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

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SECS , and 5) to provide our results to acoustic investigators to assess uncertainty in acoustic prediction.

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.

WORK COMPLETED

- On August 3–9, 2009 we successfully deployed six subsurface moorings, each equipped with 9 CTD sensors at 30, 50, 80, 120, 170, 230, 300, 380, and 470-m depths and one upward-looking 75-kHz Long Ranger ADCP at 510-m depth (Fig. 1). Two moorings were deployed at 900-m water depth, and four at 680-m water depth. Mooring locations are shown in Fig. 2. All six subsurface moorings were recovered on September 12–16.

- On August 23–September 7, we deployed six EM-APEX floats near the North Mien-Hwa Canyon. In each of 16 EM-APEX float missions the float cycled between the ocean surface and bottom. When the float surfaced, it reported its GPS position, transmitted data, and received new mission commands. Most of floats were deployed within and north of North Mien-Hwa Canyon. Float trajectories are shown in Fig. 3. During the float missions, shipboard ADCP profiles were collected while underway and CTD casts were conducted on station.

RESULTS

Results of preliminary analysis of QPE observations are summarized as follows:

- Large-amplitude NLIWs are present at the continental slope of the East China Sea. As an example, one depression wave with a maximum vertical displacement greater than 100 m and maximum vertical speed of 0.15 m s^{-1} was observed at QP2 on August 22, 0800–0900 GMT (Fig. 4).

- Rapid salinity anomaly events are present in the lower layer of moorings QP4, 5, and 6 (Figs. 5 and 6). These events appear at time scales of ~10 min in a layer ~100 m thick, and the magnitude of salinity variation was ~0.5 psu with an upward salt anomaly and downward fresh anomaly. There is no significant temperature anomaly accompanying these salinity events.

- The low-pass filtered meridional velocity at QP1, located at I-Lan Ridge, shows large temporal and vertical variations (Fig. 7). Because QP1 is on the Kuroshio path, meridional velocity at QP1 could be used as a measure of the strength of Kuroshio. Meridional velocity is northward and strong in the upper 150 m. It is stronger in the first half of the experiment than the second half.

Centered on August 20, the northward current disappears. This is presumably due to the passage of one cold eddy (Fig. 8).

- Strong semidiurnal internal tides are found with a vertical displacement greater than 100 m. The velocity fluctuation of semidiurnal internal tides is as large as 0.5 m s^{-1} (Fig. 9).

- Shipboard velocity measurements reveal spatially coherent layers of strong vertical shear with vertical scales of 10s m (Fig. 10). These shear layers were common features on the continental slope of the South East China Sea during the QPE experiment.

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 of 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).

