Quantifying, Predicting and Exploiting (QPE) Uncertainty in the Southern East China Sea

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LONG-TERM GOALS

The long-term goal of this research is to develop a systematic approach to understanding acoustic uncertainty as it pertains to the passive sonar system. The approach combines measurements and modeling, and has been broken into three stages: quantifying, predicting and exploiting uncertainty. This requires an understanding of the environmental drivers of acoustic uncertainty (oceanographic, geoacoustic and bathymetric variability). To this end OASIS has conducted and will continue to study the results of acoustic transmission and ambient noise measurements in the Southern East China Sea (SECS) during two joint field studies with Taiwanese and US collaborators. The first, a pilot study, was completed in September, 2008, and the second, an Intensive Observation Period (IOP), was just completed in August and September of 2009. The acoustic measurements focused primarily on quantifying the major physical mechanisms giving rise to uncertainty in the acoustic data. Candidates evaluated included ocean mesoscale effects due to the Kuroshio Intrusion and frontal structures such as the Cold Dome, effects due to internal waves and internal tides, and spatial variability in the sea-bed and the sea surface.

OBJECTIVES

The primary objectives of this research are to quantify the major physical mechanisms of uncertainty in the acoustic transmission loss (as described by the mean, standard deviation and probability density function) and in the local ambient noise field in the SECS by conducting extensive, high resolution ocean and acoustic observations during a pilot study in Fall 2008 and the Intensive Observation Period (IOP) in Fall 2009. Given an understanding of the dominant mechanisms of uncertainty, methods for predicting and exploiting the uncertainty will be developed during the latter stages of the IOP with the intent to demonstrate improved system performance. Here, the objective is to demonstrate effective Adaptive Sampling strategies to optimize the placement of sensor systems for the reduction of uncertainty and optimum utilization of the environment. These objectives will be accomplished via extensive collaborations with the many US and Taiwanese scientists involved in the program.

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14. ABSTRACT
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APPROACH

the method of quantifying, predicting and exploiting uncertainty begins with an extensive experimental and theoretical understanding of the environment, including the spatial and temporal variability in the physical oceanography, and the spatial variability of the bottom characteristics. These environmental variabilities give rise to uncertainty in the predictions of acoustic propagation and ambient noise, and they impact overall sonar system performance. Our technical approach will determine, through measurements and models, the SECS environmental uncertainty estimates through the use of probability density functions (PDFs), which then lead to a probabilistic representation of sonar performance. The PDFs must be determined for spatial and temporal scales of the TL and ambient noise as dictated by the specific system under consideration. These scales will include SECS meso- and sub-mesoscale effects (e.g. Kuroshio intrusions and the Cold Dome), internal tides and internal waves, interference variability (ambient noise) and spatially variable bottoms.

In collaboration with US and Taiwanese scientists, we have conducted two extensive acoustic sea trials, a Pilot Cruise during the fall of 2008 and an Intensive Field Program in August and September of 2009. OASIS' participation in the IOP focused on two distinct cruises conducted onboard the Taiwanese Research Vessel Ocean Researcher 1 (OR1). The first leg was conducted from Aug. 23-Sept.1, and the second leg ran from Sept. 4th to the 12th. Measurements and observations obtained during the first leg of the QPE'09 cruise were used to determine the overall test plan for the second leg. Figure 1 shows the tracks conducted during the IOP onboard the OR1 for leg 1, and Figure 2 provides the tracks from leg 2. A total of twenty (20) calibrated OMAS vehicles were used as mobile sources (operating in the 550 to 1,200 Hz frequency range), programmed to run in linear and circular tracks within the area of interest. Various sonobuoys (DIFAR, and Omni) were deployed as the long baseline tracking system for the vehicle and for measuring the transmission loss (and ambient noise to the extent possible). The circular tracks were designed to address azimuthal and vertical isotropy, as well as translational and temporal invariance.

The following environmental uncertainty keys were selected to be located and measured in close to real time and then exploited by strategic placement of the acoustic sources and receivers: intrusions from the Kuroshio, cross-shelf differences in bottom-mixed layer depth associated with the Cold Dome, and variations in surface mixed layer depth and vertical gradients within the thermocline. In as near-real-time as possible, the data and observations were assimilated into MIT's (Lermusiaux) real-time data assimilation and modeling results and OASIS' (Heaney) near-real time Genetic Algorithm solutions (both being located either at-sea or nearby on the Taiwan shore), to attempt measurements that could exploit the acoustic signal and noise uncertainty.

