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Predictability of Short-Period Variability in the Philippine Sea and the Influence of Such Variability on Long-Range Acoustic Propagation

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LONG-TERM GOALS

My long-term goal is a complete and thorough understanding of the properties of acoustic pulses sent over basin to global scales. In particular, I want to understand the forward problem for calculating travel times of the early ray arrivals in long-range acoustic transmissions and to understand the sampling associated with those arrivals.

OBJECTIVES

This work aims to determine the extent to which models of ocean variability can be used for the study of long-range acoustics. Models of ocean variability in the Philippine Sea are to be developed from historical data and from the PhilSea'09 and PhilSea'10 experiments. These models will then be used to obtain the relevant acoustic properties (e.g., full-depth sections of sound speed) such that the effects of variability on long-range acoustic propagation can be calculated and compared to field data. Another objective is to examine data obtained on deep hydrophone arrays during the SPICEX experiment to establish general properties of receptions that occur in the shadow zone.

APPROACH

Work this past year (2009) involved three separate projects:

(1) Completion of paper describing a decade of acoustic thermometry in the North Pacific (1996-2006) and a comparison of those measurements to several numerical ocean models. This paper was published in the *Journal of Geophysical Research* (Dushaw et al. 2009). Peter Worcester at the Scripps Institution of Oceanography was a close collaborator; there were other collaborators.

(2) Participation in a test experiment in the western Philippine Sea (PhilSea'09) and preliminary analysis of data acquired during that month-long experiment. This

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
This work aims to determine the extent to which models of ocean variability can be used for the study of long-range acoustics. Models of ocean variability in the Philippine Sea are to be developed from historical data and from the PhilSea’09 and PhilSea’10 experiments. These models will then be used to obtain the relevant acoustic properties (e.g., full-depth sections of sound speed) such that the effects of variability on long-range acoustic propagation can be calculated and compared to field data. Another objective is to examine data obtained on deep hydrophone arrays during the SPICEX experiment to establish general properties of receptions that occur in the shadow zone.

15. SUBJECT TERMS

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analysis was to guide the final design of the more extensive PhilSea'10 experiment. The PhilSea'09 and PhilSea'10 experiments are conducted by Peter Worcester at the Scripps Institution of Oceanography.

(3) Development of a "Community White Paper" as an advocacy document for the implementation of acoustic remote sensing capabilities, both passive and active, in the Ocean Observing System. This paper was a contribution to the international *OceanObs'09* conference held in Venice, Italy in September 2009 (Dushaw et al. 2010; http://www.oceanobs09.net). An international collaboration was brought together for this purpose (see the author list of Dushaw et al. 2010), and a "Special Plenary Session" focused on acoustic applications for ocean observation was organized and given during this conference (Fig. 1). (This work was an explicit goal for Year 1 of this grant.)

WORK COMPLETED

Acoustic Thermometry in the North Pacific. The paper describing the acoustic thermometry data acquired in the North Pacific is now completed and published. A related paper entitled *"On the time-mean state of ocean models and the properties of long-range acoustics"* has been written and should be submitted for publication soon.

OceanObs'09 Community White Paper. This work is now complete and the community white paper is in press. I believe the sense of our coauthors was that, with this paper and the Special Plenary Session, the utility of acoustics as a remote sensing tool for the ocean observing system was effectively conveyed to the larger oceanographic community. This white paper was a follow-on to a similar community white paper (Dushaw et al. 2001) prepared for OceanObs'99 a decade earlier.

PhilSea'09 Thermistor Data. Dense sampling of the water column by thermistors was obtained on both the acoustic source mooring (T1) and receiver mooring (DVLA) deployed during PhilSea'09 (Fig. 2). These data were acquired from John Colosi of the Naval Postgraduate School, who was responsible for the acquisition of the thermistor data in PhilSea'09. These data provided excellent measurements of the vigorous tidal variability of the Philippine Sea, allowing separation of the tidal variability into both tidal constituent and model components. This analysis follows that of Dushaw et al. (2005).

RESULTS

An accurate analysis of these data first required corrections to the time series for mooring "pull down". Ocean variability frequently caused the moorings to be pulled down by O(50 m). This change in depth significantly affected the thermistor records. After correcting for these displacements using the ambient temperature gradients, the observed tidal variability was both more temporally coherent and more sinusoidal. The large numbers of thermistors deployed gave particularly good resolution of the internal wave modes.

