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Automated estimation of seabed properties from acoustic recordings by an autonomous moving system

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This work develops an automated Bayesian method to infer fluid seabed properties as a function of depth along tracks that are surveyed by an autonomous underwater vehicle (AUV). The AUV tows an acoustic source and a 32-element array. The source bandwidth is from 950 to 3000 Hz and frequency-modulated signals are emitted at regular intervals ('pings') as the AUV moves along the track. The recordings of each ping are processed to account for source directionality and reflection coefficients as a function of frequency and grazing angle are extracted by taking the ratio of time-windowed direct and bottom-interacted paths. Each ping provides one data set. This process results in large data volumes with an information content that is much higher than for traditional seismic profiling. However, extracting interpretable results about the lateral and vertical spatial variability of the seabed requires sophisticated and efficient inversion methods.

The seabed is approximated as a horizontally stratified, lossy fluid for each ping. Each layer is homogeneous and parametrized by a thickness, velocity, density and attenuation. Since both source and array are towed close to the seabed, a plane-wave approximation is not sufficient to model these data and spherical reflection coefficients must be computed to predict data. Therefore, for each specular angle at each frequency, the Sommerfeld integral is solved efficiently by massively parallel implementation of Levin integration on a graphics processing unit (GPU).

The inverse problem is strongly non-linear and requires application of Bayesian sampling to quantify parameter uncertainties. To account for the unknown number of layers in the seabed at each ping, the seabed is parametrized by a trans-dimensional (trans-D) model which treats the number of layers as unknown. To constrain model complexity and improve efficiency, we apply a Poisson prior with even-numbered order statistics to the number of layers. The trans-D model is sampled with a reversible-jump algorithm and efficiency is addressed by parallel tempering.

The method is applied to data acquired along a 14-km track on the Malta Plateau with water depths from 144 to 152 m. The reflection coefficient data are sensitive to the upper 7 m of the seabed. Data sets are available at 4-m spacing along this track which is currently still intractable. Therefore, we apply ping averaging and consider data at 40-m spacing. A total of 340 inversions were carried out employing 8 K80 GPUs for approximately 2 weeks of computing time. The results resolve layering along the track with previously unreported complexity and detail. An erosional boundary with rough topography is clearly resolved as a high-velocity, high-density layer. This boundary appears rougher and is buried deeper in more shallow water. Depressions along this boundary are filled in with lower velocity material along the shallow parts of the track. In addition, attenuation is well constrained in a thick low-velocity wedge. [Work supported by ONR and SERDP.]