The QPE '09 Leg 1 cruise was designed to address basic ocean and acoustic issues such as evaluating the effectiveness of the chosen environmental keys (discussed above) that give rise to acoustic uncertainty, evaluating the type of variability to expect for the ocean and acoustic measurements, providing an acoustic baseline for comparisons with the IOP tests, and determining what type of fishing activity will be encountered when operating in this region. In order to meet these goals, extensive meetings were held with OASIS (Abbot) and WHOI (Gawarkiewicz, Lynch) PIs in order to produce detailed run programs for the first ten OMAS

vehicles that were launched during the Leg 1. The measurements and observations obtained during the Leg 1 cruise (combined with input from the MIT and OASIS acoustic modelers on the East Coast) were then used to help plan the Leg 2 experiments, in an effort to fully exploit the uncertainty of the area.

Philip Abbot is the lead OASIS Principal Investigator (PI), primarily responsible for the extensive acoustic testing. This included test planning and coordination with US and Taiwanese PIs participating in the two sea trails off Taiwan, and will continue during further data processing and physical interpretation of the acoustic data. The second PI, Kevin Heaney leads the OASIS modeling efforts, and has been performing acoustic sensitivity studies and developing automated optimal adaptive sampling.

WORK COMPLETED

The majority of FY2009 efforts were aimed at analyzing data from the Pilot Cruise, and planning and carrying out the IOP test in August/September of 2009. OASIS personnel participated in numerous meetings throughout the year, designed to brief results from the Pilot Cruise and plan various aspects of the IOP.

OASIS co-PI, Kevin Heaney, supported FY2009 QPE efforts, by providing real-time daily optimal adaptive sampling guidance for directing oceanographic and acoustic measurements. The EMPath algorithm, developed under a SPAWAR SBIR and subsequently transitioned to NAVOCEANO, was successfully integrated with an MIT ocean model. Three cost functions, temporal variability, spatial variability, and model uncertainty, were chosen to optimize oceanographic searches. These were normalized, weighted and summed to form a single time and space dependent cost function. The Genetic Algorithm (GA) was then used to determine optimal SeaSoar sampling tracks. An example of the daily output is shown in Fig. 1. The upper left is the temporal variability. The lower left is the spatial variability. The upper right is the model uncertainty and the lower right is the combined morphology. The three best solutions for a two platform search are plotted. These results were computed daily, and forwarded to personnel, aboard the OR-1.

The GA approach was also used to provide optimal adaptive sampling guidance for the acoustic measurements The cost function in this case was the difference in averaged TL between sources above and below the mixed layer depth (60m). This provided a way to guide acoustic measurements to regions where a direct observation of environmental variability could be obtained. An example of the daily product, showing the spatial variability of the cost function is shown in Figure 2. The region of significant impact (>3 dB difference in TL) is along the 130 m isobath. Guidance from the acoustic genetic algorithm was forwarded to personnel aboard the OR-1 for inclusion into their discussion of optimal source and receiver placement.

OASIS was also responsible for conducting the acoustic Transmission Loss experiments onboard the OR1 during both Leg 1 and Leg 2. Ten OMAS units were deployed on each leg. There were no premature failures of any of the vehicles, and all were successfully tracked by sonobuoys for an average of more than six hours each.

RESULTS

The acoustic oceanography conducted during both legs of the IOP by OASIS utilized OMAS vehicles as the sound sources, and standard US Navy sonobuoys. A total of twenty OMAS units were launched during the nineteen days at sea, and over 120 hours of transmission loss data were acquired. Figure 3 shows a reconstruction of the ten OMAS tracks of the Leg 1 cruise. The primary objective of the first leg of the IOP was to conduct pre-planned OMAS missions, centered about Site A to the north (26° 2'N, 122° 32' E) and Site B to the south (25° 43'N, 122° 37' E). This was to establish baselines, and determine methods of exploiting the uncertainty of the area during the second leg of the cruise.

