SOUND PROPAGATION FROM THE CONTINENTAL SLOPE TO THE CONTINENTAL SHELF - NPS AND WHOI MOORED SENSOR EFFORTS

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LONG-TERM GOALS

Our goals are: (1) to understand the variability and dynamics of the shelf-break current and its coupling to the adjacent slope-water circulation, and (2) to determine the effect of this variability on the propagation of sound from the continental slope to the continental shelf.

SCIENTIFIC OBJECTIVES

The objectives of the Shelfbreak PRIMER field study are to improve our understanding of the physical variability of the shelf break front south of New England, and to apply this improved knowledge to problems in acoustical propagation. To do this, we have made detailed measurements of physical and acoustical properties during the contrasting summer and winter seasons. These measurements are being related to physical and acoustical modeling studies. Results from these modeling efforts, tested against the observations, should be broadly applicable to shelf-break regions on a more global basis.

APPROACH

The field program surveying the frontal region have just been concluded. The field work included two intensive three-week experiments, one in July 1996 (summer) and the other one in February 1997 (winter). Specifically, each of the two experiments successfully employed a suite of observational techniques including an acoustic tomography array consisting of multiple transceivers/sources and two vertical hydrophone arrays (VLAs) straddling the shelf-break front, several high-resolution, three-dimensional surveys of the frontal region with a SeaSoar, a shelf-to-slope hydrographic section, and moored arrays of ADCPs, current meters and thermistors. The resultant data set is both comprehensive and of high quality, and will allow for gaining fundamental insights into the oceanographic processes which influence acoustic propagation in a slope-shelf region. The measurements are being supplemented by model studies, both oceanographic and acoustic. The detailed analysis of the data and the modeling has begun in earnest, with an initial emphasis being

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upon understanding the oceanographic field through which the acoustic signals have propagated.

WORK COMPLETED

We have accomplished a large amount this year, both experimentally and analytically. Experimentally, we successfully completed our winter PRIMER cruise, gathering a large amount of data from all the measurement systems noted above. The amount of moored oceanographic and acoustic data was somewhat less than that obtained during the 1996 summer cruise, mainly due to extremely poor weather conditions. However, the data was quite sufficient to address the science issues posed by the project. Analytically, we have worked hard on processing the moored sensor data, both acoustic and oceanographic, with the preliminary emphasis on the summer 1996 data. All of the summer data from the moored systems has now been reduced to useful quantities, and detailed modeling and analysis efforts have now begun (Lynch et al., 1997). Modeling efforts have been initiated for both the oceanography (the solibore field in particular) and the acoustics (the 224 and 400 Hz tomography transmissions), with some interesting results. Winter oceanography data has been reduced as well, and the winter acoustic data will soon follow suit.

The processing of the acoustic VLA data has included modal beamforming to resolve the cross-front, upslope arrival structure of individual acoustic normal modes as a function of geophysical time. Investigations into the degradation of beamformer performance due to sound speed mismatches, inadequate VLA aperture and sparsed hydrophone elements were conducted. The degradation was found to be unacceptable for conventional beamforming algorithms. Therefore, new bandpass techniques were developed to improve modal resolution. In particular, an optimal model-based method was successfully formulated and tested (Chiu et al., 1997a).

Initial acoustic data analysis and modeling have been performed to investigate (1) the temporal stability and variability of modal arrivals at the VLA due small-scale internal waves and mesoscale frontal features, and (2) the spatial variability of the upslope propagation as it is influenced by the shelfbreak front, the associated frontal ocean processes and the shoaling bathymetry. A quick assessment of these issues at this initial post-cruise stage can lay a good foundation for the follow-on work in quantifying the predictability, repeatability and space-time coherence of slope-to-shelf, low-frequency transmissions, and in establishing the forward relation between acoustic data and ocean variables which preambles the inverse mapping of the four-dimensional thermal structure of the frontal zone (Chiu and Lynch, 1997b).

RESULTS

Though we have only had this rather extensive data set for a year, and though a large amount of our initial efforts have gone into routine data reduction chores, there are still a few preliminary scientific results from the moored component of the experiment that we can point to.

