynamics are likely related to the Kuroshio and its intrusion as well as the shelf/slope oceanic processes. The cold pool could produce a significant acoustic anomaly that is the focus of the present project.

HONORS/AWARDS/PRIZES

Gledden Sr. Visiting Fellowship at U. Western Australia (Sanford, October 2008).