Modal Leakage in Range Dependent Oceans

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Abstract: The validity of the adiabatic approximation for modal propagation at low frequencies and over megameter ranges is evaluated. An simulation analysis for the ATOC and Arctic modal coupling is and group delay coherence are presented.

INTRODUCTION

One of the considerations in designing the sources and receivers for the Acoustic Thermometry of Ocean Climate (ATOC) was to place them on the sound channel axis such that the coupling to axial propagation would be strongest. Tomographic experiments historically have used the high angle, early arriving ray like components for inversions; however, the axial, late arriving modal components have the highest energy for a source placed near the sound channel axis. Since source power was an important concern for ATOC, significant emphasis was placed upon using the most energetic component of the received signals. Nevertheless, the axial arrivals have been the most difficult to exploit because they are not well resolved with internal wave scattering suggested to be its cause. [1,2] This contrasts with the results from the Transarctic Propagation (TAP) experiment where the propagation is almost entirely axial and the modal arrivals are well resolved. [3] While in Arctic Ocean propagation the internal wave power is lower; underice roughness leads to modal scattering. [4] In both situations modal scattering where there is nonadiabatic coupling is felt be the fundamental problem.

MODE ESTIMATION

Modal estimation can be separated into temporal and spatial approaches. In the temporal one the differential time dispersion of the modes separates them so they can be resolved with a single receiver, and this has been demonstrated in several experiments. For wideband signals such as M sequences or frequency modulated chirps one needs to compensate for the dispersion across the bandwidth, so the pulse spreading suggested by Brown, at al, can be compensated for by the appropriate signal processing. [5] The additional time spread in modal estimates after dispersion compensation can be attributed to modal coupling such as described by Colosi. [2] For spatial resolution of modes one uses a vertical line (VLA) array and exploits the modal orthogonality. The VLA's in ATOC were deployed with this motivation. For wideband processing the subtle part is the frequency dependent shape of the modes versus the resolution bin widths for the processing as discussed by Wage. [6] Spatial processing for modes with VLA can be done and represents the best opportunity to understand modal coupling at long ranges.

MODAL COUPLING

Modal coupling at a single frequency was examined by Tappert and Dozier using a parabolic equation approach for a Garret and Munk internal wave model. [7,8] Their results indicated that the modes scattered to equipartition if no loss mechanism were included. The important issue was how fast equipartition was approached. For modal travel time measurements an important issue is how much of the “adiabatic energy” remains in the mode in comparision to energy introduced by repopulation from multiple scattering. Figure 1 illustrates the results of a simulation done with Collins' PE RAM code with an ensemble of 1/2 Garret and Munk (GM) perturbations which seems to be a realistic level for the ATOC environment. FEPE was initialized with mode 1 for the perturbed field. In figure 1 The doted line indicates the total mean mode 1 amplitude for the full solution, while the solid line indicates the propagation which has been forced to be “adiabatic” by removing the scattered energy at every 50 km. One can see that a relatively small fraction of
Figure 1: Adiabatic vs full solution for 1/2 GM and perturbation (left) and modal amplitudes scattered from start mode 1 (right)

the level of mode 1 is due to repopulation since the difference is quite small. Consequently, for this simulation travel time estimates of mode 1 should be dominated by the adiabatic component out to ranges of 2000 km. The amount of energy transferred from mode 1 to the other modes is indicated in figure 2 where the mean level for the first 20 modes is plotted at 50, 500, 1000 and 2000 km.

Travel time estimation requires that a broadband signal remain coherent across frequency for matched filter replica correlation. When one does matched filtering on the axial section of the ATOC data, so an important aspect of modal coupling analysis is the coherence of the group delays versus frequency. Finally, the same type of analysis for modal amplitude scattering and group delay coherence for Arctic Ocean transmissions is appropriate for the acoustic thermometry experiments in the Arctic.

REFERENCES