Vigorous, but ordinary, internal tides dominated the thermistor records from both T1 and DVLA moorings (Fig. 3). The typical vertical displacements caused by the internal tides were sinusoidal and varied by ±30-40 m. A fit of 8 internal wave modes to the thermistor records accounted for about 80% of the temperature variance at all depths. The variations in the amplitudes of modes 1 and 2 were mostly temporally coherent (phase-locked) over the month long record. The tidal fit to the mode-1 (mode-2) amplitude time series accounted for 90% (50%) of the RMS. The diurnal internal tide variability was large and comparable in size to the semi-diurnal variability. However, the ratio of amplitudes derived for the various tidal constituents roughly corresponded to the ratio of barotropic "forcing" amplitudes. The “forcing” amplitudes were estimated using the barotropic tidal currents predicted by the TPXO tidal model (e.g., Fig. 4). Therefore, the large amplitudes of the diurnal internal tide cannot be considered as indicative of any unusual process. Given the strong zonal barotropic currents, the Luzon Strait is a likely origin of this internal tide variability.

IMPACT/APPLICATIONS

The OceanObs'09 Community White Paper is aimed at securing community support for implementing sustained, long-term observations of the ocean using both passive and active acoustic systems deployed globally. The impacts of such observations on our understanding of many aspects of ocean variability and the oceanic responses to such things as climate change can probably not be overestimated.

The results from the preliminary analysis of T1 and DVLA thermistor records have allowed our collaboration to better design the themistor sampling during PhilSea'10, when seven moorings are to be deployed.

RELATED PROJECTS

This project is a contribution to the North Pacific Acoustic Laboratory (NPAL) collaboration, which comprises researchers from the Applied Physics Laboratory, the Scripps Institution of Oceanography, and the Massachusetts Institute of Technology, among others. (http://npal.ucsd.edu/)

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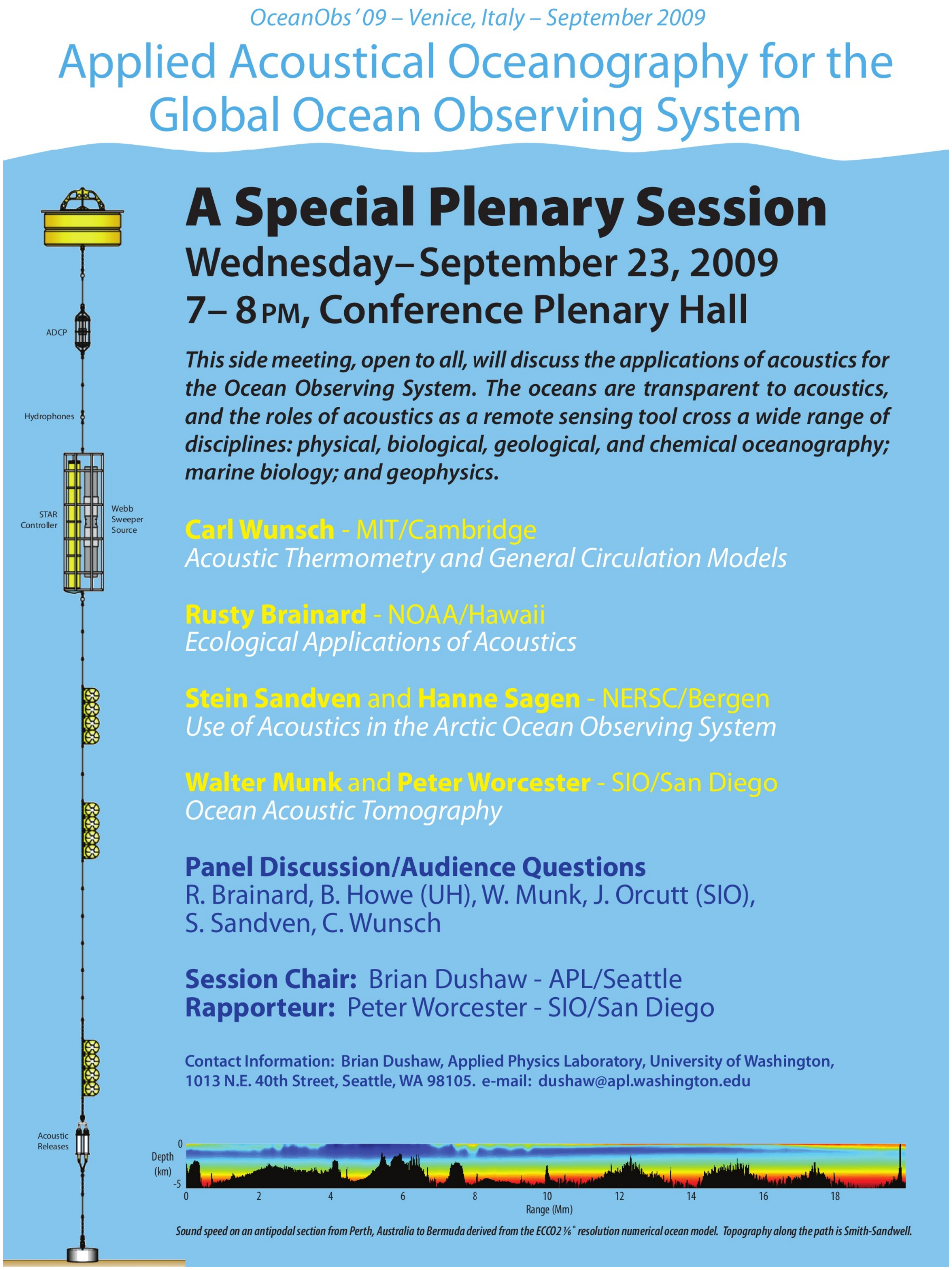

