OBSERVATIONS OF MESOSCALE VARIABILITY IN SOUND SPEED STRUCTURE

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ABSTRACT Temperature data from multi-ship XBT (expendable bathythermograph) surveys are used to compute three-dimensional near-synoptic sound speed fields in mid-ocean regions. A model for calculating sound speed throughout the deep ocean from the XBT data which is available only to 800 m depth is applied to a North Pacific data set. Mesoscale variability due to the presence of prominent eddies and fronts yields an rms variability of about 6 m/s in sound speed from the surface to the vicinity of the sound channel axis.

BACKGROUND The variability in received sound in the ocean is caused by ocean fluctuations on many scales and frequencies. At a given location in the deep ocean, these fluctuations include the fine- and microstructure, the internal waves, and the mesoscale. The mesoscale variability includes features having sizes from many tens to several hundred kms, and is characterized by eddies and fronts. This scale has received intensive investigation in recent years in the POLYGON, MODE, and POLYMODE programs.

OCEANOGRAPHIC DATA A series of multi-ship surveys has been organized in order to acquire data of a synoptic nature (nearly frozen field) on the mesoscale over large mid-ocean regions. U.S. Navy ships of opportunity have been used to cover regions about 2° in latitude and 30° in longitude in four days time. The data is acquired by using XBTs which give a continuous profile of temperature versus depth from the surface to either 500 or 800 m depth from a ship while underway. The horizontal resolution is about 25 km along ship tracks and 40-50 km between tracks. These upper ocean temperature data exhibit numerous mesoscale features having isotherm displacements of hundreds of meters. Since the only quick data acquisition method (fast ships using XBTs) gives only upper layer data, a model is required to extend the data down into the deep ocean.

SOUND SPEED MODEL A model has been developed to extend the upper ocean temperature profiles into the deep ocean, and to estimate salinity for an objective estimation of the sound speed field from the surface to the bottom over the survey regions. To extrapolate any given temperature profile, the model uses the mean and standard deviation profiles of all deep historical hydrographic data that is available for the region. The importance of having measured temperature data that extends to the vicinity of the sound channel axis is apparent in the results, and all short profiles are interpolated to deeper levels by using surrounding deeper profiles. Then, salinity profiles are estimated by using T-S diagrams generated from the historical hydrographic data, and sound speed profiles are calculated by using Wilson's formula.

RESULTS The data from one survey in the North Pacific have been run through the model. Fig. 1 shows a sequence of several sound speed profiles. It may be seen that the 800 m depth of the real data barely extends to the mean sound channel axis. The profiles on the right are inside a warm eddy, while those on the left are outside of it. There is considerable change in the top several hundred meters, and the sound channel axis drops down about 300 m in the eddy. The standard deviation of all profiles roughly is constant at about 6 m/s to the depth of the channel axis, and it decreases uniformly below this depth in a manner specified by the model. Fig. 2 is an isovel section from the southernmost ship in the survey. It shows warm eddies near 157°E, 166°E, and 175°E. In each case, the channel axis is depressed below surrounding axis depths. There also are lenses of sound speed minima just to the outside of the eddies. Fig. 3 shows maps of the temperature, salinity, density, and sound velocity at 500 m depth for the whole survey. The three warm eddies are apparent in the southern edge, and a large warm eddy occurs near 170°E in the middle of the survey swath.

DISCUSSION We conclude that models like this one are useful for extending XBT data into the deep ocean. The method is only as good as the hydrographic history of the area, and even in good geographic regions there are problems in computing high quality sound speed data from casually acquired XBT data.

