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Predicting the Impact of Seabed Uncertainty and Variability on Propagation Uncertainty

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LONG TERM GOALS

Develop capability for quantifying, predicting and exploiting (QPE) the impact of seabed uncertainty on sonar system performance.

OBJECTIVES

The objectives are to: 1) develop techniques required to create a 2D geoacoustic uncertainty model (2D-GeUM) over an operationally significant area, 2) demonstrate techniques to create 2D-GeUM in area off northeast coast of Taiwan, and 3) demonstrate ability of 2D-GeUM to predict propagation uncertainty.

APPROACH

In order to predict the impact of seabed geoacoustic uncertainties and variability on propagation uncertainty along a radial of interest, a 2D geoacoustic uncertainty model (2D-GeUM) is required. Such a model quantifies depth- and range-dependent geoacoustic properties and their uncertainties over the area of interest. For the QPE experiment, the ~50 km x 50 km area of interest was off northeast Taiwan, including part of the Chilung shelf, the East China Sea shelf and upper slope.

The original approach exploited direct-path wide-angle seabed reflection data and geologic modeling as the basis for generating the 2D-GeUM. The 2D-GeUM is the key model for predicting the impact of seabed uncertainties and variability on TL uncertainties along a specified radial. The approach envisioned collecting sparse, wide-angle reflection data during the QPE experiement site northeast of Taiwan in FY09. However, weather and equipment problems prevented the data from being acquired.

In lieu of this, the focus has turned to a spatially densely sampled wide-angle reflection data set from the Malta Plateau in the Mediterranean Sea. A drawback is that analysis of these data would not be expected to shed direct light on the geoacoustic variability in the main QPE experimental area. However, the opportunity is that these data will provide a basis for developing and demonstrating the ability to create high-resolution 2D geoacoustic uncertainty models, a capability the community currently does not have.

WORK COMPLETED

The FY10 efforts included:

1. developing processing approaches for analysis of densely-sampled wide-angle reflection data from an AUV

2. collaborating with Jan Dettmer and Stan Dosso (both at University of Victoria) on inverse approaches to address geoacoustic variability from 2D measurements (see Ref [1]).

RESULTS

In order to produce reflection data from the AUV, the following data processing steps were taken: source calibration, determination of source stability (ping-to-ping, and depth variation), and validation using a well-tested measurement approach (e.g., Refs [2-3]). The processing that was developed is

$$\left|R_s\left(\theta,f,\tau\right)\right| = \frac{\left|p_r(k(\theta),f,\tau)\right|}{\left|p_d(k,f,\eta)\right|}\frac{\gamma_d(k,f)}{\gamma_r(k,f)}\frac{\left|q_d(\sim 0,f,\eta)\right|}{\left|q_d(\theta,f,\eta)\right|}\frac{\beta_d(\theta,f)}{\beta_d(\sim 0,f)}$$

where R_s is the spherical wave reflection coefficient; $p_{r/d}$ pressure of bottom reflected/direct path; $\gamma_{r/d}$ transmission factor for the bottom reflected/direct path; q_d pressure of source calibration data (in the vertical plane); β_d transmission factor for calibration data; k is channel number, τ the integration time for bottom reflected path and η the time extent of the matched filtered direct arrival (including scattered arrival from AUV)□ The data processing was designed to eliminate uncertianties associated with hydrophone calibration. The processing also removes the requirement to know absolute source level, however, the source beampattern is important (taken into account in the last 2 factors).

The resulting spherical reflection coefficient can be used to estimate the geoacoustic properties and their uncertainties. Performing the inversion on the plane wave (vice spherical) reflection coefficient, R_p, is considerably more computationally efficeint and this possibility was investigated using Hankel transform relations (Ref [4]). However, the potentially significant advantage of reduced computational load is accompanied by two disadvantages: 1) integral edge effects reduce the total angular range of $|R_p|$, and 2) data uncertainties (especially phase uncertainties) propagate non-linearly to the estimate of R_p so that the resulting uncertainties of geoacoustic estimates and propagation loss estimates are also increased. Preliminary estimates indicate that of the 40º angular window in the AUV data a total of 20º is lost (10º at the lower and upper end respectively) by edge effects, thus, at present inversions are being performed with the full spherical wave reflection coefficient. Investigations are ongoing to examine strategies to reduce edge effects and quantify propagation of phase errors.

