

North Pacific Acoustic Laboratory

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LONG-TERM GOALS

As the limits of long-range sonar are affected by ocean variability, the overarching goal of this work is to characterize, understand, and predict sound-speed variability in the upper ocean. Sound speed is a function of the ocean state variables temperature T , salinity S , which are themselves affected by such processes as stirring, mixing and internal waves. A long-range goal is thus the inversion of acoustic data to measure these processes.

OBJECTIVES

Internal waves have long been considered the primary cause of acoustic energy fluctuations. However T/S variations at constant density, often called spice (Munk 1981), also affect sound speed. An objective of this work is to separate and quantify the effects of internal waves and spice on sound speed. The Garrett/Munk spectrum is an empirical characterization of internal waves that has withstood the test of time as a zero-order description. An equivalent statistical description of spice is an objective. Because spice is strongly intermittent, a description in terms only of power spectra is inadequate, and kurtosis must be considered. Armed with realistic statistical descriptions of internal waves and spice, a final objective is numerical experimentation on acoustic propagation through oceans of varying amounts of internal wave and spice fluctuations.

APPROACH

The experimental approach is to get several realizations of an ocean section between acoustic transceivers. We plan to obtain horizontal resolution of 10 km or better and vertical resolution of about 5 m. Two instrument systems will be used. SeaSoar is a standard oceanographic instrument towed at a speed of 8 knots, and capable of profiling to as deep as 400 m with a cycle distance of about 3 km. One SeaSoar cruise is planned in February 2005. The Underway CTD (UCTD) is a newly developed device intended to profile from ships steaming as fast as 20 knots. We plan to make profiles to 500 m every 30 min while riding along on P. Worcester's acoustic mooring deployment cruise, yielding resolution of 9 km at a ship speed of 10 knots. The approach to data analysis will involve the calculation of spectra and distributions to quantify the effects of internal waves and spice on sound speed.

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WORK COMPLETED

This project was initiated very late in FY2003, as funds arrived in July 2003. However, work on this topic has been ongoing for over the past year, with funding from other sources. A manuscript on sound propagation through spice and internal waves was submitted in January 2003 (Dzieciuch et al. 2003). The manuscript puts forth a method for separating spice and internal waves in SeaSoar data, and then uses a numerical model to examine acoustic propagation through oceans with either spice and/or internal waves filtered. Development on the UCTD has been rapid over the past year, with a full-scale operational test in April 2003. A total of 35 UCTD casts were done to as deep as 400 m at ship speeds sometimes exceeding 12 knots, all at no cost in ship time.

RESULTS

The mixed layer is replete with horizontal T/S structure that compensates in its effect on density. That is, fronts in the mixed layer tend to go from warm and salty to cool and fresh such that the density contrast across the front is small (Rudnick and Ferrari 1999). Temperature, salinity, density, spice and sound speed in the mixed layer of the North Pacific along 140°W are shown in Fig. 1. Temperature and salinity nearly completely compensate in their effect on density, and sound speed is strongly correlated with spice.

