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Summary

Multiples are traditionally considered as noise for conventional data processing. However, it can be used for imaging in order to extend the illumination recovery. In this paper, we present the results of imaging using multiples on PRM datasets from the North Sea including two vintage surveys and minimal data pre-conditioning. For 4D analysis, the up-going wavefield is used as it is less affected by water layer variations. The images using multiples show very little footprint in the shallow overburden and, to some extent, an interpretable image in the large obstruction zones. We show that the images using multiples also contain the expected 4D effects, though the results seem to be contaminated with crosstalks. Finally, we propose to test the method on different wavefields recorded by the multicomponent system to demonstrate the robustness of the deconvolution imaging conditions and observe the difference in illumination provided by different components.
Introduction

Imaging using multiples takes advantage of the extended illumination provided by surface multiple reflections which are traditionally considered as noise for conventional processing and imaging. We briefly review the concept when applied to Ocean Bottom Seismic surveys, as introduced by Lu et al (2016). By turning every source of the survey into virtual sources and receivers, the source-side free surface multiple reflections are treated as signal. The resulting image has a greater spatial extent than the one obtained with conventional imaging, thanks to the dense and wide distribution of sources. Furthermore, in shallow water environments, the angular diversity provided by multiples means that the recovered reflectivity sections are free of traditional distortions observed in conventional imaging. The concept is applied on PRM data, from the Snorre field, where six surveys have been acquired since the installation in 2013. Two of the vintages, PRM3 and PRM4, are used in order to study the validity of the method for time-lapse (4D) imaging.

In previous applications (Lecerf et al, 2016), the method has shown great potential in recovering more information from survey layouts which are designed to provide an optimal image at reservoir level using conventional imaging techniques. In addition, we investigate the benefit below the platform which is generally not covered by the shot carpet and would require additional surveying plans. The deconvolution imaging condition removes the history of the prior reflections/conversions and the use of the single Vp model enables the focusing of the last two-way PP reflections of any raypath, thus making the imaging method practically suitable for any type of records. Therefore it is also tested on various input datasets which consist of the up-going pressure wavefield, the down-going pressure wavefield and finally the horizontal components.

Methodology

The Snorre Permanent Reservoir Monitoring system (PRM) is designed to record four component (4C) data with high repeatability in order to provide detailed 4D interpretation results several times a year. So far, these results have been based on conventional migration which requires thorough data pre-conditioning. This includes in an non-exhaustive way: denoising, wavefield separation, source-designature and demultiple.

The imaging using multiples is currently based on wave-equation migration where both the source- and receiver wavefields consist of the data containing primaries and multiples. Moreover, the imaging condition is changed from a cross-correlation to a deconvolution which implies that the source signature and the ghost effects are cancelled at the imaging step. Therefore the data which are used in the study have only undergone a denoising step and the wavefield separation to produce the up-going pressure wavefield. The separation is done just below the seabed such as the up-going wavefield is free of receiver-side ghost and receiver-side water layer multiples. The velocity model was built using older datasets and assumed to be good enough for evaluating the differences between various tests.

In this study, the imaging tests are conducted on a patch of receivers which is severely limited compared to the available layout (figure 1). This may result in edge effects and lack of certain dips when imaging with multiples, though we still expect some illumination right below the available source carpet. The latter is limited by only keeping the shots contributing to the selected receivers with a surface offset smaller than 8000 m. Furthermore, the source carpet is restricted around the platform and its safety zone. The resulting large hole means that conventional imaging using up-going or down-going wavefields will still suffer from the lack of illumination and in the worst case, in the very shallow overburden, only produces migration artefacts.

The results are compared to two sets of existing data: a legacy short offset streamer stack dataset, acquired before the platform installation and PRM conventional imaging results. It is relatively free of
distortion in the shallow section and provides an excellent benchmark for the shallow imaging- and the undershoot potential in the obstructed zone.

For the 4D quality assessment, the images obtained using multiples are corrected with 4D matching filters as is done for the benchmark datasets. However, one significant cause of non-repeatability is observed between the PRM3 and PRM4 vintages: the water layer varies in arbitrary ways due to tides and water velocity. A simple workflow was employed to correct for the relative travel-time differences between the source- and receiver wavefields input to imaging using multiples. The source wavefield is corrected for the one-way-time variations, as done for conventional imaging. The receiver wavefield is corrected for an equivalent of three-way-time variations to account for the additional source side multiple reflection paths. Because the data are migrated in receiver domain, this correction, although still valid, is less effective to multiples of second and higher orders. The final imaging step is performed using one common velocity model which includes a constant water velocity and datum.

