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Sensitivity of Acoustic Propagation in Coastal Water

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Abstract: A coupled environmental and acoustic prediction system for shallow water was used for evaluation of the sensitivity of acoustic propagation to changes in environmental parameters. Two scenarios corresponding to the active upwelling and the wind relaxation off central California were examined. The preliminary model results indicated that the propagation loss is sensitive to both the water column thermal structure and the physical property of bottom sediment. Fluctuations in the propagation loss due to thermal variability are about 5-10 dB. The coupled prediction system allows a systematic evaluation of the acoustic variability in shallow water.

1. INTRODUCTION

The transmission of sound in shallow water depends on several environmental factors, such as the depth and the configuration of the ocean bottom, the physical properties of the bottom sediment, the sound velocity profiles, and the shape of the ocean surface. Since most of these environmental parameters have large spatial and temporal variations, the sensitivity of acoustic predictions to these environmental variabilities must be carefully investigated. For example, Jensen et al. (1991) found strong acoustic effect due to the Iceland-Faeroe front, and Rubenstein and Brill (1991) observed acoustic fluctuations caused by surface and internal waves.

Coupled environmental and acoustic prediction systems have been used to study the sensitivity of long-range acoustic propagation in open ocean (Robinson et al., 1991). The spatial and temporal structures of environmental fields are obtained from an open ocean model, and the acoustic effects due to changes in the environmental parameters are calculated from range dependent acoustic models. A similar approach, but for a hypothetical environmental condition was adopted by Sherwin (1991) to study acoustic effect due to internal tidal fluctuation on the shelf edge. In this study, we demonstrated a shallow-water environmental and acoustic prediction system. The sensitivity of acoustic propagation loss to the coastal ocean variability is evaluated.

2. ENVIRONMENTAL PREDICTION SYSTEM

The environmental prediction system is a three-dimensional coastal ocean circulation model. The system solves time-dependent primitive equations for conservation of momentum, temperature, and mass. The system was used in Chen and Wang (1990) for a two-dimensional simulation of coastal upwelling off central California. Using wind stress and surface heat flux data from weather buoys, the system predicted the thermal field on the continental shelf and slope for the entire summer upwelling season (May to August). The predicted temperatures agree well with the observations obtained from moored current meter arrays. The difference between predicted and observed mean temperatures is typically less than 0.2°C, and the difference of variance also is very small. The changes in thermal field are quite dramatic. For example, Figures 1a and 1b show environmental conditions corresponding respectively to the active upwelling and the wind relaxation. During active upwelling, cold subsurface water is brought to the shelf and the temperature profile is homogeneous. In contrast, during wind relaxation, a shallow mixed layer is formed nearsurface and the temperature profile is stratified. The transition from active upwelling to wind relaxation is sudden, typically in 1-2 days.

3. ACOUSTIC PREDICTION SYSTEM

The acoustic prediction system is a two-dimensional parabolic equation model IFD (Lee and McDaniel, 1988). The model is range dependent and is capable of treating bottom layering. In this application, the acoustic source is located at a 90 m depth on the shelf break with a frequency of 150 Hz. The sediment layer on the shelf is 10 m thick and the bottom attenuation is 0.35 dB/λ. The sound velocity structure in the sediment layer is assumed to increase continuously from the value at sediment-water interface to 1600 m/s at the bottom of the sediment layer. It is noted that the model sediment layer structure is only an approximation to the much more complicated actual distribution of bottom sediment property. The computational range step is 2 m. An averaging window length of 1 km is used in presenting the propagation loss value.

4. SENSITIVITY RESULTS

The simulation by Chen and Wang (1990) provides a daily prediction of the thermal field for over 100 days. However, in this study, only two scenarios, corresponding to the environmental conditions presented in Fig. 1a and 1b, were used for evaluation of the sensitivity of acoustic propagation. The shelf break (depth = 160 m) is located at 20 km from the coast, and only results from the up-slope (towards the coast) propagation is presented. Figures 2a and 2b show the predicted propagation loss for active upwelling case and wind relaxation case. The general pattern between two cases is similar. Figures 3a and 3b compare in detail the propagation loss at two selected receiver depths of 20 m and 30 m. For range < 5 km, the propagation loss does not depend on the environmental condition. However, the difference in propagation loss becomes quite significant for range > 10 km. In general, the propagation loss for active upwelling case is smaller than for wind relaxation case; the deviation is about 5 dB.

