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Imaging the Near Surface Using Surface-consistent Prediction Operators - Examples from the Middle East

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SUMMARY

The scope of this paper is to illustrate how surface-consistent deconvolution operators can help to image the shallow subsurface on land data. Two case studies from broadband, dense, wide-azimuth surveys recently acquired in Oman are presented. The predictive deconvolution operators were computed from an advanced simultaneous inversion of surface-consistent scalars and autocorrelations. Source and receiver operator volumes are compared to the migrated stack of primary reflections. A good match is observed, meaning that surface multiples were captured by the prediction operators. Furthermore, a significant improvement in the imaging of the shallow layers is achieved up to very shallow times. Some structures that are almost invisible on the migrated stack are revealed and the shallow reflectivity is recovered in undershoot areas. A good correlation with a shallow velocity well log is also observed. The deconvolution operators are derived from high fold, good quality reflection data. Therefore, they overcome the usual difficulties of near surface imaging from primaries such as low, irregular near-offset coverage and strong noise contamination. These high-resolution reflectivity volumes can be used as a guide for velocity model building of the shallow subsurface or as an input to internal or surface multiple modelling.

Introduction

Getting a good quality primary image of the shallow subsurface on land data is a challenge. Primary reflections from standard seismic surveys suffer from well-known limitations: interfering ground roll and refracted arrivals, low fold, irregular offset distribution, and sensitivity to velocity errors. Optimal imaging of the near subsurface would require densification of sources and receivers which prohibitively increases the acquisition cost.

A shallow velocity model can be inverted from ground roll or first break arrivals present on any seismic records but the results need to be calibrated to a compressional velocity model using auxiliary information like up-hole data. Multi-physics methods such as microgravity, resistivity or electro-magnetics can produce models which also need careful calibration with seismic (Gallo et al., 2014). None of these methods yields direct access to the reflectivity of the very near-surface which generates most of the distortions of the seismic signal on land.

In shallow water environments, the water bottom reflectivity can be retrieved from multi-channel predictive deconvolution operators, and used to model water layer related multiples (Moore and Bisley, 2006; Yang and Hung, 2012). For land data sets, surface-consistent deconvolution operators, which are routinely applied to correct the distortions generated by the near-surface irregularities, can also give access to the reflectivity of the shallow subsurface. This will be illustrated in the following examples.

Description of the surveys and processing sequence

The two presented cases, here named A and B, are broadband, dense, wide-azimuth surveys recently acquired in Oman. They are both characterized by large maximum cross-line offsets (greater than 6000 m) and huge folds (around 8500 in a 25 m x 25 m bin). On both surveys, a broadband vibroseis source was used with emitted frequencies ranging from 1.5 Hz to 86 Hz.

The processing sequence included a simultaneous joint inversion of surface-consistent scalars and deconvolution operators, as described by Garceran and Le Meur (2012). The first step consisted of computing the amplitude scalar and autocorrelation spectrum of each individual trace in a time and offset window showing good signal to noise ratio. The autocorrelation spectra and amplitude scalars were simultaneously and iteratively decomposed into four components: global mean, source, receiver, and offset. Finally, predictive deconvolution operators were derived from the re-combined autocorrelation spectra using the classical Wiener algorithm and applied to the data. Looking at stacked data, the impact of the surface-consistent deconvolution step seemed fair. In both cases, the wavelet ringing was attenuated but it was impossible to spot the attenuation of obvious short or long wavelength multiples.

Comparing prediction operators and primary reflections

The source and receiver prediction operators were extracted and regularized to their nominal acquisition grids, i.e., 250 m x 25 m for the receivers on both surveys, 50 m x 50 m for the shots of survey A, and 25 m x 100 m for the shots of survey B. On survey A, the shot operators were also interpolated onto the 25 m x 25 m bin grid by means of an irregular Fourier transform (Poole, 2010). After a basic processing sequence (10 Hz to 60 Hz band-pass filter and a single gate scaling), the operators were shifted to the same datum as the current migrated stack by applying twice the full shot or receiver static corrections. Finally they were migrated using the current migration velocity field.

Generally, on both surveys, a good match is observed between the events seen on the operators and the events seen on the primary reflections down to 300 ms, which means that surface multiples were captured by the prediction operators. Interestingly, the image from the operators looks much cleaner, with continuous, structurally consistent events appearing almost up to the surface. As usual, the near surface image from primary reflections suffered from the very low and irregular near-offset coverage. This limited not only the accuracy of migration velocity picking, but also the accuracy of noise filtering. The primary reflections are still contaminated by residual ground roll and refracted energy. On the contrary, the prediction operators were derived in a deeper time window, from high fold, good quality reflectivity data.

On survey A, in a corridor where a major regional SE-NW fault system affects the entire section up to the ground surface, the migrated deconvolution operators are able to image very shallow anticline and syncline structures which are almost invisible on the migrated stack of primary reflections (Figure 1). Both source and receiver operators display interfering, ringing, flat events which correspond to the correction of coupling or distortion effects. They usually appear stronger on the source side (Figure 1c and 1d, below the syncline or anticline structure).

