Multiple diffractions and coherent noise in marine seismic data  
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Summary

Multiple diffractions and coherent noise in marine seismic data are caused by irregularities on the sea floor. These irregularities can share characteristics with the primary scattering that is also generated by such irregularities. The kinematics of the primary scattering were investigated in a classic 1983 Geophysics paper by Ken Larner and his colleagues, as part of a study of coherent noise in marine seismic data. Where the sea floor is generally smooth except for isolated irregularities, many of the conclusions of that paper can also be applied to the multiple scattering. In particular, strategies for removal of scattered noise from sea-floor irregularities can also be applied to attenuate sea floor and other multiple diffractions.

Like the primary scattering, the multiple diffractions are organised in mid-point gathers in such a way that mid-point stacking may enhance portions of the multiple. Also like the primary scattering, the multiples can be distinguished from primary reflection events in the data by their dip in pre-stack shot and receiver gathers. Pre-stack dip-filtering in those domains can be used to remove the portions of the multiple diffractions that would otherwise be enhanced by the mid-point stack, in the same way that dip-filtering can be used to remove the primary scattering.

Shot and receiver dip-filtering can, however, damage diffractions and lateral amplitude changes from geology-related primaries in the data. A partial strategy, in less complex structure, is to apply pre-stack imaging in conjunction with multiple removal, with the aim of simplifying the geology-related primaries and hence increasing the separation between the primaries and the multiples. The pre-stack imaging does however increase the complexity of the multiple diffractions, and can also introduce aliasing and dispersion-related artefacts. The multiples are mis-migrated, but the degree of mis-migration varies smoothly with offset. Multiple removal can still be applied, but with a reduced potential for primary damage.

Introduction

In many areas of the world marine seismic data contains multiple reflections from water-bottom scatterers that are highly resistant to conventional processing techniques for multiple removal. Multipes of this type may be present in data from northern latitudes, e.g. offshore Norway or Alaska, where glacial scouring has deposited debris on the sea floor, and they can also be present in data from deep-water areas such as offshore West Africa or the Gulf of Mexico, where the sea floor contains marine canyons and other isolated obstacles. Multiple diffractions of this sort often have relatively strong amplitudes, are not periodic, can have complex moveout in CMP gathers, and are inherently 3D in nature. Standard multiple removal techniques based on either the periodicity or the moveout of the multiple will fail to treat these types of multiples adequately, as will 2D approaches to surface-related multiple elimination (2D SRME).

In past work (verWest, 2002) it has been shown that the moveout curve in CMP gathers of multiple diffractions and multiples from dipping layers can have its minimum traveltime, or apex position, shifted away from zero-offset. In addition, the multiple splits into a pair of events, one for either the shot or receiver side multiple bounce. The typical kinematics of a pair of split multiple diffractions are shown in the schematic in Figure 1. It follows from this moveout behaviour that a possible strategy for the removal of multiple diffractions is to extend the Radon multiple model to include apex-shifted events in the model space (Hargreaves et al. 2002).

Another possible approach to removal of multiple diffractions is 3D surface-related multiple elimination. It is well known, however, that 3D SRME requires a fully sampled dataset with a source at every receiver location, and that typical marine surveys are undersampled for 3D SRME in the crossline shot direction. Various strategies have been proposed to deal with this undersampling: additional shots can be created by interpolation from the available shots (Kleemeyer et al. 2003; Lin et al., 2004), the missing contributions to the multiple model can be interpolated (van Dedem and Verschuur, 2001), or the
Multiple diffractions and coherent noise in marine seismic data

survey data could of course be acquired using a smaller shotline separation.

Coherent noise in marine seismic data

The SRME perspective that multiples are combinations of primaries can also help to provide some insight into the behaviour of multiple diffractions, at least when the seabed is predominantly smooth except for a number of isolated irregularities. Most of the multiples from the scatterers will then be a simple combination of a straightforward primary reflection at the water-bottom with the primary response of the scatterer.

The kinematics of the primary scatterer response were analysed in depth by Ken Larner and co-authors (1983) in an investigation of coherent noise in marine seismic data. Figure 2 reproduces the results from that paper that were derived from a synthetic model containing a set of scatterers randomly distributed around the survey line. The figure summarises one of the central conclusions of the paper: that the primary scattered energy can have a moveout in mid-point gathers that is close to the moveout of other primaries in the data, and the scattered energy is therefore enhanced by stacking. As the authors comment, “the CMP stack is widely considered to be the most powerful general processing tool for suppressing a variety of noises...however, much of the side-scattered noise is actually enhanced by the stack”.

When the water-bottom is relatively uncomplicated, the scatterer’s multiples behave in a very similar way to the scatterer primary. Figure 3 is a comparable set of displays to those of Figure 2, showing the behaviour of the multiples of the scatterer (the diffraction multiples). This synthetic, which is shown courtesy of BP, was generated with a set of near-surface scatterers randomly distributed around the survey line, and the primary scattering produces the events in the upper portion of these displays, whilst the multiple diffractions are the events in the lower part of the displays. The synthetic model had a smooth gently dipping water-bottom plus a small number of primary reflections from gently dipping horizons. The water-bottom multiple is at 4s at near offsets in Figures 3(a) and 3(b), and there is a primary reflection in these displays at approximately 3.8s at near-offsets. There is a weaker primary visible in the stack, dipping down from left to right between 4.5 to 4.7s, but which is obscured by multiples in the pre-stack gathers.

The multiple diffractions in Figure 3(a), like the primary diffractions in Figure 2(a), have a mixture of positive and
Multiple diffractions and coherent noise in marine seismic data

negative dips in the gathers. Many events have close to linear moveout in either the positive or negative direction, with a velocity equal to the velocity of propagation of the scattered energy. Where the events have negative dip they are clearly recognisable in both displays as being noise of some type rather than as signal.