The propagation loss is sensitive to the source depth. For example, when the source is located near the surface (source depth of 10 m), the difference between the active upwelling case and the wind relaxation case is much smaller than when the source is located in the lower water column. The propagation loss also is expected to be affected by the source frequency. However, in the present condition, change to a lower frequency (e.g., 100 Hz) yields essentially identical result. The propagation loss also is dependent on the physical property of bottom sediment. In the base case, the sound velocity gradient in the sediment is large. Consequently, the penetration depth and the associated reflection loss are small. On the other hand, if the bottom sediment is made up of fine clay, the sound velocity gradient will be smaller, and the reflection loss larger. For low velocity-gradient sediment, the sound velocity at the bottom of the sediment layer is assumed to be 1550 m/s. Figures 4a and 4b show comparison between high velocity-gradient sediment (base case) and low velocity-gradient sediment at a receiver depth of 40 m. The propagation loss in low velocity-gradient sediment case is larger by about 5 dB than in high velocity-gradient sediment (Fig. 4a). It is also noted that when the bottom loss is high, the water column condition (active upwelling versus wind relaxation) becomes inconsequential (Fig. 4b).

5. DISCUSSION

A coupled environmental and acoustic prediction system is used to study the sensitivity of acoustic propagation to changes in environmental parameters. The preliminary study indicates that both the water column temperature profile and the physical property of bottom sediment can profoundly affect the propagation loss for range >10 km. The acoustic effect due to ocean (water column) variability in shallow water was highlighted in a recent NATO Workshop (Potter and Warn-Varnas, 1991). This study, however, is probably the first time a coupled prediction system was used to estimate the shallow-water acoustic variability. The acoustic effect due to bottom sediment property has been examined for simple (range independent) bottom environment conditions (Jensen and Kuperman, 1983; Eller and Gershfeld, 1985). This study also considered only a simple, highly idealized sediment layer.

This study emphasizes the variability of coastal thermal field associated with the atmospheric forcing. On the shelf edge, internal tides and high-frequency internal waves may also lead to sharp thermal change. For example, Rosenfeld (1990) found strong internal tidal activities off central California during periods of wind relaxation (when the water column was highly stratified). Eddies and filaments off the shelf break also can cause large changes in thermal field. A complete environmental prediction system for coastal ocean will have to take all these processes into account. Also, the sediment distribution on the continental margin is far from being homogeneous, as both the thickness and the physical property of sediment layer can change abruptly across the shelf. A better understanding of the shallow-water acoustic prediction will require a realistic model of the bottom attenuation.

The three-dimensional effect is not addressed in this study. The continental shelf edge is not smooth, but is usually interrupted by submarine canyons. It is well known that the coastal upwelling also is enhanced near canyons. The acoustic prediction system eventually will need to incorporate full three-dimensional capability, such as FOR3D (Botseas et al., 1987).

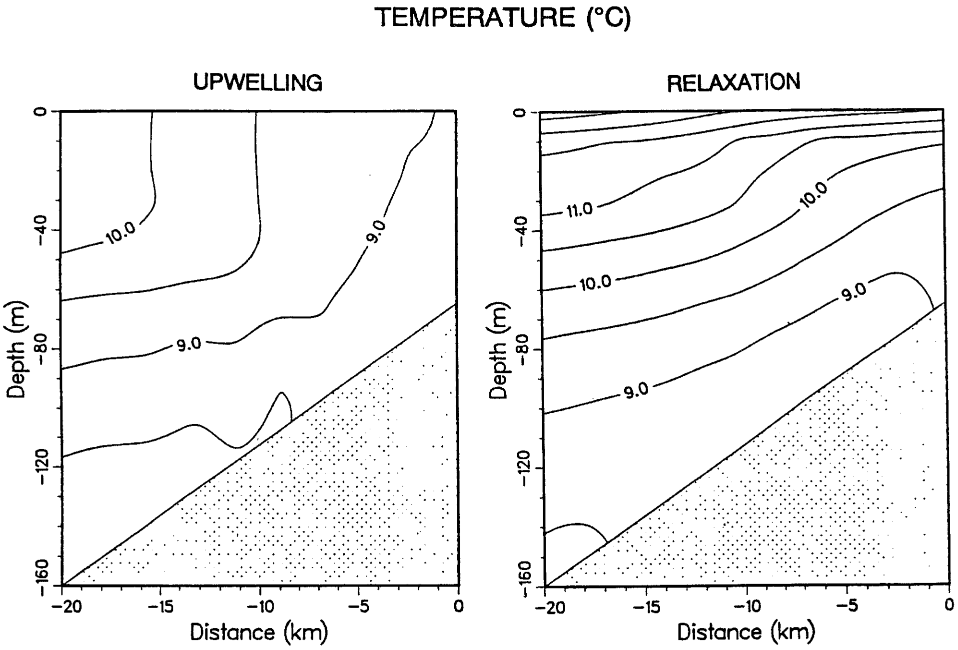

Fig. 1. Thermal field (°C) for (a) active upwelling and (b) wind relaxation.