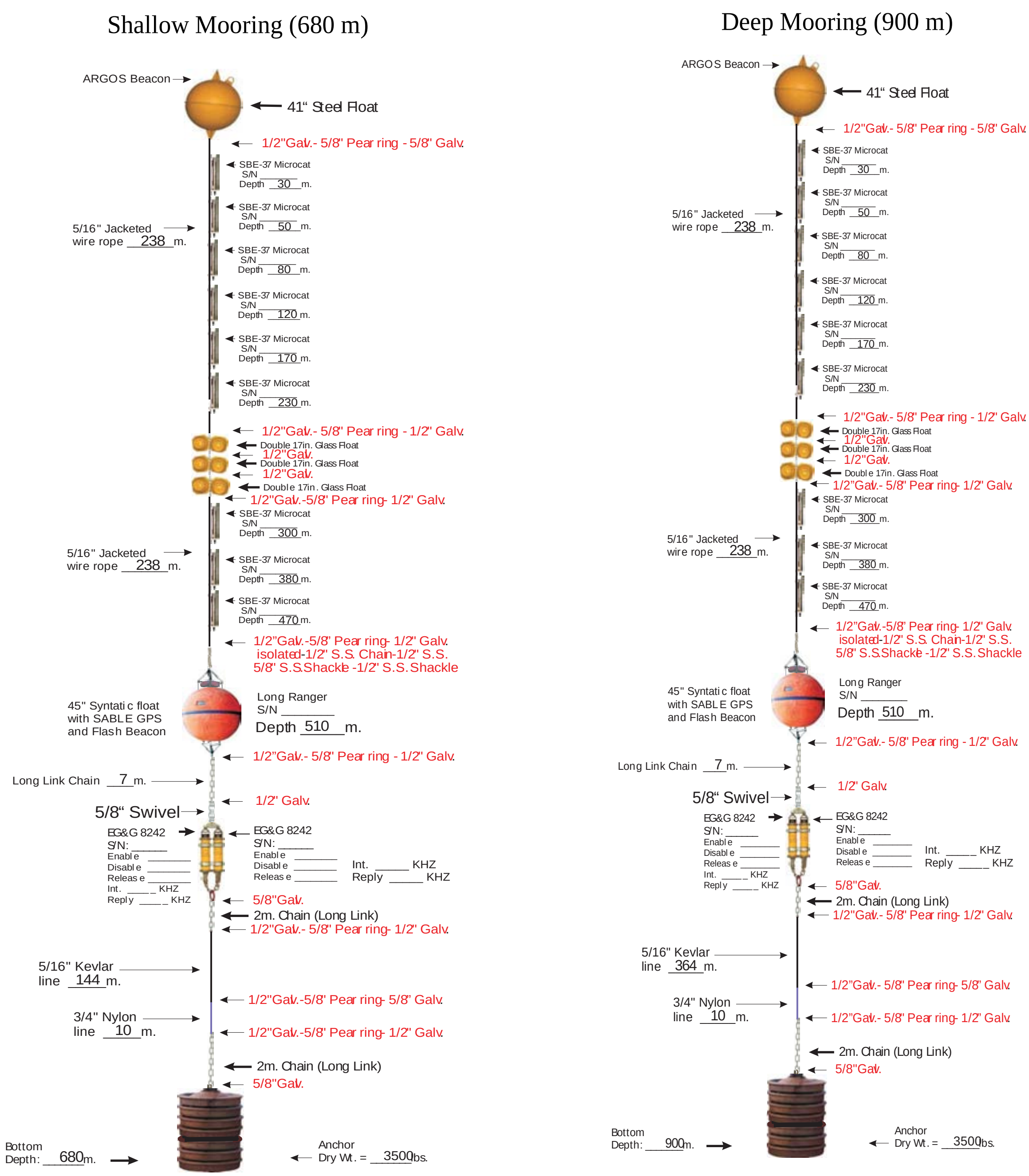

Figure 1. Schematic diagram of QPE shallow mooring (left) and deep mooring (right). Four shallow moorings (680-m water depth) and two deep moorings (900-m water depth) were deployed during the QPE experiment. Each mooring was equipped with one 75-kHz Long Ranger ADCP, nine CTD sensors, dual EG&G acoustic release, one steel float at 30 m, one syntactic float at 510 m, six glass floats, one Argos beacon and one submersible Iridium transmitter (SABLE).

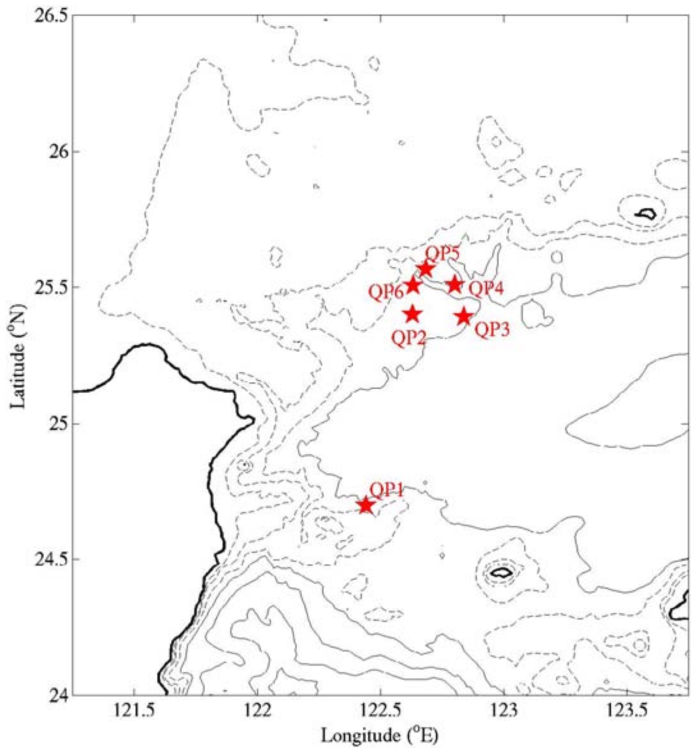

Figure 2. Bathymetry map of the southern East China Sea. The dashed contour lines are isobaths of 100 m, 200 m, and 500 m. The solid contour lines are isobaths of 1000 m, 2000 m, 3000 m, and 4000 m. Positions of six moorings, QP1-6, are labeled.