The dense sampling of shot operators in both directions allows the construction of a more precise 3D image of the shallow subsurface, as illustrated by the time slices in Figure 2. However, there are a few areas, as large as 10 km^2, which the vibrators could not access, but where the geophones could be laid out. In these cases, despite the absence of near traces, the reflectivity of the shallow subsurface can be retrieved from the receiver operators as illustrated in Figure 3.

For the second example, survey B, the imaging uplift brought by the operators can be seen in Figure 4. In particular the top and base of a high-velocity carbonate layer, which is known regionally as a major generator of surface and internal multiples, appears clearer and more continuous on the operators compared to the migrated section (see red arrows). The improvement is more pronounced when this layer is approaching the near surface (on the left-hand side of the picture). A very good correlation with a shallow well velocity log is also observed. Indeed, a sharp velocity increase observed on the well log corresponds to a strong reflector on the seismic section (see pink arrows).

Conclusion and outlook

This paper has demonstrated that a continuous and accurate image of the shallow subsurface of land surveys can be retrieved from 1D shot and receiver prediction operators. The high source and receiver density in the above examples allowed the construction of 3D finely sampled near-surface volumes. The modern broadband sweep, without side lobes, was favorable to provide clean operators in which reflections could be extracted up to very shallow times.

These high-resolution images of the subsurface are helpful in various ways: detection/correction of static or phase anomalies, creation of shallow velocity models for depth imaging, and creation of shallow reflectivity models for multiple prediction and attenuation, as implemented by Retailleau et al. (2012). Beyond the 1D case (Retailleau, 2014), computing 2D or 3D prediction operators, which theoretically have the same kinematics as primaries, could give access to the velocity information, as recently shown by De Maag (2014) on another land case.

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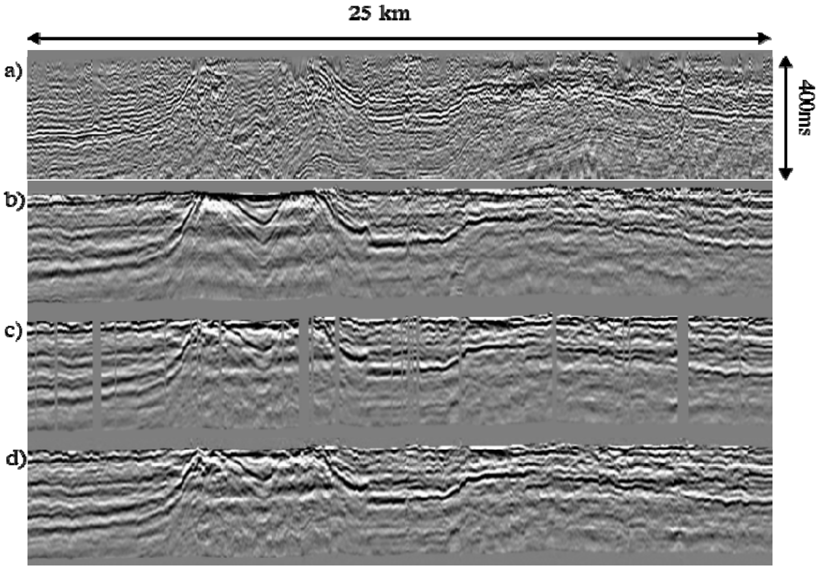

Figure 1 *Survey A, vertical section parallel to the receiver lines: (a) migrated stack, (b) migrated receiver deconvolution operators, (c) migrated source deconvolution operators and (d) migrated source deconvolution operators after interpolation.*

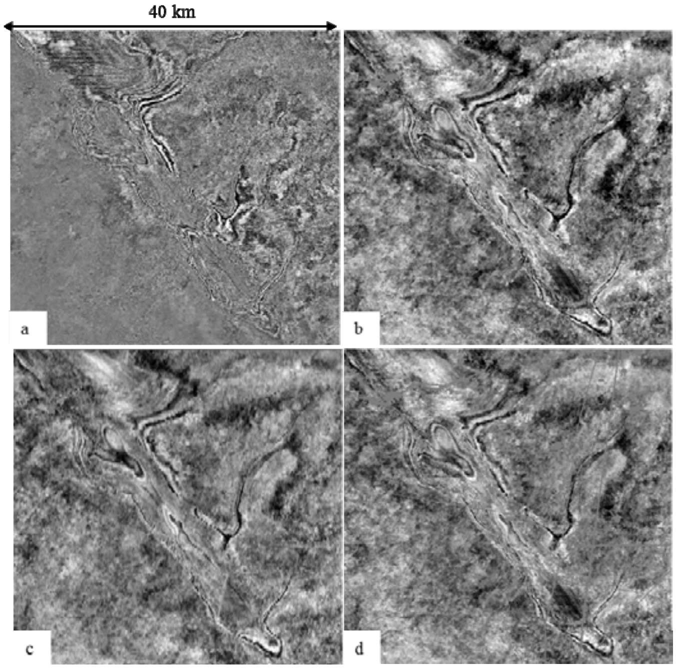

Figure 2 *Survey A, time slice approximately 48 ms below the average ground surface: (a) migrated stack, (b) migrated source deconvolution operators after interpolation, (c) migrated source deconvolution operators and (d) migrated receiver deconvolution operators.*