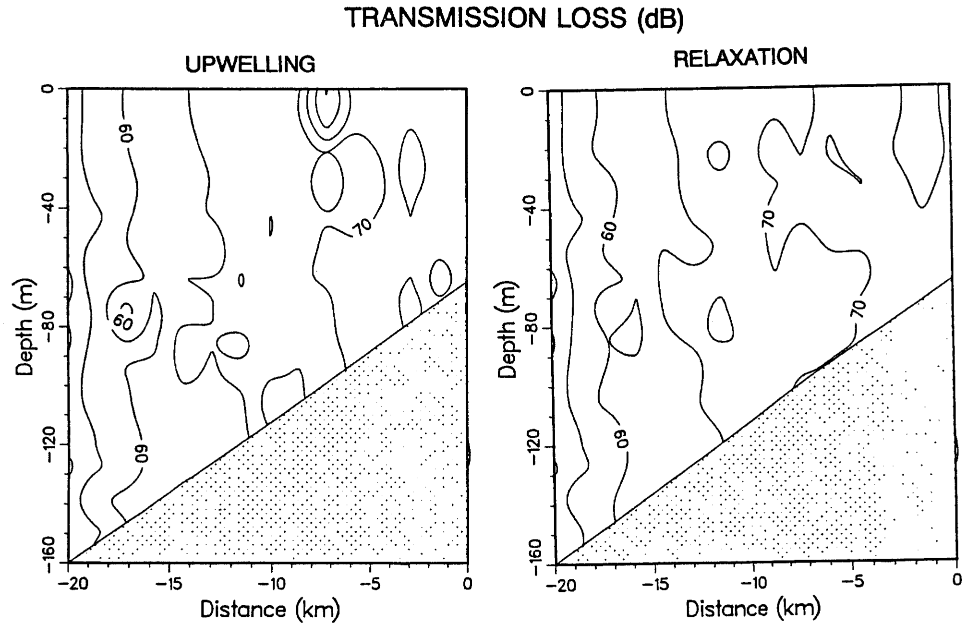

Fig. 2. Propagation loss (dB) for active upwelling and (b) wind relaxation.

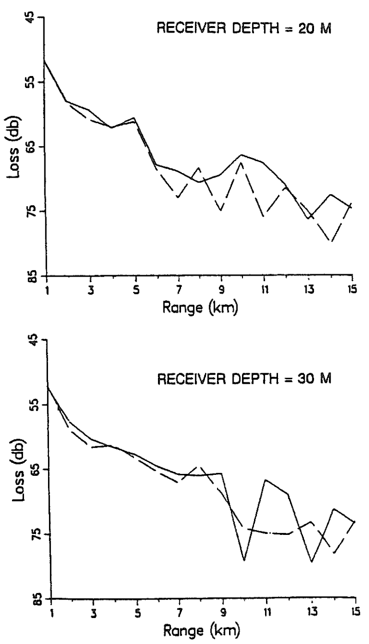

Fig. 3. Propagation loss (dB) for (a) 20 m receiver depth and (b) receiver depth = 30 m. (Solid line: active upwelling; dashed line: wind relaxation.)

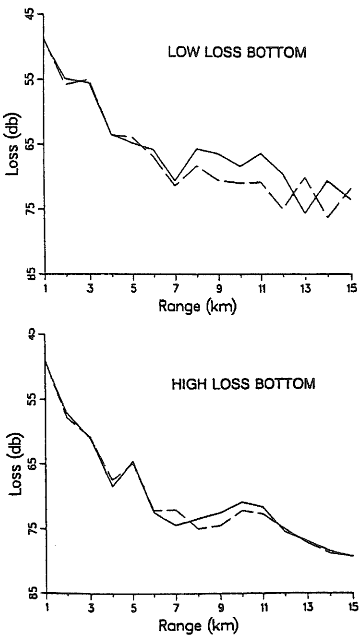

Fig. 4. Propagation loss (dB) at 40 m receiver depth for (a) low bottom loss (base case) and (b) high bottom loss. (Solid line: active upwelling, dashed line: wind relaxation.)

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