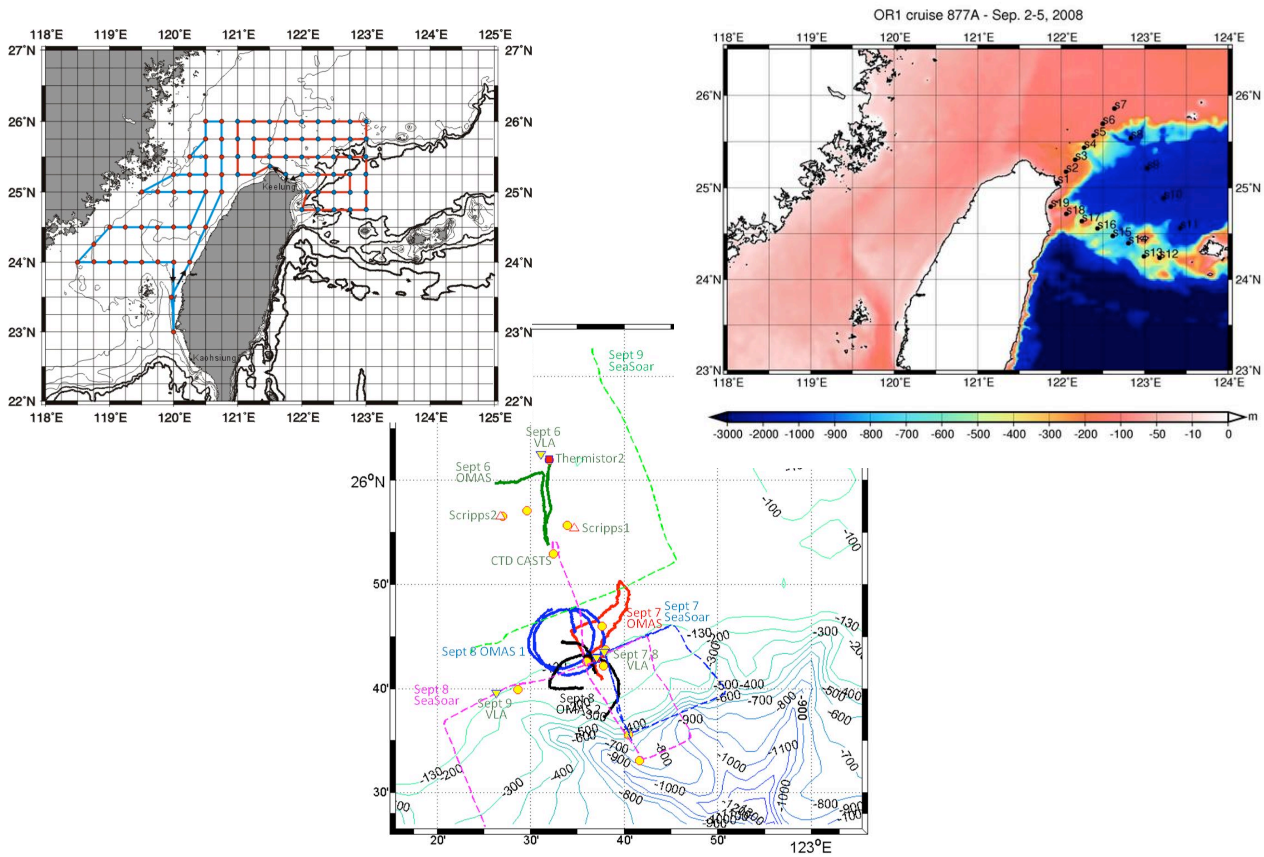
Quantifying, Predicting, & Exploiting Uncertainty (QPE), 2008 Pilot Experiment; Aug. 22nd - Sept. 11th , 2008 Technical Report



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1.0 Overview

The Quantifying, Predicting, and Exploiting Uncertainty (QPE) 2008 Pilot Cruise involved joint Taiwanese-U.S cruises involving the Ocean Researcher I, II, and III. The goals of the Pilot Experiment were to test equipment in the demanding environment of the East China Sea shelf and slope, to establish procedures for logistics and operations, to integrate model forecasts and data inputs, and to measure baseline oceanographic and acoustic propagation conditions for planning of the main experiment in 2009. In addition to these cruises, continuing efforts by researchers from Scripps Institute of Oceanography and National Central University continued long-term observations of the western Pacific Ocean including drifter observations and sea surface height anomalies from satellite based altimeters.

This technical report describes highlights of the Pilot Experiment including brief descriptions of the science activities from the three ships as well as the long-term observations.

Figure 1A shows the CTD stations and cruise tracks made by OR 2 and OR3 during the Large Scale Hydrography measurements obtained August 22-27. Figure 1B presents the CTD stations obtained as part of the Offshore Boundary Conditions during the OR1 Leg 1 cruise, Sept. 2-5. Highlights from the Large Scale Hydrography and Offshore Boundary Condition measurements include:

- The OR3 survey team collected 37 shallow water CTD casts, and approximately 720 nm (nautical miles) of current velocity and depth data (via the onboard ADCP and EK500 instruments).
- The OR2 survey team obtained 43 CTD casts (with 1/3 obtained in deep waters up to 3000m deep) and approximately 680 nm of current velocity and depth data (via ADCP and EK500).
- The OR1 Leg 1 survey resulted in 28 CTD casts, 455 nm of ADCP and EK500 data, and deployment of two RADOS-V Restrained Moorings which included thermistor chain data and one mooring with an ADCP.

Fig. 1C summarizes all of the measurements made during the second leg of the Pilot Cruise to identify the oceanographic and acoustic processes present in the area identified for the main experiment. Highlights of the data obtained during the typhoon shortened cruise that are identified on the figure include:

- Three moorings deployed providing 120 hours of continuous thermistor and ADCP data;
- Three different SeaSoar runs conducted with NTU's Institute of Oceanography vehicle, totaling over 18 hours of data, covering over 144 nm;
- Four successful Transmission Loss experiments conducted with four OMAS vehicles over three days, with TL obtained at ranges in excess of 14 km (although high ambient noise levels caused intermittent TL measurements after 6-7 km).

- Four distinct vertical line array (VLA) measurements conducted, including three with OMAS sources, and one twelve hour experiment utilizing a Taiwanese Navy surface ship as the source.

2.0 Introduction

The Quantifying, Predicting, and Exploiting Uncertainty Department Research Initiative (DRI) involves both field experiments and numerical modeling of oceanographic, geoacoustic, and acoustic propagation processes. The ultimate goal of this program is to determine what factors determine the amount of uncertainty in modeling of these related processes and their impact on prediction of the signal-to-noise ratio of low-frequency acoustic propagation in the complex environment of the East China Sea outer shelf and slope. This program builds on an earlier DRI, Capturing Uncertainty in the Tactical Environment, in which a number of tools were developed to quantify and predict uncertainty of oceanographic, geoacoustic, and acoustic variables. The goals of this program are to apply the earlier tools, which include Predicted Probability of Detection (PPD), coupled oceanographic/acoustic models with ensemble techniques to quantify uncertainty, and novel techniques for quantifying uncertainty in geoacoustic parameters as well as bathymetry. Taiwanese scientists, led by Dr. Sen Jan of National Central University, have a number of additional science questions including the role of tidal energy conversions over the upper continental slope, the wind response of the flow in Taiwan Strait, the directionality of the ambient noise field, the mode structure of low frequency propagation over the continental shelf and its relation to environmental variability, and upwelling processes affecting the structure and maintenance of the Cold Dome present over the outer continental shelf.

The Pilot Experiment for QPE involved three separate cruises. The OR2 and OR3 operated northeast of Taiwan and in Taiwan Strait from August 22-27. The OR1 operated between Ilan Ridge and the Main Study Area on Leg 1, from September 2-5. Leg 2 was in the Main Study Area from September 6-11. The OR2 and OR3 cruises were affected by the passage of Tropical Storm Nuri and the OR1 Leg 2 was shortened by two days due to the passage of Typhoon Sinlaku, which passed over the Main Study Area.

Dr. Y.-J. Yang was the Chief Scientist for the OR2 and Tweng-Chi Liu was the Chief Scientist for the OR3. Dr. Jan Sen was the Chief Scientist for Leg 1 of the OR1 cruise and Dr. Chi-Fang Chen was the Chief Scientist for Leg 2 of the OR1 cruise. In addition to the Chief Scientists, research groups involved included Dr. Joe Wang's SeaSoar group, including Bee Wang, Yu-Fang Ma, Cheng-Che Lai, and Shiang-Chih Shie, and Dr. Chi-Fang Chen's group which included Hsiang-Chih Chan, Yung-Sheng Chiu, and Yuan-Ying Chang. U.S research groups included OASIS Inc., with Dr. Kevin Heaney, Dave Morton, Chris Emerson and Ted Abbot, Scripps Institution of Oceanography with Dr. Luca Centurioni and Chris McCall, and Woods Hole Oceanographic Institution group including Dr. Glen Gawarkiewicz, Frank Bahr, and Craig Marquette. The regional modeling was performed by Dr. Pierre Lermusiaux and his group at MIT including Wayne Leslie, Pat Haley, Jinshan Xu and Eric Heubel.

While further details are reported below, scientific highlights include concurrent measurements of Taiwan Strait and the Main Study Area during the OR2 and OR3 cruises including resolving the Cold Dome, successful data transfer in real-time and 24 hour oceanographic and acoustic propagation forecasts in the Main Study Area as well as calculation of uncertainty in the oceanographic fields due to Taiwan Strait transport, and several deep casts in the Okinawa Trough resolving deep stratification as well as a detailed section along the Ilan Ridge giving details of the Kuroshio upstream of the Main Study Area.

Highlights of Leg 2 of the OR1 cruise include successful operation and measurements of the transmission loss with OASIS Mobile Acoustic Sources and sonobuoys, successful deployment of a Vertical Line Array, identification of a strong Kuroshio Intrusion event onto the shelf via drifter trajectories, high-resolution SeaSoar transects, and successful deployment of the RADOS-V telemetered moorings for real-time information on high-frequency motions.

3.0 Summary of Operations

The CTD and ADCP surveys using the R/V OR2 and OR3 were originally scheduled during Aug. 23-27 and Aug. 22-27, 2008, respectively. The OR2 was planned to measure the sea off northeastern Taiwan, and the OR3 was designated to measure the middle to northern reaches of the Taiwan Strait (Fig. 1A). As this was high typhoon season and the cruise dates had to be fixed ~2 months in advance, we were lucky that the joint observation was not seriously disturbed by typhoons in terms of their uncertainties. Indeed, it was fortunate that the cruises were scheduled just after Typhoon *Nuri*, which developed from a tropic depression into a typhoon in the west Philippine Sea on Aug. 19th, moved west-northwestward through the Luzon Strait and the southern Taiwan Strait, and touched the southeastern coast of China about 220 km east of Hong Kong on Aug. 21st.

In addition to the July to September typhoon season, the East Asian northeast (winter) monsoon is another atmospheric factor that may cause shortening or cancellation of a cruise. The northeast monsoon normally begins in mid-September, peaks in December and January and weakens in March. The first winter monsoon of this year came earlier than its climatological mean period, bringing a weak cold front over northern Taiwan, which caused the frontal rains on the morning of Sept. 2nd. We thus expected a bad sea state before the cruise. The cruise was in spring tide and the tidal currents were expected to be strong (> 1 m/s) over the shelf.

The major instruments available on both ships were: CTD (SBE 9/11 plus); ADCP (Ocean Surveyor 150 kHz recording at 2 min interval); echo sounder (EK500) and marine radar.

3.1 Large Scale Hydrography (OR2 & OR3, Aug. 22-27)

The OR3 cruise (CR1313), led by NTU's senior technician, Tweng-Chi Liu, left Kaohsiung for the northern Taiwan Strait at 0900 LT, on Aug. 23, 2008, which was actually one day behind the scheduled date due to Typhoon *Nuri*. The OR3 arrived at the first CTD station at 1200 LT, on 23rd and finished the last CTD cast at 0700 LT, on the 26th. Since the wind speeds ranged from only 2 to 8 m/s and the sea state was fairly good, the OR3 returned to Kaohsiung on Aug. 26 which was one day earlier than the scheduled date. This four-day survey produced 37 shallow water CTD casts and approximately 720 nm of ADCP measured current velocity and EK500 measured depth data. The cast locations and cruise tracks are shown in Figure 1A (with red lines and blue dots).

The OR2 cruise (CR1570), led by Dr. Yiing-Jiang Yang of CNA, departed Keelung on Aug. 23, 2008, and arrived at the first CTD station on the shallow shelf at 1000 LT. Although the spatial coverage of the OR2 is smaller than that of the OR3, it took a longer time for the overall CTD measurements than the OR3 survey because one third of the OR2 survey area are deep waters. The wind speeds on the sea off northeastern Taiwan were higher than that over the northern Taiwan Strait. Even so, the sea state was still good during the cruise. The observation was finished at 0840 LT on the 27th and the OR2 returned to Keelung about one hour after the last CTD cast. Note that the CTD stations No. 3, 4 and 5 were canceled due to unresolved technical problem. The OR2 survey, shown in Figure 1A as blue track lines and red dots, obtained 43 CTD casts and approximately 680 nm ADCP and EK-500 data.

3.2 Offshore Boundary Conditions (OR1, Sept. 6-8)

The OR1 departed Keelung Harbor on Sept. 2nd, heading for the southernmost point of Side #1 of the QPE triangle at 1100 LT. We planned to sail clockwise for the triangle observation (see Fig. 1B). The deployment of the Scripps mooring was scheduled after CTD cast S6. The sea state was unexpectedly excellent. About 2 h and 20 min after leaving Keelung, the OR1 arrived at the CTD station S1 where the water depth is only 35 m and it took only 5 min for the first CTD cast, then the OR1 kept heading towards the northeast. It was noticed from the reflection intensity shown on the EK500 screen that the bottom topography changed abruptly between S3 and S5, particularly around the Mien-Hwa Canyon. The depth changes within some sections reached as high as 200 m in a horizontal distance of a few hundred meters (important for operational planning for the SeaSoar measurements in the next leg of the cruise). The CTD cast at S6 in Side #1 was done at 2155 LT, on Sep. 2nd. After this cast the OR1 was sailing towards the northwest to the Scripps mooring site, located approximately 16 nm northwest of S6. Before the deployment, Luca requested that a 1 nm × 1 nm square topographic survey be conducted with the mooring site in the center to ensure the smoothness of topography in this area. The depths were measured around 112 m with variations less than ±5 m. The deployment was completed at 0230 LT, on Sept. 3rd. The sea surface remained calm during the operation and the cardboard box which covered the mooring was quickly disintegrated by the swift tidal currents. We then moved to S7 to continue the CTD survey.

During the 2nd day of the cruise, Luca noticed that the satellite tracking indicated that the mooring position was shifting slowly to the southeast. At that moment, we could do nothing to the mooring but just kept monitoring its movement. Later we found that the surface buoy moved periodically to the southeast and to the northwest for 3 repeats in approximately one and a half days with a net horizontal displacement of about 1 nm to the south. Luca suggested that the possible resonant vibration of the mooring induced by the swift tidal currents may be the cause for the periodic jumping and shifting of the mooring position.

The OR1 continued its CTD and ADCP surveys along Transect #2 and between the Yonaguni and Iriomote Islands, to the east end of Side #3 at 2102 LT, on Sept. 3rd. The CTD casts along this transect were finished at 0948 LT, on Sept. 4th. At that time we decided to recover the Scripps mooring. When the OR1 was close to Turtle Island right after S19, we saw a strip of rough sea surface, such as is frequently seen in the northern South China Sea due to large amplitude internal waves. We took ~8 h from S19 to the mooring site and recovered the restrained mooring in 35 min without problem. The planned observations were completed at 1835 LT on Sept. 4th. Thereafter we still had ~16 h before returned back to Keelung. Since the result derived from a baroclinic tide model indicates that the northwestern end of the Mien-Hwa Canyon may be an active generation site of internal tides, it was decided to have an hourly CTD observation there. After ~4 h of transit, the OR1 arrived at the location where the depth was ~440 m and the first cast was done at 2259 LT, on the 4th. We remained there and got 8 hourly CTD casts which was not sufficient to analyze the energetics of internal tides. Nonetheless, the data helped provide a basic understanding of how big the temperature and salinity fluctuations were in that area. The OR1 returned to Keelung at 1000 LT, on Sept. 5th.

The primary data collected during the 71 h cruise include 28 CTD casts, 455 nm of ADCP and EK500 data and one restrained mooring data of Scripps, with locations shown in Figure 1B.

3.3 Oceanographic & Acoustic Processes

The OR1 got underway from Keelung Harbor at 1100 on September 6. After a 5 hour transit, five moorings were deployed throughout the study area. In order to provide the best use of shipboard time, it was decided to operate the SeaSoar during daylight hours (in order to increase safety while operating amongst the squid fishing fleet), and to conduct the acoustic studies during the night. The locations and tracks for all of the measurements made during the leg 2 cruise are shown in Figure 1C.

The original schedule planned for tests to be conducted through the 11th, with the 12th reserved for mooring recoveries and the return transit to port. The first two days of tests went according to the schedule, with 12 hours of SeaSoar data and 12 hours of OMAS runs obtained (recorded by sonobuoys and the VLA). In addition, 5 SVP drifters, each fitted with a GPS receiver, were deployed during the along-shore SeaSoar track on September 7.

The rapid development of a tropical depression into Typhoon *Sinlaku* required adaptations to the plan, beginning on the evening of September 8th. On the 8th, two OMAS runs were successfully conducted (events 4A and 4B), and 8 hours of VLA data were recorded. On Sept. 9th, an additional 6 hours of SeaSoar transits were conducted, and the ship was positioned for a 12 hour VLA event that was held in conjunction with a Taiwanese ship. As the seas continued to increase and the forecasts continued to suggest increasingly poor sea states, it was decided to recover all moorings on the 10th, before proceeding with any other measurements. The first two moorings were recovered without incident, but the third buoy was more difficult to recover, since it was found to be moving at approximately 6 kts to the NE, away from Keelung Harbor, and presumably the typhoon. A chase ensued, and after 4 hours on an intersecting course, the surface expression of the buoy was found sitting on the deck of a fishing vessel. The crew of the fishing boat threw the float over the side to allow the OR1 to recover, while relating that the mooring had gotten tangled in their fishing gear, prompting them to cut the line. We returned to the final known location of the mooring (prior to the cut), and attempted to recover the remainder of the mooring, but the sub-surface components of the gear, including the ADCP sensor, were lost.

The final two buoys were recovered without incident at night in a rainstorm.

3.4 Real-Time Ocean and Acoustics Modeling and Predictions

Real-time modeling of physical oceanography and acoustics was carried out during the Pilot Experiment at MIT. Seven sets of daily forecasts were issued for the period 6-12 September 2008. Each day, a pair of forecasts were issued, contrasting different initial transports through the strait of Taiwan. Each forecast was from a free surface simulation forced with COAMPS (wind stress) and NOGAPS (heat-flux, E-P) atmospheric forcing, initialized with a combination of the Taiwanese OR2 and OR3 CTD data (see Fig. 1a) and a summer climatology created using June-August profiles and the HydroBase2 software. The bathymetry used was the NCOR bathymetry. When available, the OR1 CTD (Fig. 1b) and the SeaSoar data (Fig. 1c) were assimilated. For each day's forecast, on the order of 10 simulations were run with different parameters for both sensitivity study and for parameter tuning. As a means to determine forecast skill, we calculated the volume averaged bias and RMS errors of 3 different 9 day forecasts for the period 2-5 September 2008. The forecasts differed in the initial transport imposed between Taiwan and mainland China (0, ±1 Sv).

Daily acoustic transmission estimation products were provided for each forecast along five 20 km-long acoustic propagation paths which had been identified during a planning meeting at MIT. Those five paths generally represent typical transmission paths for exploring effects of ocean variability in this region. The frequencies chosen were 300, 600, and 900 Hz; which are in the range of OMAS sources. Acoustic simulations were performed with the Coupled SACLANTCEN normal mode propagation loss model (C-SNAP). It is a range-dependent one-way coupled modes model with impedance matching to account for energy conservation.

A web page (http://mseas.mit.edu/Sea_exercises/QPE/index.html) was created and utilized for operational support and product dissemination during the Pilot Experiment. Available via the site were: real-time analyses and forecasts; real-time description of the ocean and acoustic dynamics and findings; information on preparation and plans; and other links. In addition to the complete web page, a smaller specialized page for the planning purposes of at-sea participants was created to achieve rapid download and reduce network bandwidth needs.

4.0 Instrumentation

4.1 WHOI Moorings

Five moorings were deployed in support of the QPE Pilot Cruise. WHOI provided two thermistor chains (T1 and T2) at the 110 and 130 m isobaths and a near-bottom ADCP mooring at the 130 m isobath. The locations of these moorings are shown in Figure 1C.

4.2 SIO Real-Time Drifter and ADCP V(z)

Scripps deployed two 130m long restrained drifters, referred to as the R-ADOS-V prototype, and other drifters during the QPE pilot cruise. The results obtained from their systems were documented in a report by Luca Centurioni and Pearn Niiler that is included in its entirety in this report as Appendix B.