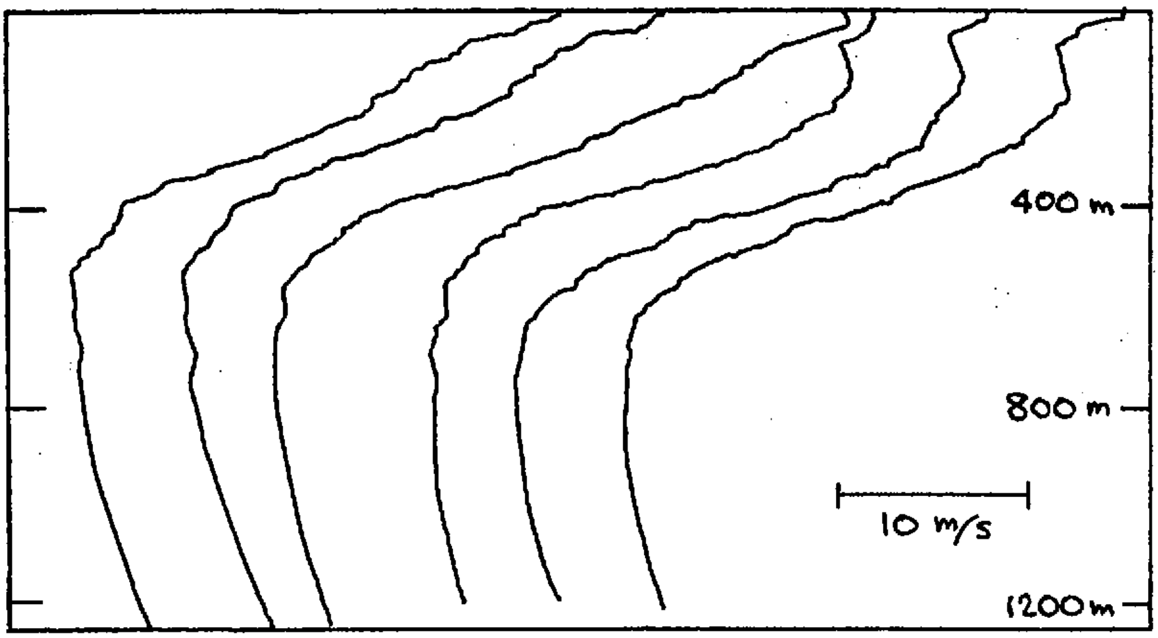

FIGURE 1. Sequential Sound Speed Profiles