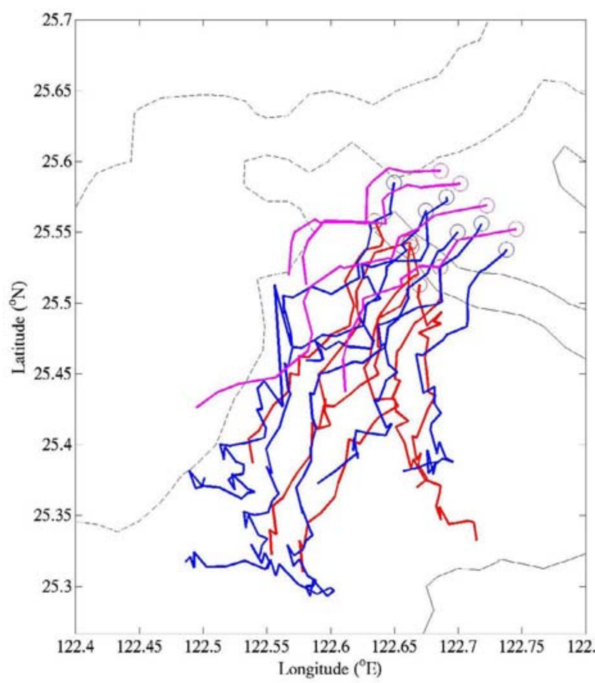

Figure 3. Trajectories of EM-APEX floats in QPE experiment. There were 16 float missions. Circles mark the positions of the float deployment.