4.3 SeaSoar

The SeaSoar Mk II (S/N 012 026) used throughout this cruise is owned and operated by the Institute of Oceanography of National Taiwan University. The SeaSoar, and the Taiwanese and WHOI team members are shown in Figure 2. Three different SeaSoar runs were conducted from 9/7 – 9/9, and the individual legs are shown in Figure 1C. The SeaSoar was towed for over 18 hours, covering 144 nautical miles of ocean in the test area. An example of the SeaSoar data is included in this report in Section 5.3 (see Figures 3-8).

4.4 OASIS Transmission Loss

In support of the transmission loss experiments, OMAS (OASIS Mobile Acoustic Sources) units were used as the sources, and three sonobuoys (in either a DIFAR or Omni mode) were used as the long-baseline receiver system. During three tests, four OMAS events were conducted, with the details provided in Table 1. Due to the potential difficulties incurred on previous cruises with trying to tow the SeaSoar at night amongst potentially crowded fishing areas, it was decided before the cruise to tow during daylight hours, and conduct OMAS operations at night. This format proved to be the best use of shipboard time, and OMAS runs were typically planned to permit spar buoy recovery at daybreak.

A typical signal generated by the OMAS unit, and rebroadcast each minute, is shown in Figure 9. Some of the preliminary TL data obtained during this cruise is included in Section 5.4.

4.5 Vertical Line Array

The vertical line array that was used is owned and operated by National Taiwan University's Ocean Acoustics Laboratory, directed by Chi-Fang Chen, the Chief Scientist of Leg 2 of the OR1 cruise. It is a 16 element array that was suspended beneath surface floats, drifting over 100 yards from the stern of the OR1. Data was acquired during all of the OMAS runs, and during a twelve hour event on Sept. 9th that used a Tawanese Navy surface ship as the source. Results from VLA data are included in this report as Appendix C.

5.0 Preliminary Results

5.1 OR2 & OR3 Large Scale Hydrography

The CTD stations obtained from the OR2 Cruise are listed in Table 2. The survey was able to resolve the thermohaline structure in Taiwan Strait, the shelf north and northeast of Taiwan including the QPE Main Study Area, and east of Taiwan as far south as the Ilan Ridge. This data was used to initialize the Regional Model run at MIT. A map of the temperature and salinity fields at 50 m depth appears in Figure 2.

5.2 OR1 Leg 1 Offshore Boundary Conditions

The OR1 provided a well-balanced suite of oceanographic measurements throughout the cruise, with data obtained from the onboard sensors delivered to the scientists on a disk at the end of the cruise. This data package includes:

- RADAR – screens saved every 5 minutes
- ADCP – Ocean Surveyor Model 75 (kHz), operated in narrow band mode, with 8m bins, and 5 minute profiles (processed by Frank Bahr, WHOI)
- Fathometer – Simrad Model EK500 Scientific Sounder System – continuous recording of the 38 kHz signals
- GPS – ship's position recorded
- Sea surface temperature and salinity
- wind speed and wind direction;

CTD casts were taken during mooring deployments and recovery as well as during OMAS deployments. Locations and times of the casts from the OR1 Leg 2 cruise are presented in Table 3.

5.3 Oceanographic Sampling

Due to the rapid development of the tropical depression 15D into Typhoon *Sinlaku*, the overall test schedule was modified and abbreviated. Tests were conducted up through September 9th, and the 10th was used primarily for recovery and transit.

The shipboard ADCP measurements were collected throughout both legs of the OR1 QPE cruise. A preliminary look at the data showed a primarily zonal flow offshore (the Kuroshio) with some strong onshore flows as well onto the shelf. The ADCP flows over the shelf will need to be de-tided before anything can be concluded about low-frequency flows.

The EK500 fathometer provided high-resolution bathymetric measurements as well as backscatter within the water column. The bathymetry was quite steep near the shelfbreak, with cliffs ranging from 80-120 m near the shelfbreak and extremely broken and irregular bathymetry in the depth range of 200-700 meters. Within the water column, just shoreward of the shelfbreak, a number of features were identified which appeared to be gas seeps. This data will be passed on to appropriate investigators after the cruise for more careful analysis.

5.3.1 SeaSoar, Thermistor & Bottom-Mounted ADCP Observations

WHOI personnel worked closely with NTU SeaSoar team members during the three SeaSoar events. A cross-shelf SeaSoar transect from September 8 appears in Figure 5. Note that the stratification from offshore, over the continental slope, extends onshelf to the northern end of the transect. The track overlaid on the bathymetry appears in Figure 4. Signatures of high-frequency processes such as internal waves and a potential internal bore are apparent in the transect.

Figure 6 shows the track from an along-shelf transect along the 130 m isobaths. The temperature field is fairly uniform in the along-shelf, as can be seen in Figure 7.

The SeaSoar run the previous day, September 7th, spanned the shelfbreak. All the soundspeed profiles from this survey appear in Figure 8. While the spread of soundspeed is fairly tight in the upper 50 m of the water column, there is a considerable spread between depths of 60-120 m. Figure 9 shows the water mass structure in the T/S plot. There is a considerable spread in T/S properties between the warm, fresh surface water and the cool saline Kuroshio water at depth. The salinity maximum is roughly at the depth of the shelfbreak, 100-150 m on the offshore side of the cross-shelf transects.

5.3.2 Drifters & ADCP (V(z) Observations)

In addition to the 2 restrained drifters, Scripps also deployed 5 SVP drifters on September 7th. Although not part of the cruise, Scripps and NTU personnel are also supporting ONR and the QPE program with drifter deployments from land, and the weekly release of two SVP drifters from south-eastern Taiwan continued throughout the duration of the experiment and will extend through 2009. Luca Centurioni and Pearn P. Niiler documented their work for QPE in a report entitled *"Real-Time Drifter and ADCP V(z) Observations of Kuroshio Intrusions on East China Sea Shelf"*, included in this report in its entirety as Appendix B.

5.4 Acoustic Results

The acoustic oceanography conducted during leg 2 of the Pilot Cruise utilized OMAS vehicles as sound sources, and both standard US Navy sonobuoys and the NTU VLA as the receivers. This section will briefly cover the four OMAS events that occurred over three evenings, including preliminary tracks and measured transmission losses. The overall details of the OMAS runs are presented in Table 1, and a typical OMAS signal is shown in Figure 10. This section will also present some of the acoustic modeling conducted onboard during the cruise. The VLA data is discussed in detail in Appendix C.

5.4.1 Transmission Loss Measurements & Modeling

The Baseline OMAS runs were determined prior to the cruise, and were identified as Events 1 through 5. Due to weather constraints, only 4 events, 1, 2 and 4A and 4B were able to be conducted, and TL from these runs are discussed here. Further details of all of the events can be found in Appendix D.

5.4.1.1 OMAS Run 1, Event 1

OMAS event 1 was a repeat of the LWAD06 experiment, an ONR sponsored event that OASIS participated in by measuring TL. During LWAD06, TL measurements were made at a point that was within the area of interest for QPE, in approximately 110m of water. The OMAS and receivers were set at 90 feet depth to duplicate the previous measurements (made in July, 2006). The OMAS speed was 5 knots. The event was initiated at 01:42 Local. All systems were deployed without event. The omni buoy failed soon after launch and upon recovery it was found that the inflation buoy popped off the signal head. The reconstructed tracks and preliminary TL vs. range from the second leg of the event are presented in Figure 11. The TL data is from Track 2, a run from the south to the north. Throughout the entire event, noise associated with OR1 significantly increased the ambient noise (by ~ 10 dB). The first hour of data was contaminated by fishing boats, OR1 self-noise, and the transit of a 500 ft long ship within a mile of the SPAR buoys causing intermittent tracking of leg 1. OMAS was tracked relatively continuously throughout legs 2-3 out to ranges of 12 km. At the end of the run, both SPAR buoys were recovered after sunrise using RDF and visual sightings of the buoys. *(Additional run notes: Water Depth 109m, Wind Speed ~ 4.9 m/s, Wind Direction ~ SE 122 deg, Sea State 1, 1-3 ft seas, ~ 10 ships within 5 nmi according to the RADAR. Most ships were 50-60 ft squid boats, but freighters were not uncommon.)*

5.4.1.2 OMAS Run 2, Event 2

Event 2 was along and across the 130 m isobath. Figure 12 presents the run reconstruction and transmission loss vs. range for track 3 (west to east). DIFARs were set at 200 ft, the omni at 90 ft and the OMAS was at 200 ft with a 5 knot speed. To ensure that we obtained good signals on both SPAR buoys immediately after deployment, we programmed the OMAS to do two short 2 km legs before the 15 km legs. Event 2 began at 22:00 Local as planned. The first SPAR buoy and OMAS were launched at position 2A. The second SPAR buoy was launched at position 2B, which was shifted to the southeast an additional ½ mile to increase the length of the baseline for higher resolution at longer ranges. The second DIFAR deployed with 2nd SPAR buoy failed to operate and a 3rd was immediately launched. The ship was then moved 1.5 mile away (modified 2C) to reduce own-ship ambient noise. (Thrusters/engine evolution for OR1 significantly increased ambient noise with separation of 1 nmi.) DIFAR #1 gave good results for the first 3 hours, then inexplicably failed. Omni #1 and DIFAR (position 2B) provided good signals until the end of the run. The run ended at 03:30 (local) when we lost the OMAS at a range in excess of 11 km and both SPAR buoys were recovered in total darkness using RDF and visual sightings of the strobes. *(Additional run notes: Water Depth 124m, Wind Speed ~ 5.8 m/s, Wind Direction ~ 80 deg, Sea State 1, 1-3 ft seas, ~ 25 ships within 10- nmi according to the RADAR. Most ships were 50-60 ft squid boats, but freighters were not uncommon.)*

5.4.1.3 OMAS Run 3, Events 4A and 4B

Due to the rapid approach of Typhoon *Sinlaku*, Event 3 was cancelled in order to conduct two circular OMAS runs Events 4A and 4B on September 9th. The reconstructed tracks are shown Figure 13, along with the DIFAR sonobuoy locations. The diameters of the circles for both of the runs were modified based on TL information obtained during the first two OMAS events. The programmed radius for Event 4A, the northern circle, was set to 5 km, and 6 km for the southern circle. The OMAS vehicles and the sonobuoys were all set to run at 200'. The northern circle was centered at approximately 110m, and represented a relatively flat, slightly sloping bottom. The southern circle was positioned over the steeply breaking shelf. Figure 13 presents the TL obtained from both circles, with the 1100 Hz TL vs. bearing shown in blue for the northern circle (Event 4A), and 900 Hz TL data shown for the southern circle in red (Event 4B). As can be seen in the top figure, the TL, which has been range corrected to 6 km, is spatially variable, with increased loss seen along propagation directions parallel to the 125m isobaths. As can be seen in the bottom figure for the southern circle that was positioned over the shelf break, no TL was measured during the portions of the circular run when the OMAS was in deeper waters. The means of these two TL plots were combined in Figure 15, showing that there were nearly 5 dB more TL measured over the shelf break. *(Additional run notes: Shipping density ~ 20 ships within horizon (visible); Water depth 132 m; Wind 5.8 m/s; Wind direction 79 deg (E); Sea State 2, 3-5 ft with swell.)*

5.4.1.4 Acoustic Modeling

In order to support test planning and initial environmental characterization a set of numerical model runs were computed while at sea. The initial runs were computed using the measured profile from the CTD measurements, shown in figure 16. Broadband Normal Mode computations were performed for range-independent sections corresponding to OMAS runs 1 and 2. The intention was to move to range-dependent sound speed, bathymetry and propagation modeling using SeaSoar data, 1-minute resolution bathymetry and Parabolic Equation modeling, but the change in test schedule due to the Typhoon Sinlaku pre-empted this work. For post-test analysis a higher resolution bathymetry will be used as well as the SeaSoar sound speed structure.

Three sediments were used as initial provinces for the propagation modeling: sand, silty-clay and mud. These sediments were chosen in discussion with Charles Holland during the pre-test sensitivity analysis and are described in detail in the Pilot Test Environmental Sensitivity Analysis by Kevin Heaney. The 900Hz Transmission Loss for the 106m isobath (OMAS 1) is shown in Fig. 17.

In order to directly compare measured TL from the OMAS system with models, we computed the broadband arrival structure. The field at the receiver depth is computed for each frequency across the band, a normalized FFT is performed with a window moving with the pulse. The evolution of the pulse in range for each sediment type is shown in Fig. 18.

Each consecutive arrival at a particular range is due to one additional bottom bounce. Two mechanisms drive the shape of this distribution. The critical angle is driving the slope of the closest range that a particular bottom bounce is observed. For these sediments, with a 12 m bottom, the effective critical angle of the silty-sand bottom is higher than the sand bottom. This is due to the very soft sediment's acoustic transparency the relatively hard basement (c_p=1800 m/s). The mud sediment has a very low critical angle. The second effect is the attenuation, which governs the number of bounces observed at longer ranges, commonly referred to as mode-stripping. The silty-sand sediment, although it has a higher effective critical angle, is more attenuative so it strips energy away at longer ranges. An example of range-dependent modeling for the cross-slope run, which unfortunately was cancelled due to the typhoon, is shown in Fig. 19.

The OMAS TL results are computed from estimating the peak of the HFM matched filter output. Another option is to do the energy integral but for low SNR cases this is problematic because noise is included in the TL estimate. The broadband acoustic modeling results above can be used to compare directly with the peak of the HFM matched filter. The comparison between narrowband TL, peak of the matched filter output and frequency averaged TL are shown in Fig. 20.

Fig. 20 illustrates that the normalization (from received energy pulse) to Transmission loss has been correctly calibrated. It also reveals that the peak of the matched filter output is within 1 dB of the band averaged TL except for shadows of the convergence zone where it is up to 5 dB higher.

We are now in a position to directly compare OMAS TL estimates with model predictions. The data-model comparison for OMAS Run 1 (as well as LWAD06) estimates with the acoustic predictions is shown in Fig. 21. This curve shows the 1/3 octave range averaging performed on the data by Chris Emerson. The same range-averaging has been applied to the model results. Future analysis involves directly comparing the matched filter output with the broadband model predictions to examine the structure of the pulse vs. range.

5.4.2 Acoustic Vertical Line Array (NTU ARL)

Chi-Fang Chen and her team from the Department of Engineering Science and Ocean Engineering, National Taiwan University, deployed and operated a VLA for all of the OMAS TL runs. In addition, they also conducted a separate experiment utilizing a ship as a source, when no other hydrophones were in the water. She and her team provided a report to describe the work conducted, entitled "*Deployment Report of NTU-VLA*". It is included in its entirety as Appendix C.

5.5 Bathymetric Observations (UNH)

UNH scientists Brian Calder and Larry Mayer acquired the EK500 data from the three OR ships, and have processed a significant amount of the data. The results from this work will be published in a separate report.

5.6 Regional PO and Acoustics Modeling and Forecasting Results (MIT)

The MSEAS group at MIT conducted real-time data assimilation, ocean model forecasting and acoustic propagation modeling in support of the QPE Pilot Experiment. Results were posted daily and on the web site: http://mseas.mit.edu/Sea_exercises/QPE. Two figures were downloaded daily from the web site by scientists aboard the OR1 for use in planning. The modeling and forecasting results were described and discussed daily on the web-site.

5.6.1 Pre-Pilot Experiment

Prior to the Pilot Experiment, studies were carried out to examine available bathymetries (Fig. 22) and determine conditions which influence the formation and strength of the Cold Dome. Two versions (improved Version 9 and Version 10.1) of the Smith and Sandwell (S&S) bathymetry were studied, along with a bathymetry provided by NCOR. S&S V9 was found to have an overly smooth shelf and a questionable trench following the west coast of Taiwan while S&S 10.1 has numerous unverifiable small scale structures in the shallower regions. The NCOR bathymetry seems most accurate but is too smooth. The pre-pilot simulations found that the transport through the Taiwan Strait has a significant influence on the formation and strength of the cold dome north of Taiwan, with southward transport being more favorable to the cold dome's formation. This result is independent of the bathymetry utilized. Secondly, the amplitudes of the vertical velocities are found to be sensitive to the slope of the bathymetry utilized and horizontal resolutions and mixing parameterizations.

5.6.2 Dynamical Ocean Modeling and Forecasting

Nowcast and forecast products with dynamics and uncertainty descriptions were provided for physical (T, S, velocity) and acoustical (sound speed and transmission loss) variables for the period 6-12 September 2008. An analysis of the regional dynamics and a description of the simulations were part of each product set. Forecast skill metrics were computed to compare the results utilizing differing initial transport imposed between Taiwan and mainland China (0, ±1 Sv). Based on these metrics it appears that, in the period 3-5 Sep 2008, the net transport between Taiwan and mainland China was either zero or 1Sv northward.

The five sets of synoptic data have been found to be in good agreement. The mixed layer depth is found to vary greatly in time and space, ranging from a depth of a few meters to over 50m, indicative of sub-mesoscale features and internal tides and waves. Figure 23 shows plots of sound speed versus depth for the CTD casts and SeaSoar. The CTDs show a deep (~800m) sound speed minimum. In the range of 0-200m, the data shows the large sound speed variability (15-30m/s) which can be found at any particular depth, even in the limited geographical extent covered by the SeaSoar.

The dynamical simulations were forced with a combination of COAMPS (wind stress) and NOGAPS (heat-flux, E-P) atmospheric forcing in light of unexpected values in certain forcing data. The winds were found to be highly variable in both speed and direction during the Pilot Study. The data collection was extended in order to capture the passage of Typhoon Sinlaku in mid-September. The passage of this storm is well-captured in both the COAMPS and NOGAPS products.

The ¼^o June-Aug summer climatology both supported the Kuroshio structure and provided a reasonable match to the data, while a 1^o September climatology was found to have insufficient horizontal resolution to support the Kuroshio. SST and model simulations assimilating the in situ data indicated some upwelling of deeper Kuroshio water on the shelf just north of Taiwan, with nice filaments being advected north-eastward along the shelfbreak on the edge of the Kuroshio. This situation of a meander of the Kuroshio was common in the pilot study area. The transport through the Taiwan Strait remained a major uncertainty. For each forecast 2-3 different initial transport cases were tried and compared to available in situ data and SST. Two transport cases were issued, one being designated the primary issue (Figure 24).

Issued and tested initial transport cases							
Transport	**6 Sep**	**7 Sep**	**8 Sep**	**9 Sep**	**10 Sep**	**11 Sep**	**12 Sep**
2.5 Sv S	Issued	Issued	tested				
1 Sv S			Issued	Issued	tested	issued	issued
0 Sv				tested	Issued	Issued	Issued
1 Sv N	issued	issued	issued	issued	issued	tested	tested
Key: Issued=primary forecast; issued=secondary; tested=unissued run							

Seven snapshot realizations of the OR1 initialization survey were created by objectively analyzing the data every 12 hours in the period 2-5 Sep 2008. From these realizations, volume averaged bias and RMS errors were computed for each forecast of 3 different 9 day forecasts, using the misfits between these forecasts and the objectively analyzed data where the error estimates of the OAed data are small enough. Results are presented in Figure 25. It appears that, after 2 Sep 2008, the net transport between Taiwan and mainland China was either zero or 1Sv northward.

5.6.3 Acoustical Modeling and Forecasting

Acoustic forecast simulations were run in both along-section directions for each frequency and for the two contrasting different initial transports through the strait of Taiwan for each daily forecast pair. The source depth was set at 50m below the sea surface. Figures 26 and 27 illustrate results for September 12, 2008, where one simulation has a zero initial net transport in the Taiwan Straits and the other simulation a southward transport of 1.0 Sv. Acoustic Forecasts were issued daily. For example, figure 24 shows transmission loss for the two differing initial Taiwan Strait transports, while Figure 25 shows the differences in transmission loss from an average of the upper 50 m layers for those same cases. The analysis shows the acoustic uncertainties fluctuations can reach 10-15 dB at some distance, particularly in the cases with complicated bathymetry profiles, such as the across-shelf2 case and canyon case. These uncertainties are of the same order as the reported uncertainties (approximately 20-30 dB) due to sea bed bottom properties.

6.0 Marine Mammal Observations

Care was taken throughout the experiment to be aware of, and record the presence of, any and all marine mammals in visual or acoustic range during these experiments. The only visual sighting of any marine mammals occurred during September 6th, within an hour of leaving Keelung Harbor, when a pod of approximately 30 dolphins were noticed swimming near the ship. No other marine mammals were sighted throughout the entire Leg 2 cruise. Monitor speakers were used during all of the acoustic experiments, and no obvious whale vocalizations were identified.

Acknowledgements

During the cruise, a number of people were in contact with the ship via the satellite communications system. Sen Jan of National Central University provided forecasts of the tropical depression and typhoon as did Joe Wang of National Taiwan University. Joe Wang also provided wave forecasts which were extremely useful in planning weather limited activities such as the mooring recoveries. Professor Wang monitored the ocean buoys east of Taiwan. Pat Cross of OASIS Inc. also provided information from US Navy forecasts. Chris Miller of NPS assisted greatly with shipping.

We also thank our managers at ONR, Captain Douglas Marble and Professor Ching-Sang Chiu of the Naval Postgraduate School, for their support and encouragement.