Figure 1. Poster for the special plenary session that focused on implementing applied acoustics systems as components of the global ocean observing system. This session was organized for the OceanObs'09 conference in Venice, Italy September 2009.

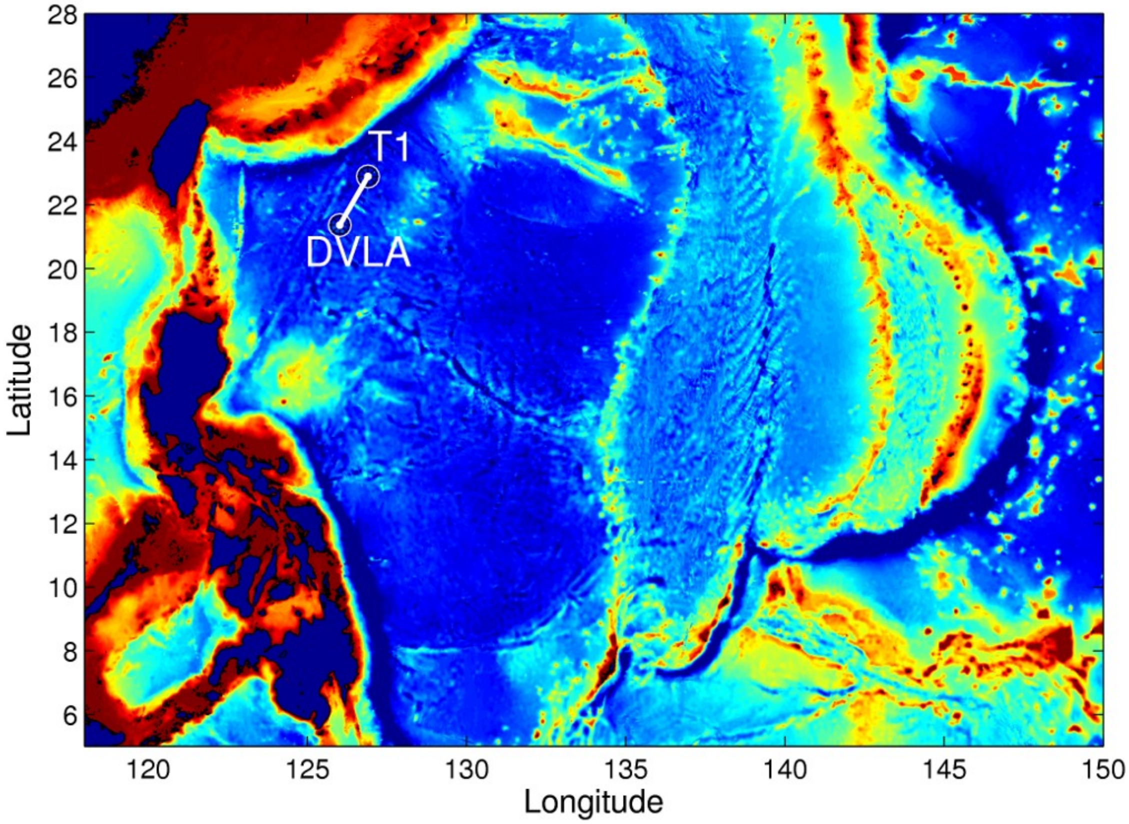

Figure 2. The Philippine Sea showing the locations of the acoustic source mooring (T1) and the vertical line array of hydrophones (DVLA). The colors indicate depths derived from the Smith-Sandwell global seafloor topography.

