

B036

Seismic Processing in the Inverse Data Space, Removal of Surface-Related and Internal Multiples

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SUMMARY

Considering the dominant role of multiple scattering in seismic data, it is proposed to replace data matrix P by its inverse P^{-1} before starting seismic processing. Making use of the feedback model for seismic data, it is shown that surface-related multiple scattered energy is mapped onto the zero time axis of the inverse data space. The practical consequence of this property may be significant: multiple elimination in the inverse data space simplifies to removing data at zero time only.

After a wavefield redatuming step towards the next important multiple generating boundary, the process can be repeated for internal multiples. Thus, moving to the inverse data space may lead to a fundamental change in the way we solve the surface-related and internal multiple problem.

Introduction

The presence of surface-related and internal multiples is still one of the major issues in seismic data processing. Whereas many processes are looking at a prediction and subtraction of multiples, here it is proposed to move to the so-called “inverse data space”, which may lead to a fundamental change in the way we solve the surface-related and internal multiple problem.

Forward data space

Using the detail-hiding matrix notation (Berkhout, 1982), the total data with all multiples, \mathbf{P} , can be written in terms of the data without surface multiples, \mathbf{P}_0 :

$$\mathbf{P} = \mathbf{P}_0 + (\mathbf{P}_0\mathbf{A})\mathbf{P}_0 + (\mathbf{P}_0\mathbf{A})^2\mathbf{P}_0 + \dots, \quad (1a)$$

where

$$\mathbf{P}_0 = \mathbf{D}\mathbf{X}_0\mathbf{S} \quad \text{and} \quad \mathbf{A} = \mathbf{S}^{-1}\mathbf{R}^\wedge\mathbf{D}^{-1}, \quad (1b)$$

with \mathbf{D} and \mathbf{S} being the detector and source properties respectively, \mathbf{X}_0 represents the multi-dimensional impulse response of the earth without surface multiples, \mathbf{R}^\wedge describes reflection against the surface from below and \mathbf{A} is the so-called surface operator (see Verschuur et al., 1992). Bear in mind that \mathbf{P}_0 contains internal multiples only.

In mathematical terms, multiplication with $(\mathbf{P}_0\mathbf{A})$ means a spatial convolution process. In physical terms, multiplication with $(\mathbf{P}_0\mathbf{A})$ means adding one roundtrip through the subsurface. Equation 1a can also be written as (see Berkhout and Verschuur, 1997):

$$\mathbf{P} = [\mathbf{I} - \mathbf{P}_0\mathbf{A}]^{-1}\mathbf{P}_0 \quad \text{or} \quad \mathbf{P} = \mathbf{P}_0 + \mathbf{P}_0\mathbf{A}\mathbf{P}. \quad (2)$$

The continuous formulation of Equation 2 represents a set of multidimensional integral equations of the second kind. Multiple scattering equation 2 define the theoretical base of multiple removal algorithms such as SRME (Berkhout, 1982). Note that Equation 2 represents the surface-related version of the well-known Lippmann-Schwinger equation (Weglein et al., 1997). For practical purposes it is essential that equation 2 includes the influence of the data acquisition operators \mathbf{D} and \mathbf{S} (Verschuur et al., 1992; Kelamis and Verschuur, 2000). It is also important to realize that surface operator \mathbf{A} does *not* contain traveltime (see Equation 1b). This property of \mathbf{A} is used in the next section.

Inverse data space

The series expansion of Equation 2 is given by Equation 1a, showing that in practice the forward data space may be very complex. From expression 2, multiple scattering data in the inverse data space (IDS) can be easily derived (see Berkhout, 2006):

$$\mathbf{P}^{-1} = \mathbf{P}_0^{-1} [\mathbf{I} - \mathbf{P}_0\mathbf{A}] \quad \text{or} \quad \mathbf{P}^{-1} = \mathbf{P}_0^{-1} - \mathbf{A}. \quad (3)$$

Equation 3 may be referred to as the surface-related multiple scattering equation in the inverse data space. It shows that the *inverse* data space is very simple with respect to the *forward* data space: it consists of the inverse surface-free response, primarily situated at negative times, and the surface-related properties at and around zero time. This can be well understood if we bear in mind that the inversion process transforms the poles in the reverberant forward data to zero's in the non-reverberant inverse data. Surface operator \mathbf{A} can be found at and around zero time. Knowing that for marine data the surface is stress free, meaning for the reflectivity $\mathbf{R}^\wedge = -\mathbf{I}$, matrix \mathbf{A} contains for each shot record the data acquisition information (wavelet, directivity) as materialized in the field. Hence, \mathbf{A} can be used to apply a full deconvolution process for sources and detectors. This capability may also offer new opportunities for the improvement of time lapse pre-processing.