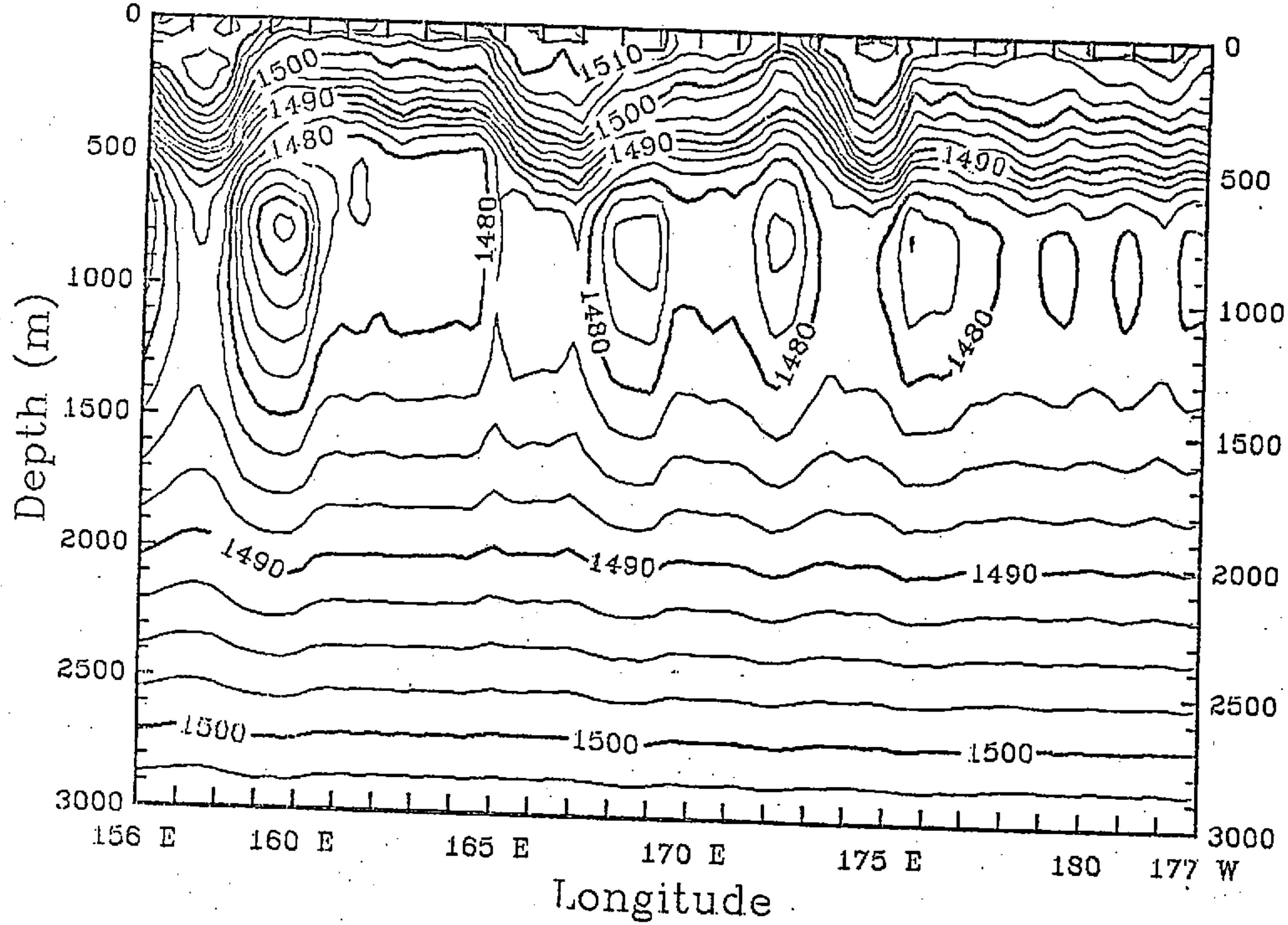

FIGURE 2. Sound Velocity Section for one ship (m/s)