Table 1. Acoustic Mobile Source (OMAS) Run Descriptions

Date	OMAS S/N	Geometry	Signal	Max Range	Depth	Lifespan	Buoy Type	Buoy Depth
9/6/2008	15304	EVENT 1: LWAD06-01 FAST Site 2 Repeat 15km South, 15km North, West Until Vehicle Scuttles	3x 2-sec 800-1000Hz Upsweeps 3x 2-sec 550-650Hz Upsweeps 800, 900, 1000Hz CWs	13km	90ft	4:00	DF,OM,DF	90ft , 90ft , 90ft
9/7/2008	15306	EVENT 2: Parallel and Perpendicular to 130m Isobath	3x 2-sec 800-1000Hz Upsweeps 3x 2-sec 550-650Hz Upsweeps 800, 900, 1000Hz CWs	12.5km	200ft	5:00	DF,OM,DF	200ft , 90ft , 200f
9/8/2008	15311	EVENT 4A: 5km radius circle over shelf "Spatial Coherence" Run	2 x 2-sec 1000-1200Hz Upsweeps Alternating 2-sec 800-1000Hz Upsweeps and 2-sec 550-650Hz Upsweeps	14km	200ft	7:00	DF,OM,DF	200ft , 200ft , 200
	15305	EVENT 4B: 6km radius circle - half over shelf, half over deep water	3x 2-sec 800-1000Hz Downsweeps 3x 2-sec 550-650Hz Downsweeps 780, 880, 980Hz CWs	13km	200ft	6:30		

Table 2. CTD cast time, locations and depths for OR2.

CTD #	Date	Lat, °N	Lon, °E	Water Depth (m)	Time (hhmm)
1	8/23	25-30.269	121-59.839	120	1333
2		25-29.917	122-15.123	276	1516
3		25-15.032	122-14.995	209	1926
4		25-14.966	122-00.034	148	2138
5		25-00.000	122-05.068	231	2342
6	8/24	24-44.953	122-05.016	111	0139
7		24-45.090	122-15.176	338	0248
8		24-45.135	122-30.203	1032	0427
9		24-45.112	122-45.201	1332	0750
10		24-45.064	123-00.110	1583	1001
11		25-00.133	123-00.226	1604	1213
12		25-00.063	122-45.131	1494	1553
13		25-00.120	122-30.205	1456	1939
14		25-00.549	122-14.850	1018	2222
15	8/25	25-15.046	122-30.060	775	0117
16		25-15.194	122-45.129	1279	0320
17		25-15.080	123-00.286	1629	0523
18		25-29.966	123-00.146	781	0755
19		25-44.939	123-00.134	340	1004
20		25-59.911	122-59.956	99	1151
21		25-59.970	122-45.038	115	1333
22		25-45.088	122-45.114	137	1524
23		25-30.257	122-45.449	1291	1812
24		25-29.927	122-30.177	433	2043
25		25-44.931	122-29.898	117	2249
26	8/26	26-00.000	122-30.158	111	0036
27		26-00.000	122-15.138	104	0224
28		25-44.956	122-14.981	118	0427
29		25-44.851	122-00.413	119	0704
30		25-59.781	122-00.574	102	0917
31		25-59.986	121-45.002	115	1224
32		25-59.883	121-29.831	71	1431
33		26-00.002	121-14.983	84	1604
34		25-59.949	120-59.986	84	1739
35		25-44.956	121-00.132	86	1928
36		25-44.987	121-14.980	80	2056
37		25-45.025	121-30.055	81	2222
38		25-45.078	121-44.913	116	2348
39	8/27	25-29.950	121-45.067	114	0142
40		25-29.939	121-29.514	116	0321
41		25-30.040	121-14.896	78	0447
42		25-22.569	121-30.000	81	0647
43		25-15.027	121-45.076	92	0829

Table 3. CTD cast time, locations and depths for OR1 Leg 2.

CTD #	Station	Date	Lat, °N	Lon, °E	Water Depth (m)	start time hhmm	end time hhmm	Temp °C	Wind Dir. deg	Wind Speed m/s	Pressure mb
1	3	9/6	25-55.71	122-33.92	114	2259	2312	27	060	5	1018
2		9/7	25-56.55	122-27.00	114	0005	0020	27	110	8	1018
3	1-C		26-24.41	122-31.06	108	0225	0235	27	090	6	1018
4			25 57.10	122 29.61	113	0600	0610	27	090	6	1012
5	1-A		26-01.97	122-31.96	112	0828	0841	28	080	7	1018
6	S2		25-39.88	122-28.67	162	2011	2026	27	050	5	1016
7	2-A		25-42.60	122-36.04	125	2125	2137	27	050	5	1017
8	2-C		25-42.20	122-37.76	145	2225	2237	27	050	5	1017
9	2-C	9/8	25-43.72	122-38.01	132	2259	2313	27	050	5	1017
10			25-46.01	122-37.65	129	0320	0330	27	050	5	1017
11			25 52.94	122 32.41	112	0643	0646	28.7	62.6	4.6	1011
12	8B		25 33.10	122 41.66	699	1845	1925	27	50	10	1010
13	S6		25-35.52	122-40.45	599	1957	2035	27	060	10	1015
14	9A	9/9	26-13.66	122-36.58	104	1039		28	060	9	1016

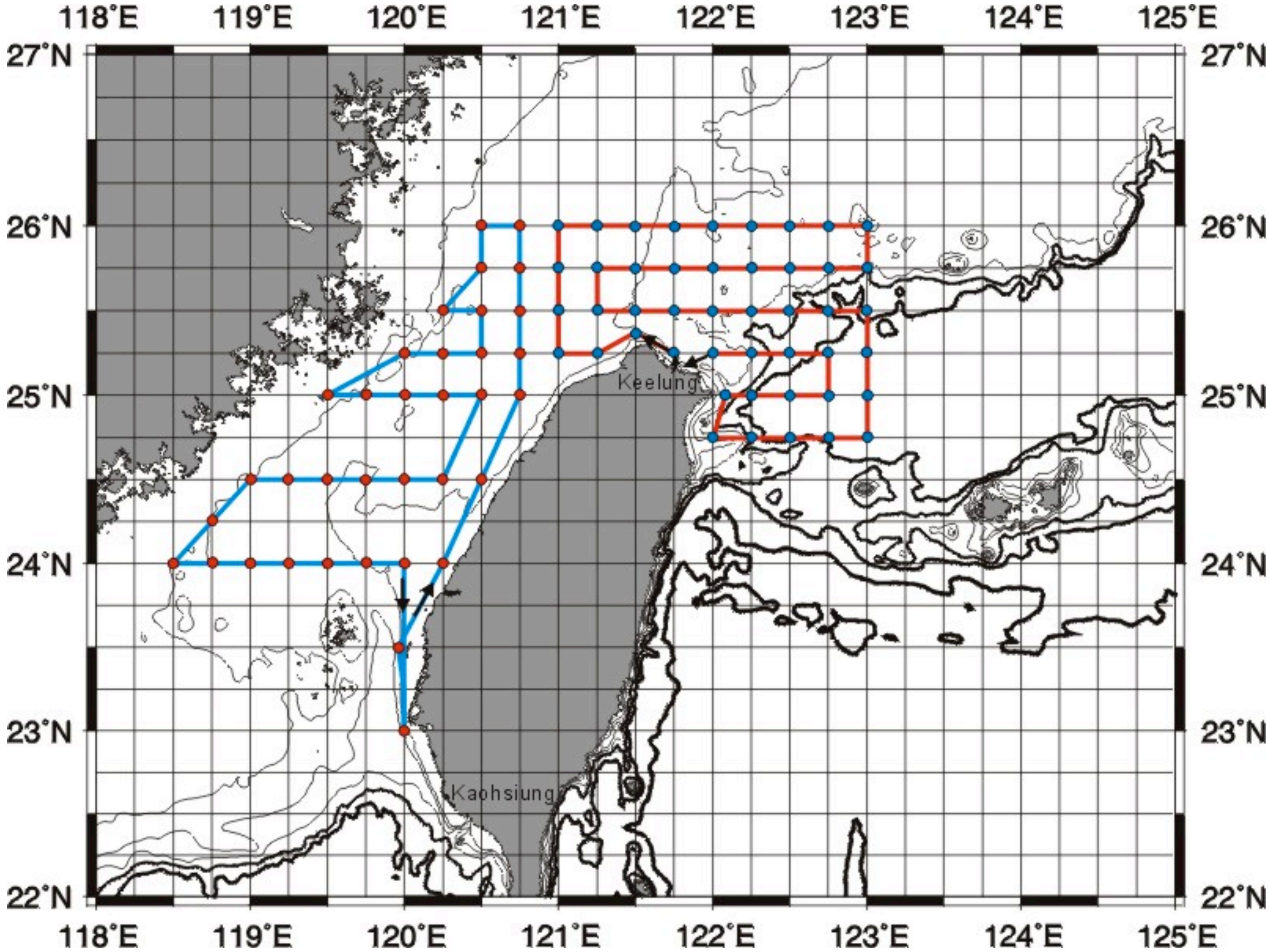


Fig. 1A. This figure shows the CTD stations and cruise tracks for the OR2 (blue line) and OR3 (red line) obtained during the Large Scale Hydrography cruises made during Aug. 22-27. The isobaths indicate 50, 100, 200, 500, 1000 and 3000 m from thin to thick lines.

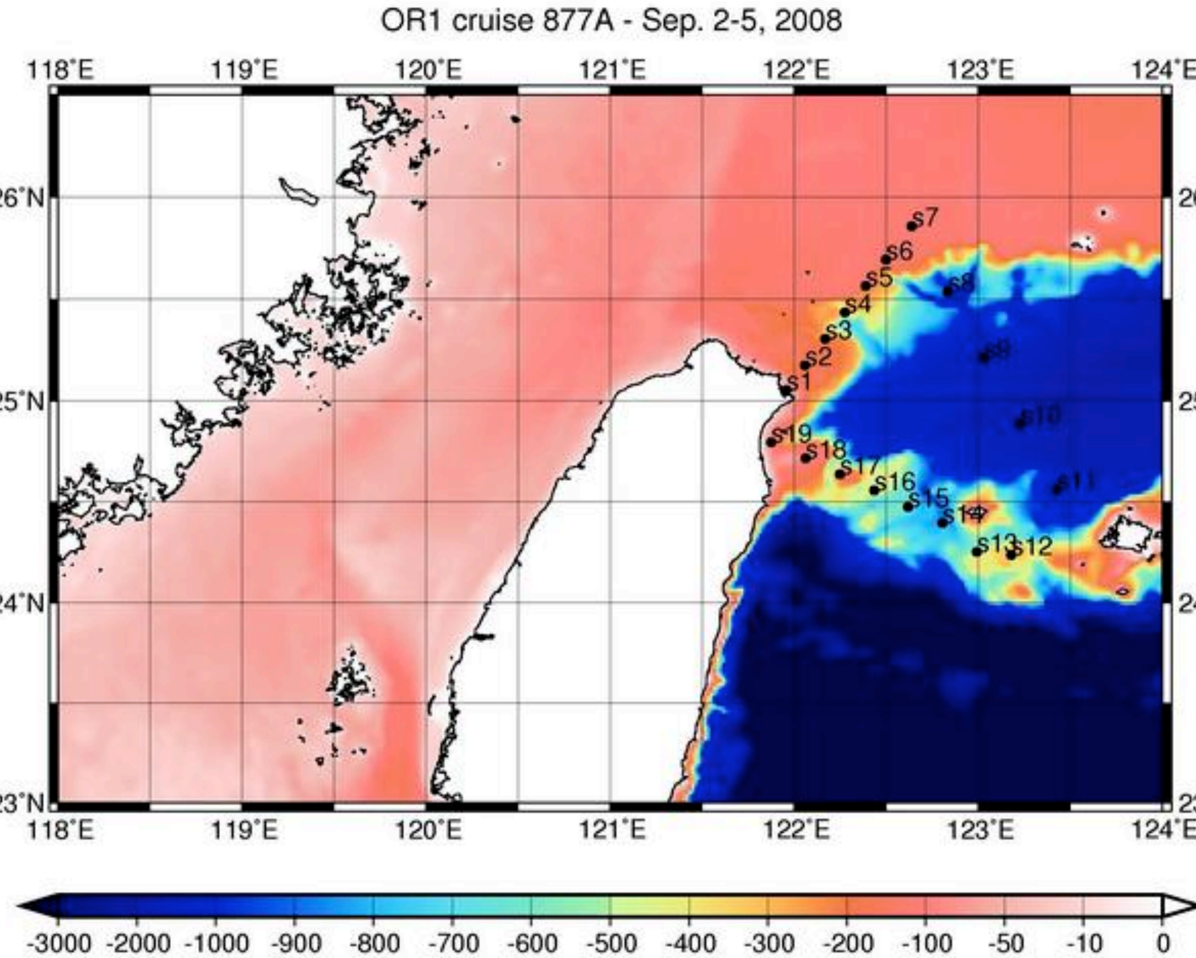


Fig. 1B. CTD stations for the OR1 cruise no. 877A, in which line S1 to S7 is the Leg #1, line S7 to S11 is the Leg #2 and line S12 to S19 is the Leg #3 of the triangle.

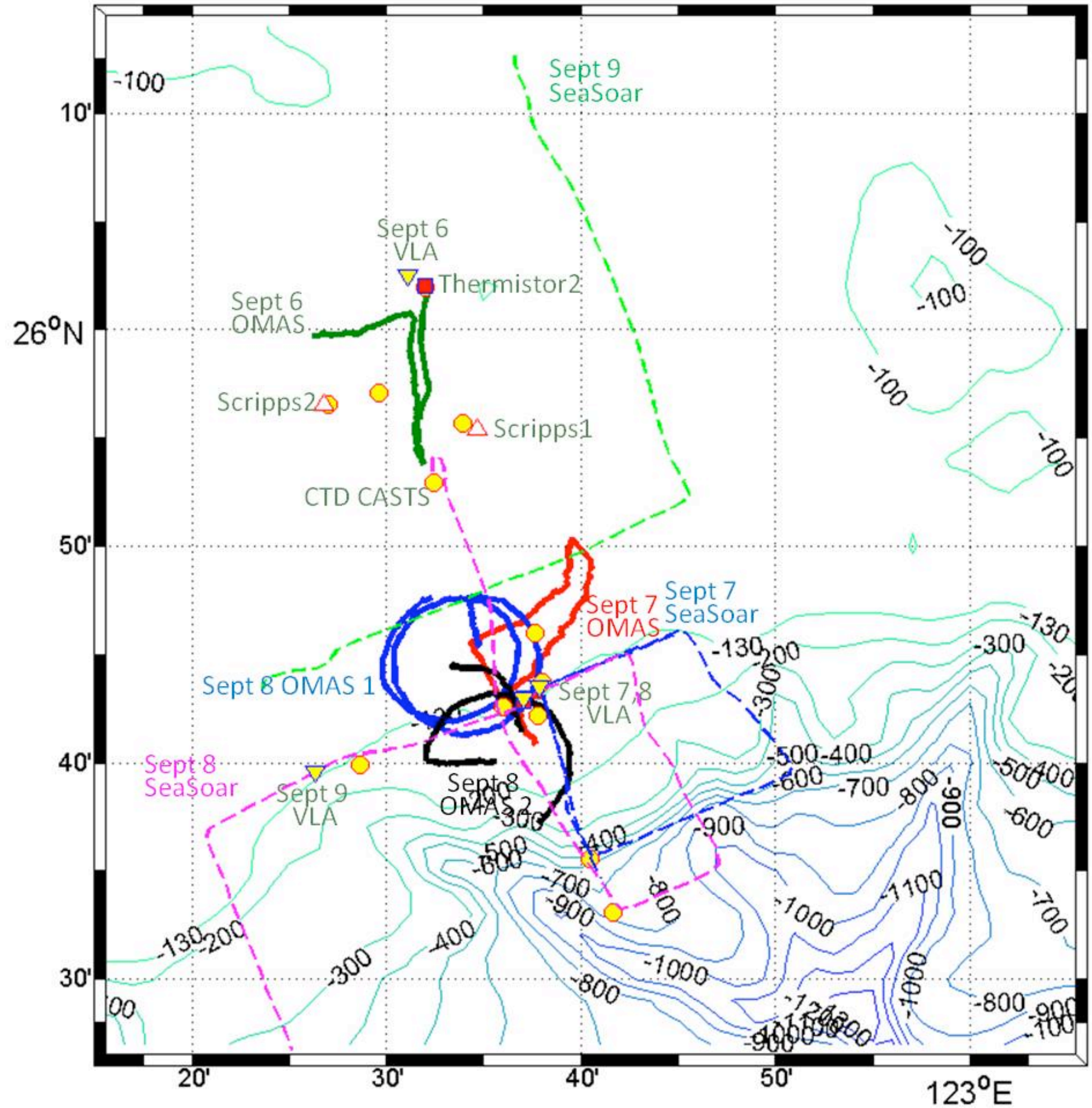


Fig. 1C. Overview of QPE '08 Pilot Cruise, Leg 2 measurements. The overall area of interest is identified with the solid red box. CTD casts are solid yellow circles, VLA locations are solid yellow triangles, Scripps moorings are identified with red and white triangles, thermistor moorings are solid red (one thermistor mooring cannot be seen, but is in the center of the activity near the 9/7 and 9/8 VLA deployments). The SeaSoar tracks are identified with dotted lines, and solid lines denote the reconstructed OMAS tracks.

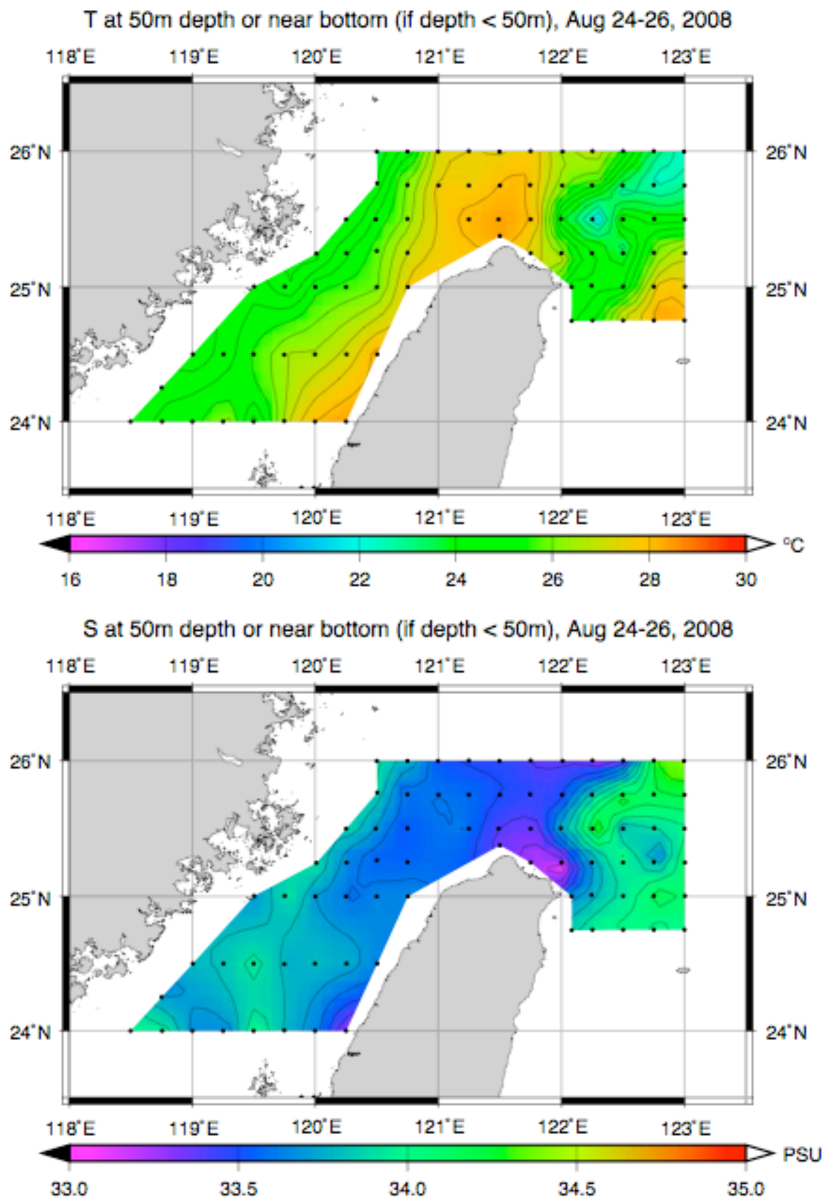


Figure 2- Temperature (upper panel) and salinity (lower panel) from combined OR2 and OR3 hydrographic data from August 22-27.

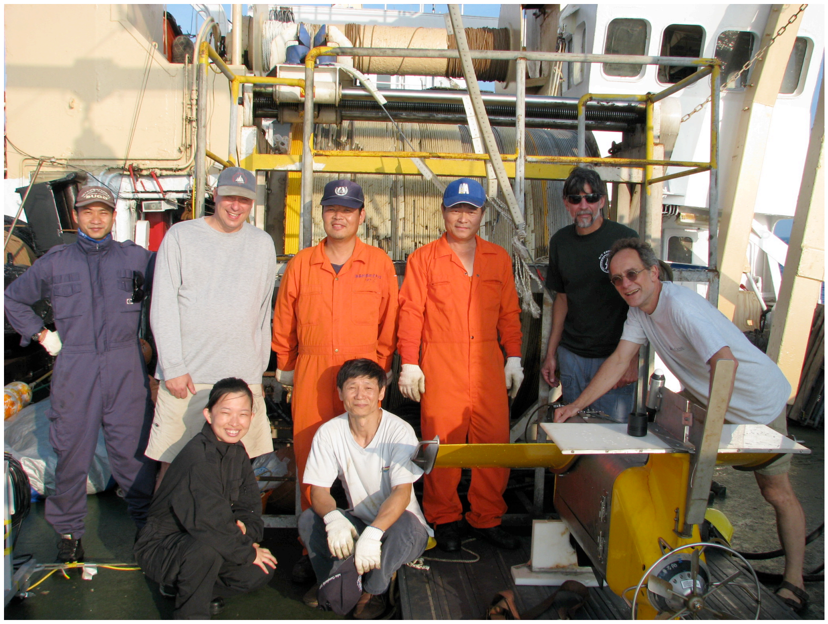


Fig. 3. NTU's Institute of Oceanography's SeaSoar, with the full SeaSoar team.

