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Depth migration of monostatic and bistatic georadar data

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Summary

In this abstract we compare migration image quality based on a 200 trace subset of a large georadar survey conducted in the "aniti-blast" tunnel of the Inter-Disciplinary Underground Science & Technology Laboratory. These data are unique in that two distinct acquisition geometries are acquired simultaneously. The first, and we will call it "bistatic", is the conventional georadar acquisition where the transmitting and recording antennae are separated by a metre (65 cm in this instance). The second we will call "monostatic". Monostatic acquisition is unique in that the transmitting and recording antennae are exactly co-located - they are the same physical antenna, and this is a recent technical development. Monostatic acquisition reproduces exactly the geometry of the well known "exploding reflector model" of seismic imaging and therefore, zero-offset migration (ZOM) of the data is not an approximation but a legitimate imaging approach. In particular, the image of the near-surface (1 m or so) should be precisely imaged (given an exact velocity model) - bistatic data require prestack depth migration (PSDM) to achieve equal precision. PSDM, of course, is much more expensive and time consuming than ZOM and so monostatic acquisition is very desirable. Here we demonstrate a number of important differences..

Introduction

Georadar data were acquired in March 2011 in the anti-blast tunnel within the Inter-Disciplinary Underground Science & Technology Laboratory at the Laboratoire Souterrain a Bas Bruit (LSBB, http://lsbb.oca.eu), Rustrel, France (Yedlin et al., 2010). Georadar data are acquired at LSBB in experiments for detection of water content by mapping permittivity over depths of several metres. One of the most interesting technical aspects of these recordings is the use of both a conventional bistatic recording geometry (the source / receiver offset is about 65 cm) and what we will call a monostatic recording geometry where the emitting antenna is also the receiving antenna. The monostatic data correspond precisely to the exploding reflector model of seismic migration. This correspondence means that zero-offset migration (ZOM) should return a very good image of the subsurface for a low computational effort. In contrast, bistatic acquisition (Ferguson et al., 2010) should be migrated using a prestack or constant offset method - in particular for the shallow section.

Here, we compare migration images for ZOM of the monostatic data to ZOM of the bistatic data and prestack depth migration (PSDM) of the bistatic data. (Just prior to imaging, we use a Gabor-domain deconvolution procedure restores much of the the amplitude and phase effects of Q attenuation). We use depth-variable velocity analysis and we determine that there are two distinct velocity zones. The first zone is shallow (0 - 5 m depth) with $\alpha = 0.2c$ m/s where α is the measured georadar velocity and $c = 3\times10^8$ m/s. Note, all α values quoted are "half velocities" as in ZOM applications. For PSDM they are doubled. The second zone extends from 5 m downward at $\alpha = 0.27c$ m/s.

Method

The georadar data from LSBB were acquired in March 2011 using an exponentially tapered slot antenna (ETSA) of the Vivaldi type (Yedlin et al., 2010). The ETSA is connected to an agilent vector network analyzer and it operates between 150 MHz to 2 GHz with a noise floor of -120 dB. The monostatic (reflection) data and bistatic (transmission) data are recorded as $a+ib$ complex numbers and each recorded number is a stack of 17 monochromatic wave measurements. This system is reported to have a number of outstanding attributes including long depth of resolution due to its wide bandwidth. Compared to other systems it has a greater dynamic range plus low distortion, and this is achieved with low-noise, low-loss cables and shielding with ultra-wideband absorbers (Yedlin et al., 2010). Note, as a prototype, this georadar is quite large (roughly 1 m by 1 m) and it is quite heavy - about 1/2 a ton (Yedlin et al., 2010).

ZOM is applied to the monostatic and the bistatic data, and those images are compared to PSDM of the bistatic data in Figure 1 (for the shallow section) and Figure 2 (for the deeper section). Note, PSDM is done using twice the half velocities.

Examples

The shallow images for monostatic ZOM and bistatic ZOM are given in Figures 1a and 1b respectively, plus bistatic PSDM in Figure 1c. Note that the bistatic PSDM appears to have slightly better focusing and more event definition that the monostatic ZOM, and it is much better in the upper .5 of a metre than the bistatic ZOM. This latter observation is true only if ground excavation reveals that the upper half metre are indeed homogeneous because monostatic ZOM and bistatic PSDM reveal little reflection energy in this zone, and ZOM of the bistatic data, in contrast, returns significant spurious reflection energy in this zone.