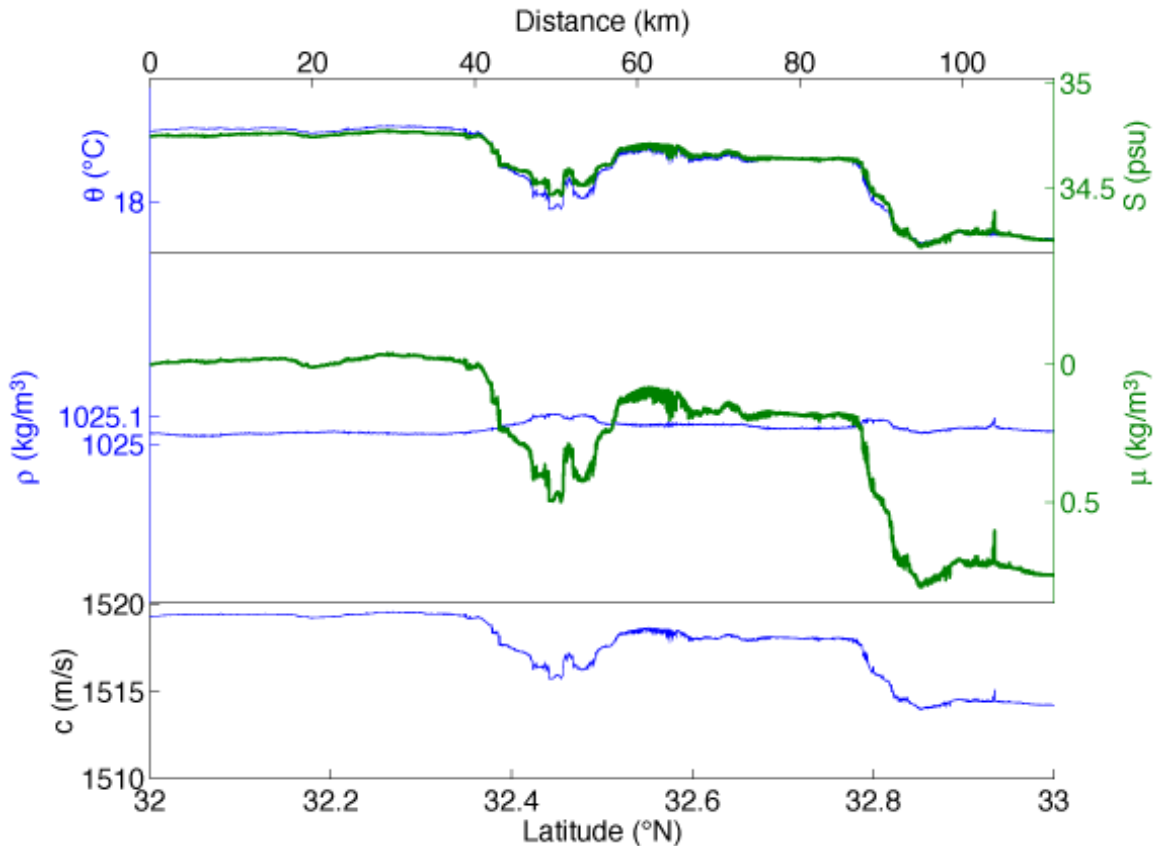


Figure 1. Potential temperature θ , salinity S , potential density ρ , spice μ , and sound speed c at 50 m along 140°W in the North Pacific. Note the compensating temperature/salinity structure and resulting sound speed fluctuations.

Spice can also be important in the thermocline. Sound speed variations due to the tilting of isopycnals (as due to internal waves) is determined by using a range-independent T/S relation and the observed density field. Spice-only sound speed fluctuations are revealed through examination of range-dependent T/S at constant density. The tilt sound speed at 200 m and spice sound speed on isopycnal 25.6 kg m^{-3} (average depth 200 m) are shown in Fig. 2. At the largest scales, sound speed changes are due to shoaling isopycnals and latitudinal trends in the T/S relation. Smaller scale changes in the tilt sound speed are caused by internal waves, while those in the spicy sound speed are the result of stirring of T/S gradients. Standard deviations of sound speed gradients (from 3 km horizontal differences) are 0.74 m s^{-1} for tilt and 0.35 m s^{-1} for spice, so while internal waves are more important, spice gradients may be a relevant sound scatterer.

