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Short Note

Imaging oceanic thermohaline structure with reflection seismology

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INTRODUCTION

Temperature and salinity contrasts between volumes of seawater can generate reflections that are recorded before the water-bottom arrival on marine seismic data. While explorationists commonly mute them without observing them, seawater reflections are of interest to researchers of ocean dynamics.

Yilmaz (2001), at page 1809, maintains that such reflections are due to density contrasts. Holbrook et al. (2003) use a towed submersible to directly measure the salinity and temperature of water while performing a seismic survey. They conclude that thermohaline anomalies result chiefly in acoustic velocity deviations of less than 20 m/s from the average. Velocities are found by calibrating reflectivity values with local direct measurements, in the context of the aquatic medium, which lacks illumination and focusing problems.

Images of the thermohaline fine structure of the seas can be a useful tool for oceanographers. We describe a processing flow designed to extract seawater reflections from under the shot noise using prediction-error filters (PEFs). We also show an image of thermohaline reflection, as well as evidence that velocity varies with depth and midpoint in the ocean. We propose performing wave-equation migration velocity analysis (WEMVA) to find the corresponding velocity anomalies in the seawater.

PREPROCESSING

Figure 1 shows the input data from the Gulf of Mexico with a strong source component that masks the water column reflections (Figure 1a). Our goal is to unravel these reflections by performing signal/noise separation. We opted for a pattern-based signal/noise separation technique with stationary prediction-error filters (Guitton, 2003b).

This technique separates the signal and the noise by assuming that both components have different multivariate spectra that PEFs approximate. Therefore, we needed one PEF for the

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noise and one PEF for the signal. We designed 2D PEFs on common-shot gathers. The noise level is so overwhelming that designing a model for it was relatively easy. We selected nine shot gathers with no water column reflections. This choice was made by inspecting all shot gathers after applying a high-pass filter to them to remove most of the source energy. We then stacked the selected gathers to increase the noise coherency and attenuate any remaining signal.

From this noise model we estimated a stationary 25×5 PEF. The signal PEF was obtained using the Spitz approximation (Guitton, 2004). The size of the signal PEF is 5×2. Having had estimated the noise and signal PEFs, we proceeded to perform noise removal. Figure 2 displays the estimated signal. A reflection is clearly visible in Figure 2a. Figures 1 and 2 have the same clip for direct comparison. In Figure 2b, the thermohaline structure of the water column is revealed. We followed with a 10-60 Hz bandpass, a gain with the first power of time, and a mute. Since several near offsets needed for prestack wavefield-continuation migration were missing (not acquired or lost to PEFs boundaries), we used an offset continuation tool for regularly sampled data (Vlad and Biondi, 2001). An image of the denoised data prestack migrated with a constant velocity of 1520 m/s is shown in Figure 3. The reflections are clearly visible throughout the section. The coherency of these events decreases for depths greater than 600m.

