Mode tomography for the Long Range Ocean Acoustic Propagation Experiment

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Ocean acoustic tomography uses acoustic signals to infer the environmental properties of the ocean. The procedure for tomography consists of underwater low frequency acoustic transmissions to receivers located at hundreds of kilometer ranges. The arrival times of the signal at the receiver are then inverted for the sound speed of the background environment. Using this principle, experiments conducted in the past 15 years have used acoustic signals recorded across Vertical Line Arrays (VLAs) to infer the Sound Speed Profile (SSP) across depth. The acoustic signals across the VLAs can be represented in terms of orthonormal basis functions called modes. The lower modes of the basis are concentrated around mid-water depths and propagate longer distances. Tomographic inversions should hence include the low modes to invert for the sound speed around mid-water depths. Mode tomography has however not received much attention. One of the important reasons for this is that internal waves in the ocean cause significant amplitude and travel time fluctuations in the modes. The amplitude and travel time fluctuations cause errors in travel time estimates. The absence of a statistical model and the lack of signal processing techniques for internal wave effects have precluded the modes from being used in tomographic inversions.

This thesis develops an empirical statistical model for modes affected by internal waves and then uses the estimated model to design appropriate statistical methods to obtain tomographic observables for the low modes. The statistical model, developed using numerical simulations and experimental data from the Long Range Ocean Acoustic Propagation EXperiment (LOAPEX), quantifies the mode amplitude coherence and the travel time variance as a function of range and frequency. The model suggests that Matched Subspace Detectors (MSDs) based on the amplitude statistics of the modes are the minimum mean square error travel time estimators for modes up to 250 km. Simulations for travel time estimates using the MSDs show that the mean of the travel time estimates is close to the mode travel times for the background SSP. In addition to that, the variance of the travel time estimates is less than other signal processing methods that do not take into account the statistics of the mode signals. The MSDs are applied to the LOAPEX signals to make travel time estimates for modes received at ranges of 50 km and 250 km. The estimated sound speed inverse for the mid-water depths is consistent with point measurements made during LOAPEX.