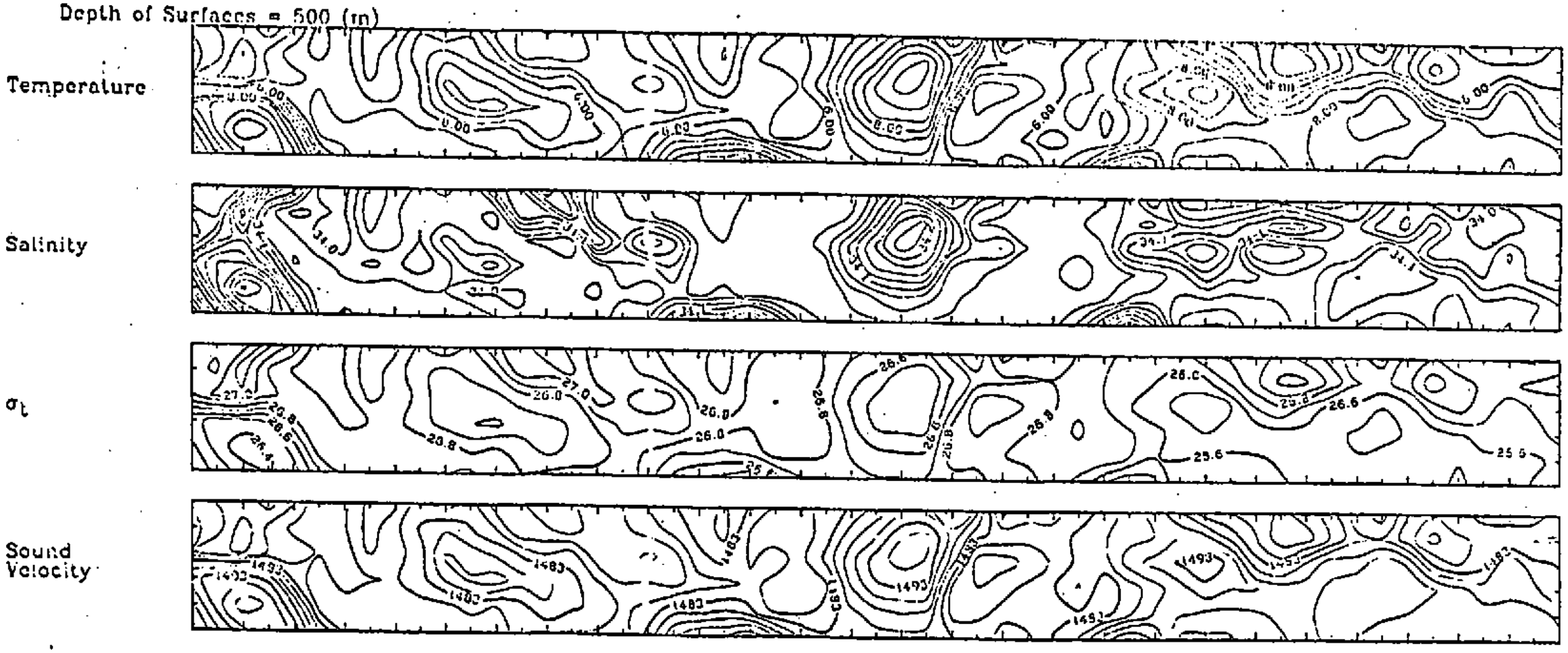

FIGURE 3. Temperature (°C), salinity (‰), density (σ_t) and sound velocity (m/s) at 500m for the survey.

these three loss mechanisms (δ_S, δ_{AC}, and δ_{AS}) on the reflection coefficient is given in Fig. 4 as a function of shear speed. We have here chosen a maximum attenuation of both compressional and shear waves, which means that the magnitudes of δ_{AC} and δ_{AS} are over-estimated in this example. However, it is clear from Fig. 4 that the coupling of energy into shear waves (δ_S) is negligible for shear speeds below 200-300 m/s. Since also δ_{AS} will be small for realistic shear attenuations, the only important loss mechanism is attenuation of compressional waves. For shear speed above 800-900 m/s, on the other hand, the excitation of shear waves is the dominant loss mechanism, and both δ_{AC} and δ_{AS} are negligible [2]. At intermediate shear speeds all three loss mechanisms are important.

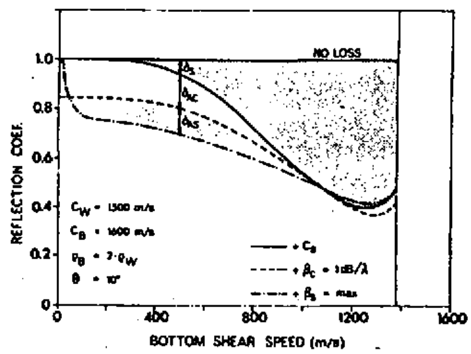

Fig. 4 Relative importance of three loss mechanisms

The general frequency-dependent effect of shear waves on propagation has been computed by means of the normal-mode model for the environment shown in Fig. 5. Propagation loss versus frequency is given in Fig. 6 at a range of 20 km and for both source and receiver at mid-depth. The upper curve is for a fluid bottom (c_S=0), while one of the three lower, almost identical curves is for c_S=500 m/s. We see that the effect of shear waves in the bottom (δ_S) is increased losses for propagation in the water column, particularly at lower frequencies. The remaining two curves in Fig. 6 show that shear waves can be simulated either by increasing the compressional attenuation (0.25 → 0.52 dB/λ) or by decreasing the compressional speed (1600→1555m/s). However, such a simulation only works for low-speed shear waves.