An example of processed spherical reflection data from the Malta Plateau is shown in Fig. 1 near the beginning of the track shown in Fig. 3c. The striation pattern is due to interfernce structure from sub-bottom layering. The amplitude and spacing of the striations contains information about the layer geometry and geoacoustic properties. The associated with geoacoustic properties and uncertainties are shown in Fig. 2 where the 95% confidence bounds are in red (inversion performed by Jan Dettmer at

University of Victoria). For this ping, the sound speed and density are reasonably well-constrained, whereas the attenuation has much wider uncertainty bounds.

While the previous figures show 1D results (as a function of depth), our interest here is in 2D variability/uncertainty. Reflection data processed along a 13 km track at ~ 20m lateral resolution on the mid shelf region of the Malta Plateau are shown in Fig. 3a at a fixed height (12m) above the seabed. The AUV was quite stable showing a standard deviation of 8.5 cm in altitude, which modeling indicates has a negligible effect on the reflection data. Note that the observations show substantial variability along the track. Some of the variability is expected to arise from variability in layer thickness. In order to separate layer thickness from other variability, a simulation was performed (Fig. 3b) using layer thicknesses obtained from seismic reflection data (Fig.3c). The geoacoustic properties were based on a previous geoacoustic inversion near the beginning of the track (see Ref [5]), and were assumed to be constant within a layer. Comparison of Fig. 3a and b shows that some large scale trends are grossly predicted by the simulation, including the interference pattern in the first 1/3 of the track with reflection nulls that increase along track. This effect is due to a low-speed silty-clay layer that pinches out along track. A few small scale features are also captured in the simulation. e.g., near latitude 36.44 degrees which is due to variable thickness of the layer at ~5m sub-bottom. However, there is considerable fine-scale variability in the amplitudes that are believed to contain information about the sediment variability potentially not apparent in the seismic reflection data. The principal hypothesis for the variability is geoacoustic variability within a geologic layer (geoacoustic properties are usually assumed to be laterally invariant in a given layer). Future work will be aimed at recovering the full 2D geoacoustic variability and uncertainty along the track. The geoacoustic model with uncertainties will be used to compare against TL (and its associated uncertainties) collected along the same track.

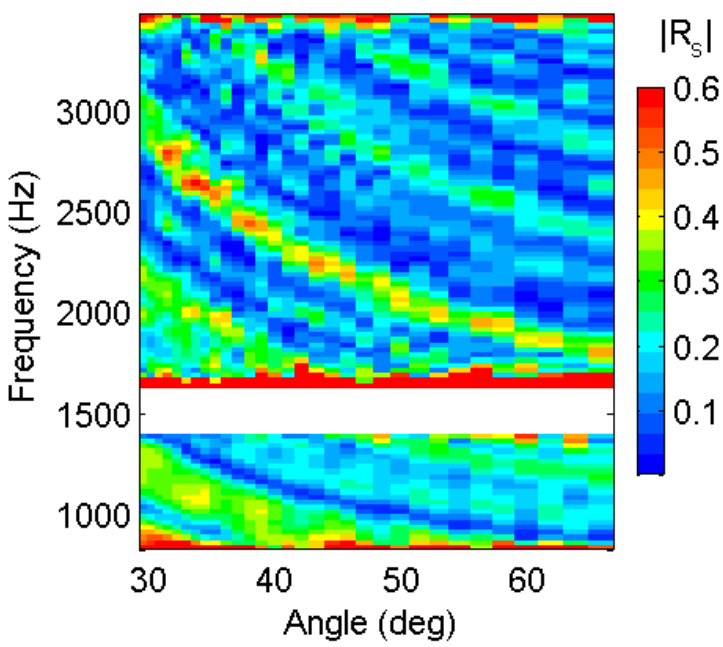

Figure 1. wide-angle seabed reflection data at the beginning of the track in Fig 3c.