It is more difficult to unambiguously identify events as noise in the mid-point gathers of Figures 2(b) and 3(b). In Figure 2(b) many events could plausibly be identified as primary reflections, although this synthetic gather contains only scattered noise and no other events. The situation is slightly clearer perhaps in Figure 3(b), since a number of the moveout curves in this gather have the type of apex-shifted behaviour that is indicative of diffraction multiples or possibly multiples from dipping layers. (A similar type of moveout could be present, however, in primary reflections from complex structure.) If we were to apply velocity analysis to the data of either figure we would find that many events in these gathers would stack at a geologically plausible primary stacking velocity. In fact there will always be a portion of an apex-shifted event that will stack regardless of the velocity. Figures 2(c) and 3(c) show the resulting linear patterns that appear after stack.

Suppressing multiple diffractions

In the 1983 paper from Larner and co., it was suggested that pre-stack dip filtering could be used to remove scattered noise, exploiting the varying dip characteristics of the noise in different pre-stack domains. It is tempting to consider using a similar approach in order to remove the multiples of the scattering.

This could, however, cause damage to portions of other events in the data. Figures 2 and 3 show, after all, that primary and multiple scattering can have similar dip characteristics in pre-stack gathers, and that processing that removes multiple diffractions can also remove primary diffractions.

In later work from Ken Larner and his colleagues various imaging approaches to scattered noise removal were proposed. It was shown, for example, (Chambers et al., 1984), that constant-velocity DMO can remove scattered noise as a result of its reduction of the apparent stacking velocity of the dipping limbs of the scatterer response. After DMO, the noise stacks at its true velocity, and along the limbs of the scatterer response this velocity is usually lower than the primary velocity at that time. It was similarly suggested that 3D imaging of the scatterer might be a way of treating scattered noise, although the relatively low velocity of the scatterer might pose problems related to aliasing and dispersion.

Can we similarly find an imaging-related approach to removal of the scatterer multiple? It would appear at first sight that pre-stack migration, for example, could be used to focus the primary reflections and reduce their potential damage by the multiple diffraction removal. It’s not immediately clear, however, how this would affect the multiple and whether it would still be possible to use the multiple’s pre-stack kinematics to distinguish multiple from primary. A further difficulty is that pre-stack imaging, in addition to increasing the complexity of the diffraction multiple, might also introduce sampling-related aliasing and dispersion.

Figure 4(a) shows a portion of a stack section from a deep-water West Africa survey after pre-stack migration. The main features in the display are multiples from an anticlinal feature on the water-bottom and from horizons near to the water-bottom, together with some lower frequency horizontal primary reflections. The migration has badly over-migrated the multiples, and they have been spread over the flatter primary events and upwards towards the shallower primaries. Pre-stack constant offset-panels also show a similar behaviour for the multiples. Rather than improving the separation between primaries and multiples the migration appears to have increased their overlap, both in the stack and also in the pre-stack constant-offset data.

Figure 5(a) shows two NMO-corrected mid-point gathers from the West Africa survey, the first of which is from near to the centre of the stack display in Figure 4 and the other from the right hand side of the display. In the first gather there is an event with apex-shifted moveout, which is not present in the other gather, and this is the multiple diffraction from the anticlinal feature on the water-bottom. These gathers are post-migration, yet despite the mis-migration that is evident on the stack, the multiple diffraction and the other more conventional multiples in the displays are still coherent in mid-point gathers. Although the multiples are mis-migrated, it would appear that the mis-migration varies sufficiently slowly with offset that the moveout versus offset remains reasonably consistent.

When multiple removal is applied to the multiple diffraction according to Larner’s prescription for scattered noise removal, together with Radon multiple removal for conventional multiples, almost all of the energy from the multiple diffraction can be removed from the mid-point gathers. The stack in Figure 4(b) shows that despite the over-migration and smearing of the multiple diffraction in the stack and in constant-offset panels it is still possible to remove this multiple by exploiting its coherence in other pre-stack domains.

Conclusions

The attenuation of multiple diffractions such as those generated by sea-floor scatterers remains a difficult problem for standard multiple attenuation methods. The apex-shifted moveout and associated moveout velocity of these events are a problem for Radon de-multiple and, unless the diffraction occurs within the shot-receiver acquisition plane, they will not be not accurately modelled
Multiple diffractions and coherent noise in marine seismic data

by 2D SRME. The pre-stack moveout behaviour of the scatterer multiples is similar to that of the associated primary events, so that there is little dip or moveout separation between these different types of events that would allow the attenuation of the multiple without damage to the primary. Application of pre-stack migration collapses the primary diffractions but mis-migrates the multiple diffractions. However, sampling effects notwithstanding, the mis-migration varies smoothly with offset and in simple geology the mis-migrated multiple remains coherent within the pre-stack domain, so that approaches that could not be applied pre-migration can be successfully applied in conjunction with the migration with less risk of damage during focusing of the primary data.

References


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Figure 4. (a) A portion of stack data from a deep-water West African survey after pre-stack migration, showing an over-migrated multiple from an anticlinal feature on the water-bottom. The arrows indicate the positions of the mid-point gathers in Figure 5. (b) The data of the previous panel after the pre-stack processing applied to generate Figure 5(b)

Figure 5. (a) Two pre-stack migrated mid-point gathers from the stack panel in Figure 4, after NMO correction. Note the apex-shifted event in the first of the gathers and the absence of this type of event in the second gather. (b) Gathers from the previous panel after pre-stack multiple removal according to Larner’s prescription for scattered noise removal, plus Radon multiple removal.