A clear example of using multiples to enhance and improve imaging

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SUMMARY

Migration is a concept that only relates to primaries, and, in principle, requires (only) a complete set of recorded primaries. In this paper, we use an analytic example show that when the recording of primaries is incomplete/inadequate, a recorded multiple together with a recorded subevent of the multiple, can be used to find an approximate image of an unrecorded primary subevent of the multiple. Furthermore, we show that the approximate image of an unrecorded primary (extracted from a recorded multiple) can be used to augment and enhance subsurface imaging when there is inadequate or insufficient recording of primaries

INTRODUCTION

In Claerbout's imaging condition II (i.e., space-and-time coincidence of upgoing and downgoing waves), the source wavefield is forward propagated to the subsurface and the receiver wavefield is backward propagated to the subsurface. The imaging result is obtained by deconvolution via equation 1 (or cross-correlation, via equation 2) imaging condition (e.g., Claerbout (1971), Whitmore et al. (2010)):

$$I(\vec{x}) = \sum_{\vec{x}_s} \sum_{\omega} \frac{U(\vec{x},\vec{x}_s,\omega)}{D(\vec{x},\vec{x}_s,\omega)}, \tag{1}$$

$$I(\vec{x}) = \sum_{\vec{x}_s} \sum_{\omega} D^*(\vec{x},\vec{x}_s,\omega) U(\vec{x},\vec{x}_s,\omega). \tag{2}$$

In equation 1 (and equation 2), $D(\vec{x},\vec{x}_s,\omega)$ and $U(\vec{x},\vec{x}_s,\omega)$ represent downgoing and upgoing wavefields, respectively, and $*$ in equation 2 represents the complex conjugate.

Claerbout's imaging condition II assumes that the data consist of primaries. Hence, multiples need to be removed prior to imaging (see e.g., Carvalho et al. (1991), Verschuur et al. (1992), Araujo et al. (1994); and Weglein et al. (1997)). Claerbout's imaging condition II also requires a velocity model for wavefield propagation, and velocity-analysis methods assume that multiples have been removed.

However, whereas imaging requires only primaries, circumstances exist in which the extent, sampling and acquisition of primaries is incomplete and less than adequate to achieve imaging objectives. Researchers (e.g., Berkhout and Verschuur (1994); Guitton (2002); Shan (2003); Muijs et al. (2007); Whitmore et al. (2010); Lu et al. (2011) and Valenciano et al. (2014)) seeking methods that use multiples to extract an approximate image of an unrecorded primary were influenced and inspired by the Claerbout imaging condition II (designged for imaging primaries) to consider the space-and-time coincidence of other events for different useful purposes. The example in Figure 1 illustrates one way that such an extension has been realized.

For the purpose of using a multiple to find an approximate image of an unrecorded primary, we consider the field U (in equation 1 or 2) as the source-and-receiver deghosted first-order multiple, and the field D as the source-deghosted, but the receiver ghost of the primary that is a subevent of a recorded multiple. That interpretation of equations 1 and 2, with that input D and U, will produce an appropriate image of the unrecorded subevent of the multiple (see Weglein (2016) for more details).

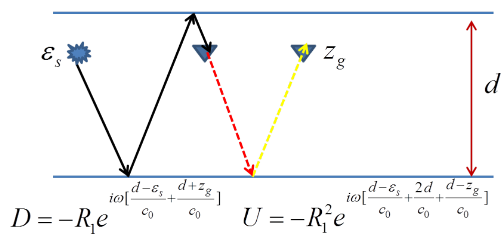

Figure 1: Imaging of an unrecorded primary that extracted from a recorded multiple. Figure adapted from Weglein (2016).

Methods that seek to use a multiple to produce an approximate image of an unrecorded primary also require a velocity model for wavefield propagation. That in turn requires a step in which multiples are first removed. Therefore, the recent interest in (and approaches for) using a multiple to provide an approximate primary depend on an effective removal of multiples before the method starts.

Within that understanding, we use a 1D prestack example to examine the imaging result of an unrecorded primary that we can extracted from multiples following Claerbout's imaging condition II (i.e., equation 2). We compare that result with the image results obtained from the recorded primaries, following that same Claerbout's imaging condition.

PRESTACK IMAGE ENHANCEMENT BY IMAGING AN UNRECORDED PRIMARY EXTRACTED FROM A MULTIPLE

In this section, we provide a 1D prestack numerical example to examine the result of approximately imaging an unrecorded primary extracted from a recorded multiple. Multiples can be useful for extracting an unrecorded primary's image and thereby for enhancing the subsurface image.