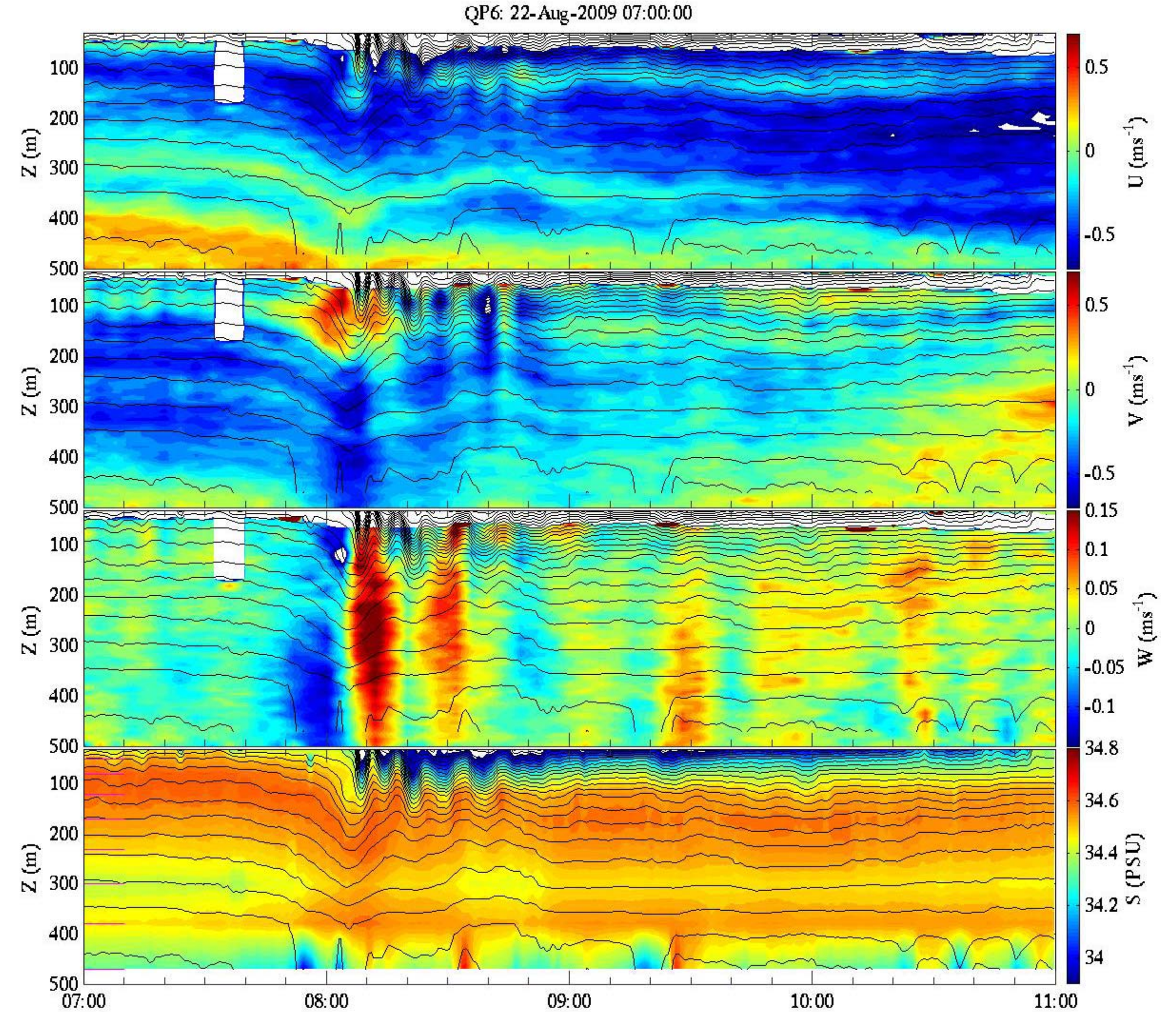

Figure 4. Example of one large-amplitude depression nonlinear internal wave event observed at QP6 mooring on August 22, 0800–0900 GMT. The maximum vertical displacement is more than 100 m and the maximum vertical speed is 0.15 m s^{-1}. The NLIW depresses fresh water in the upper layer.