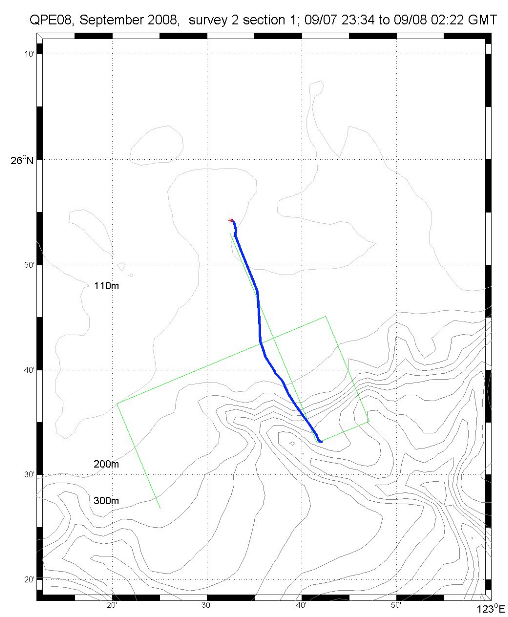


Figure 4. Cross-shelf track of SeaSoar, Sept. 8. The total track length is 40 km.

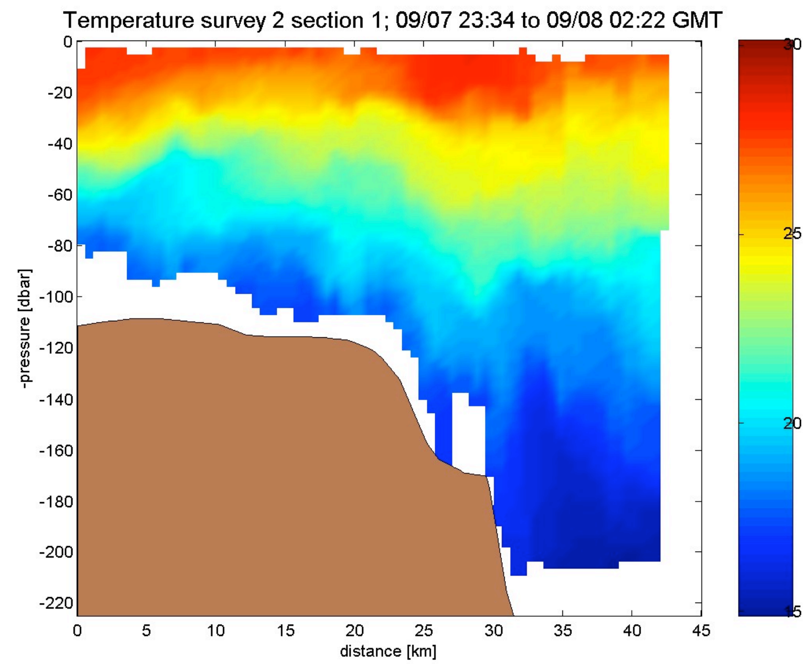


Figure 5. Cross-shelf SeaSoar temperature transect on Sept. 8.

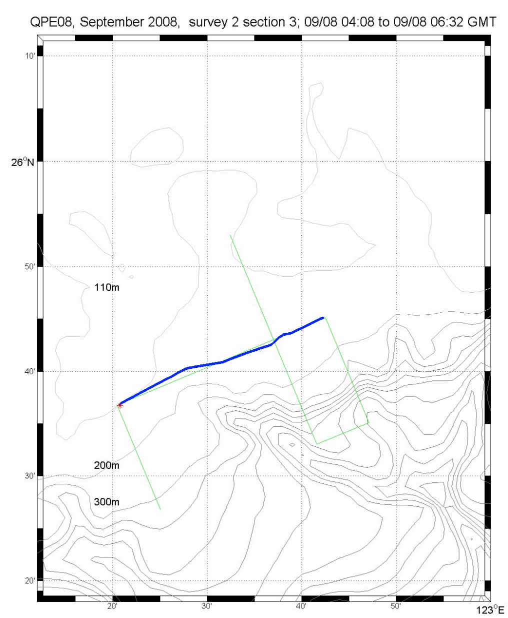


Figure 6. Along-shelf tracks of SeaSoar, Sept. 8. Total track length is 40 km.

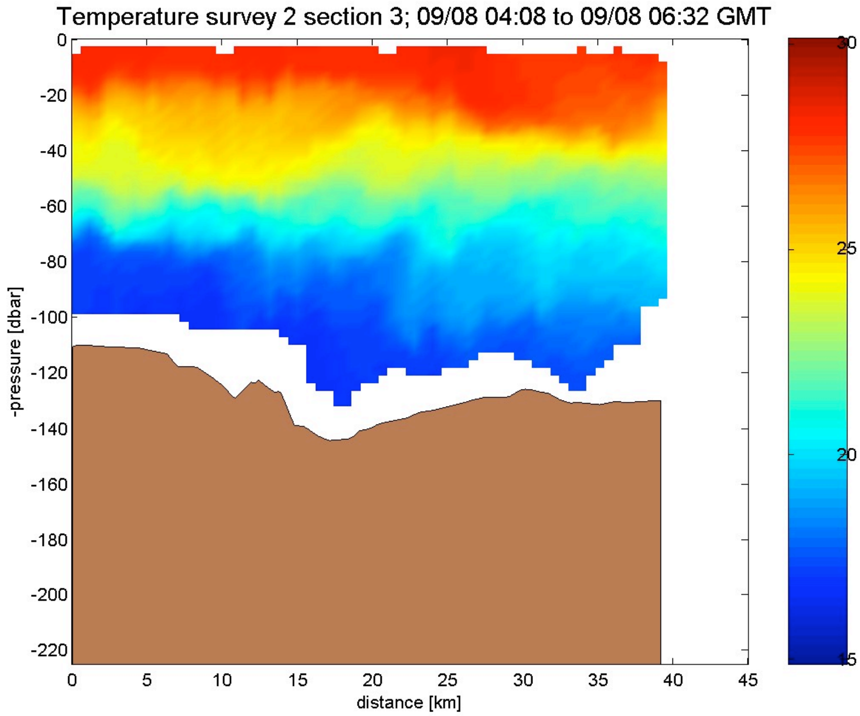


Figure 7. Alongshelf SeaSoar temperature transect on Sept. 8.

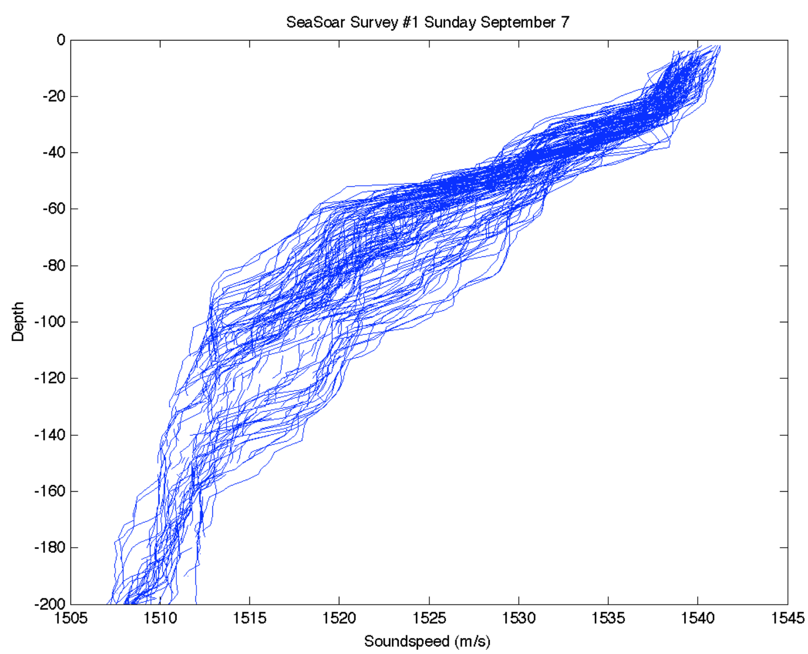


Figure 8. Seasoar Survey #1, Sept. 7^{th}; all soundspeed profiles.

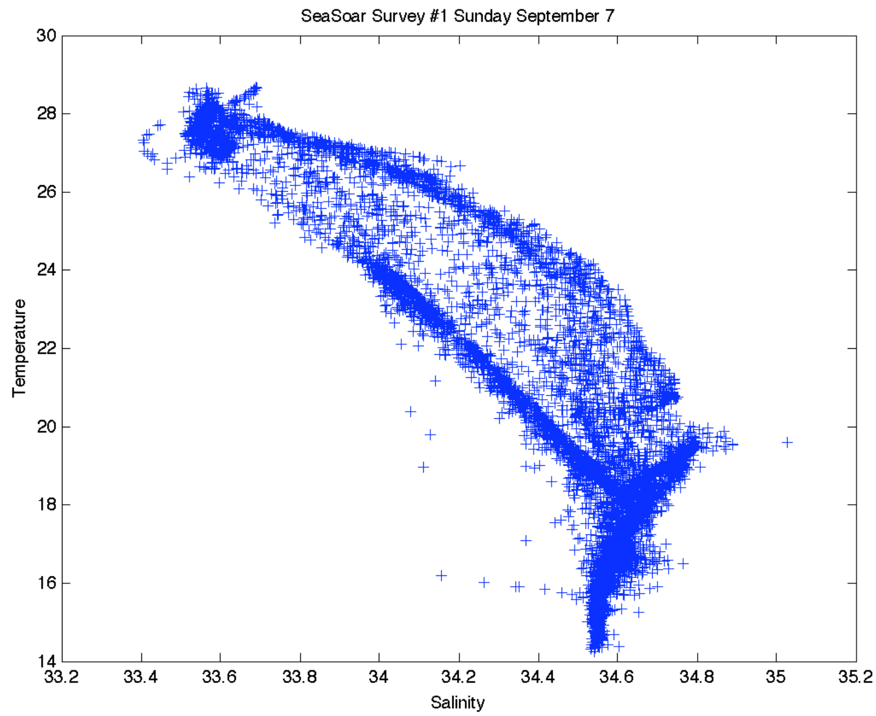


Figure 9. Seasoar Survey #1, Sept. 7th; Temperature/Salinity diagram.

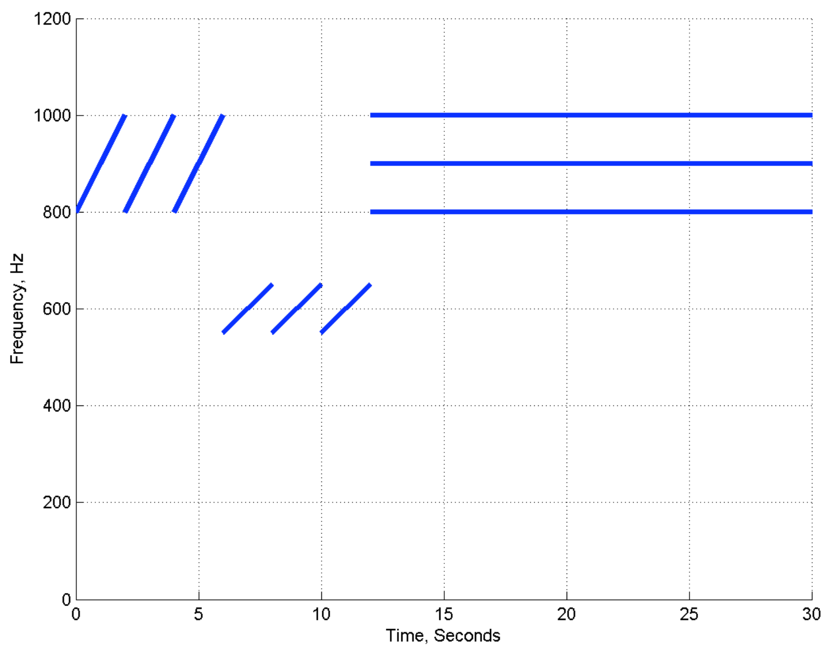


Fig. 10. Typical broadcast signal of OMAS vehicle (used during events 1 and 2), repeated every minute. The signal starts with three 200 Hz BW HFM upsweeps (800-1000 Hz), followed by three 100 Hz BW HFM upsweeps (550-650 Hz). The remainder of the minute (48 sec) consists of three CW's at 800, 900 and 1000 Hz.

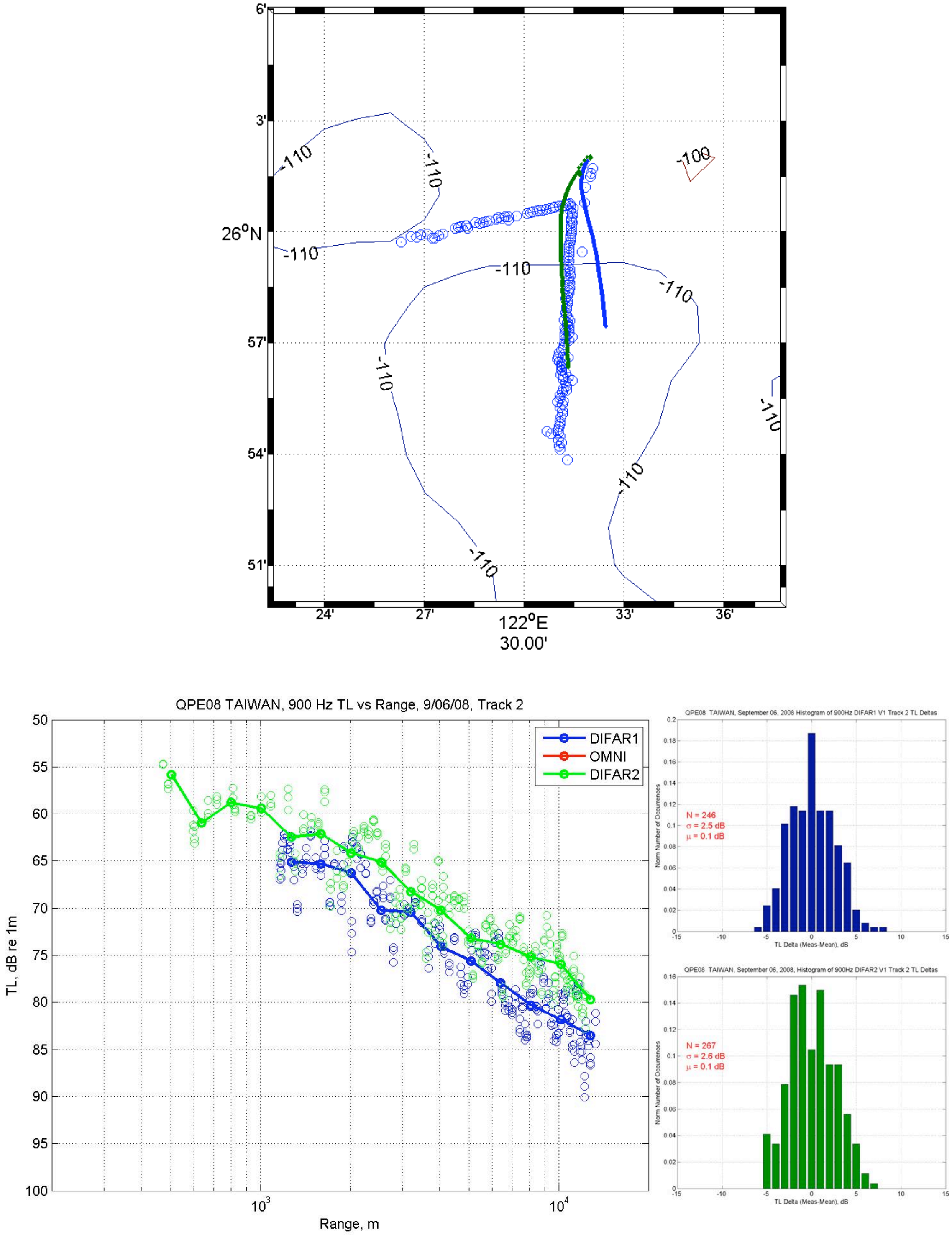
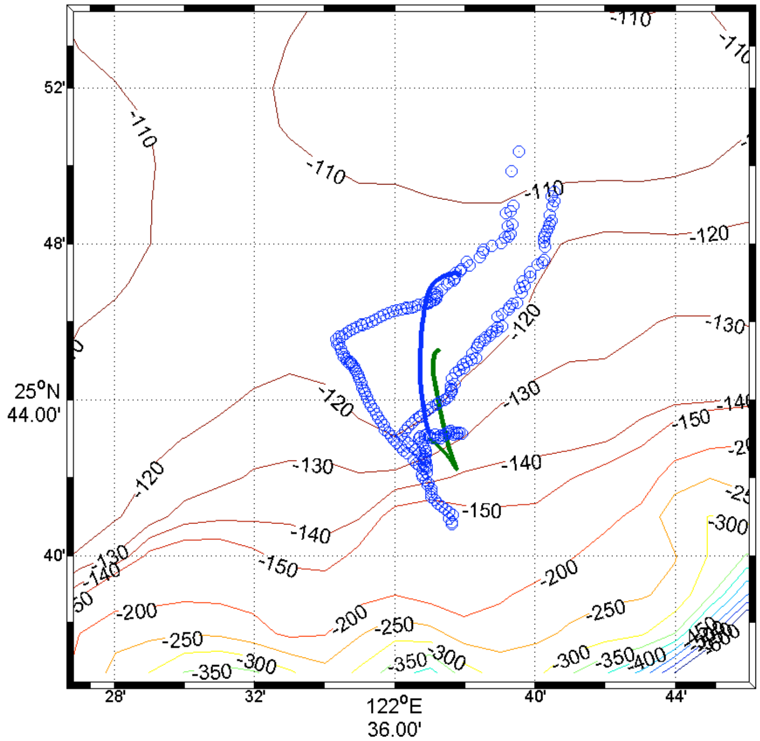
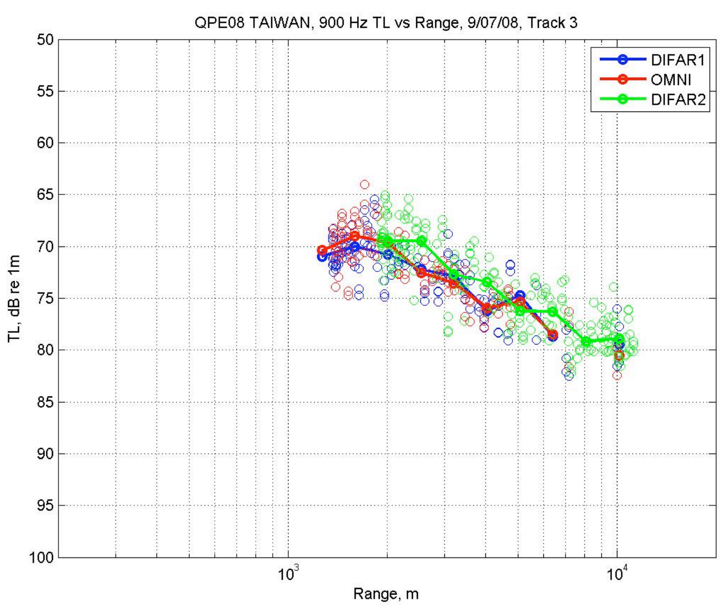


Fig.11. September 6, Event 1 Reconstruction (top) and 900 Hz TL from track 2 (bottom). OMAS # 15304; ds=90ft, dr = 90ft. (no data was obtained from the omni hydrophone).





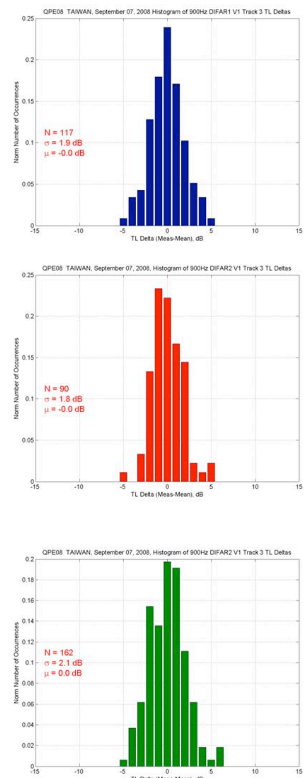


Fig.12. September 7, Event 2 Reconstruction (top) and 900 Hz TL from track 3 (bottom). OMAS # 15306; ds=200ft, dr = 200, 90, 200ft

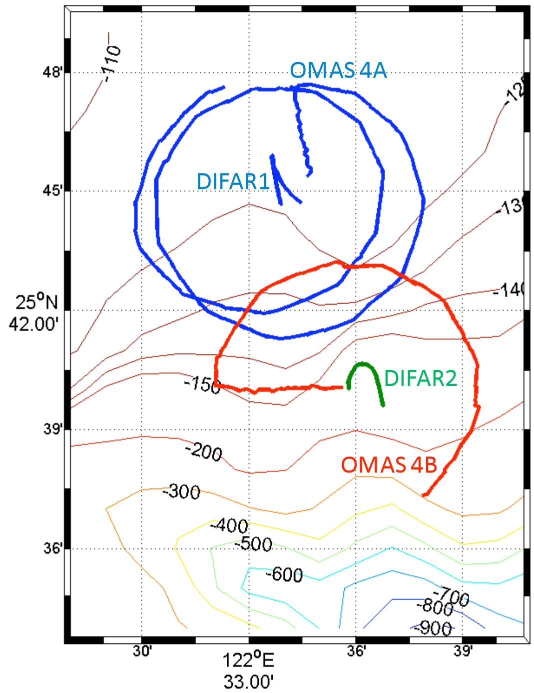


Fig.13. September 9, Event 4A and 4B Reconstruction. The diameter of the northern circle (Event 4A) was 5km, and 6km for the southern one.