There were no preset missions for the second leg, and the OMAS tracks were determined prior to each deployment from recently acquired measured and/or modeled oceanographic data. (The reconstructed tracks of the ten OMAS units deployed during this leg are shown in Figure 4.) OMAS tracks were designed to:

- examine translational invariance by deploying two OMAS units the same time, operating at the same depth, but at different locations

- explore variability over depth by deploying two OMAS units at similar locations, but different depths during the same time period.

- explore oceanographic effects, by running OMAS vehicles across areas of obvious oceanographic variability (though this variability decreased notably over the course of the test).

As of September, 2009, preliminary 900 Hz transmission loss data from all of vehicles has been processed. As an example of the type of results expected, TL data from a twenty-four hour temporal invariance experiment conducted at the end of Leg 1 are included here. During the course of this test, three OMAS units were launched in succession, with the first launched at 12:07Z on Aug. 29th, and the final ping from the third received at 11:41Z the following day. The vehicles were tracked continuously, and there was only about an hour of down time between subsequent launches. Each of the three OMAS units were deployed at the same location and completed two full 4.5km radius circles (distorted by drift), centered about Site A. Figure 5 shows the post-processed OMAS tracks for all six revolutions. The corresponding mean 900 Hz TL vs. bearing is shown in Figure 6 (note that the TL shown in Figure 6 were measured over the reconstructed path of the same color in Figure 5). This preliminary data set shows a 5-10 dB variation in the mean transmission loss vs. bearing and seems to exhibit a marked increase in loss as a function of time and/or bearing.

Additional 900 Hz TL data from this cruise are currently being analyzed and will be included into a quick look cruise report. Throughout FY10, additional processing and analysis of the 900 Hz and 600 Hz TL data will be performed, and will be presented to ONR in a final report.

IMPACT/APPLICATIONS:

It is expected that this research will result in a greater understanding of acoustic uncertainty in the Southern East China Sea (SECS) as it pertains to the passive sonar system. This includes the identification of the environmental drivers responsible for acoustic uncertainty (oceanographic,

geoacoustic and bathymetric variability). Analysis of the acoustic measurements described above will focus primarily on quantifying the effects of these environmental drivers. Candidates to be evaluated include ocean mesoscale effects due to the Kuroshio Intrusion and frontal structures such as the Cold Dome, effects due to internal waves and internal tides, and spatial variability in the sea-bed and the sea surface.

In addition, the continued development of the OASIS Mobile Acoustic Source and long baseline sonobuoy receiver system for TL measurements will provide the Navy with important off-the-shelf tools for obtaining in-situ TL in oceanographically complex environments. The source will also serve as a useful anti-submarine warfare training tool, acting as a realistic target source while also providing range information to sonar operators.

RELATED PROJECTS

OASIS work for the QPE program is closely related, though with an acoustic measurement focus, to the work being performed by Dr. Kevin Heaney under the Environmental Measurements Mission Planner (EMMP) SBIR for SPAWAR. In this program, an optimal adaptive sampling approach has been developed to determine the best way to deploy various oceanographic assets. Oceanographic measurements are used as input data for oceanographic models that are then used in ASW acoustic performance prediction. The algorithm has been installed and operationally tested within the NAVO ASW reach back cell. Any future algorithms or approaches generated within the QPE program could be installed in the acoustic ASW portion of the NAVO Reachback cell.