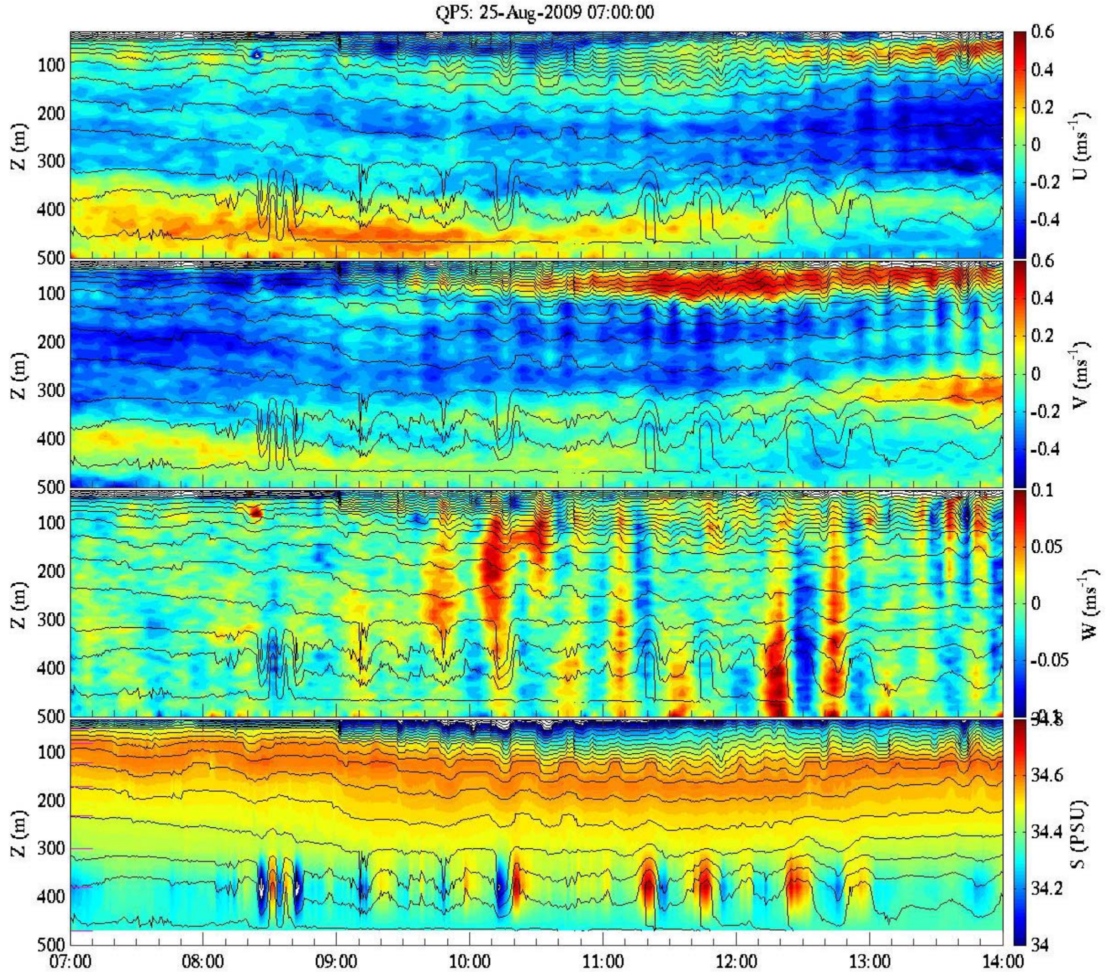

Figure 5. Example of rapid salinity events in the lower layer of QP5 mooring. These salinity events happen at a time scale of minutes and appear in pairs, i.e., salty and fresh. They have a vertical scale of ~100 m. They are associated with vertical motions suggested by the vertical displacement of the isopycnal surface and the direct vertical velocity measurements.

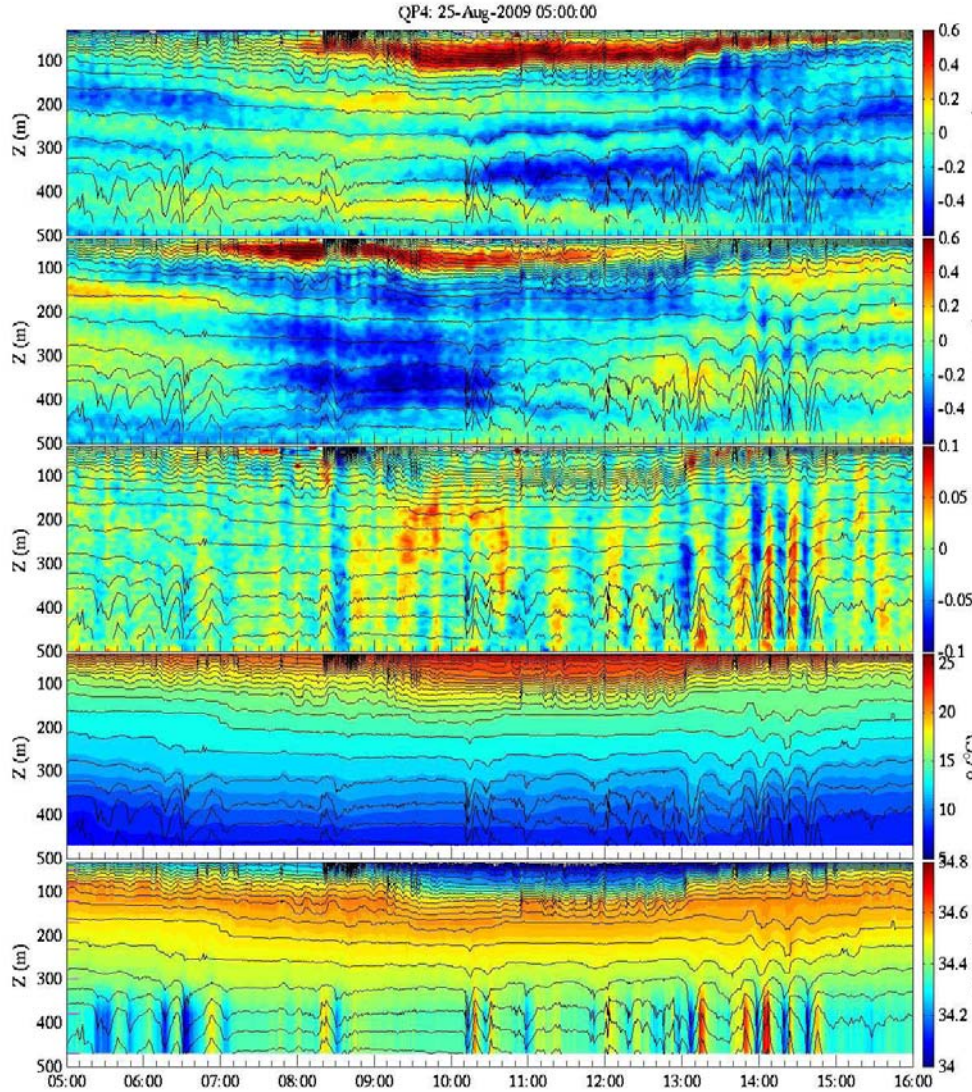

Figure 6. Example of rapid salinity events in the lower layer of QP4 mooring, similar to that at QP5 mooring. Note that these events do not have a significant temperature signature.