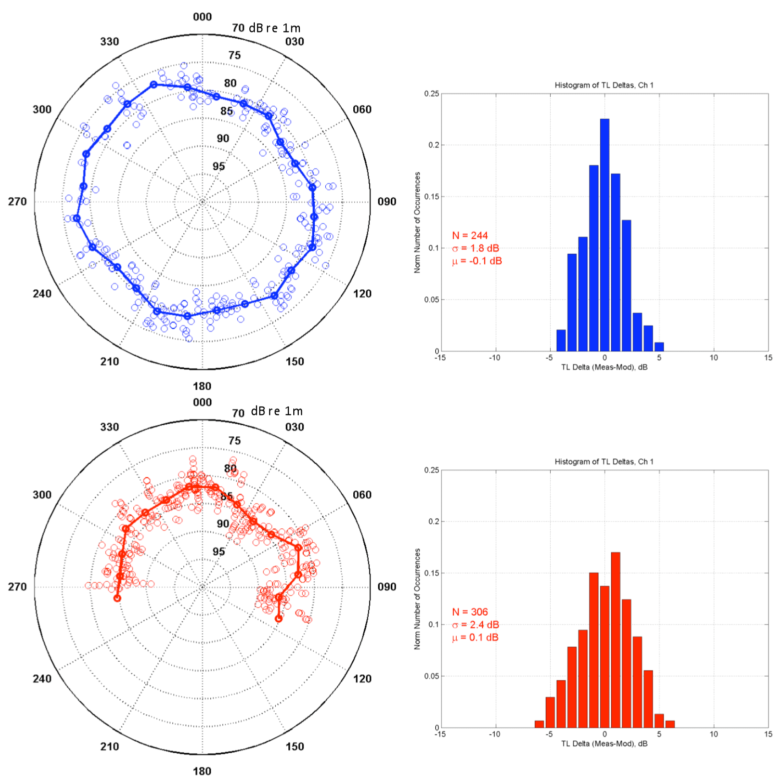


Fig.14. QPE08 TAIWAN, 9/8, OMAS 4A (Top in Blue) and 4B (Bottom in red) TL. The left side shows TL vs. bearing with 15° bearing sector averages (bold lines). Histograms of the variation of individual TL data points about the mean are shown to the right. Center frequencies are 1100Hz for OMAS 4A and 900Hz for OMAS 4B. For both vehicles, ds=200ft. dr = 200ft.

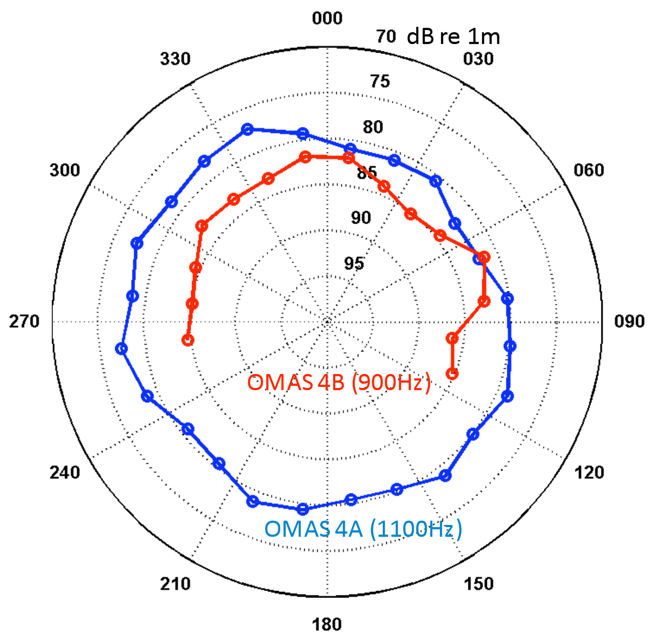


Fig.15. Comparison of the Sept. 9th mean TL data from OMAS 4A (Blue, 1100Hz) and 4B (Red, 900Hz) vs Bearing.

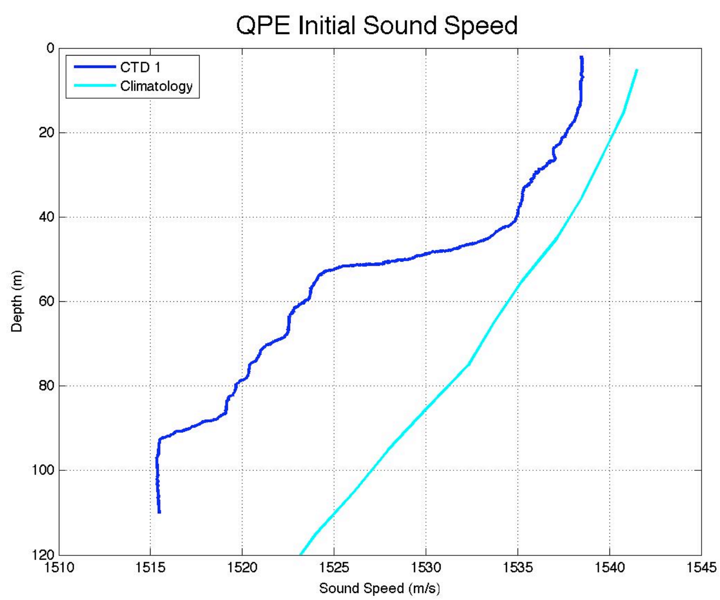


Figure 16. Measured (CTD) sound speed profile compared to the Climatological average (provided by Glen Gawarkiewicz).

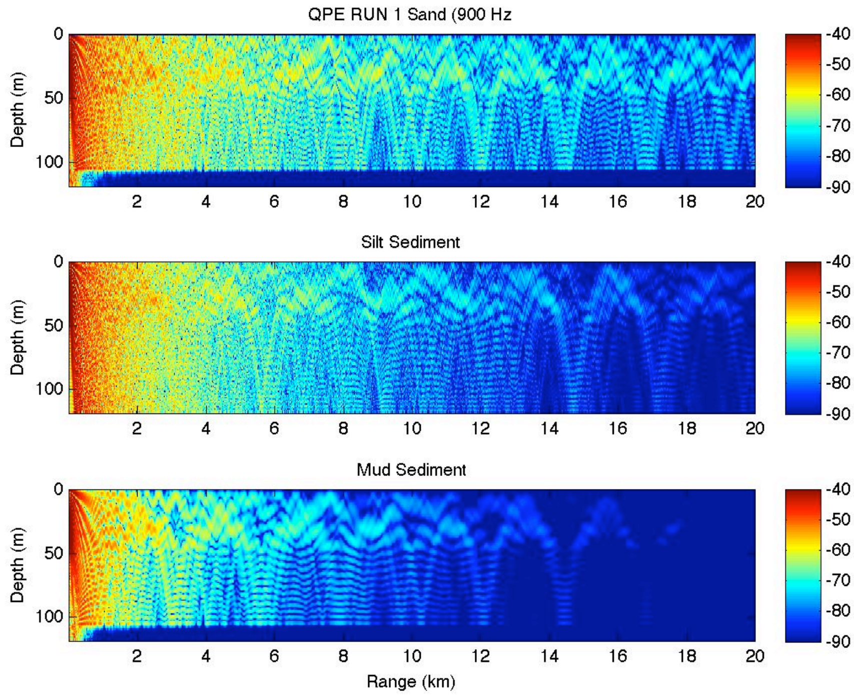


Figure 17. 900 Hz TL for 3 sediment types for OMAS 1. Sediments are Sand, Silty-Clay and Mud. The source depth is 30m, corresponding to the 90 ft used in the test.

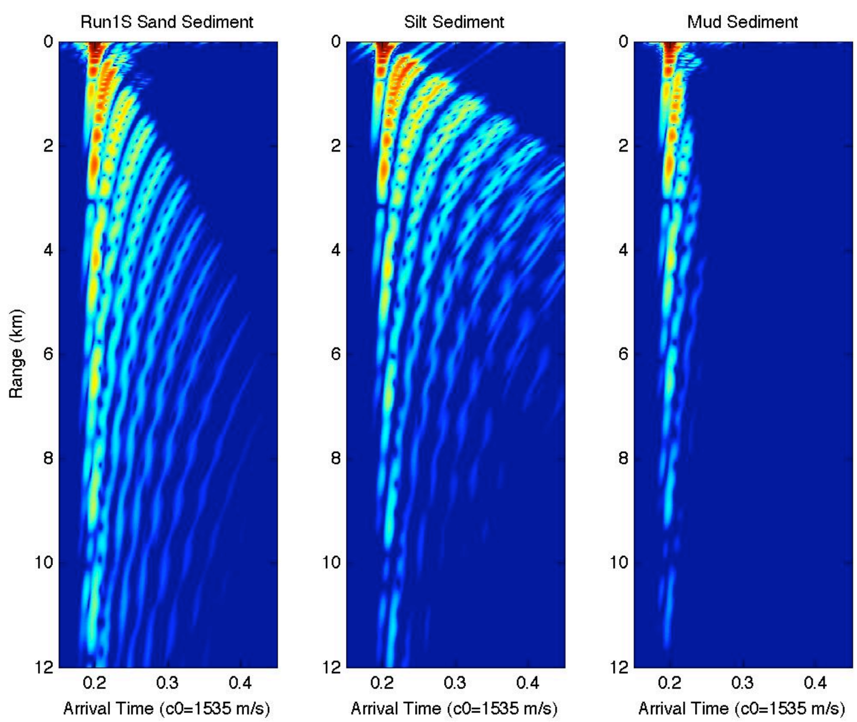


Figure 18. Broadband modeled pulse evolution for 900Hz center frequency pulse. The window is moving with a constant 1535 m/s speed.

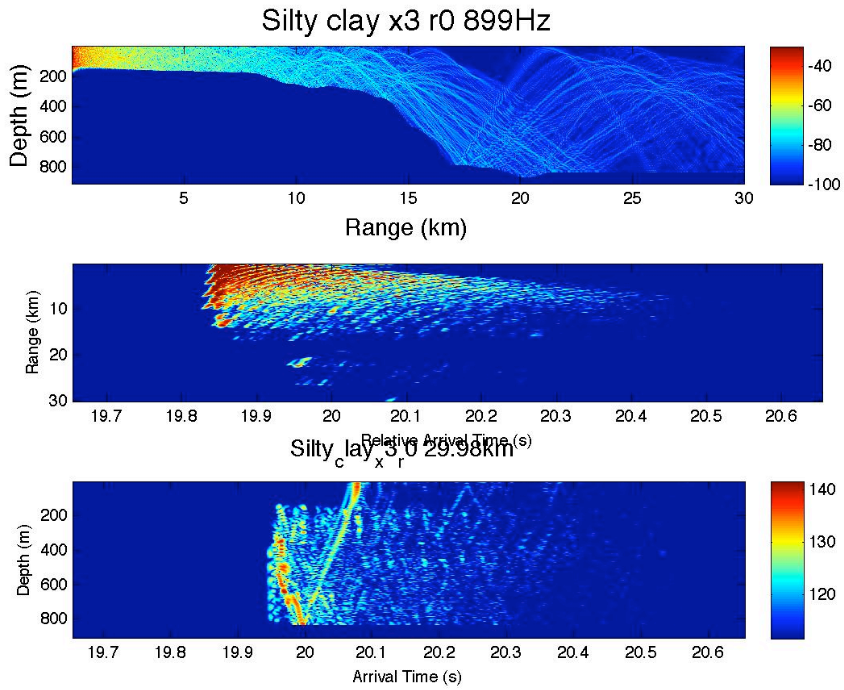


Figure 19. Cross-slope PE modeling with silty-clay. The TL vs. depth is shown in the upper panel. The broadband arrival structure vs. range is shown in the center plot. Not the shadow and subsequent arrival of a later bottom bounce. The pulse arrival vs. depth at 30 km is shown in the lower panel. Also note that most of the energy passes below 200m.

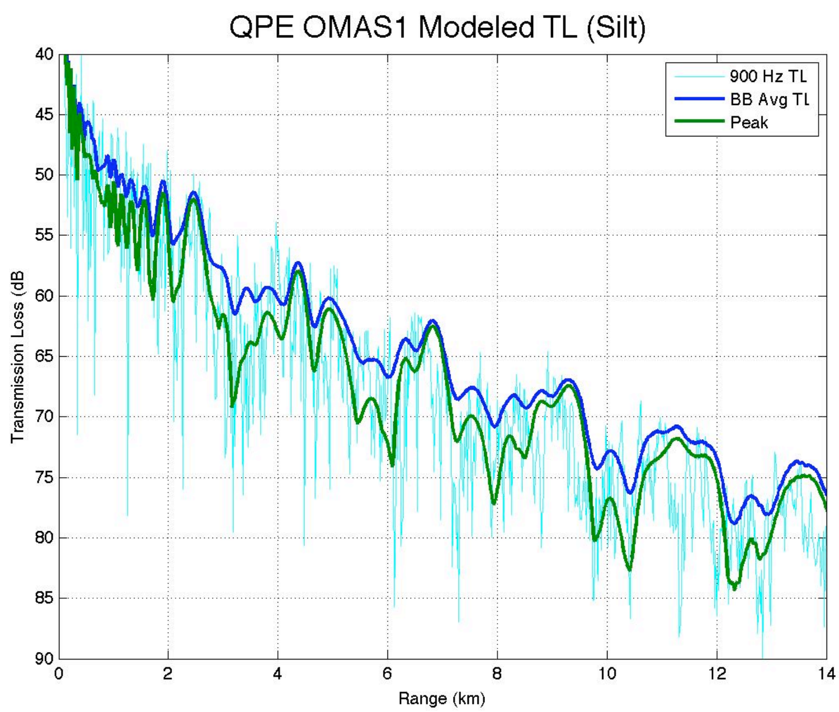


Figure 20. Comparison of TL model estimates. Narrowband TL (900 Hz) for silt (cyan), Broadband (BB) average (800-1000 Hz) and peak of the BB pulse (green) are shown below.

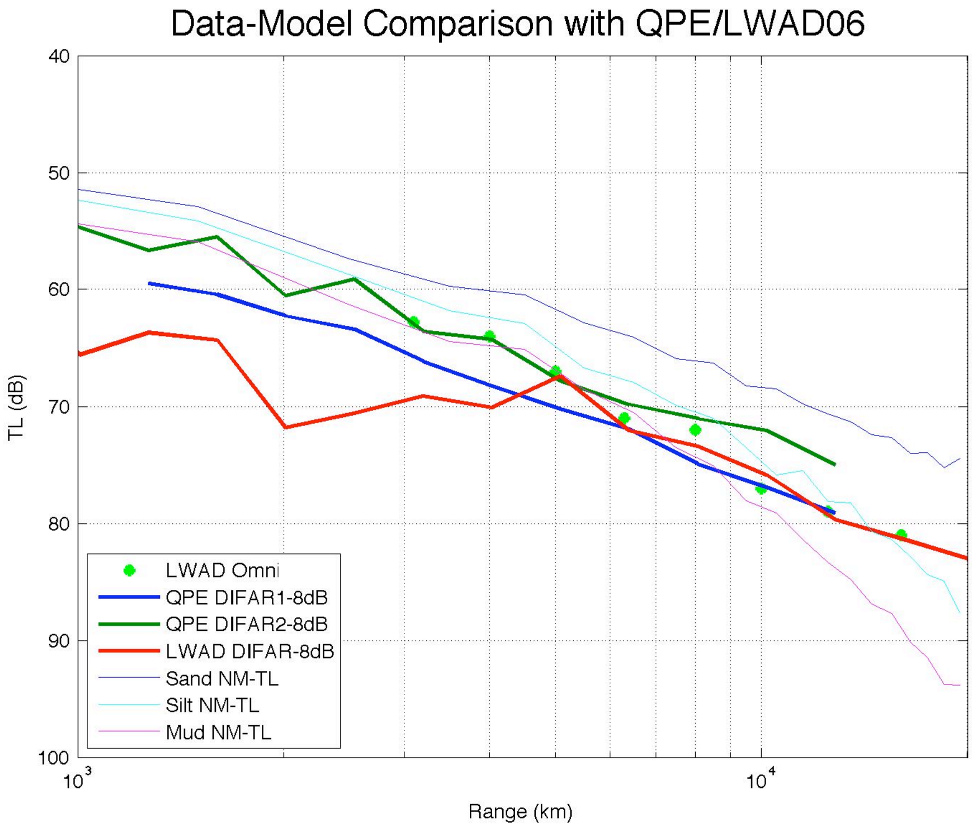


Figure 21. Comparison of LWAD and QPE run 1 TL with 3 different sediments.

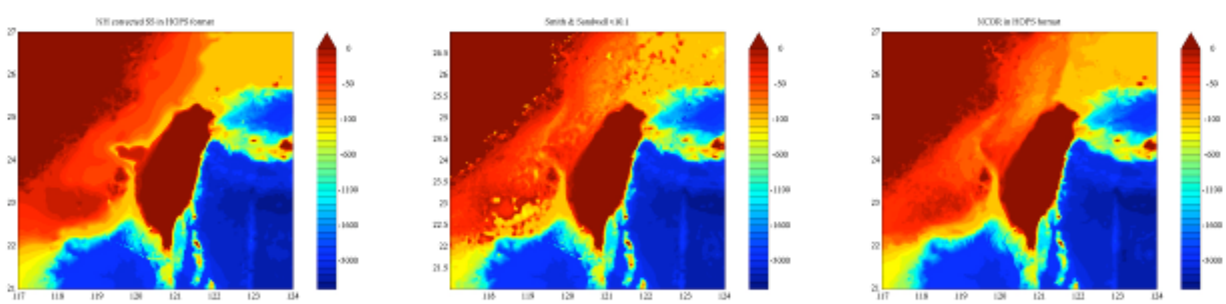


Figure 22. Bathymetries; (left) improved v9 Smith & Sandwell; (center) v10.1 Smith & Sandwell; (right) NCOR, which is the bathymetry currently used at MIT.

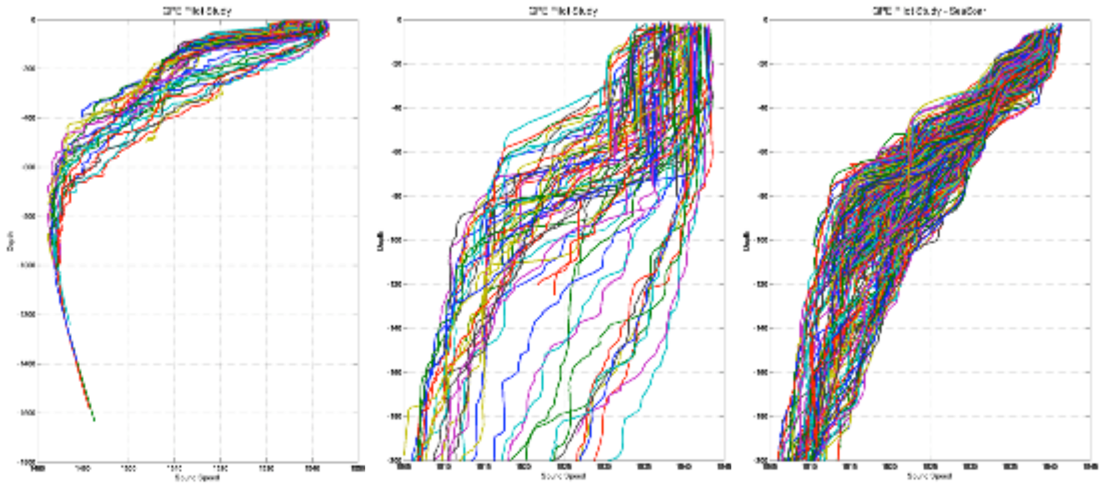


Figure 23. Vertical profiles of sound speed from CTD and SeaSoar casts from QPE Pilot Study;(left) CTD [0-1800m]; (center) CTD [0-200m]; (right) SeaSoar [0-200m], all assimilated in real-time at MIT.