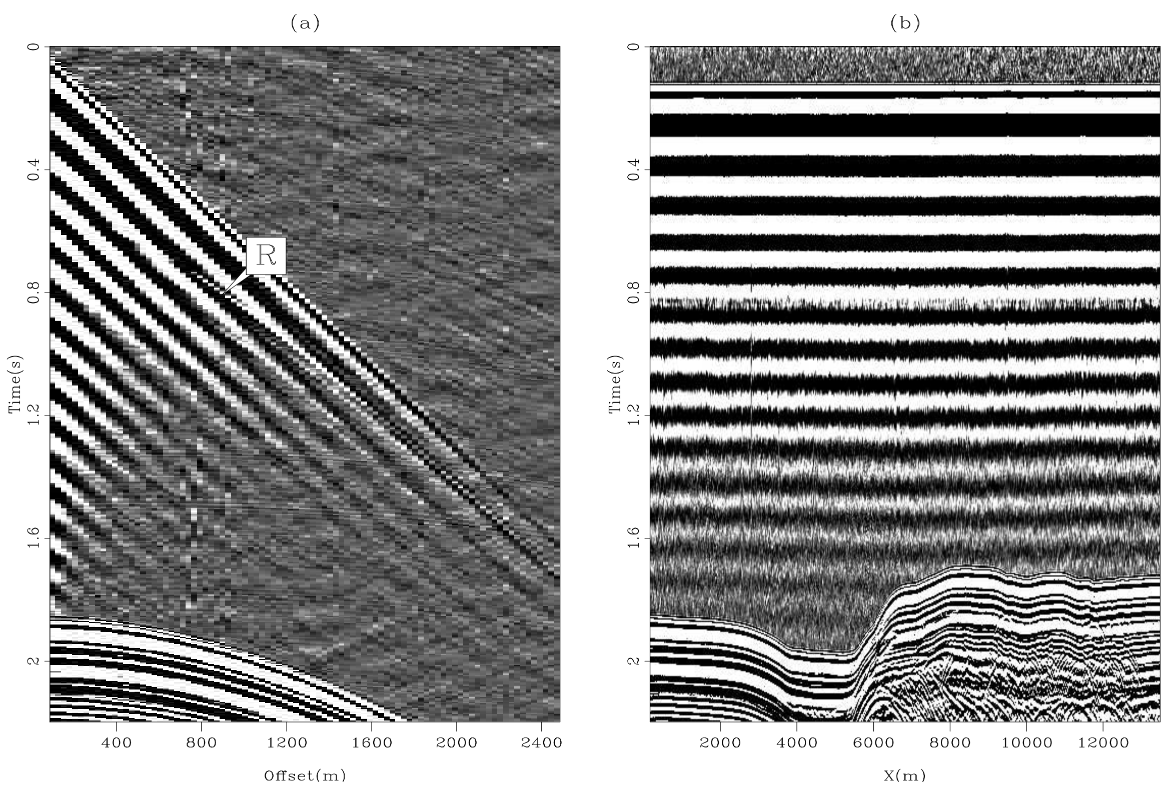

Figure 1: Input data showing the source noise in (a) a shot gather (x=2500 m) and (b) a constant-offset section (h=130 m). The water bottom is visible below 1.6 s. R points to a water reflection mostly hidden by the noise. nick2-data [ER]