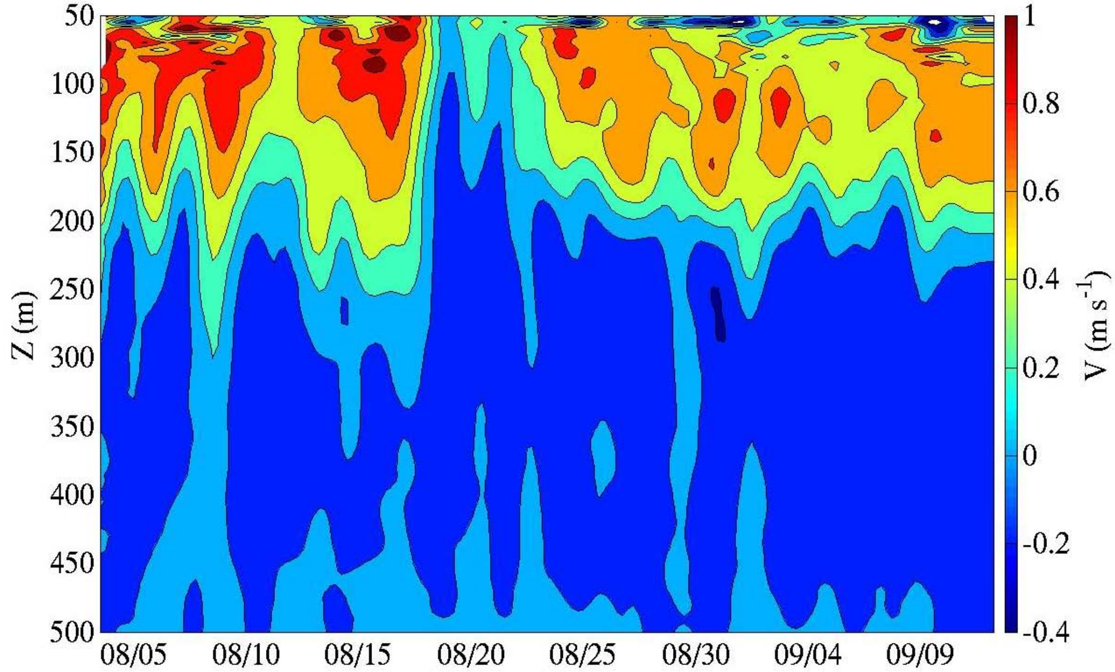

Figure 7. Meridional velocity at QP1 mooring, which is located at I-Lan ridge on the Kuroshio path. Meridional velocity is low-pass filtered at two days.