Oceanographically, we have invested a large amount of initial effort into understanding the internal wave field at the PRIMER site, both because of its intrinsic interest, but also because it is a significant noise source for both oceanographic and acoustic observations in the region of the shelf break front. The so-called solibore field has been tracked in its northward propagation along the western edge of our experimental area, showing extreme variability on phase, amplitude, duration, and spectral content. The low frequency internal tide part of the solibore has been shown to contain as much energy as the barotropic tide, radiating ~3 kilowatts/m (along shelf flux). Amazingly, the solibore field seems to persist even in the winter. Thermistor records show that the foot of the shelf break front shows distinctly nonlinear internal waves during the winter months. Though these do not require much oceanographic energy to generate (the stratification is weak), they are of great significance acoustically, as the thermal contrast of the bottom water from the front with the Cold Pool water is quite large.

Highlights of our initial acoustic analysis results include:

1. The times of arrival of the normal modes in summer are found to be stable over repeated transmissions, with small random fluctuations on the order of 10 ms due to the internal waves. A larger periodic perturbation of 30 ms rms produced by the semi-diurnal internal tides is also present. Although the amplitudes of the modes fade in and out on a time-scale of approximately 10 min., the peaks of the arrivals are easily identifiable and tractable to establish useful time-series of modal arrival time for mapping the ocean. The modal amplitude variability with the 10-min. time-scale is a result of mode coupling caused by internal solitary waves. The stability in arrival time as well as the amplitude fading caused by internal waves are illustrated in Fig. 1, where the variability of the arrival structure of two of the acoustic modes over 10 days are displayed. Aside from the short-scale fluctuations, the observed modal arrival times show a decreasing trend over the 10 days as well as an increase between yearday 210 and 212. The oceanographic data reveals that the decreasing trend was related to the westward passage of cooler, fresher shelf water whereas the 3-day increase is related to an intrusion of a warm, saline small eddy.
2. Based on three cross-shelf summer temperature sections obtained by the SeaSoar in yeardays 208, 210 and 213, the variability of the modal arrival structure caused by a mesoscale event was computed using a broadband, coupled normal-mode propagation model (Chiu, 1996). This event corresponded to the intrusion of and later exit of a warm, saline small eddy, the remnant of a warm-core ring absorbed earlier by the Gulf Stream. This intrusion caused significant distortion in the frontal boundary. The modeled arrival structure for the three different days shows that the resultant travel-time changes are on the order of 100 ms, which is in agreement with the observed changes discussed above. This is good news to tomography since the mesoscale signal (100 ms) is considerably larger than the internal-wave noise (10 ms) and is predictable. The model results also show an increase of signal level during the warm intrusion. This model prediction of a warm enhancement is also consistent with the VLA observations.

3. The spatial structure of the summer sound field is significantly influenced by both the frontal zone and the sloping bottom. While the bottom affects the higher-order modes, the frontal structure controls the variability in the lower-order modes. Our model results show strong coupling between the modes as they propagate up the slope and through the front. Complex interactions between the low modes, cascading of some energy from high to intermediate modes, as well as the eventual stripping of the high modes by the reduced water-depth were found.

1996 Yearday

Figure 1. Observed temporal variability of Modes 1 and 3 over a 10-day period. The structure shown were obtained by modal beamforming the VLA receptions of the cross-front, upslope 224-Hz Shelfbreak PRIMER summer transmissions.

IMPACT/APPLICATIONS

The oceanographic data gathered in this field study should be valuable in helping to create a general environmental model of shelfbreak regions suitable for assessing present and designing future Navy systems, acoustic as well as nonacoustic. In conjunction with the oceanographic data, the acoustic data will allow for an in-depth understanding of the coherence of the sound field in a shelf-slope environment, as well as for validating whether tomography is a useful tool for coastal monitoring.

TRANSITIONS

This program is combined with 6.2 efforts in ocean data assimilation/nowcasting and acoustic prediction in a "vertically integrated" fashion, so that the transition to higher levels and systems should be facilitated.

RELATED PROJECTS

This project strongly compliments a number of other current projects including the two other PRIMER experiments (Haro Strait and the CMO high frequency), the SWARM experiment and the CMO experiment, which study different aspects of the coastal ocean variability and the relations to coastal acoustic fluctuations.

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