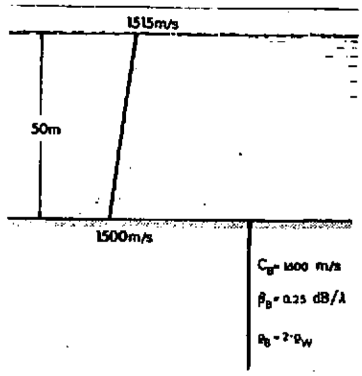

Fig. 5 Environment to calculate the effect of shear waves on propagation

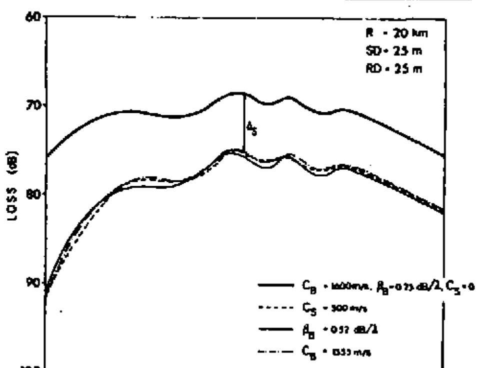

Fig. 6 Computed excess loss (δ_S) due to shear waves in the bottom

3 PENETRATION INTO THE BOTTOM

Knowing the relative effect of various bottom parameters on propagation, the next question inevitably is: To what depth is knowledge about bottom parameters required? This question was answered in [3] for simplified ocean environments (isovelocity water), but by using the normal-mode model for a parametric study we can answer the question for realistic environments, i.e. for both summer and winter profiles, and for both hard and soft bottoms (Fig. 7).

The acoustic penetration depth h in wavelengths has been defined in such a way that depth-averaged transmission loss is determined to within an accuracy of ± 1 dB over a range of 30 km, independent of which bottom properties are used below depth h. The cases compared have been: 1) Continue actual bottom speed below depth h as given by dashed lines in Fig. 7; 2) Introduce a hard layer at depth h with speed 1800 m/s ($\sim c_B/c_W=1.20$) shown as the reference speed in Fig. 7. If there is no effect on transmission loss (to within ± 1 dB) by introducing the high-speed bottom below depth h , this depth is called the acoustic penetration depth.

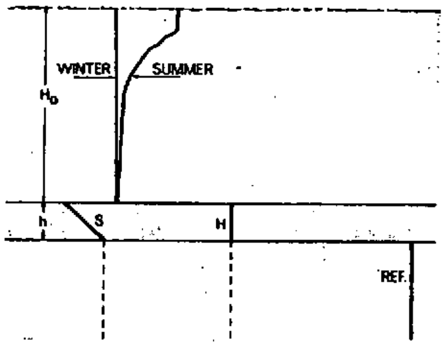

Fig. 7 Environment to study acoustic penetration into the bottom

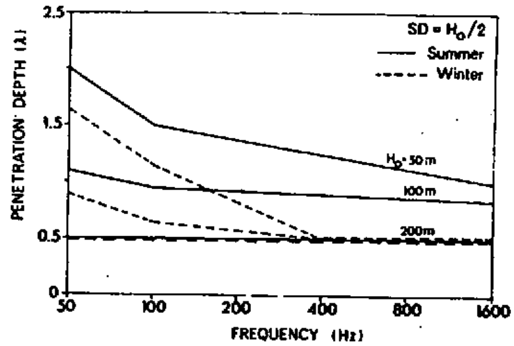

Fig. 8 Computed penetration versus frequency for a hard bottom

Environmental inputs were chosen as realistic as possible, and the numerical values used are essentially the same as the ones given in Fig. 2. Only in the case of a soft bottom was a gradient (1 m/s/m) introduced. The results for a hard bottom and two different profiles are shown in Fig. 8, where the penetration depth is plotted versus frequency for three different water depths. We see that: 1) Penetration is 0.5-2.0λ for H_o =50-200 m and for F =50-1600 Hz; 2) Penetration decreases with increasing frequency; 3) Penetration is higher for a downward-refracting summer profile than for an upward-refracting winter profile.

For a soft bottom with a speed lower than the water speed at the water/bottom interface, the definition of the penetration depth becomes more complicated. The upper part of the bottom then acts as part of the propagation channel, and it is necessary to have a detailed knowledge about bottom properties at least down to the depth h* where the bottom speed exceeds the maximum water speed. We find that for a soft bottom the penetration below h* is of the same order of magnitude as for a hard bottom, that is 0.5-2.0λ, dependent on water depth, frequency, profile type, etc.

CONCLUSIONS

When modelling sound propagation in shallow water, the most important bottom parameter is the sound speed followed by the attenuation coefficient and the density. Shear properties are unimportant for shear speeds below 200-300 m/s, while the excitation of shear waves is the dominant loss mechanism for shear speeds above 800-900 m/s. To predict propagation to within ± 1 dB over a range of 30 km, bottom properties need only be known down to a depth of 0.5-2.0 acoustic wavelengths.

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