Images for the deeper section are given in Figure 2, where Figure 2a is the monostatic ZOM and the bistatic PSDM given in Figure 2b. Though perhaps the dipping event is not as well resolved by bistatic PSDM as in the monostatic ZOM, PSDM may actually have reduced off line noise that might have a contaminating effect on the monostatic ZOM. We find that both the monostatic ZOM and bistatic PSDM are superior in image resolution and noise reduction compared to bistatic ZOM (not shown).

Our ZOM is based on Gazdag (1978) and so we estimate it's cost as proportional to proportional to $M \log M$ for each migrated frequency and where M is the number of traces. Here, the number of traces is 223 and we zero-pad this to $M = 256$ for ZOM and so cost is proportional to approximately 1400 calculations per frequency. We estimate cost for our PSDM by similar reasoning: for PSDM of a single bistatic trace, we first insert the trace as a column within a zero matrix of N columns where the zero columns around the trace act as padding. We then apply PSDM to each of the padded traces and sum them all into an image. We find that for these data, $N = 128$ was a sufficient number for PSDM of each trace for a cost per trace of $N \log N$ for each frequency. The process is then repeated for each of M traces. The relative cost of PSDM over ZOM for each frequency then is proportional to $N \log N / \log M$. For these data, this means that PSDM is about 100 times more expensive to run for what theoretically should be the same resulting image.

Conclusions

The migrated images show that ZOM of the monostatic data returns a very clean image of a number of shallow diffractors and layers that ZOM migration of the bistatic data images with less clarity. We find that PSDM of the bistatic data returns a marginally sharper image. Our findings are consistent in the deeper section with the exception that ZOM of the bistatic data is comparatively noisier that in the shallow section.

Computationally, we find that PSDM is much more expensive to run than ZOM by a factor that is $N \log N / \log M$ where M is the number of traces and N is the number of traces that we pad around a single bistatic trace prior to PSDM. For $M = 256$ and $N = 128$, the PSDM that we have used here is about 100 times more than ZOM. Then, given that the quality of the ZOM of the monostatic data is equivalent to PSDM of the bistatic data, we conclude that monostatic data acquisition has compelling advantages in terms of cost and image quality when compared to bistatic acquisition.