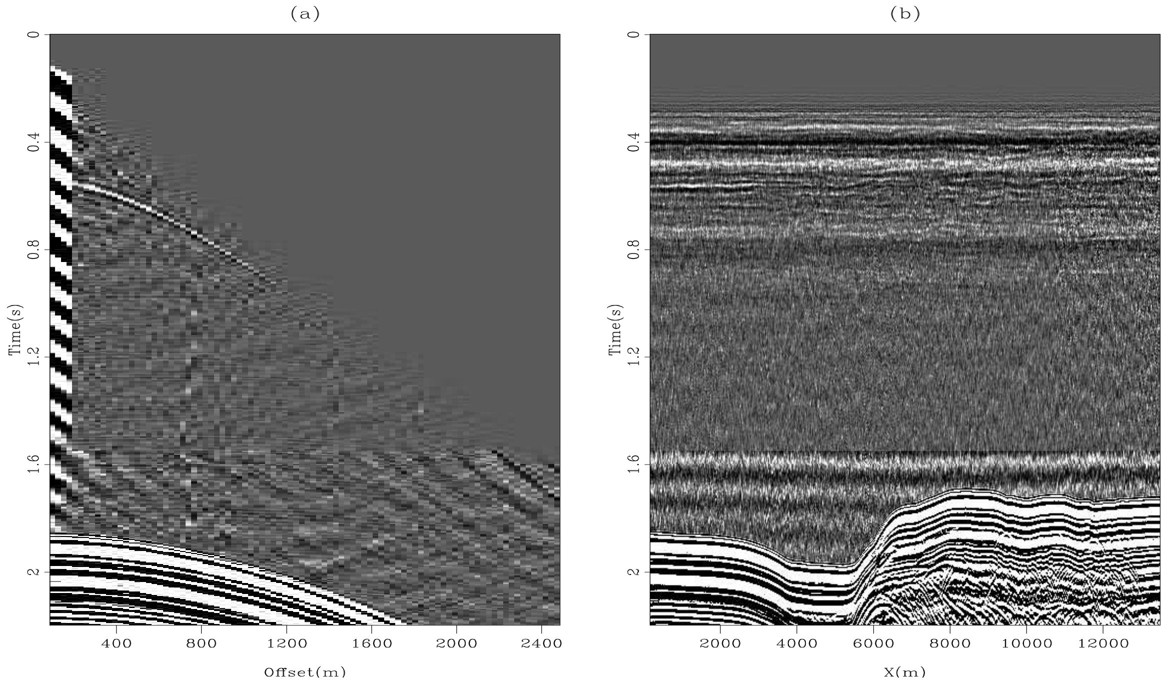

Figure 2: Estimated signal for (a) a shot gather (x=2500 m) and (b) a constant offset section (h=130 m). The water reflections are now clearly visible above 1.6 s. The four bad traces in (a) come from the boundary conditions for the PEFs. nick2-signal [CR]

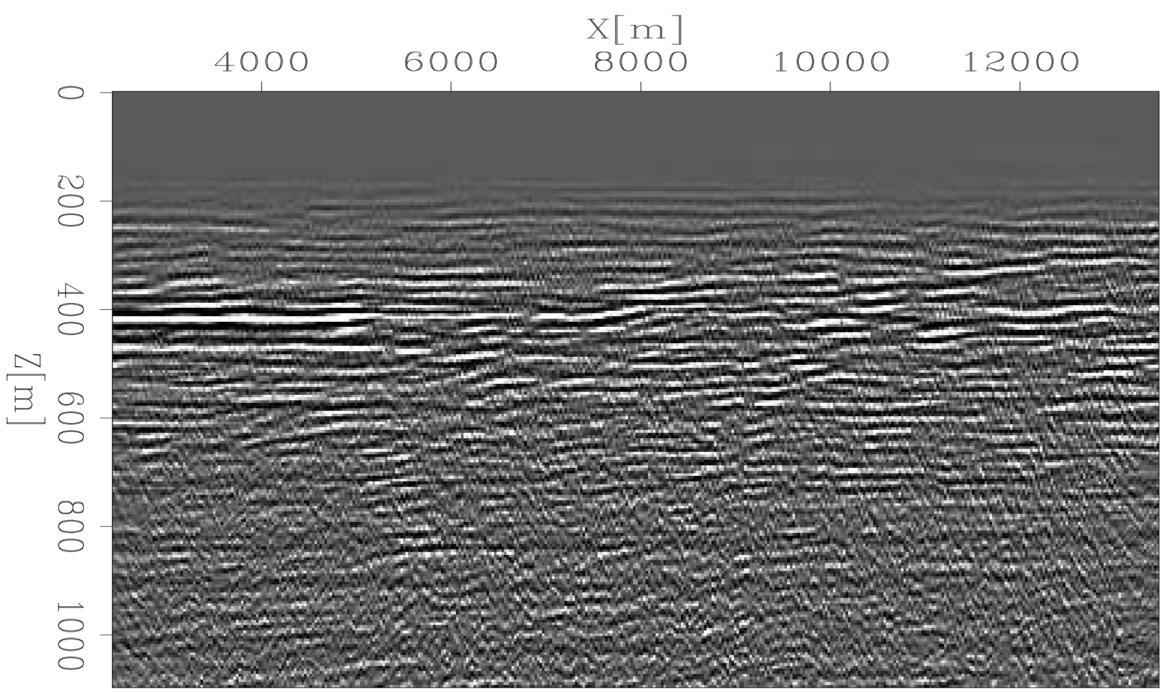

Figure 3: Migration of the denoised data with a constant velocity of 1520 m/s. nick2-stac7 [CR]

FUTURE WORK: FINDING THE VELOCITY

The left panel in Figure 2 shows that even after successful elimination of coherent non-thermohaline events, large amounts of random noise are left in the data. To be able to obtain RMS velocities in a time-efficient manner, with a high-amplitudes autopicker, we obtain the semblance of each individual CMP gather. The prior knowledge of the limits of velocity variations in water allows for a small-range, high-resolution transformation. The result is seen in Figure 4. The presence of velocity variations with depth and midpoint is apparent. The absolute value of these variations does not surpass 30 m/s.