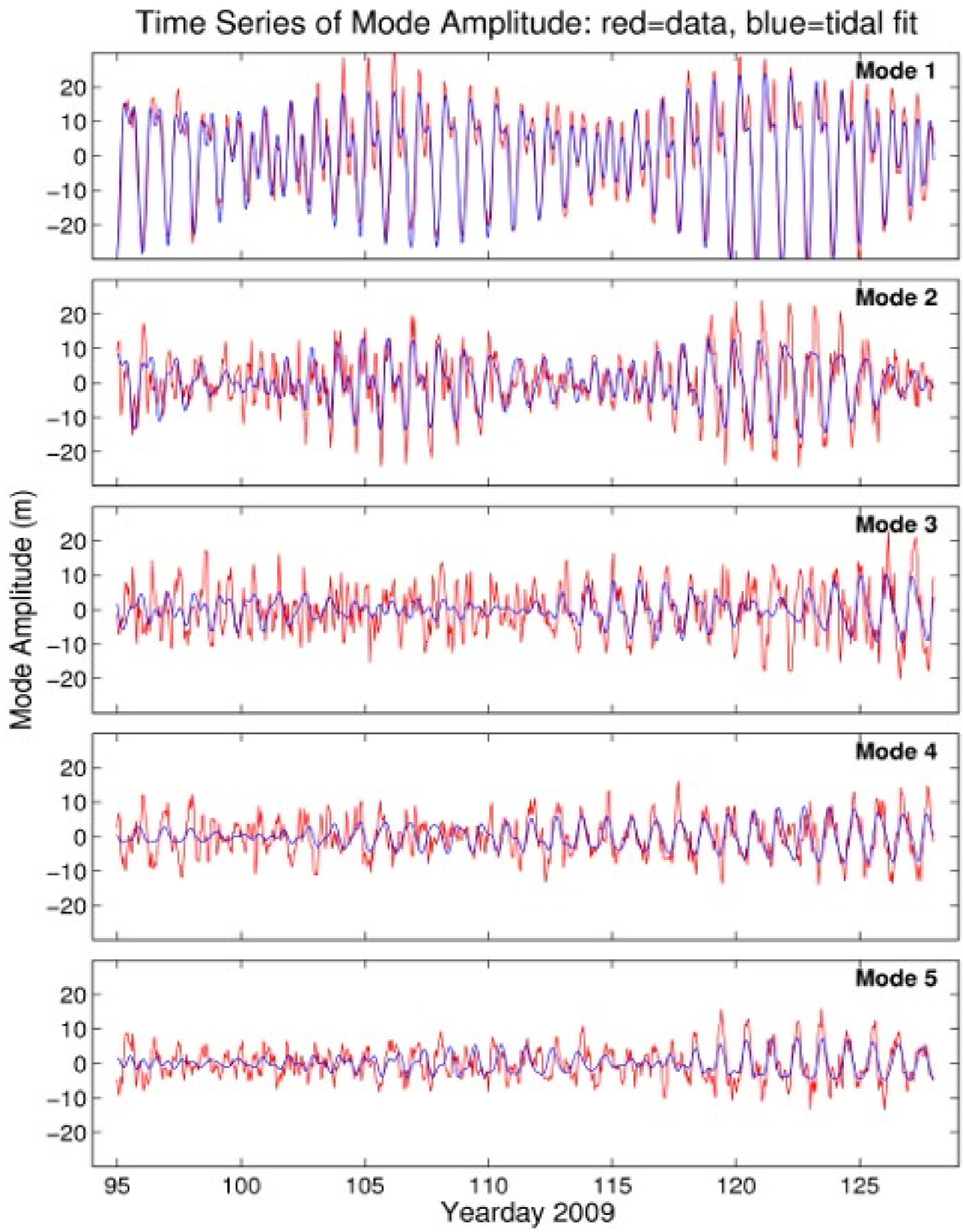

Figure 3. Time series of mode amplitude derived from the DVLA thermistor time series from the PhilSea'09 experiment. The red lines are the mode time series, the blue lines are the tidal fits to those time series. The mode functions are normalized such that "Mode Amplitude" roughly corresponds to internal displacement in meters at mode maximum; internal mode-1 displacements were ± 20 