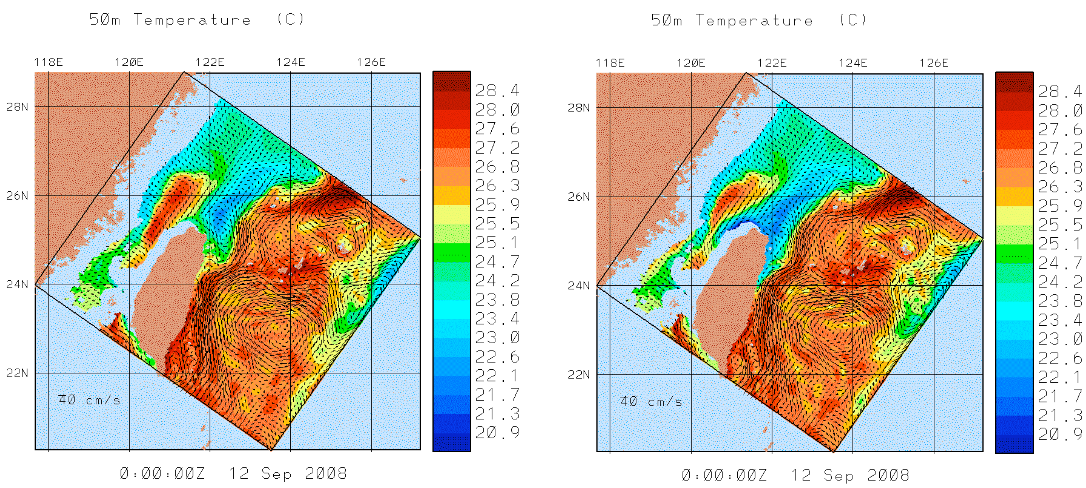


Figure 24. 50m Temperature and Velocity from 12 Sep 2008 MIT forecast.
Left: primary issue, 0 Sv initial transport.
Right: secondary issue, 1 Sv south initial transport.

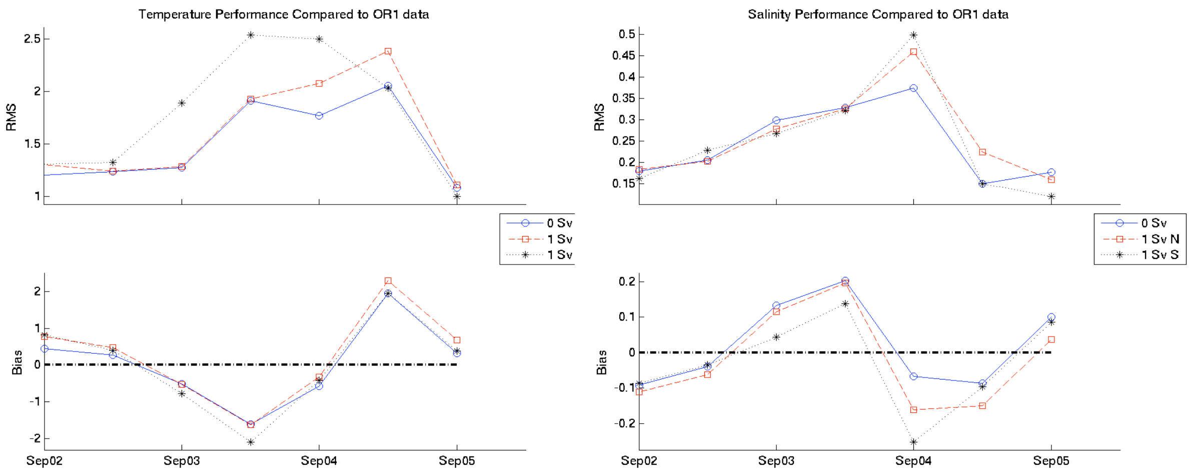


Figure 25. MIT forecast skill metrics, computed in real-time

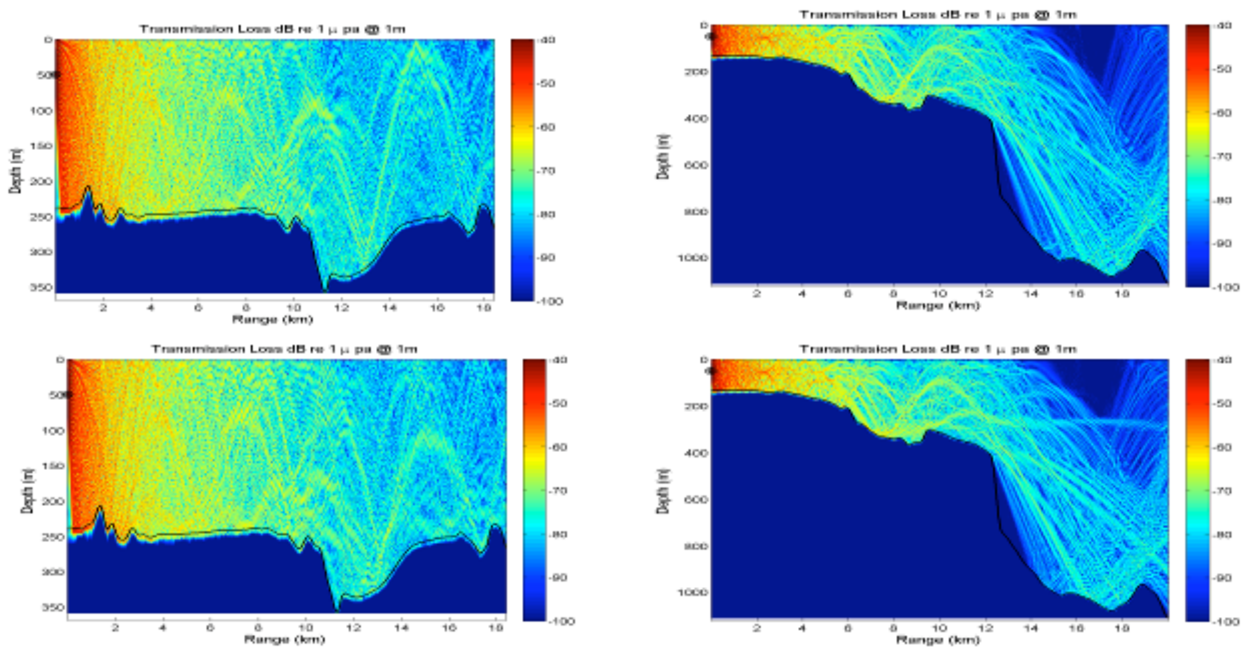


Figure 26. MIT Transmission loss (TL) forecast for 12 Sep 2008 for differing initial Taiwan Strait transports;(left) Across-shelf2 section, (right) Canyon section. For each section, shown is TL for 600Hz for runs with a 0 SV (top) and 1 SV southward transport (bottom). These TL forecasts were issued one to 2 days before the forecast time, the sound speed field obtained from the MIT ocean model driven by atmospheric forecasts.

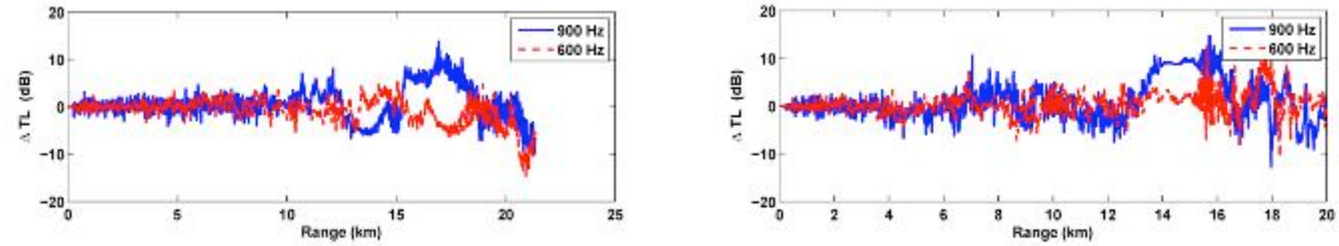


Figure 27. Difference in MIT Transmission Loss forecasts (averaged over upper 50-m) due to the difference in initial Taiwan Strait transports (12 Sep 2008); (left) Across-shelf2 section, (right) Canyon section. For each section, shown are the differences in TL forecasts between a run with a 0 SV and a run with 1 SV southward transport, for 900 and 600Hz.

Appendix A.

Table A-1. Scientists Onboard the QPE '08 Pilot Cruise, Leg 2.

	Name	Organization	Email
1	Chi-Fang Chen, Chief Scientist	NTU, OAL	chifang@ntu.edu.tw
2	Glen Gawarkiewicz	WHOI	gleng@whoi.edu
3	Kevin Heaney	OASIS	heaney@oasislex.com
4	Luca Centurioni	Scripps	lcenturioni@ucsd.edu
5	Frank Bahr	WHOI	fbahr@whoi.edu
6	Craig Marquette	WHOI	cmarquette@whoi.edu
7	Dave Morton	OASIS	morton@oasislex.com
8	Chris Emerson	OASIS	emerson@oasislex.com
9	Ted Abbot	OASIS	ted.abbot@gmail.com
10	Chris McCall	Scripps	cmccall@ucsd.edu
11	Linus Chiu	NTU, OAL	f91525002@ntu.edu.tw
12	Andrea Chang	NTU, OAL	d94525011@ntu.edu.tw
13	Wilson Yang	NTU, OAL	r96525059@ntu.edu.tw
14	Minger	NTU, OAL	v60000@yahoo.com.tw

APPENDIX B.

"Real-Time Drifter and ADCP V(z) Observations of Kuroshio Intrusions on East China Sea Shelf"

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Task 1: weekly releases of SVP drifter pairs in the Kuroshio

To date, 50 SVP drifters have been deployed in the Kuroshio south-east of Taiwan by the Taiwanese coast guard. The deployment will continue through 2009 for a total of approximately 70 weeks.

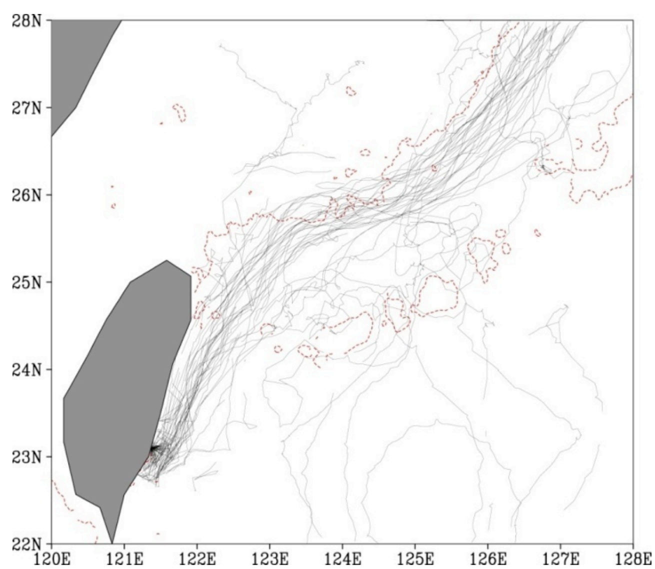


Figure B-1: *Spaghetti diagram of the 48 SVP drifters released in the Kuroshio by the Taiwanese coast guard. From April 7, 2008 to October 12, 2008.*

Task 2: test of the R-ADOS-V prototype and deployment of a 5 element SVP-GPS drifters array during the QPE pilot cruise

Two 130 m long restrained drifters were assembled at the Scripps Institution of Oceanography by Mr Chris Mc Call under the supervision of Drs. Luca Centurioni and Peter Niiler (See Figure B-2 for a schematic of the R-ADOS-V).

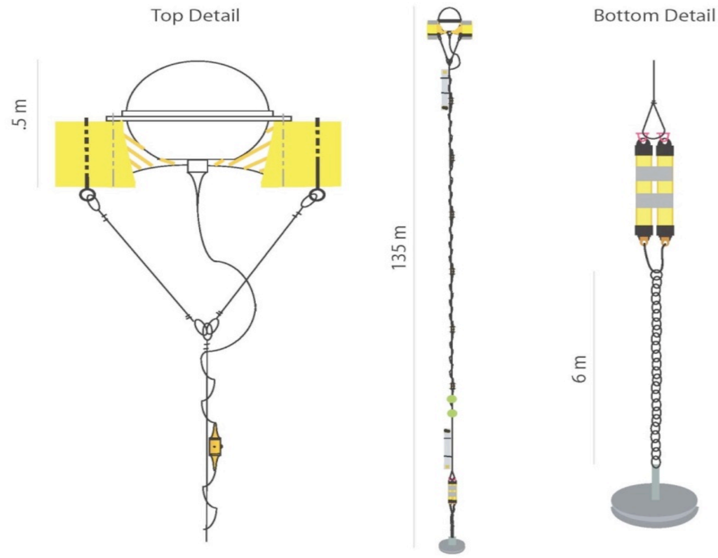


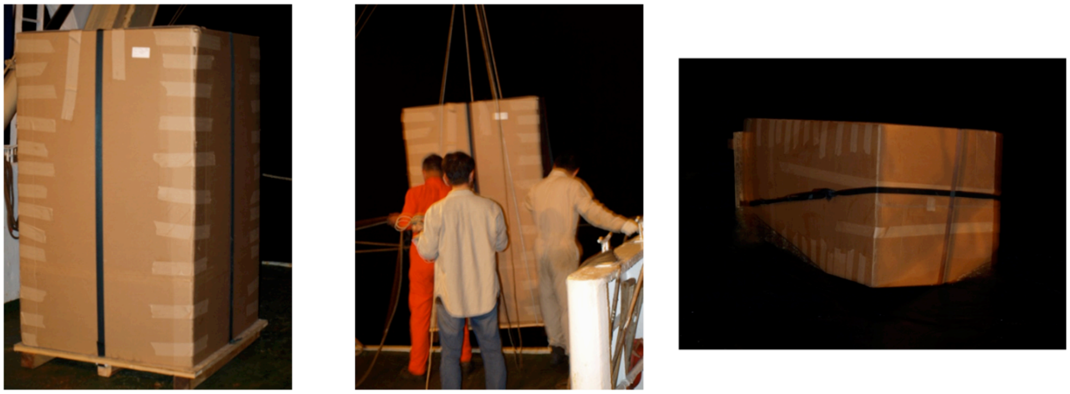
Figure B-2: *Schematic of the R-ADOS-V. The top detail shows the spherical ABS buoy that contains the batteries and the electronics. The ABS buoy in mounted onto the yellow "doughnut" shaped foam ring for extra buoyancy. Underneath is a schematic of the cables assembly and of a thermistor/pressure pod. The mid picture shows two ADCP's clamped on the cable. However, only on ADCP was used for the QPE pilot cruise. The bottom details show the assembly of the shallow water acoustic releases.*

The self deployment capabilities of the R-ADOS-V were tested extensively off Point Loma (San Diego, CA) during the months preceding the QPE pilot cruise until the correct cable configuration was identified. One restrained drifter with the ADCP (R-ADOS-V) and one with thermistor chain only were then shipped to Keelung (Taiwan) to be deployed during the QPE pilot cruise (Figure B-3).

Figure B-3: *Two restrained drifters are being prepared for deployment in the Keelung harbor warehouse. The cable is hold in the correct deployment configuration with water soluble paper tape and cardboard board and tubes.*

Dr. Luca Centurioni and Mr Chris Mc Call sailed on board of OR1 on September 2nd and successfully deployed one R-ADOS-V during leg 1 of the pilot cruise (Figure 4 and Figure 6). The R-ADOS-V was deployed on September 2, 2008, 18:10 UTC at 25°

56.64’N, 122° 27’E . The instrument was successfully recovered on September 4, 2008 at 9:47 UTC. The two restrained drifters were then re-deployed during leg 2 of the pilot cruise (Figure B-4). The R-ADOS-V was redeployed at the same location of leg 1 on September 9, 2008 at 16:40 UTC (Figure B-6). The restrained drifter with the thermistor chain only was deployed on September 9, 2008 14:19 UTC at 25° 55.54’N, 122° 34.66’E (Figure B-6). The R-ADOS-V was vandalized by a Taiwanese fishing boat on September 9 one hour before recovery (Figure B-5).



FigureB-4: *the box with the R-ADOS-V is deployed from the stern of R/V OR1 on September 2, 2008. The black straps which are holding the cardboard in place are secured to the bottom pallet with salt blocks.*

Figure B-5: *The fishing vessel that vandalized the R-ADOS-V. The red circle shows the surface expression of the R-ADOS-V on the deck of the boat.*

The fishermen cut the cable just underneath the buoy. The sub-surface expression of the buoy was lost. The fishermen loaded the buoy on their vessel and began steaming north-east. The position of the fishing vessel was known in real time and with great accuracy since our buoying kept transmitting GPS positions every minute. The R/V OR1 steamed on an interception course and we were able to recover the surface buoy a few hours later.

The second restrained drifter (thermistor chain only) was successfully recovered on September 9.

Five GPS drifters were deployed from OR1 (Table B-1 and Figure B-6)

ARGOS ID	LONGITUDE	LATITUDE	DATE AND TIME
75438	122° 46.40’E	25° 47.08’N	9/7/2008 3:31 UTC
75439	122° 40.53’E	25° 44.40’N	9/7/2008 4:33 UTC
75440	122° 28.67’E	25° 39.88’N	9/7/2008 12:30 UTC
75441	122° 38.21’E	25° 42.64’N	9/7/2008 4:59 UTC
75442	122° 34.57’E	25° 42.21’N	9/7/2008 13:09 UTC

Table B-1: *ARGOS ID, location and times of the five SVP/GPS drifters deployed during the QPE pilot experiment.*

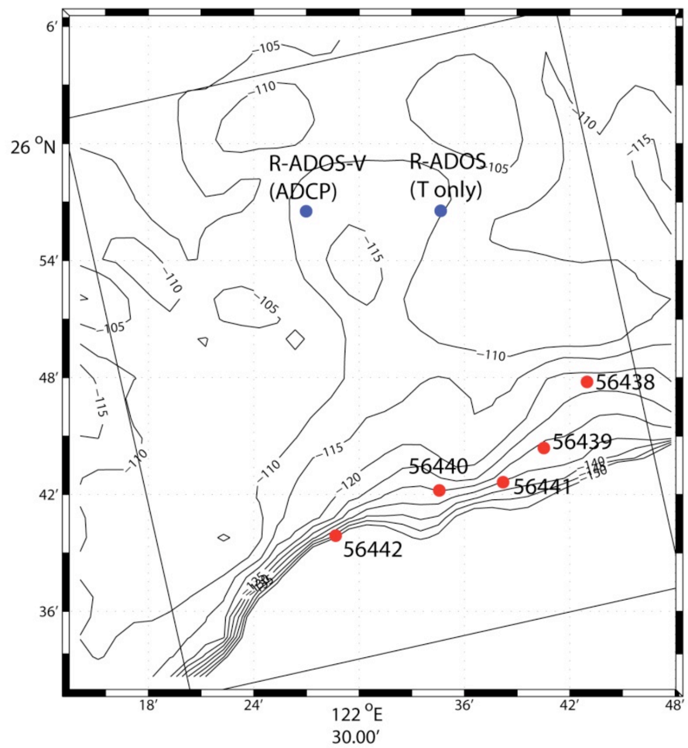


Figure B-6: *Bathymetry map of the QPE pilot experiment region: The blue dots mark the deployment location of the restrained drifters (the R-ADOS, with thermistor chain only and the R-ADOS-V, with the profiling ADCP). The red dots mark the deployment location of the SVP-GPS drifters).*

RESULTS

Task 1: Intrusion of the Kuroshio on the south East China Sea continental shelf

A regime of intruding Kuroshio onto the South East China Sea (SECS) shelf was observed in April 2008 (Figure B-7). A cyclonic eddy moved near the east coast of Taiwan, sustaining a flow directed against the Kuroshio, which then intruded onto the continental shelf, as shown by the track of the drifter released on April 7, 2008 (Figure B-7) from south-eastern Taiwan.

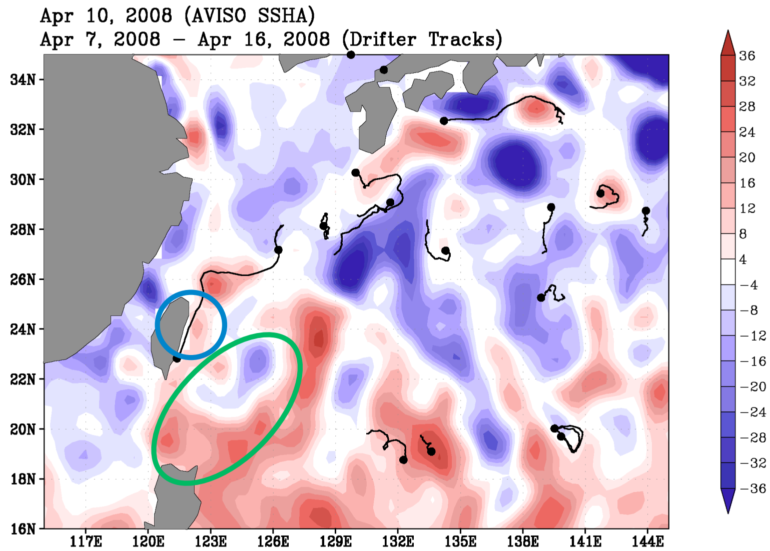


Figure B-7: *Sea Level Anomaly and drifter tracks (April 7 through April 16, 2008). The green oval marks the position of the cold cyclonic eddy that moved near Taiwan. The track of the first drifter released on April 7, 2008, the day in which our experiment begun, showed and excursion of the Kuroshio onto the continental shelf (blue circle).*

The drifter tracks from subsequent releases (from May through September 2008) did not show any Kuroshio intrusion during the following months. Figure B-8 shows a typical non-intruding regime. In October 2008 another cold eddy moved near the east coast of Taiwan. The drifter tracks then began again to show a deep intrusion of the Kuroshio on the shelf of the SECS.