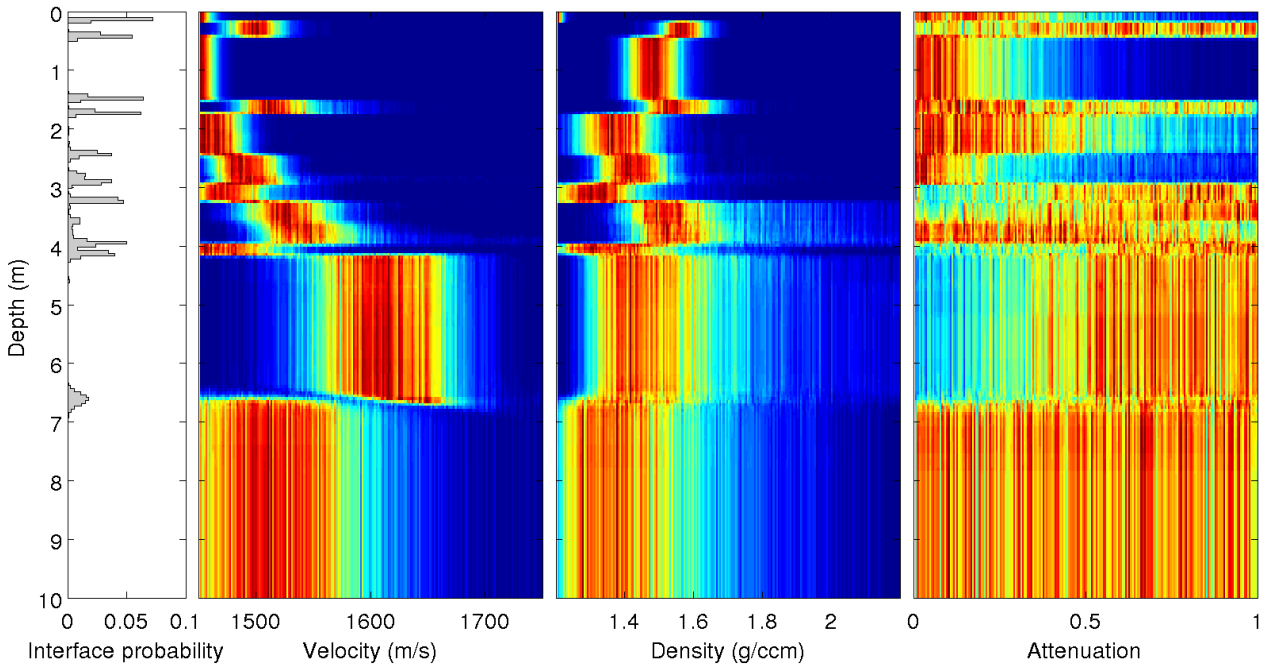

Figure 2. 1D geoacoustic uncertainty estimates from the data in Fig 1 (the inversion was performed by Jan Dettmer at University of Victoria)

IMPACT/APPLICATIONS

The development of geoacoustic uncertainty models has very broad implications for uncertainty estimation in the ocean acoustics community. In some ways, the data from Malta Plateau offer greater potential for understanding uncertainty than the originally planned sparse experiments, inasmuch as the spatial density of the sampling (roughly sampled at 20m or one Fresnel zone along the track) will provide the data needed to develop/test geoacoustic interpolation methods that would be an important part of eventual (not under this program) development of 3D geoacoustic models.

RELATED PROJECTS

ONR Broadband Clutter Joint Research Project: data collected in that project is being used to develop a full 2D geoacoustic uncertainty model under the QPE program.