REFERENCES

1.0 Gawarkiewicz, Glen, et al; "*QPE '09 Test Plan*"; WHOI Report, July, 2009.
2.0 Heaney, Kevin; "*Pilot Test Environmental Sensitivity Analysis*"; August, 2008. Posted to the QPE web-site.
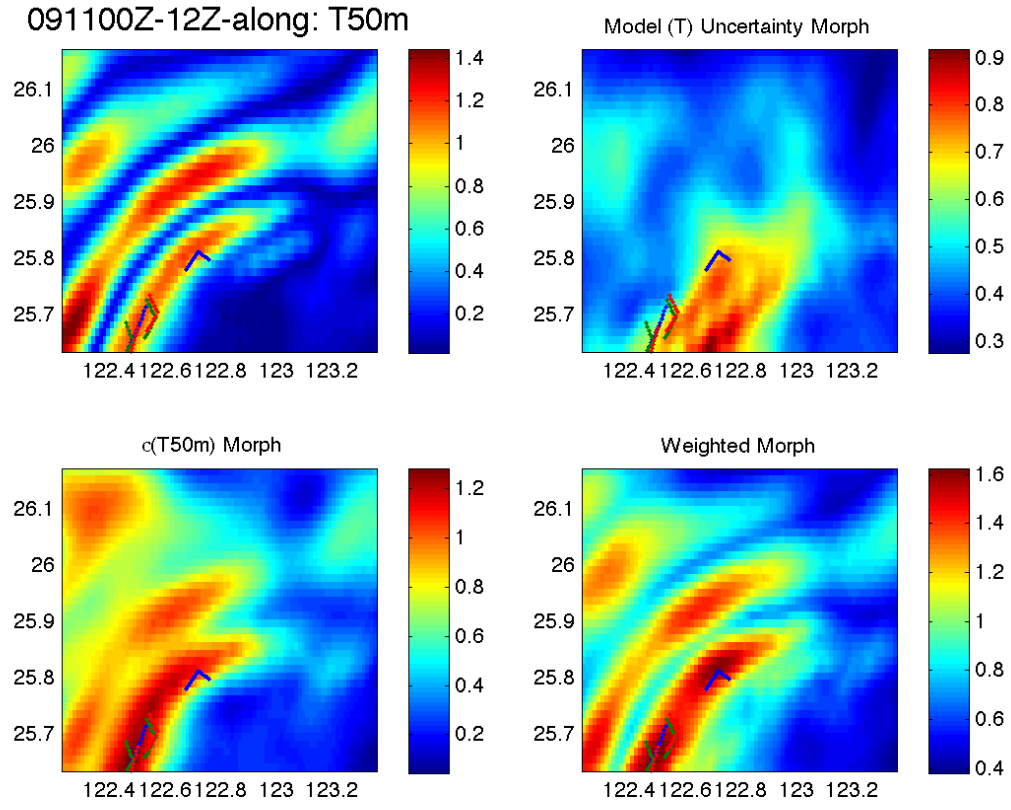
Figure 1. Cost functions input to the genetic algorithm for optimal adaptive oceanographic sampling. The constituent cost functions are – Upper left: Temporal Variability of Temperature at 50m. Upper right: Model Uncertainty, Lower left: Spatial variability of T at 50m. and Lower Right : Combined cost function morphology.
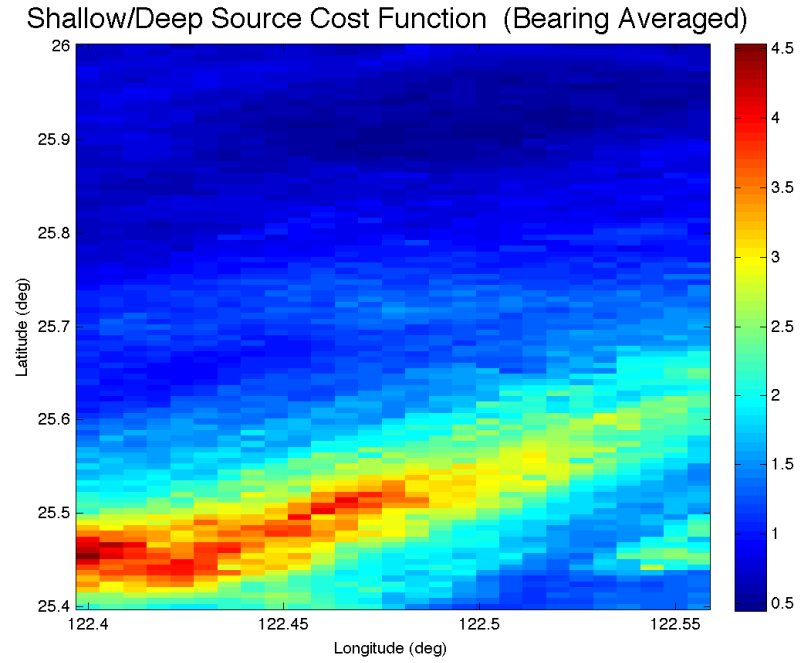
Figure 2. Acoustic TL difference (zs<60m and zs>60m) computed within the IOP area for September 5, 2009. This function was the input cost function to the Genetic Algorithm.