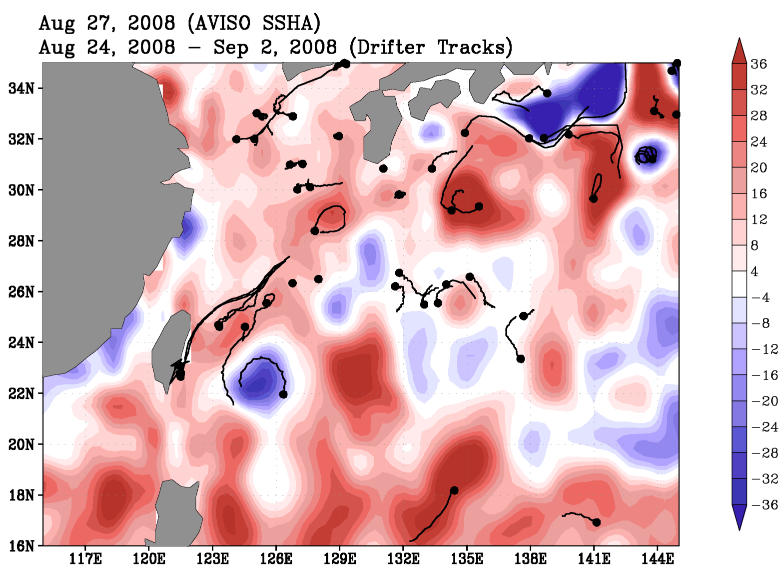


Figure B-8: *Non intruding regime. This timeframe correspond to the week preceding the QPE pilot experiment.*

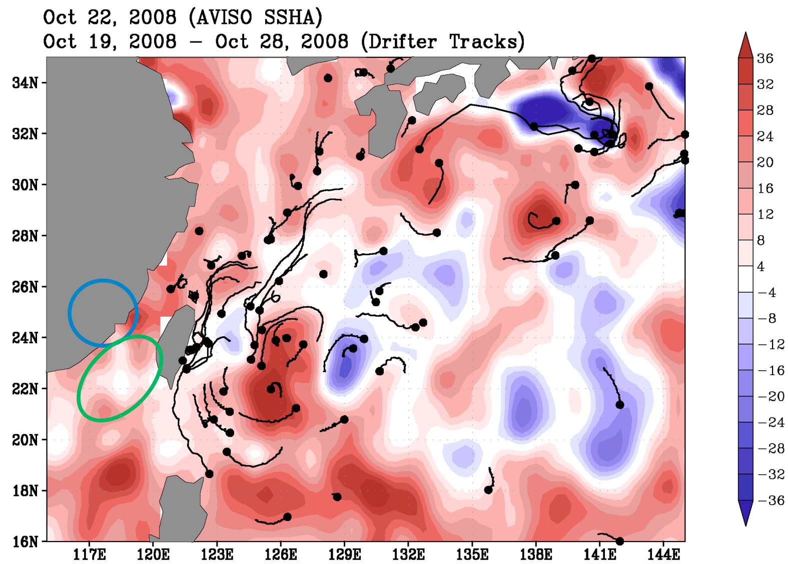


Figure B-9: *As figureB- 7. A cold cyclonic eddy is leaning against the eastern coast of Taiwan and the tracks of the drifters released off Taidong show a deep intrusion of the Kuroshio into the SECS shelf.*

Those results are suggesting that by tracking the cold cyclonic eddies that approach Taiwan from the interior of the Pacific Ocean, predictions of the onset of the intrusion of the Kuroshio onto the SECS shelf are possible.

Task2: Results from the QPE Pilot Cruise

A succession of tidal waves with amplitudes in excess of 30 m can be seen in the time series of the temperature profiles obtained from the R-ADOS-V (Figures B-10 and B-11). For the QPE pilot experiment we used old temperature pods that had been already deployed during the Non-Linear Internal Wave experiments in the South China Sea in 2005 and 2007. The reason for the numerous gaps in the data record is now under investigation. No such problem was encountered during the NLIWI '05 and '07 experiments, where the same thermistor chain was used without such problem.

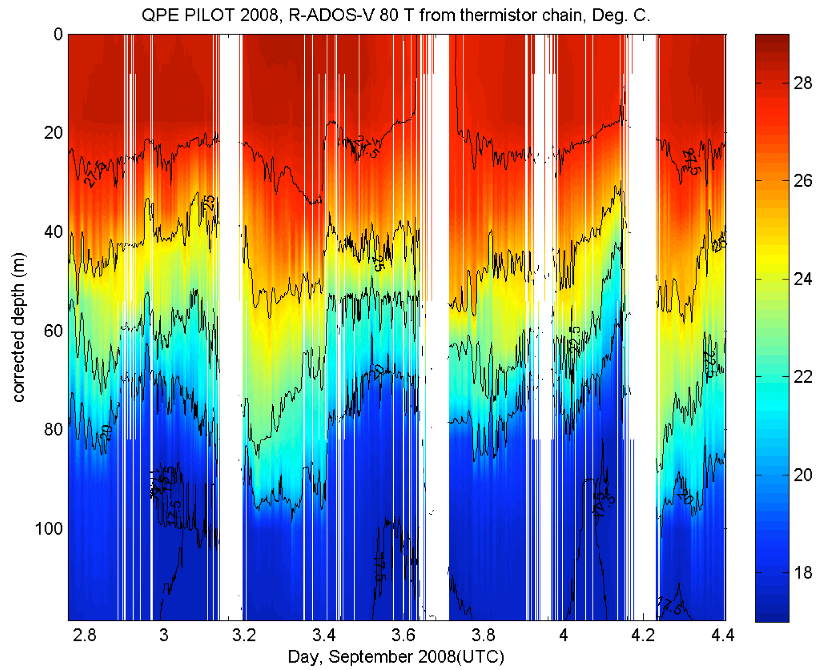


Figure B-10: *Temperature profiles time series from the R-ADOS-V thermistor chain (25° 56.64'N, 122° 27'E). Leg 1.*

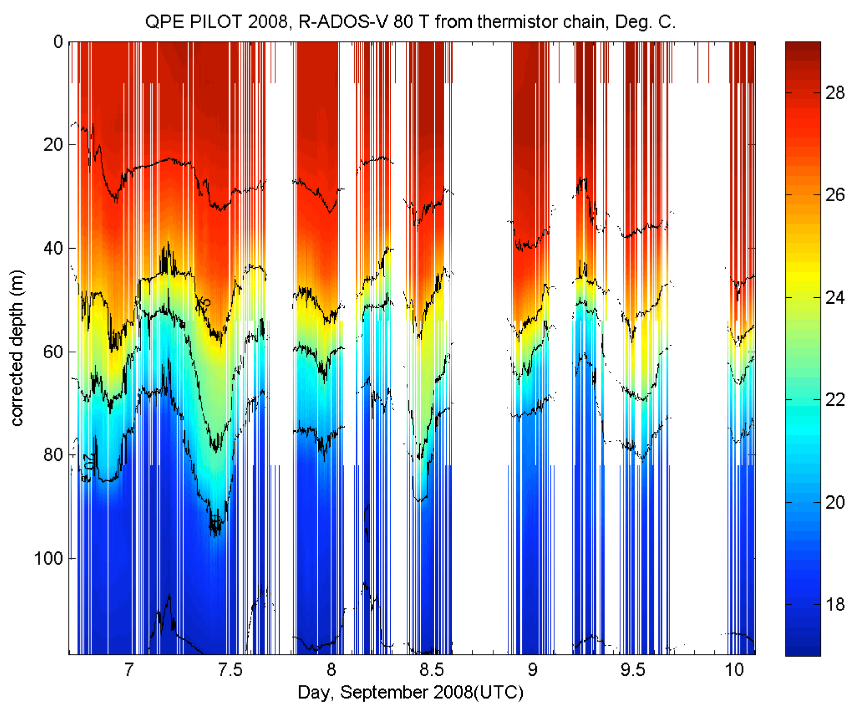


Figure B-11: *Temperature profiles time series from the R-ADOS-V thermistor chain (25° 56.64'N, 122° 27'E). Leg 2. The gaps in the data are due to the aging battery cells of the temperature pods.*

The 27.5° C isotherm deepened from approximately 20 m depth at the beginning of leg 1 to more than 40 m depth at the end of leg 2.

The current profile time series (Figure B-12), which is available only for leg 1 due to the vandalism episode reported in the previous section, show that the tidal currents can be in excess of 1 ms^{-1}.

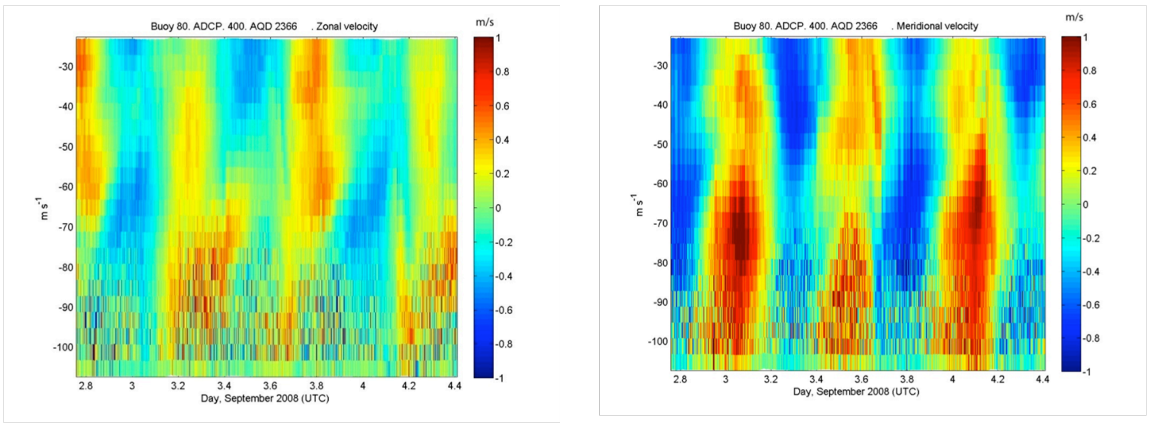


Figure B-12: *Horizontal current profiles time series from the R-ADOS-V (25° 56.64'N, 122° 27'E). Leg 1.*

The two SVP-GPS drifter deployed at the northernmost locations (blue and yellow tracks in Figure B-13) moved very rapidly (with speeds of the order of 1m/s) to the north-west.

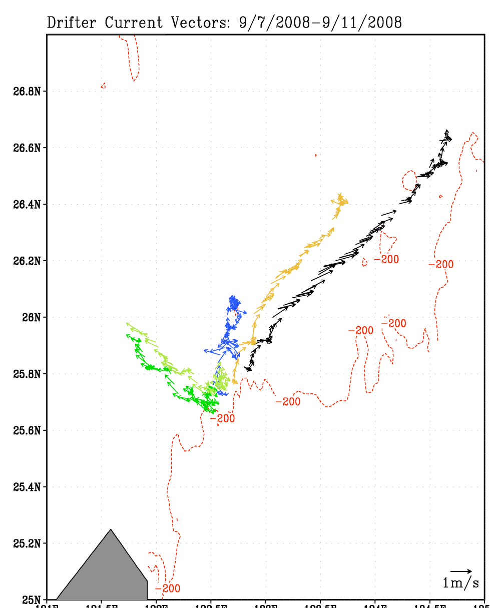


Figure B-13: *Tracks of the SVP-GPS drifters deployed during the QPE pilot cruise on September 7, 2008.*

The remaining three drifters moved with slower speeds to the north and north-east. Those results suggest the occurrence of a frontal structure and enhanced horizontal shear across the region sampled by the SVP drifters.

Overall, the QPE pilot experiment enabled us to prove that the R-ADOS-V can be successfully deployed from within a box with minimal effort and no need of technical staff with mooring operations skills. The real-time transmission of temperature, current and geographical position data is now being implemented and will be used during the 2009 QPE IOP experiment.

APPENDIX C.

Deployment Report of NTU-VLA

Hsiang-Chih Chan   Yung-Sheng Chiu
Yuan-Ying Chang
Chi-Fang Chen
Department of Engineering Science and Ocean Engineering
National Taiwan University

The NTU ship-board VLA was deployed from OR2 in April and during OR1 Leg 2 in September, 2008. This report is to give a brief description of the VLA deployment and a quick look at the data. The VLA deployment is as Figure C-1. Ambient noise measured in April with radar image is shown in Figure C-2.

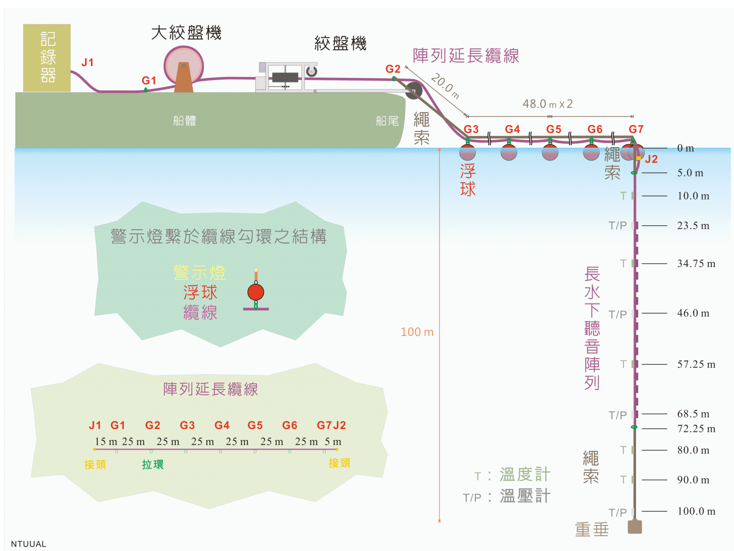


Figure C-1: Schematics of NTU VLA deployment

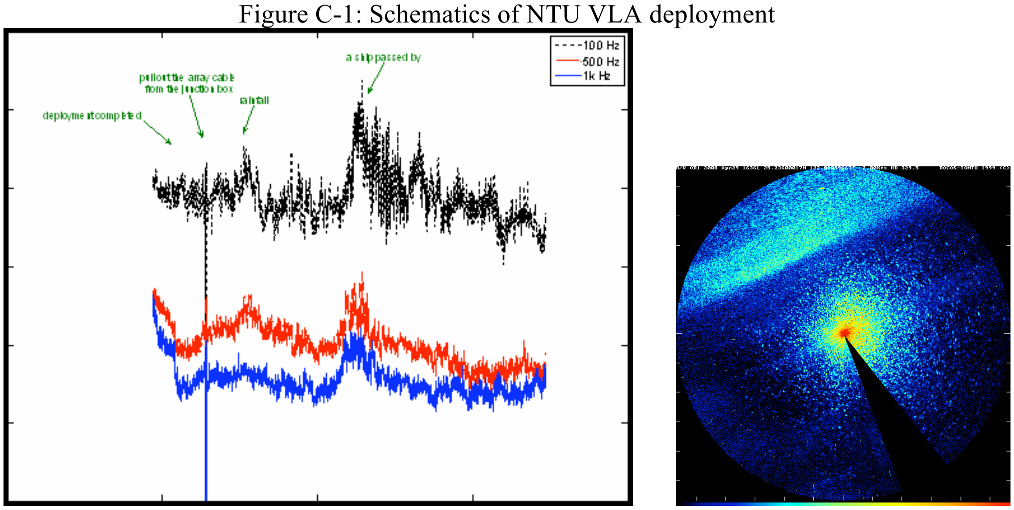


Figure C-2 : Ambient Noise data and radar image measured in April OR2 cruise

In September OR1 cruise, the first 3 VLA deployments were designed to listen to OMAS Runs on shelf and shelf break. The VLA drifted with OR1 while recording and the drifting paths are shown in figure 3. The red solid lines represent the paths of VLA and both blue and black dash lines are those of

OMAS. The VLA drifted far away from the starting point in 1st and 4th deployment, but remained around the original position in 2nd and 3rd deployment. The deployment time table is in Table C-1.

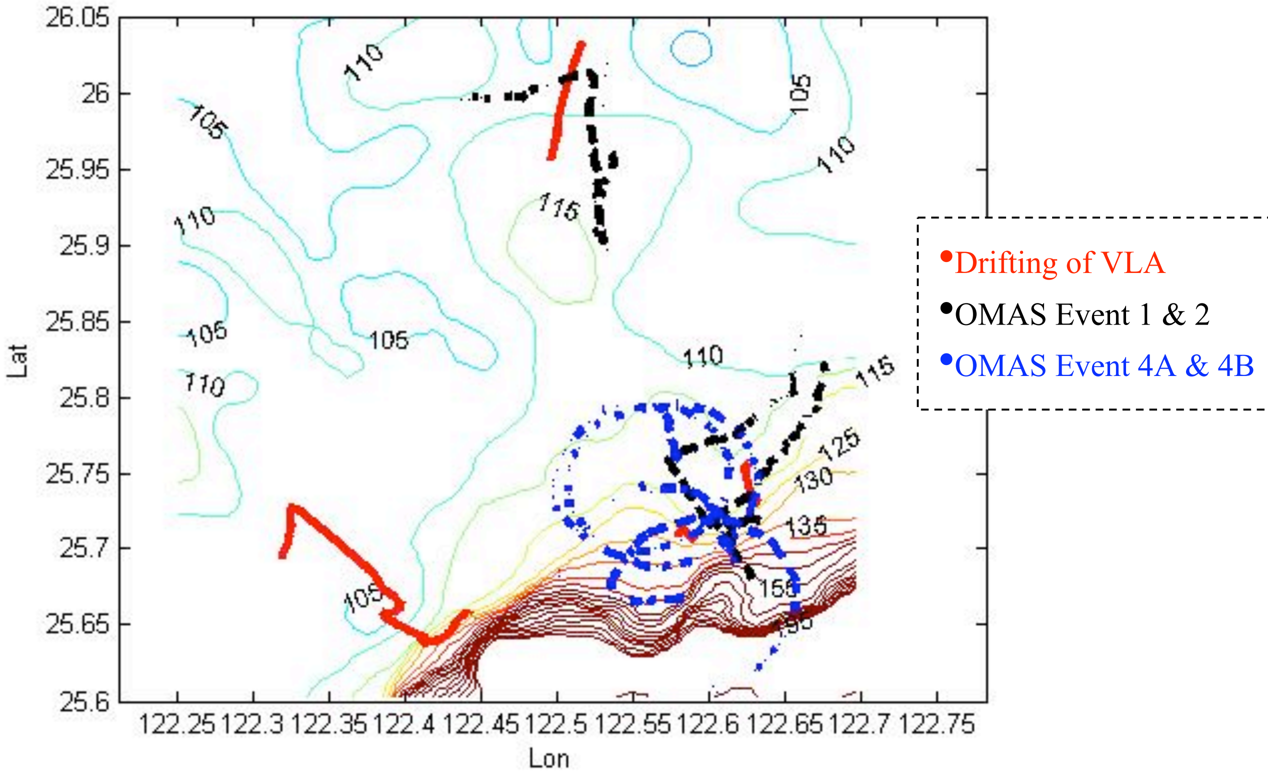


Figure C-3 : The drifting paths of OMAS and the ship-boarded VLA. The red solid lines represent the paths of VLA and both blue and black dash lines show those of OMAS.

Table C-1

	Start time	End time	Source	VLA Coverage
Deployment 1	02:50, 7 Sep	05:00, 7 Sep	OMAS Event 1	20m~50m
Deployment 2	00:00, 8 Sep	03:15, 8 Sep	OMAS Event 2	20m ~80m
Deployment 3	00:00, 9 Sep	04:15, 9 Sep	OMAS Event 4A & 4B	20m ~80m
Deployment 4	17:45, 9 Sep	09:30, 10 Sep	High frequency source	20m ~70m

The shipboard VLA has 16 elements with 3.75 m spacing deployed away OR1 over 100m with an extension cable to reduce ORI ship noise. 10 T-bits and 4 SBE (pressure-temperature) sensors are attached on VLA to collect temperature data and also monitor the VLA tilt. According to the pressure data, the deepest hydrophone was at 50-m depth at the first deployment, which is resulted from strong current. The VLA was with less tilt and covered 20 to 80 meters in deployment 2 and 3, but covered 20 to 70 meters in deployment 4 under stronger current. Figure C-4 shows the temperature data recorded by 14 sensors on VLA in deployment 1, which indicates downward refracting profiles and only some small scale variation is observed.