Acknowledgements

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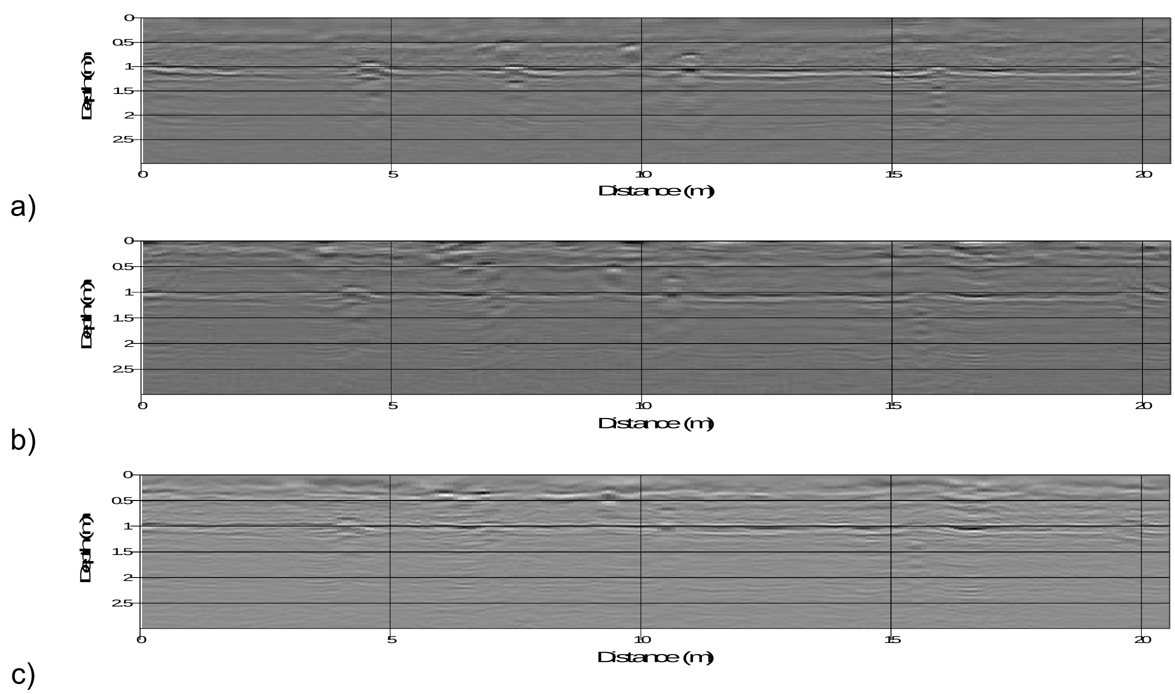
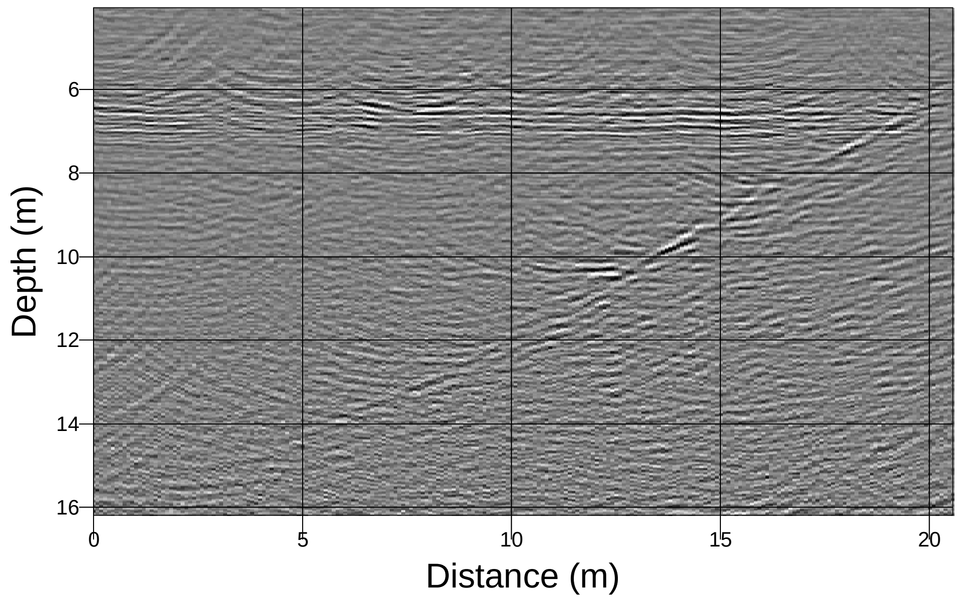
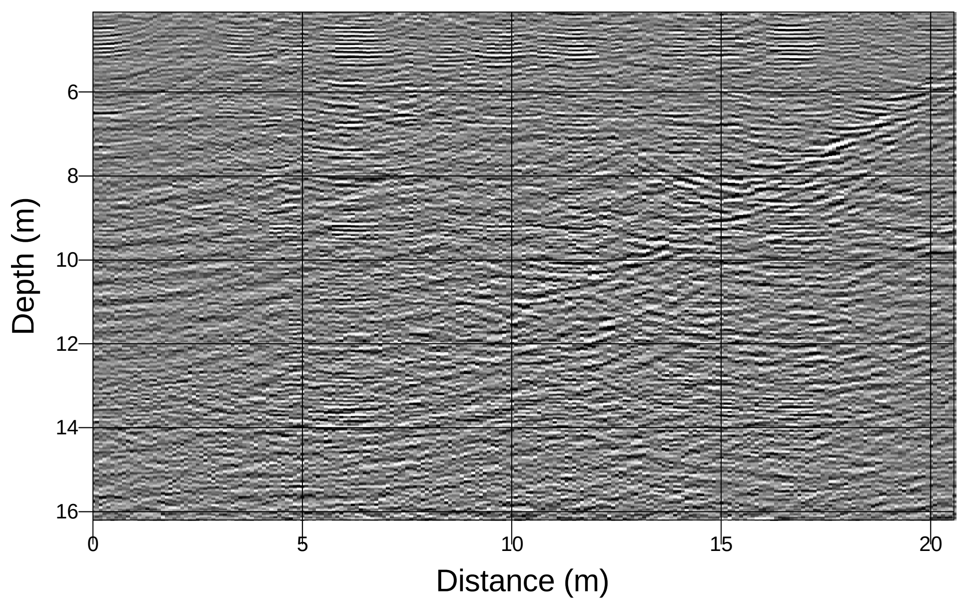


Figure 1: Comparison of migrated images of the shallow section. a) ZOM of monostatic. b) ZOM of bistatic. c) PSDM of bistatic. The reflector at 1 m depth is the base of the tunnel road, and the embedded point diffractors are re-bar within the road. ZOM of the monostatic is equivalent in quality to PSDM but much less expensive by a factor of about 100 for these data.



a)



b)

Figure 1: Comparison of migrated images of the deeper section. a) ZOM of monostatic. b) PSDM of bistatic. The dipping reflector corresponds to a fault within limestone.