Internal multiples

If we downward extrapolate to the first reflector (e.g. the sea bottom) and we remove the response of that reflector, then this reflector acts as a new ‘surface’ and the internal multiples can be removed – again via the inverse data space – by removing pseudo surface factor \mathbf{A} . Of course, this procedure can be repeated for other internal multiple generators. As such, this

process can be a new alternative to the current prediction approaches (Weglein et al., 1997; Jakubowicz, 1998; Kelamis et al., 2002; Berkhout and Verschuur, 2005).

Synthetic data examples

Figure 1a shows a shot record, simulated in a laterally invariant medium with three reflecting boundaries. Note the strong surface multiples. When bringing this data in the inverse data space, the surface operator **A** appears in the origin, as observed in equation 3. The data inverse for this lateral homogeneous example can be easily obtained by transforming the shot record to the FK domain, followed by applying stabilized data inversion. The result is transformed to the linear Radon space, as shown in Figure 1b. Note the strong event at $\tau=0$, representing the surface operator **A**. After removing this operator and applying inversion to the forward data space, the multiple free estimate is obtained, as shown in Figure 1c.

As already mentioned, a similar process can be applied for the removal of internal multiples. In this case the surface multiples are assumed to be removed. An important preprocessing step is to make sure that the next boundary acts as a new downward reflecting “surface”. Therefore, the data is redatumed towards the first boundary, and the reflection energy of this boundary – that appears in the origin after redatuming – is removed. Figure 2a shows such a redatumed dataset. Note that the second and third reflections are still visible, as well as the internal multiples. When taking this data to the inverse data space, the result is displayed in the linear Radon domain, see Figure 2b. Note that the new “surface” operator at $\tau=0$ represents the internal multiple operator related to the first reflector. After removing this operator and the noise at high p -values and bringing the result back to the forward data space, the internal multiples are removed. Optionally, the redatuming process can also be removed, meaning that the data is forward extrapolated back to the surface, yielding Figure 2c.

Field data case study

Finally, the inverse data space for field data is demonstrated. A 2D marine line from the Gulf of Mexico is considered. First, the data is organized per frequency component in a data matrix, as displayed in Figure 3a for frequency 30 Hz. Each column in this matrix represents the data from one shot record. Next, for each frequency this matrix is inverted – i.e. a full matrix inversion. For 30 Hz the result is shown in Figure 3b. After repeating this for all frequency components and bringing the data back into the time domain, the inverse data space is obtained.

Figure 4a displays a stack of the original seismic data. Note the depth of the water bottom. The first surface multiples are observed around 3.5 seconds. From the resulting pre-stack data volume in the inverse data space, the zero offset trace has been selected and displayed in Figure 4b. Note again the appearance of the surface operator at the origin. Note also that the amplitude of this surface operator varies along the surface coordinate. This particularly occurs in the area where the water bottom has a complex structure. This clear amplitude decrease may indicate that the data suffers from 3D problems, which cannot be handled by a 2D implementation of the inverse data space transform. Indeed the data is known to contain 3D effects around these locations. Therefore, the inverse data space in a 2D mode may be used to check the 3D effects in the multiples of the data.

Conclusions

If we arrange the measurements of a seismic survey in a data matrix and we determine the inverse of this matrix, all surface-related multiples map onto $\tau=0$. Surface-related multiple removal becomes a simple operation. By repeating this procedure, all internal multiples can be removed in a similar fashion.

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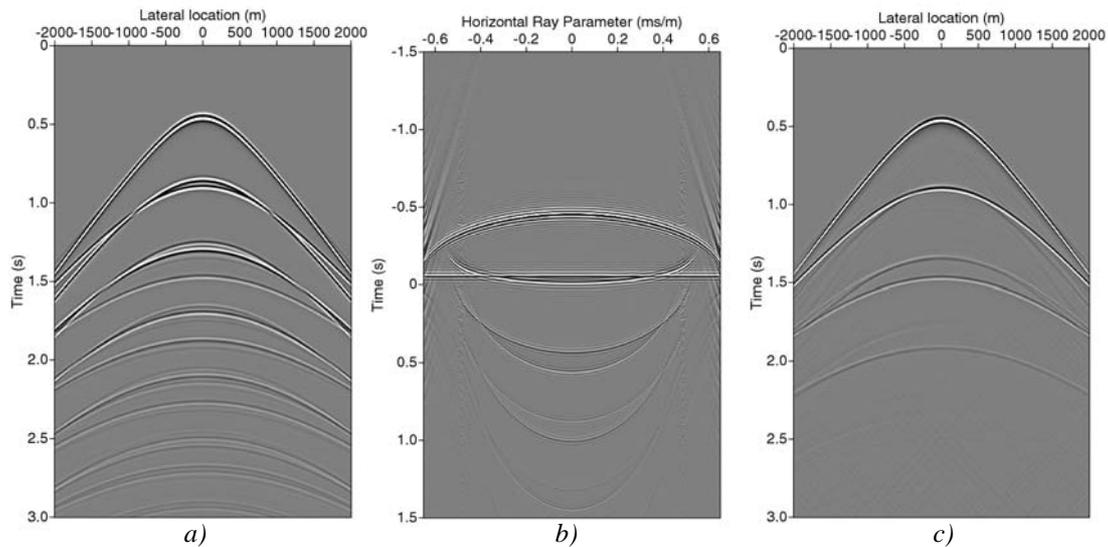