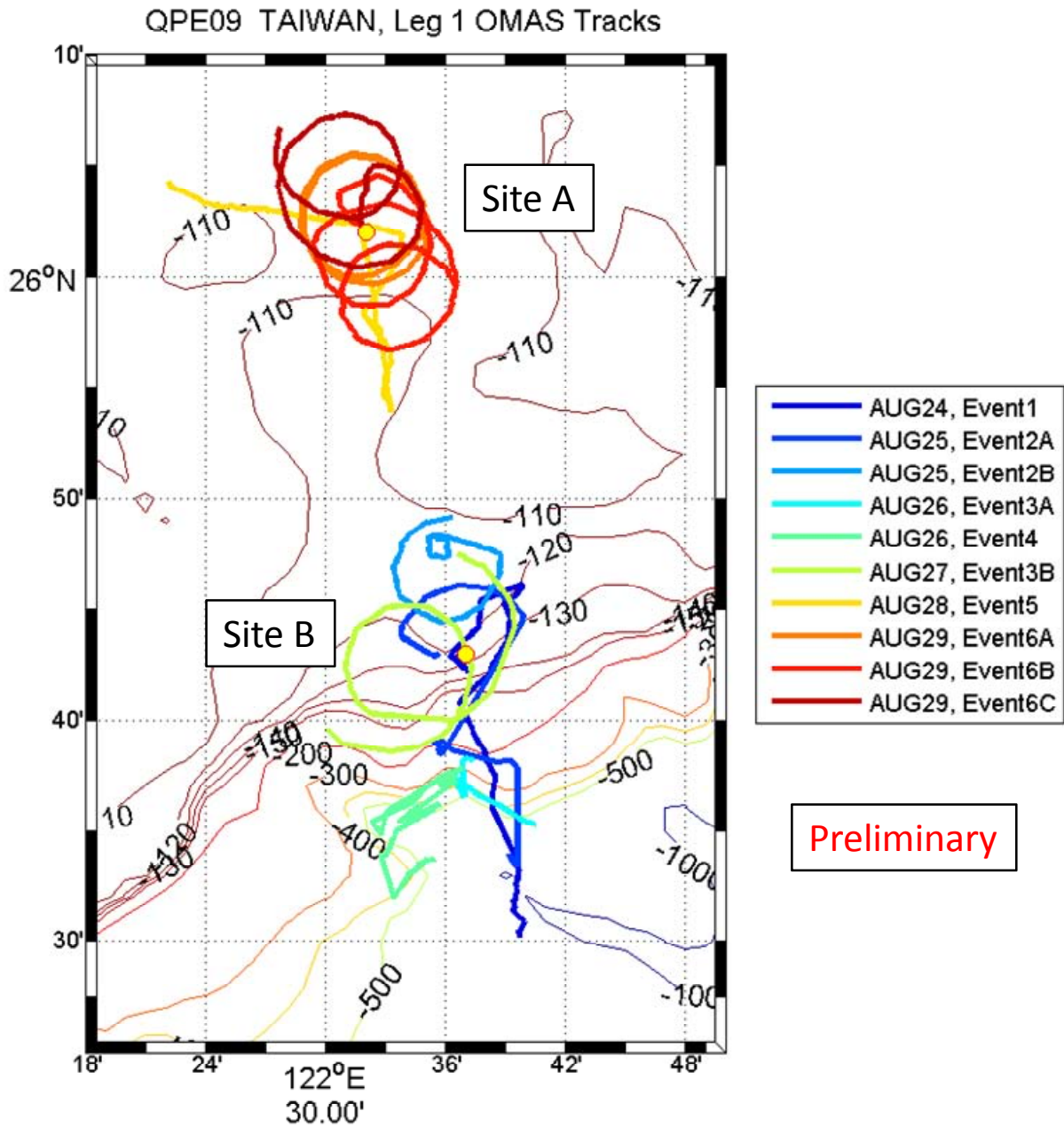
Fig. 3. Overview of QPE '09 Leg 1 OMAS measurements. The two primary points of interest for this cruise are located approximately 60 miles northeast of Taiwan, and identified as Site A, to the north, located in 110m of water on a relatively flat bottom, and Site B, a point on the 130m isobath, northeast of a small canyon. This figure shows the position of all ten of the OMAS vehicles that were launched during the Leg 1 cruise between Aug. 24th-30th.
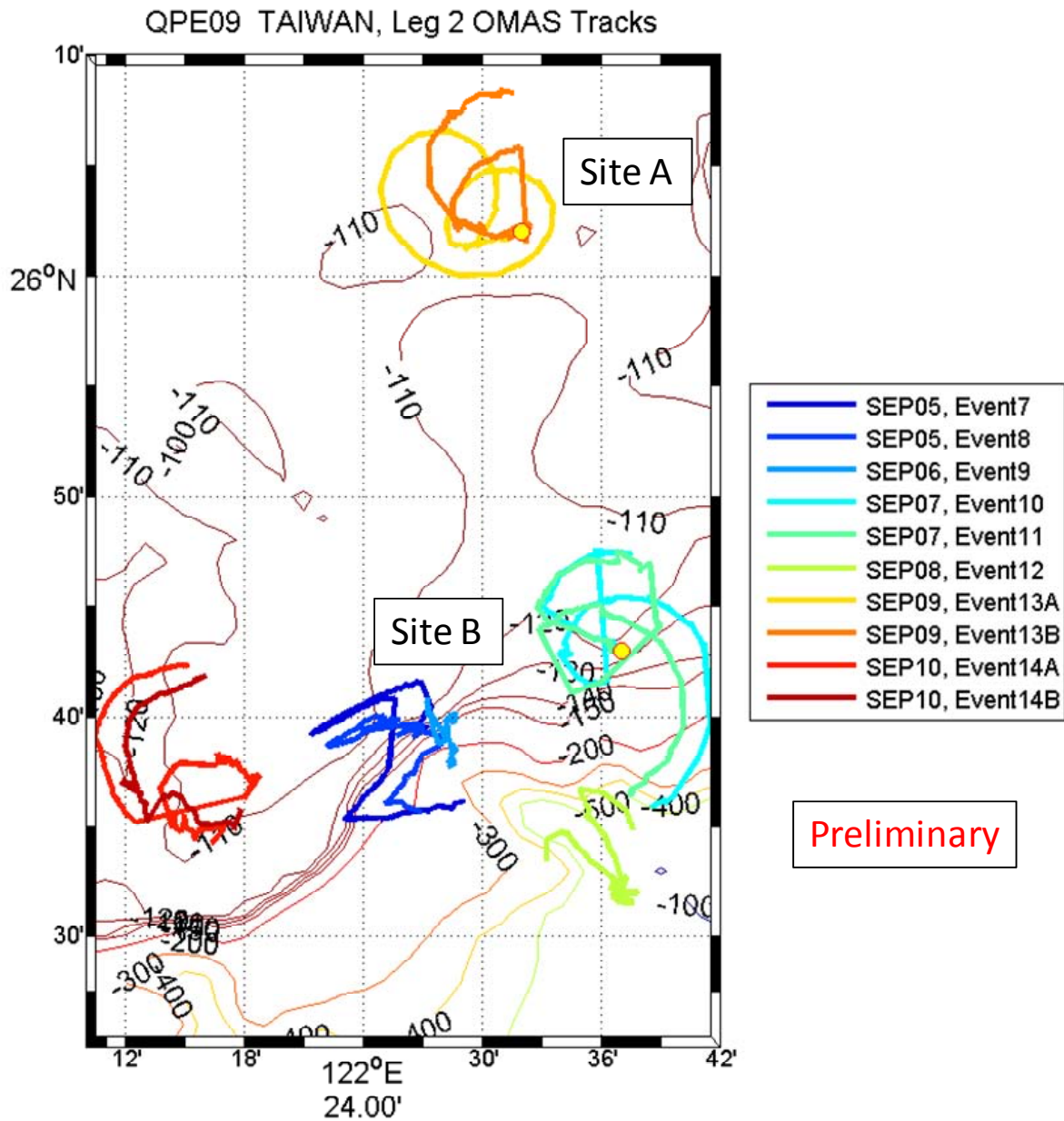