m at 1-km depth. The internal tides are quite large in the Philippine Sea, with both Modes 1 and 2 exhibiting a phase-locked, or predictable, variability. The tidal fit to the mode-1 time series accounted for 90% of the RMS.

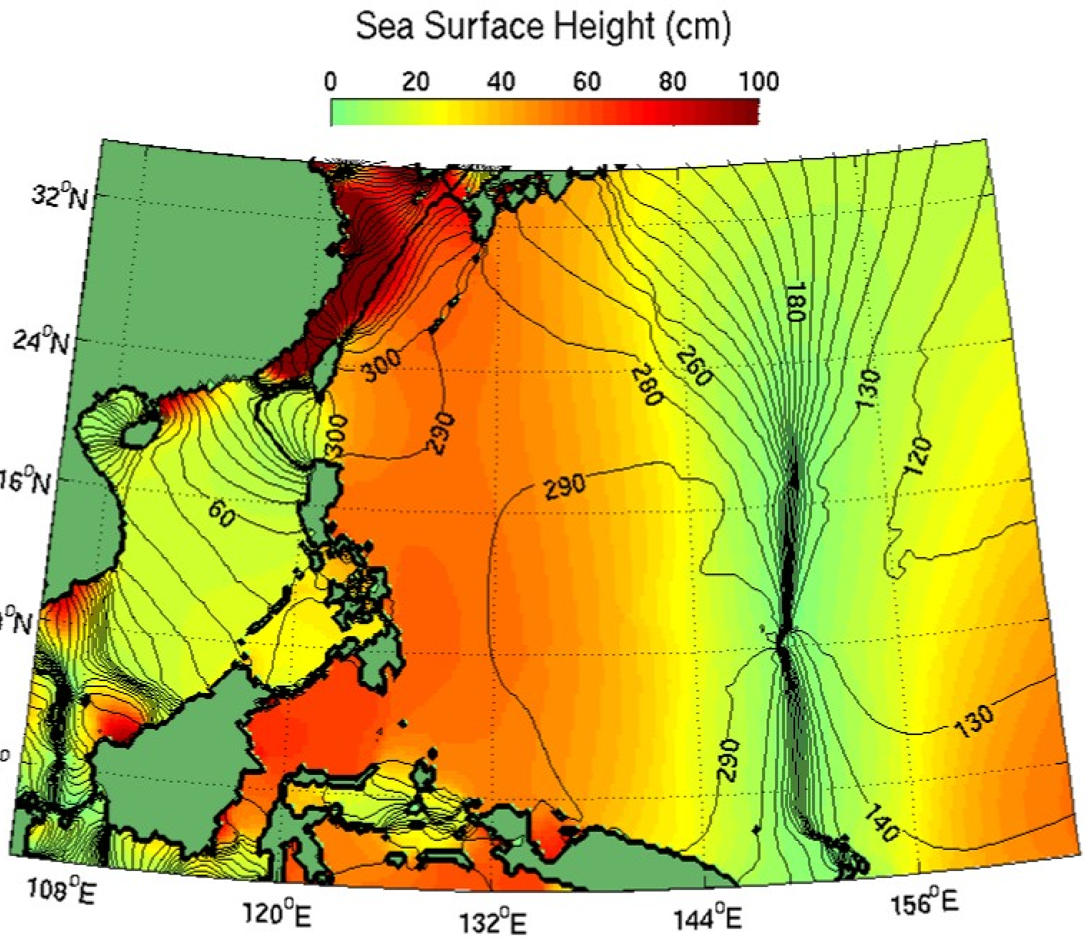

Figure 4. Cotidal map for the M_2 barotropic tide derived from the TPXO 7.1 tidal model of Oregon State. The numbers on the contour lines indicate tidal phase.