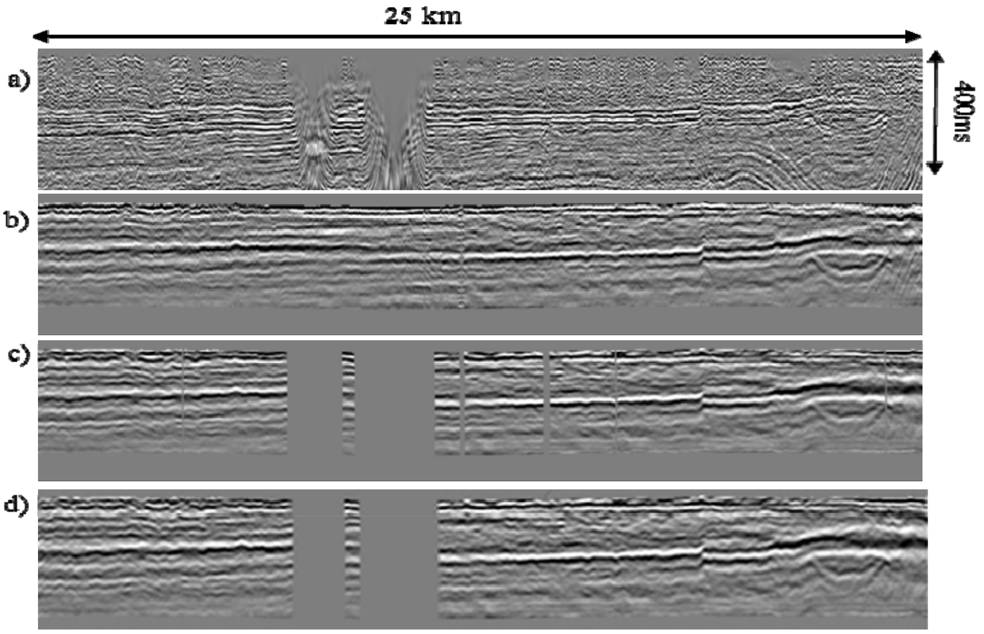

__Figure 3__ Survey A, vertical section parallel to the receiver lines: (a) migrated stack, (b) migrated receiver deconvolution operators, (c) migrated source deconvolution operators and (d) migrated source deconvolution operators after interpolation.

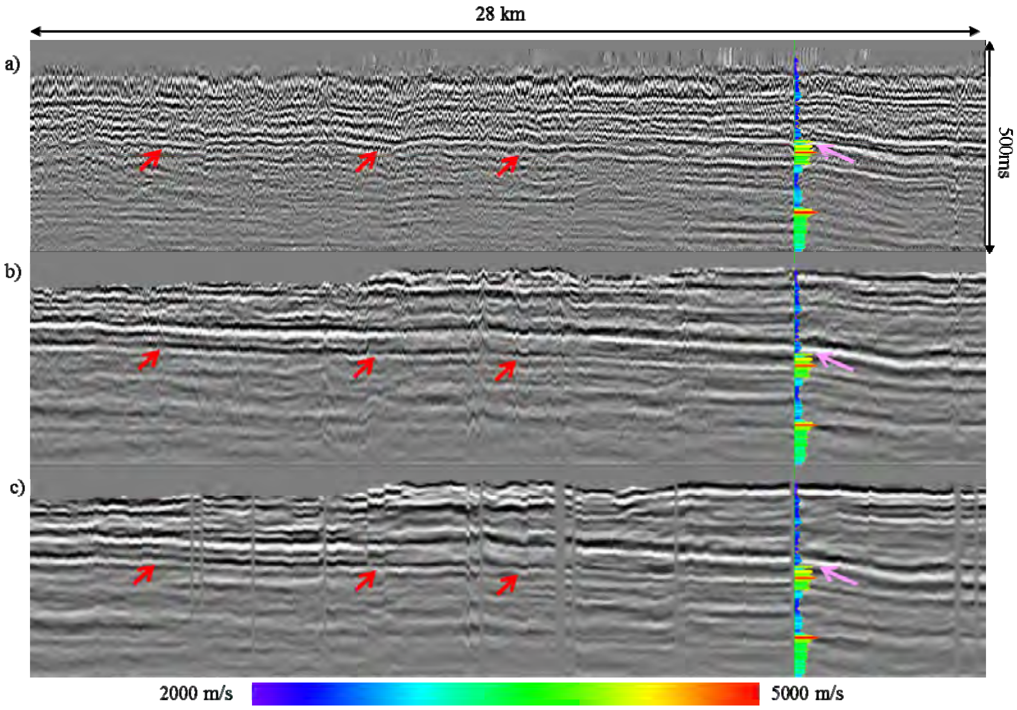

__Figure 4__ Survey B, vertical section parallel to the receiver lines: (a) migrated stack, (b) migrated receiver deconvolution operators and (c) migrated source deconvolution operators. The well log shows the P velocity.