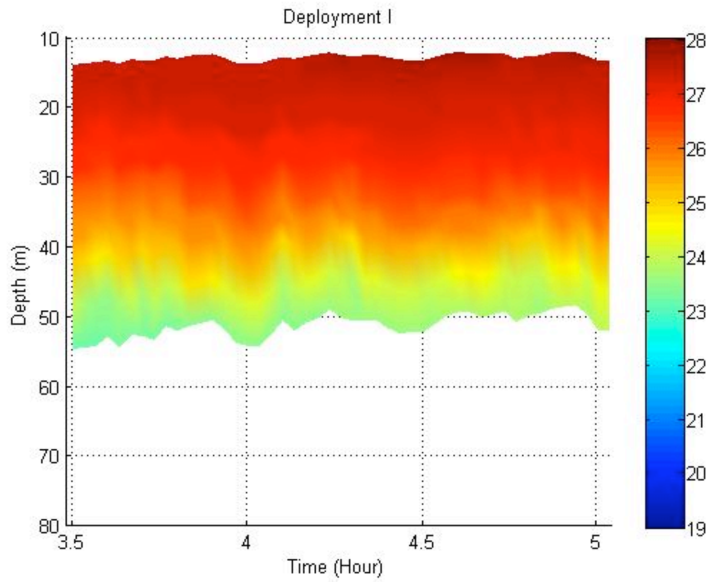


Figure C-4. The temperature data recorded by 14 sensors on the VLA in deployment 1 on 7 Sep

Although the VLA was about 100 meters away from OR1, the received acoustic data was still contaminated by ORI ship noise. The received frequency modulated signals from OMAS was weak and usually hidden in the noises. The preliminary processing focused on the 900Hz HFM signal in deployment 1. Without advanced signal processing techniques, only parts of signals could be dictated. Figure C-5 shows the sound pressure level of the received 900Hz HFM signal during 04:04 to 05:04 on 7 Sep. The three lines 10 to 20 dB lower than others are data of channel 8, 9, and 16, which would be checked later for calibration.

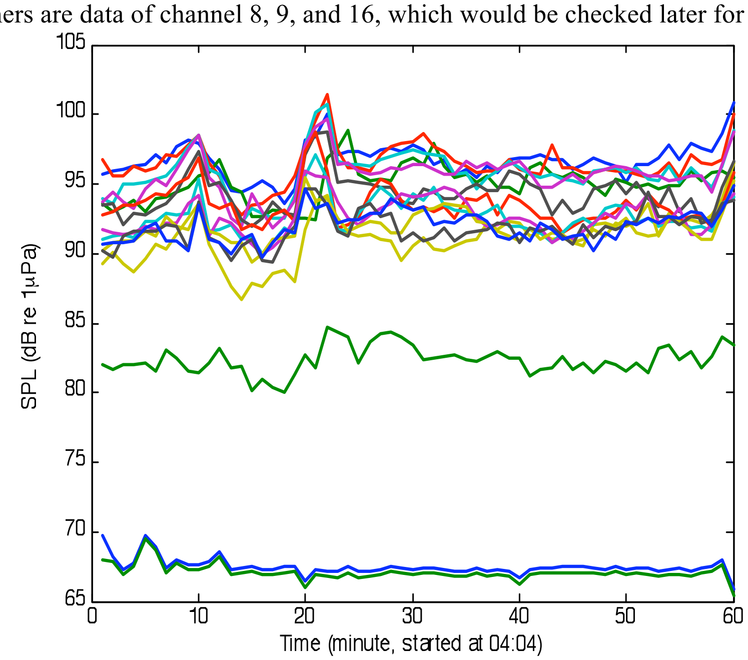


Figure C-5 :. The received sound pressure level of 900Hz HFM signal on 7 Sep.

The tracks of OMAS and VLA during 04:04 to 05:04 on 7 Sep are shown in figure C-4, in which the black circles represent the locations of OMAS, the brown stars are those of VLA and the arrows show the directions of them. From the relative positions, we can see that the acoustic wave propagated up-slope before 04:30, down-slope after 04:40, and along about 108-m isobath in between. One thing interesting is that the received energy had obvious decline and then rise during 04:10 to 04:30, and the difference could reach almost 10dB. During this time period, the acoustic path also kept being up-slope and the range between source and receiver was decreasing from 5km to 2km. If there had not been special features in water column, such as the temperature data recorded and shown in figure C-3, the unexpected energy drop might have resulted from bathymetry and sediment. Simulation work will be done to explore this phenomenon.

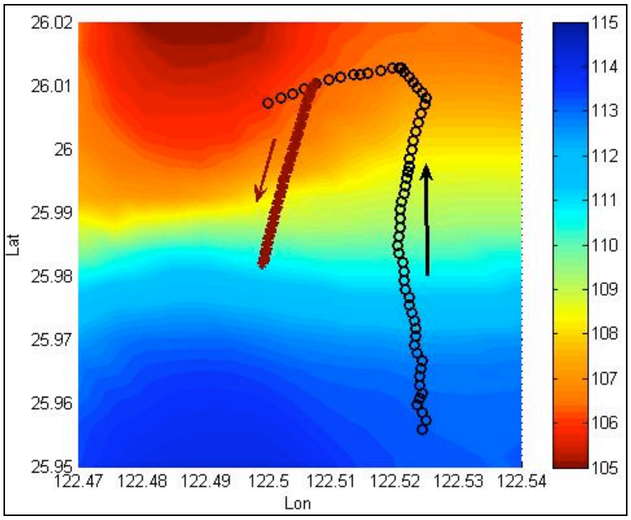


Figure C-5 :. The location of OMAS and the VLA in 04:04 to 05:04 on 7 Sep.

APPENDIX D.

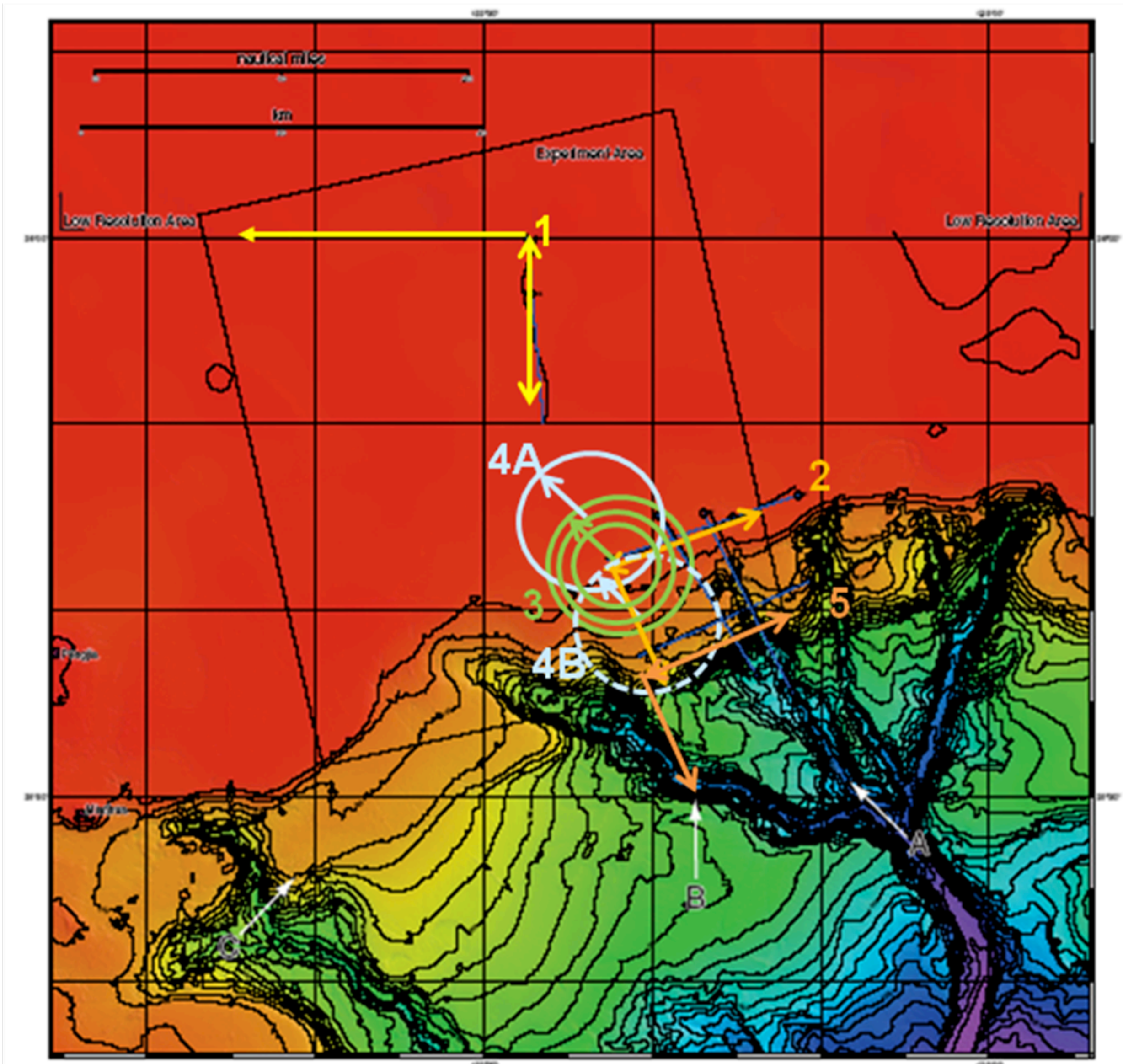
OMAS Runs for QPE Pilot Cruise
Sept. 6-13, 2008

Kevin Heaney
Dave Morton
Phil Abbot
Glen Gawarkiewicz (WHOI)

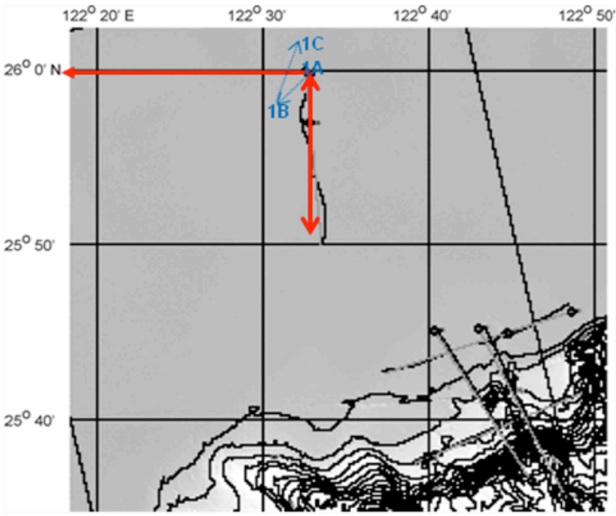
Overview of TL Runs

Date (tent.)	Event #	Description/Comments	OMAS #
9/7	1	Shallow water shakedown and Comparison: Along/Cross Shelf (see pg 3)	1
9/8	2	130m Isobath Baseline Run: Along/cross shelf (see pg 4)	2
9/9	3	Circle/Isotropy (r roughly 5-7.5 km, tbd) centered on "centroid" (see pg 5)	3
9/10	4A	Shallow Water Circle/Coherence Run; r=5-7.5 km (increased ping rate), 7.5 km NW of "centroid" (see pg 6)	4
	4B	3D-Bathy Circle Run; Constant Range(r=5-7.5 km), 7.5 km SW of "centroid" (see pg 7)	5
9/11	5A	280m Isobath Run; Along/cross shelf (see pg 8)	6
	5B	Adaptive Event TBD...	7

Overview of TL Runs



OMAS Event 1; SW Shakedown
(repeat of '06 run with cross-shelf leg)



RED: OMAS Tracks

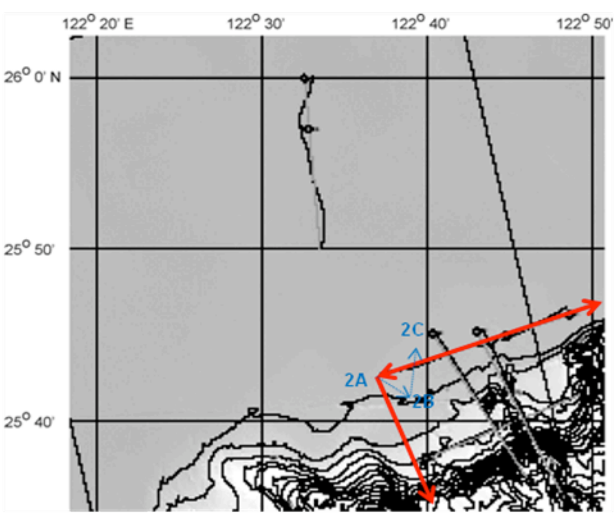
BLUE: R/V Positions

NOT TO SCALE

- 1-A. Starting Point: 26° 2' N, 122° 32' E
  - Repeat of LWAD '06, with a N/S leg added
  - Deploy Spar Buoy #1 with 2 Tethered sonobuoys
  - Launch OMAS
- 1-B. Move OR1 SW 1 km:
  - Move SW 1 km to **26° 1.65' N, 122° 31.65' E**
  - Launch Spar Buoy #2 with 1 Tethered sonobuoy
- 1-C. Move OR1 NE 2 km:
  - Move NNE 2 km to **26° 2.5' N, 122° 31.1' E**
  - As conditions, traffic permits, secure main engines, drift
- OMAS starts event with a South leg of app. 15 km, then returns to start point, and heads west, opening range until end-of-run.

12/1/2008 DRAFT 4

OMAS Event 2; 130m Isobath Baseline
Along and Cross Shelf



RED: OMAS Tracks

BLUE: R/V Positions

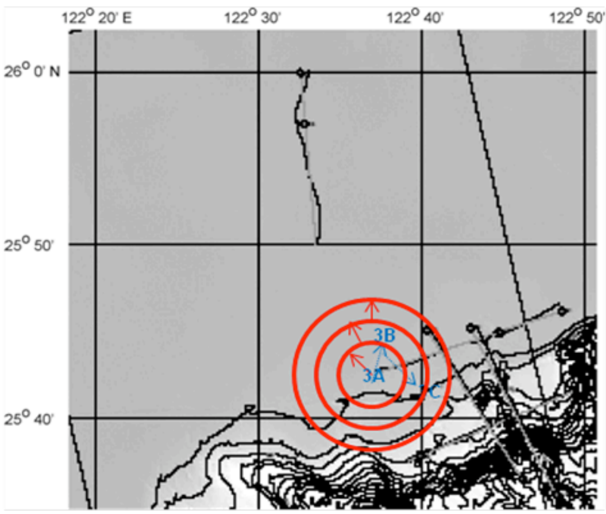
NOT TO SCALE

- 2-A. Starting Point: 25° 43' N, 122° 37' E
  - Start OMAS run at Western end of 130m isobath traverse leg
  - Deploy Spar Buoy #1 with 2 Tethered sonobuoys
  - Launch OMAS
- 2-B. Move OR1 SW 1 km:
  - Move NE 1 km to **25° 42.65' N, 122° 37.35' E**
  - Launch Spar Buoy #2 with 1 Tethered sonobuoy
- 2-C. Move NNE 2 km:
  - Move NNE 2 km to **25° 43.5' N, 122° 37.9' E**
  - As conditions, traffic permits, secure main engines, drift
- OMAS starts event along 130m isobath for 15 km, then returns to start point, then heads ESE across shelf, opening range until end-of-run.

12/1/2008 DRAFT 5

OMAS Event 3; Circle/Isotropy Run centered at "centroid"

Circles have increasing radius



RED: OMAS Tracks

BLUE: R/V Positions

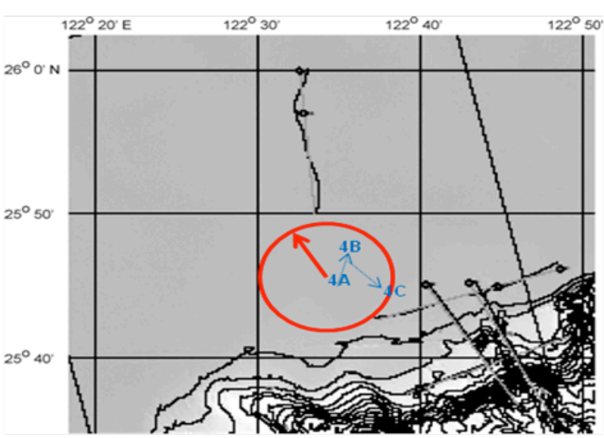
NOT TO SCALE

- 3-A. Starting Point: 25° 43' N, 122° 37' E
  - Start OMAS run at Western end of 130m isobath traverse leg
  - Deploy Spar Buoy #1 with 2 Tethered sonobuoys
  - Launch OMAS
- 3-B. Move OR1 NE 1 km:
  - Move NE 1 km to **25° 43.35' N, 122° 37.35' E**
  - Launch Spar Buoy #2 with 1 Tethered sonobuoy
- 3-C. Move SE 2 km:
  - Move SE 2 km to **25° 42.5' N, 122° 37.9' E**
  - As conditions, traffic permits, secure main engines, drift
- OMAS unit starts event running a radial leg out ~3 km, then commences clockwise circle with constant range. At end of each circumference, OMAS increases range to 5, then 7.5km until end of run

12/1/2008 DRAFT 6

OMAS Event 4A; Spatial Coherence

Constant Range (app. 7.5km) , Varying Bearing Over Constant Depth



RED: OMAS Tracks

BLUE: R/V Positions

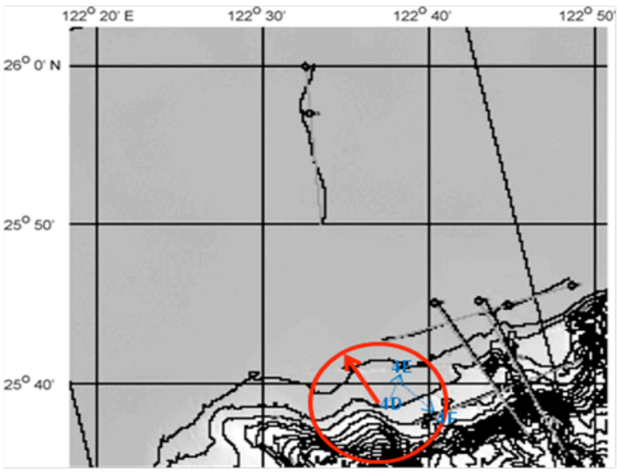
NOT TO SCALE

- 4-A. Starting Point: 25° 45' N, 122° 35' E
  - Start OMAS run 7.5 km NW of 130m isobath traverse leg
  - Deploy Spar Buoy #1 with 2 Tethered sonobuoys
  - Launch OMAS
- 4-B. Move OR1 NE 1 km:
  - Move NE 1 km to **25° 45.35' N, 122° 35.35' E**
  - Launch Spar Buoy #2 with 1 Tethered sonobuoy
- 4-C. Move SE 2 km:
  - Move SE 2 km to **25° 44.5' N, 122° 35.9' E**
  - As conditions, traffic permits, secure main engines, drift
- OMAS unit starts event running a radial leg out to 7.5 km, then commences CW circle with constant range about start point. OMAS programmed to ping at maximum rate to increase sample size.

12/1/2008 DRAFT 7

OMAS Event 4B; 3D Bathymetry Effects

Constant Range (app. 7.5km), Varying Bearing Over Varying Bottom (Canyon)

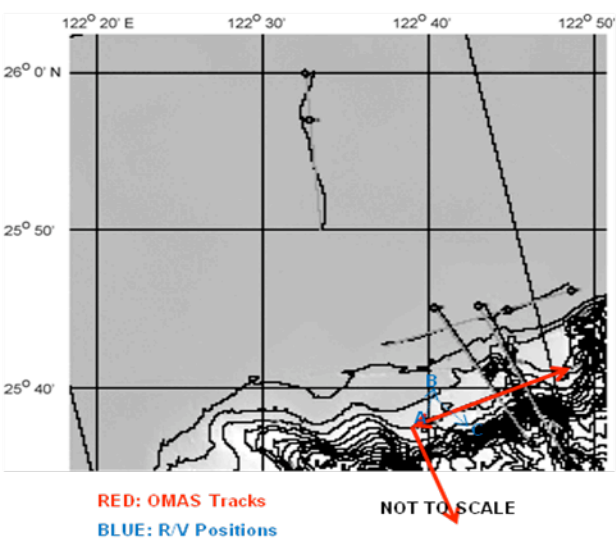


RED: OMAS Tracks
BLUE: R/V Positions
NOT TO SCALE

- 4-D. Starting Point: 25° 38' N, 122° 37' E
  - Start OMAS run 7.5 km S of Western end of 130m isobath traverse leg
  - Deploy Spar Buoy #1 with 2 Tethered sonobuoys
  - Launch OMAS
- 4-E. Move OR1 NE 1 km:
  - Move NE 1 km to **25° 38.35' N, 122° 37.35' E**
  - Launch Spar Buoy #2 with 1 Tethered sonobuoy
- 4-F. Move SE 2 km:
  - Move SE 2 km to **25° 37.5' N, 122° 37.9' E**
  - As conditions, traffic permits, secure main engines, drift
- OMAS unit starts event running a radial leg out to 7.5 km, then commences CW circle with constant range about start point.

OMAS Event 5; 280m Isobath Baseline

Legs Along and Perpendicular to the 280m Isobath



RED: OMAS Tracks
BLUE: R/V Positions
NOT TO SCALE

- A. Starting Point: 25° 37' N, 122° 39' E
  - Start OMAS run at Western end of 280m isobath traverse leg
  - Deploy Spar Buoy #1 with 2 Tethered sonobuoys
  - Launch OMAS
- B. Move OR1 NE 1 km:
  - Move NE 1 km to **25° 37.35' N, 122° 39.35' E**
  - Launch Spar Buoy #2 with 1 Tethered sonobuoy
- C. Move SE 2 km:
  - Move SE 2 km to **25° 36.5' N, 122° 39.9' E**
  - As conditions, traffic permits, secure main engines, drift
- OMAS unit starts event with a NNE leg of app. 15 km, then returns to start point, then heads ENE along 280m isobath, opening range until end-of-run. OMAS at 8 knots?

OASIS Spar Buoys