Figure 1. The Snorre PRM layout overlaid on a bathymetry map: the red dots show the PRM3 post-plot, the green dots show the receiver positions and the black polygon show the selected area for testing. There are approximately 10,000 receiver locations in total and the entire receiver spread covers an area of approximately 192 sq.km and is 22.4 km N-S.

3D and 4D results using up-going wavefields

The initial result using multiples provides a high quality shallow image down to approximately 1 km depth. The resolution is slightly superior to the one observed in the legacy streamer data. The comparison is hardly relevant against the conventional imaging results since the latter is fully distorted at water-bottom level and the footprint has a detrimental effect on the image interpretability well down to several hundred meters below the seabed (figure 2). Shallow hazard mapping and monitoring becomes possible with such migration technology but this will not be addressed further here as there was no target of interest in the given test area. Furthermore, the area below the platform becomes illuminated when using multiples as illustrated in figure 2. Some fine geological details reveal that the image is hardly a result of hole interpolation and migration smearing.

On the other hand, at reservoir level, around 3 km depth, the image using multiples show the main reflectors of interest but a higher level of noise too. The initial 4D differences and 4D attributes show that the relatively strong 4D responses are recognizable in the data but the noise levels were seen to hide the weaker 4D effects (figure 3). We can clearly identify some of the coherent noise as causal crosstalks while the non-coherent noise is likely a product of causal- and anti-causal crosstalks, as described by Lu et al. [reference SEG 2016 abstract]. Modelling and attenuation of crosstalks was tested.
using conventional multiple prediction techniques and re-migration. Although the results looked promising, they will not be discussed here as it proved to add significant time and costs to the processing of the data.

![Figure 2](image1.png)

*Figure 2. Conventional image on the left, up-going image using multiples on the right, illustrating the increase in illumination in the shallow, including below the platform when using multiples.*

![Figure 3](image2.png)

*Figure 3. Conventional image and up-going image using multiples: PRM4 dataset on the left side and 4D difference between PRM4 and PRM3 on the right side.*

**Tests using alternative wavefields**

Down-going wavefields are typically used in conjunction with mirror migration techniques in order to improve the quality of shallow images from OBS datasets. When imaging using multiples, the principle remains similar. However, the presence of the direct arrival in the source wavefield means that down-going primary reflections can be deconvolved as well and contribute to the illumination together with higher order reflections. As illustrated in figure 4, the image from the down-going wave field shows better signal focusing and less migration noise. We speculate that some of the noise visible in the image from the up-going wavefield is anti-causal crosstalks from primary energy which is not properly migrated.

However, horizontal records are seldom used in imaging and whenever they are it is mainly to exploit the properties of the shear waves propagation, such as in gas clouds. Mode-converted waves still travel significant distances in the subsurface as pure pressure waves. The example shown in figure 4 shows that this information can be isolated and recovered by the use of the deconvolution imaging condition. The resulting image has comparable resolution, though the illumination can slightly differ from the previous images using multiples, in particular on the edges of the images and at dips, as expected. Finally we observe that some events previously identified as crosstalks seem weaker, which suggests that these undesired cross-correlation effects occurs less often with mixed waveform. This should also be expected as shear waves generally travel much slower than pressure waves. It is worth noting that for this last test, the input data is raw from field tapes. The supposed Inline horizontal component (vector pointing along the cable direction) only was used, with no process to address vector infidelity and/or mis-orientation. Besides demonstrating the robustness of the imaging method, this test suggests the data pre-conditioning could be considerably reduce and so the project turnaround and costs.
Figure 4. Imaging using multiples: up-going image on the left, horizontal component image in the middle and down-going image on the right.

Discussion

We have shown examples of imaging using multiples for OBS data in typical North Sea water depth environments. The current method already shows promising signs for mapping and monitoring of shallow targets, as well as undershooting of obstruction zones. For deep reservoir monitoring, 4D effects from multiples can be exploited but the main challenge for shallow water environments remains the presence of crosstalks. We suggest that the effect is predominantly driven by the geology, in particular velocities. However, new methods such as full wavefield migration and least-square migration should mitigate this issue and additional work will be conducted on this dataset. We acknowledge that the extensive testing has been performed on a specific case study and suggest that some of the observations may vary with other water depths and geological settings.

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