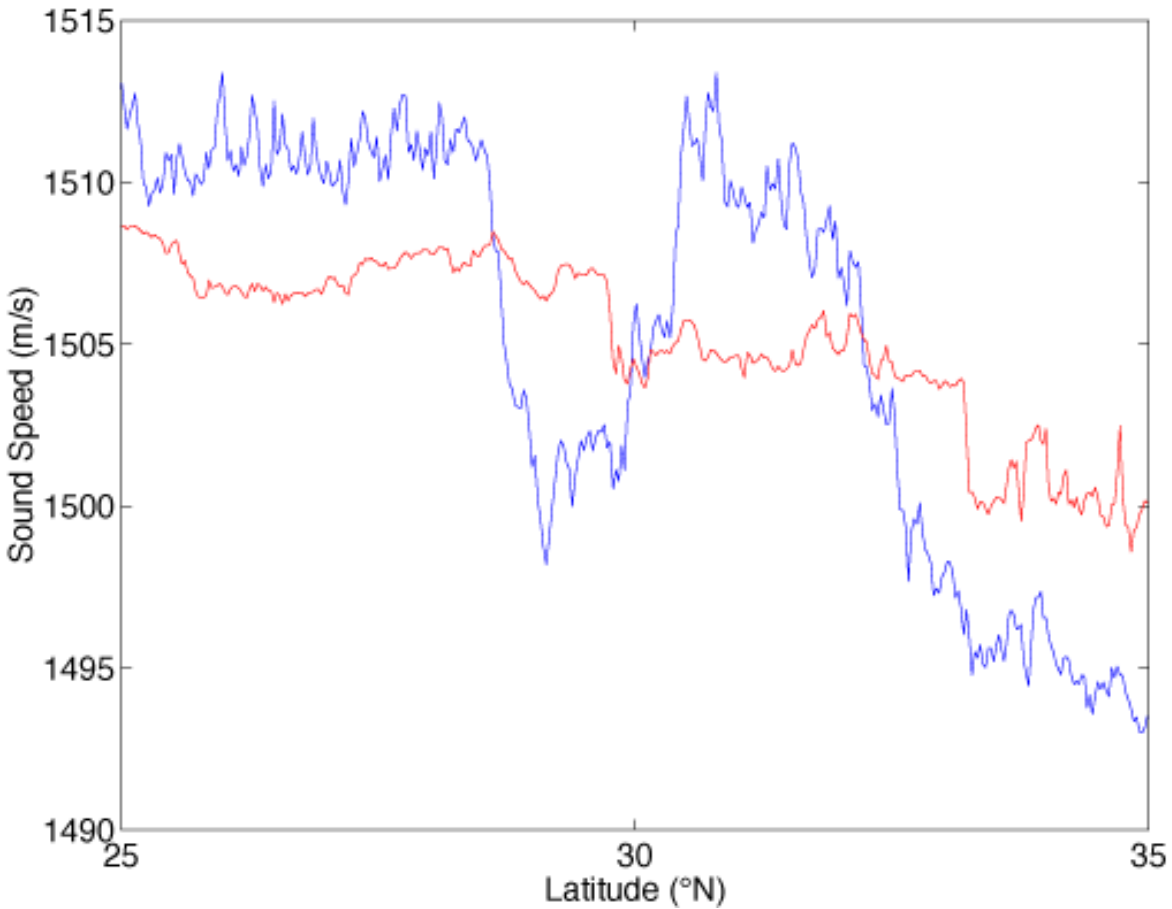


Figure 2. Sound speed variability caused by isopycnal tilting at 200 m (blue) and caused by spice at 25.6 kg m^{-3} (red). While isopycnal tilting, as due to internal waves, causes more sound speed variability than does spice, the latter effect is important.

IMPACT/APPLICATIONS

The statistical characterization of sound speed variability caused by spice promises an improved understanding of long-range acoustics propagation.

RELATED PROJECTS

This project is closely related to a number of my ongoing projects focused on upper ocean variability as observed by SeaSoar, all of which are supported by NSF. The development of the Underway CTD has been supported by NOAA.

REFERENCES

Munk, W., 1981: Internal waves and small-scale processes. *Evolution of Physical Oceanography*, B. A. Warren and C. Wunsch, Eds., The MIT Press, 264-291.

Rudnick, D. L. and R. Ferrari, 1999: Compensation of horizontal temperature and salinity gradients in the ocean mixed layer. *Science*, **283**, 526-529.

PUBLICATIONS

Dzieciuch, M., W. Munk, and D. L. Rudnick, 2003: Propagation of sound through a spicy ocean; the SOFAR overture. *J. Acoust. Soc. Am.* [submitted, refereed].