Figure 1 Inverse data processing for surface multiple removal. a) Shot record with surface multiples. b) Result in the inverse data space after a linear Radon transform. Note that the event at $\tau=0$ represents all surface multiples. c) After removing this horizontal event and transforming the result to the forward space, the data without surface multiples is obtained.

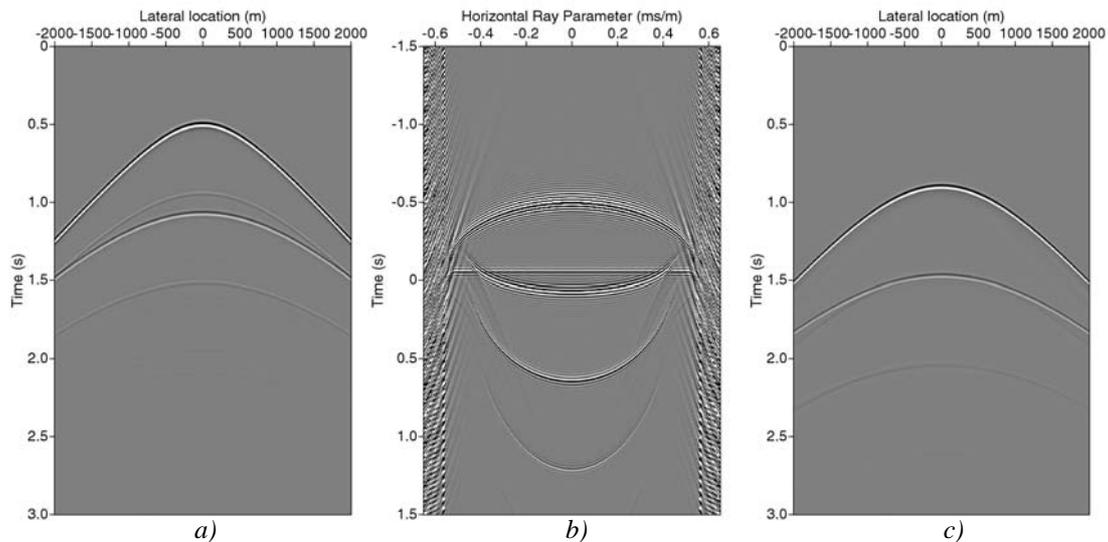


Figure 2 Inverse data processing for internal multiple removal. a) Shot record without surface multiples after inverse extrapolation and removing the first reflection event. b) Result in the inverse data space after a linear Radon transform. Note that the event at $\tau=0$ now represents all internal multiples generated by the first reflector. c) After removing this horizontal event, transforming the result to the forward space and applying forward extrapolation, the data without the internal multiples is obtained.

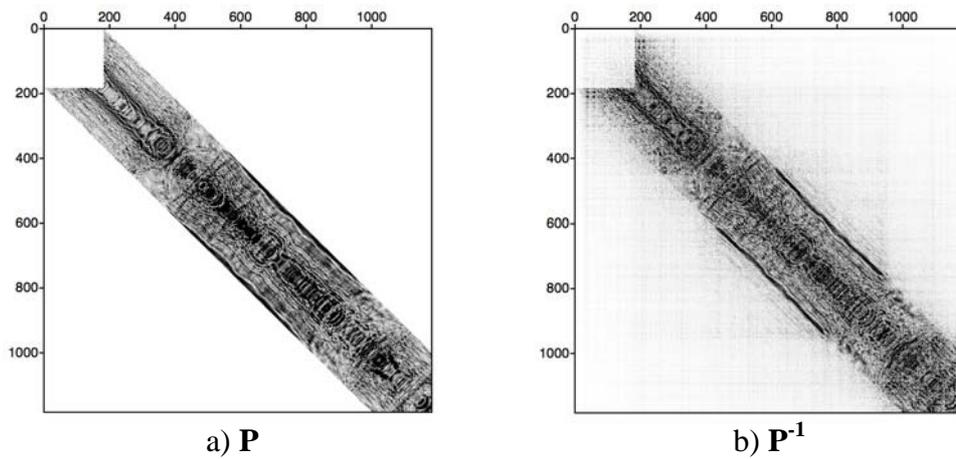


Figure 3: a) Data matrix in the forward data space (30 Hz). b) Data matrix in the inverse data space (30 Hz).