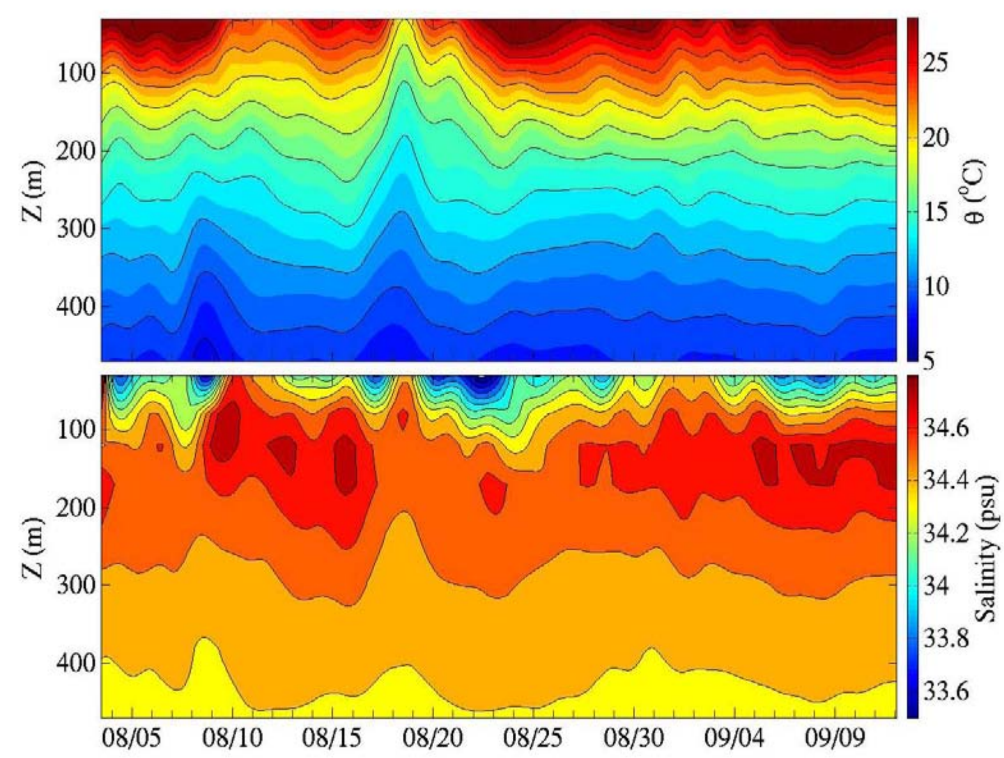

Figure 8. Low-pass filtered temperature and salinity observations at QP1.

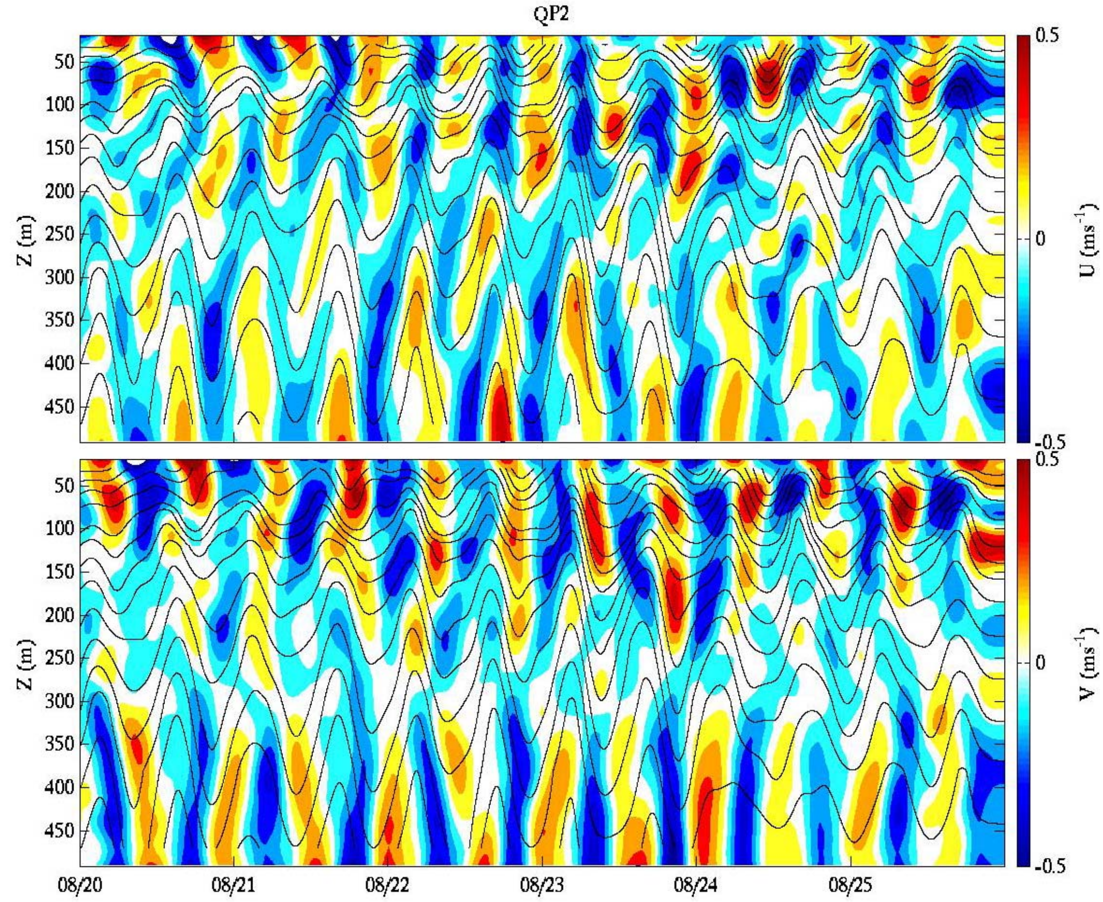

Figure 9. Contours of zonal and meridional velocity observed at QP2. Observations are band-pass filtered at semidiurnal tidal frequency.