Fig. 4. *Overview of QPE '09 Leg 2 OMAS measurements. The two primary points of interest for this cruise are located approximately 60 miles northeast of Taiwan, and identified as Site A, to the north, located in 110m of water on a relatively flat bottom, and Site B, a point on the 130m isobath, northeast of a small canyon. This figure shows the position of all ten of the OMAS vehicles that were launched during the Leg 2 cruise between Sept. 5th – 10th.*
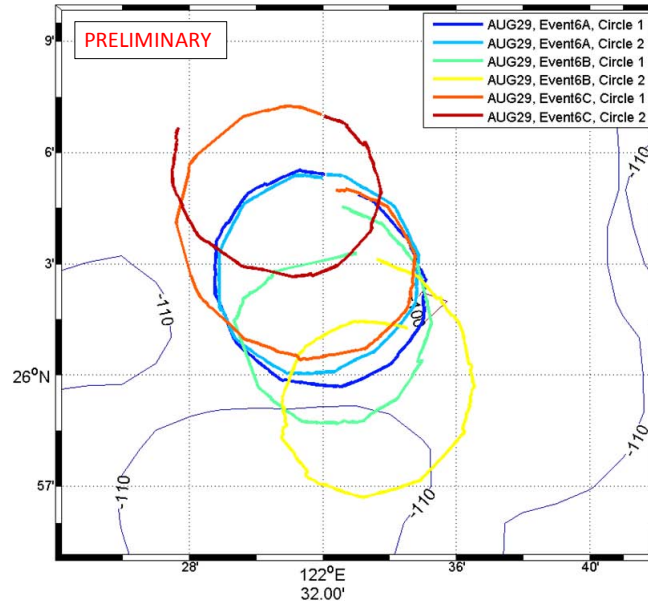
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Fig.5. This plot shows the post-processed tracks obtained from three different OMAS units during the 24 hour Temporal Variance Experiment at Site A, conducted from 12:07Z (20:07L) 29 August until 11:41Z (19:41L) 30 August, 2009.