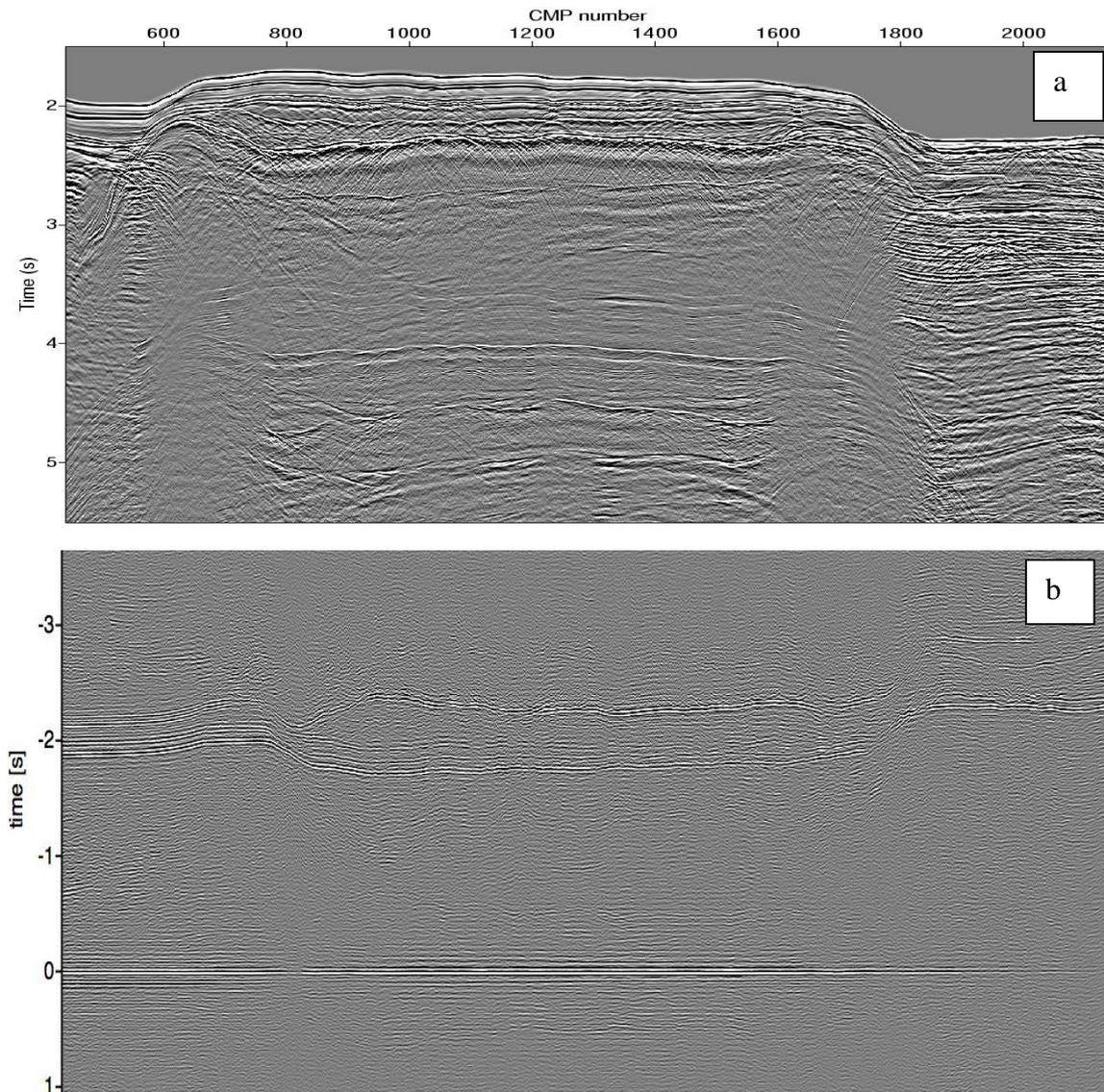


Figure 4 a) Stack section with multiples for a Gulf of Mexico 2D line from the Mississippi Canyon. b) Zero offset traces selected from the data in the inverse data space. The strong event around $t=0$ represents the surface multiples. Note the lateral variations in the amplitude of this horizontal event, indicating the 3D effects in the data.