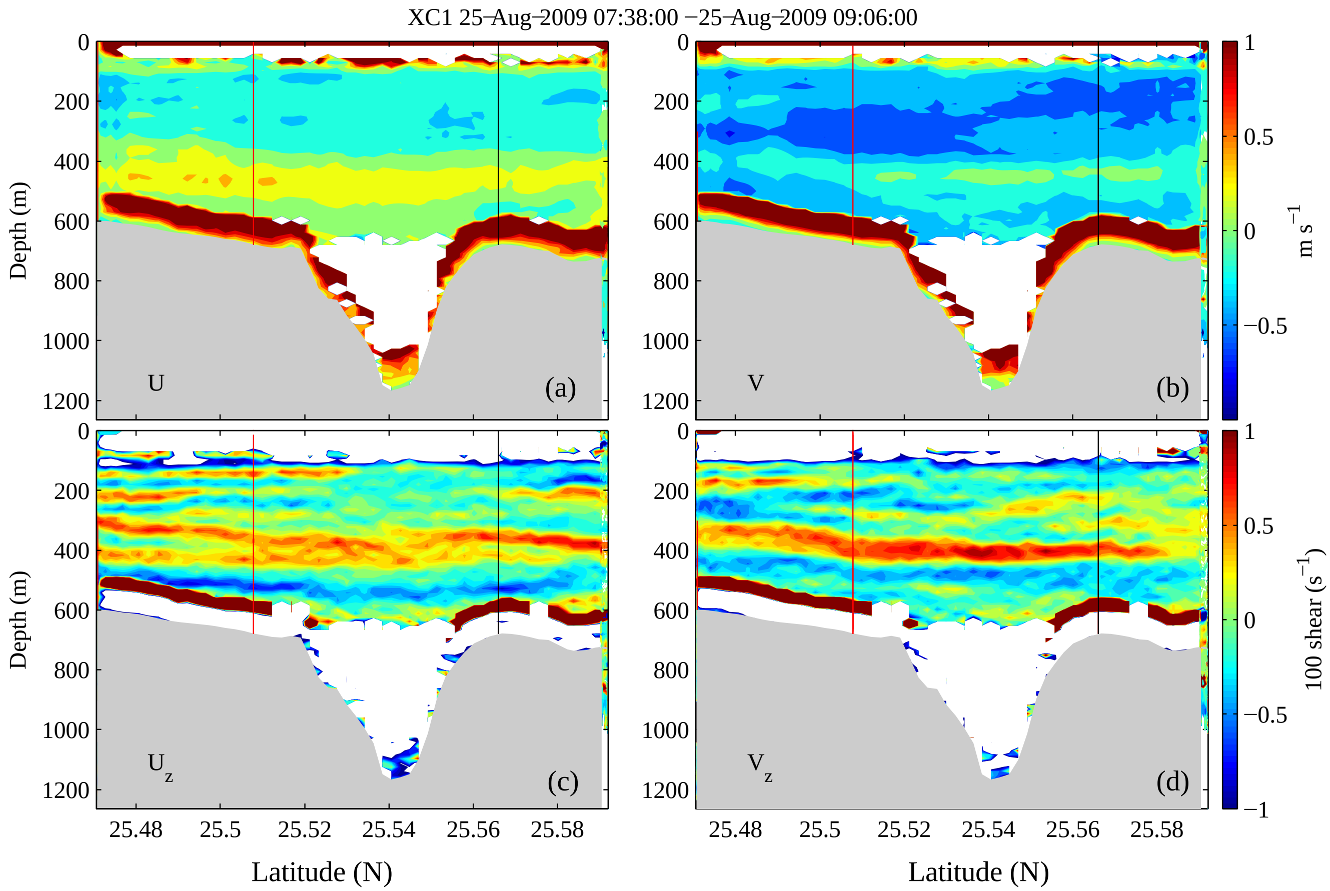

Figure 10. Shipboard velocity measurements across North Mien-Hwa Canyon, (a) zonal velocity, (b) meridional velocity, (c) vertical shear of zonal velocity, and (d) vertical shear of meridional velocity. Black and red vertical lines mark the positions of QP5 and QP6 moorings, respectively.