Velocity departures from the background can be seen in the left panel of Figure 5 as residual curvatures in angle-domain common image gathers (ADCIGs). This figure contains only the angles between 10° and 30°. Because of the small depth of the thermohaline reflections and of the missing near-offset information, information from incidence angles smaller than 10° was obtained only from the offset-continuation fill. We discarded it, since it was characterized completely by our estimate of constant velocity. The angles larger than 30° were unusable because of a loss of bandwidth during the transformation to ADCIGs. The small curvatures place the velocity anomalies well within the limits of the Born approximation. This means that WEMVA would be a suitable tool for resolving them.

WEMVA is an iterative inversion scheme that attempts to optimize the focusing of the migrated image (Biondi and Sava, 1999). Specifically, the result of wavefield-continuation migration is transformed to ADCIGs, the gathers are flattened, the difference from the unflattened image is taken to obtain an image perturbation, which is finally inverted into a velocity update. We plan to perform this procedure in the future, using moveout shifts computed by dip field integration (Guitton, 2003a) to flatten the gathers for the image perturbation.

CONCLUSIONS

Variations in the temperature and salinity of seawater generate velocity anomalies of the order of a few m/s that cause recordable reflections of acoustic waves in the seismic exploration frequency range. Imaging these bodies of seawater can provide useful insight into ocean dynamics. A specific processing flow is designed to enhance the visibility of these reflections, by eliminating shot noise with prediction error filters. The presence of velocity variations with depth and midpoint is shown in semblance scans and angle-domain common image gathers. Wave-equation migration velocity analysis is proposed as a possible tool for resolving the thermohaline acoustic velocity structure of seawater.

REFERENCES

Biondi, B., and Sava, P., 1999, Wave-equation migration velocity analysis: SEP–**100**, 11–34.

Guitton, A., 2003a, Amplitude and kinematic corrections of migrated images for non-unitary imaging operators: SEP–**113**, 349–362.