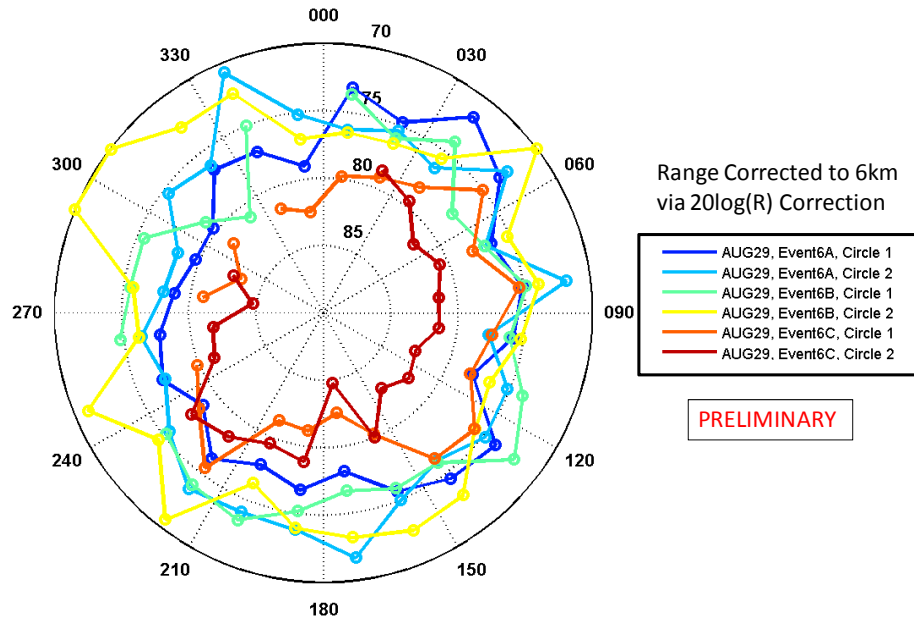

Fig.6. Comparison of the mean, 900 Hz Transmission Loss (TL) data plotted as a function of bearing obtained from three, consecutively launched OMAS vehicles during the 24 hour Temporal Variance Experiment at Site A, conducted from 12:07Z (20:07L) 29 August until 11:41Z (19:41L) 30 August, 2009. Depth of the OMAS source, and DIFAR receiver were both 90' (27.4m). The vehicles were all launched at the same starting point, and were programmed to run on identical, 4.5km radius circles, at a constant 5kt speed. The outer circumference represents 70 dB TL, and each consecutive dotted circle is 5 dB more loss, with the innermost circle representing 85 dB TL.