The test data are generated from a model that contains one horizontal reflector (Figure 2). In imaging the recorded primary (Figure 3a), the downgoing wavefield that is being forward propagated is the source wavefield, and the upgoing wavefield that is being backward propagated is the primary. In imaging the unrecorded primary (Figure 3b), the downgoing

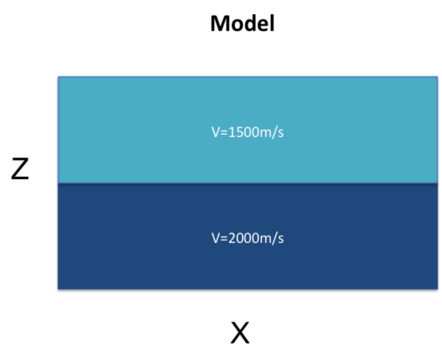

Figure 2: A test model for a case of a single horizontal reflector.

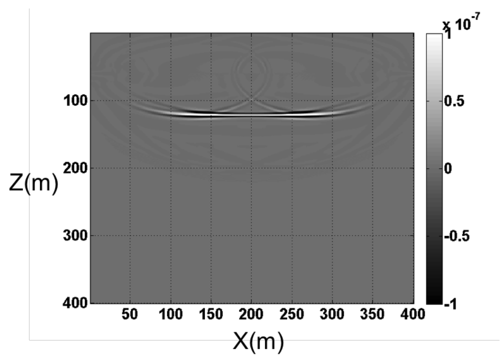

Figure 3a: Result from imaging a primary following Claerbout's imaging condition II.

wavefield that is being forward propagated is the receiver-side ghost of the primary, and the upgoing wavefield that is being backward propagated is the source-receiver-side-deghosted first-order free-surface multiple.

Comparing the result in Figure 3a with the result in Figure 3b, we note that the reflector is correctly imaged in both results. However, the image from the unrecorded primary (extracted from a multiple) shows broader illumination (with smaller image amplitude) compared with the image from the recorded primary (see Weglein (2016) for analysis in amplitude difference).

It is important to point out that in obtaining the result of Figure 3b in this synthetic example, we purposefully chose the receiver-side ghost of the primary and the source-receiver-side-deghosted first-order free-surface multiple as the down-going (D) and up-going (U) wavefields, respectively. Methods that seek to obtain an approximate image of an unrecorded primary require an effective up-down wavefield separation, which can be achieved by modern seismic acquisition techniques (e.g., GeoStreamer or over/under cable). Notice that, among different combinations

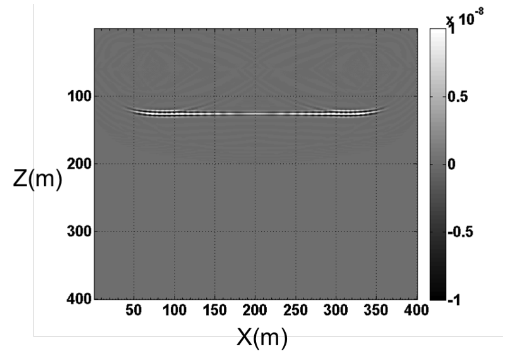

Figure 3b: Result from imaging an extracted primary from a first-order free-surface multiple following Claerbout's imaging condition II.

between the downgoing and upgoing events, cross-talk artifacts can happen (e.g., Liu et al. (2011), Lu et al. (2011)).

The reason is the prediction of an events as a multiple depends on having the subevents of the multiple recorded. Since the problem being addressed by definition has unrecorded primaries, multiples with unrecorded primary subevents cannot be identified as a multiple. To address that issue in practice the entire data set is input where on one side primaries belong and on the other side multiples are called for.

There are circumstances where the benefit derived from the enhanced imaging greatly overweights the deficit of false event prediction (e.g., Valenciano et al. (2014) and Weglein (2014)).

CONCLUSIONS

Following Claerbout's imaging condition II, multiples can be used to provide an approximate image of unrecorded primaries and thereby to supplement the subsurface imaging. However, there are artifacts (e.g., unwanted cross-talk) in the real applications that use multiples to improve subsurface imaging. Therefore, this procedure needs to be judiciously implemented in real-world applications. Whitmore et al. (2010); Lu et al. (2011); Valenciano et al. (2014) and Weglein (2014) showed several convincing field-data examples that illustrated considerable added value from using multiples to enhance imaging. The Claerbout's imaging condition II allowed/encouraged the consideration of the space-and-time-coincidence idea for different upgoing and downgoing wavefields (in addition to the use for which the original imaging concept was intended) in an interpretation to provide added value for using multiples to approximate the image of an unrecorded primary. There are numerous examples that show significant benefit for imaging from this procedure, and where that benefit outweighs any issues caused by artifacts.

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