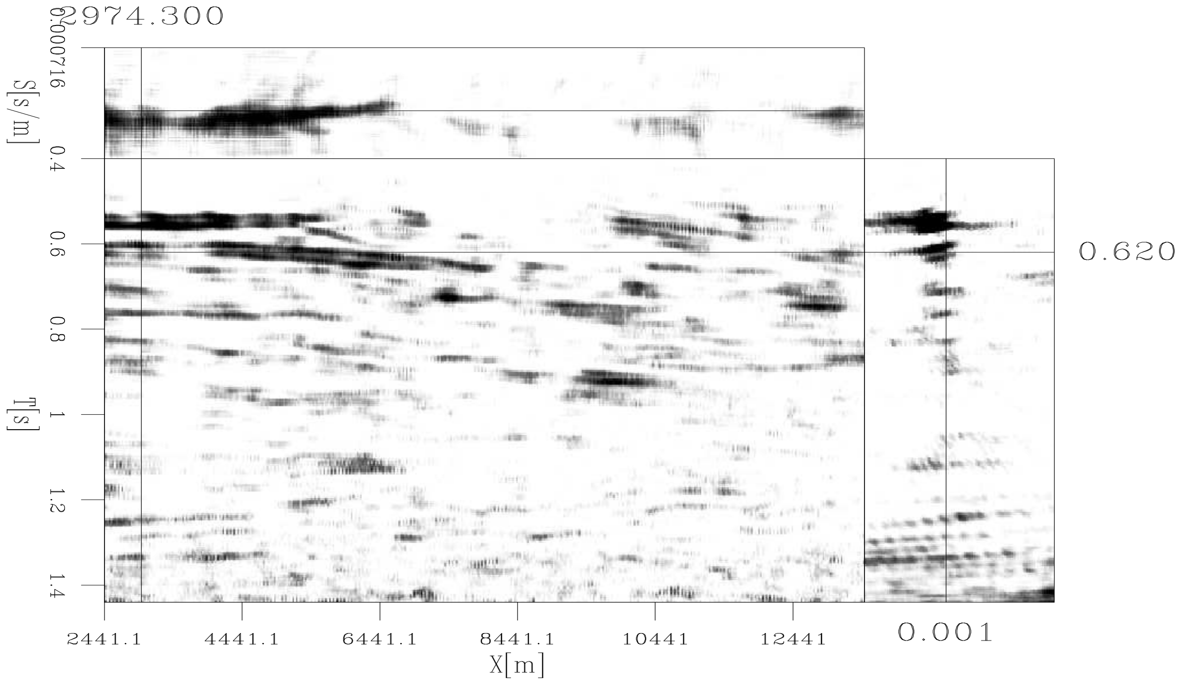

Figure 4: Semblance scan volume denoised with the procedure described in Vlad (2003). In the right panel, the vertical line delimits the 1500 m/s point on the slowness axis. nick2-stxfx [CR]

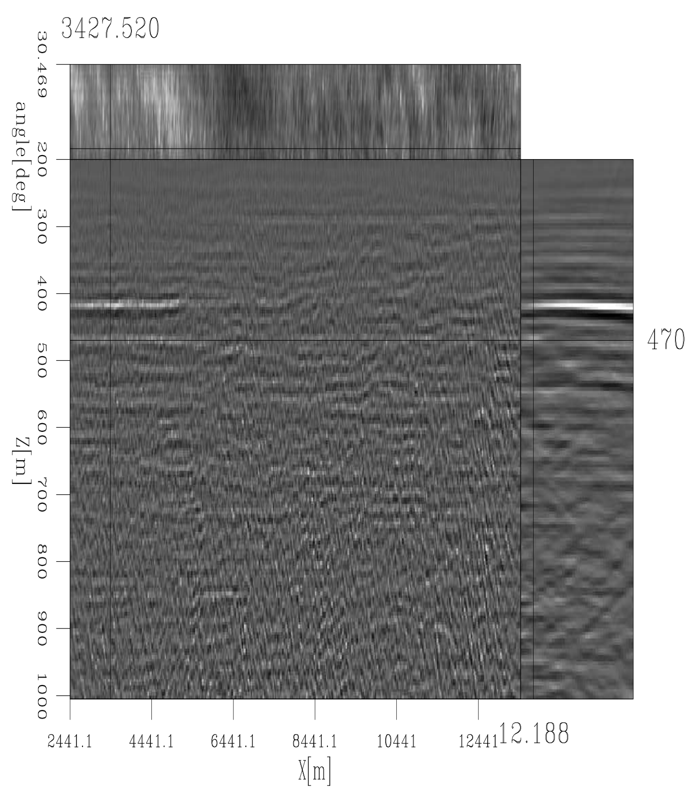

Figure 5: ADCIGs between 10° and 30° after migration with a constant velocity of 1520 m/s. nick2-Cuben4aT [CR]

Guitton, A., 2003b, Amplitude balanced PEF estimation: SEP–**113**, 261–276.

Guitton, A., 2004, Multidimensional multiple attenuation in complex geology: illustration on the sigsbee2b dataset: SEP–**115**, 109–126.

Holbrook, S. W., Paramo, P., Pearse, S., and Schmitt, R. W., 2003, Thermohaline Fine Structure in an Oceanographic Front from Seismic Reflection Profiling: Science, **301**, 821–824.

Vlad, I., and Biondi, B., 2001, Effective AMO implementation in the log-stretch, frequency-wavenumber domain: SEP–**110**, 63–70.

Vlad, I., 2003, Enhanced random noise attenuation: SEP–**113**, 291–298.

Yilmaz, O., 2001, Seismic data analysis, *in* CooperM. R.; Doherty, S. M., Ed., Seismic Data Analysis Vol. 2: Soc. of Expl. Geophys., 02, 1001–2027.