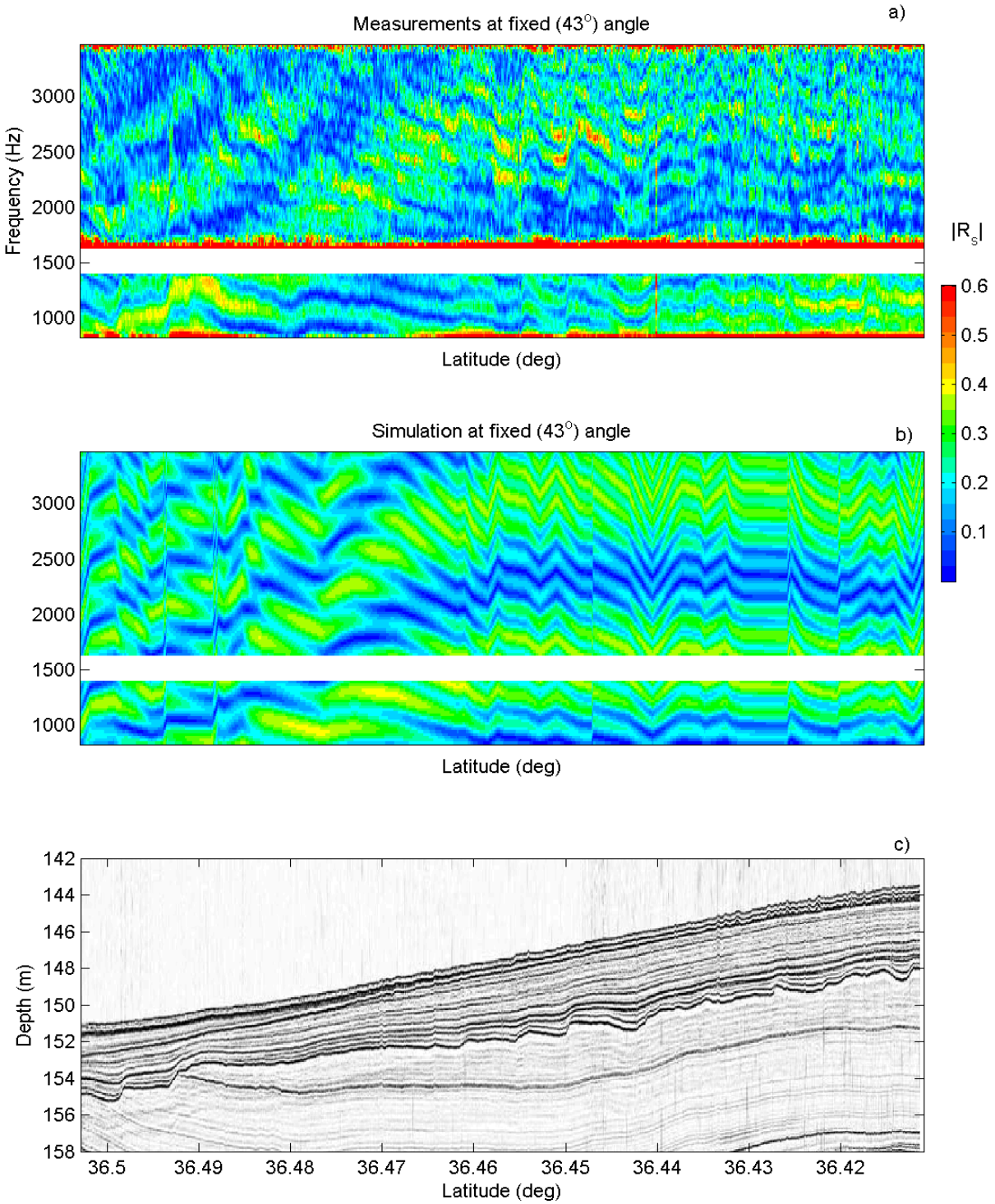

Figure 3. comparison of a) measured and b) simulated 2D seabed reflection coefficient data at fixed angle as a function of geographic position along a 13 km track c) seismic reflection data along the track. While the simulation captures some gross features of the observations, the observed fine-structure indicates (as yet) unknown geoacoustic variability. That variability is being quantified in ongoing work.

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PUBLICATIONS

Dettmer J., S.E. Dosso and C.W. Holland, Trans-dimensional geoacoustic inversion, J. Acoust. Soc. Am., [in press, refereed]

Dettmer J., C.W. Holland and S.E. Dosso, Resolving lateral seabed variability by Bayesian inference of seabed reflection inversions, J. Acoust. Soc. Am., 126, 56-69, 2009. [published, refereed]