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Acquisition Footprint Removal from Time Lapse Datasets
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SUMMARY

Water layer variations and acquisition differences are two important factors that introduce time shift or amplitude artefacts in time-lapse datasets. These artefacts are correlated with the acquisition geometry and can be seen as stripes along the shooting direction. For this reason it can be desirable to use acquisition geometry information as a guide to solve for these variations. In this paper, a novel inversion scheme algorithm guided by acquisition parameters is introduced to correct for footprints usually seen on offset planes. These corrections can be static, that is no change across offset, or when water velocity changes the corrections can be dynamic and therefore vary across offset accordingly.
Introduction

For 3D seismic, so-called “water column statics” are time shifts typically caused by changes in the properties of the water column with different times of acquisition for different sail-lines, re-shoot, or in-fills. Due to seasonal changes or ocean currents, the state of water can vary as a function of the temperature and salinity (MacKay et al., 2003; Bertrand and MacBeth, 2003) and thus can either result in a static difference or water velocity change which would cause dynamic changes i.e. varying time shift as a function of offset and time.

In time-lapse projects, different vintages are acquired in different environmental conditions (tidal effects, water temperature and salinity) and potentially recorded with different acquisition parameters (source and receiver depth, number of shots and cables and so on). All these factors lead to residual amplitude, time shift and phase shift differences between vintages of time-lapse seismic data. In the early days of time-lapse, the phrase of “repeating the error” was often used. In essence, repeating the error means that in order to get a clean 4D subtraction of base and monitor (with minimal noise, and only 4D signal), the two data have to look as similar as possible everywhere: If one of the datasets has some noise on it, then the other one needs to have the same noise, for the 4D difference to be as small as possible. It is not hard to see that this strategy is doomed to failure if pushed too far. Today, the strategy has changed somewhat and we have established what are called “simultaneous” solutions which take into account all the vintages of a time-lapse study to come up with an optimized solution.

It is also fair to say that to correct for the errors mentioned above we should be as deterministic as possible. This means that any extra information about the signal (such as the source wavelet) and sources of differences in the data (for example tides, or changes in recording instruments) must be used. This includes acquisition geometry information. A good example of this strategy is the analysis and the removal of acquisition related differences on a swath by swath basis that we generally see as striping (along the shooting direction) when we plot RMS ratio maps or time-shifts between two vintages. Knowledge of the acquisition geometry, such as swath boundaries should be signalled to any method that analyzes the spatial continuity of the data. The algorithm must be told: This is a location where potentially something can change, but not elsewhere. This is termed “acquisition guided” processing, and examples are demonstrated in the context of amplitude equalisation and time-alignment. Two different inversion based algorithms are proposed to tackle this challenge in time-lapse processing. One is based on the direct minimization of the measured time shift or amplitude discontinuities across acquisition boundaries and the other method is based on nonlinear minimization of NRMS.

Methods

Time shifts or amplitude discontinuities due to changes in water column properties, seismic source wavelet or acquisition difference can easily be observed on a crossline extracted from a near offset cube where some of the traces seem to be shifted up, down, dimmed and/or boosted relative to their neighbours. Normally, these variations can be linked with shooting direction and therefore the sail-line can be used as a guide for the algorithm to minimise the differences between different vintages (though it is possible to add any number of guiding attributes as required for example cable and gun number). Generally acquisition parameters and water layer properties do not change significantly during the recording of a single sail-line, and therefore the assumption that one correction per sail-line being sufficient can be made. Although this could be a valid assumption and can be used to simplify the inversion, it is sometimes best to allow smoothly varying corrections along the sail-line. This can be crucially important for time-lapse data. In summary, for a time-lapse project, sail-lines, acquisition vintage and variation along the sail-line can be employed as guiding attributes.

To solve this problem explicitly, Normalized RMS amplitude of the difference of two vintages (“NRMS” (Ronen et al., 1999)) can be used as a cost function which can also be extended for multi-vintage applications as introduced by Zabihi Naeini et al. (2010):

\[
\text{cost function } \text{NRMS}(c_{g(i)}T_i, c_{g(j)}T_j)_{i,j} \rightarrow \min
\]

(1)
where $g$ is the guiding attribute, $T$ is a trace belonging to different guiding attribute, $c$ is the desired correction and $i$ and $j$ are indices. By using NRMS as a cost function it is possible to invert for desired amplitude, time shift and phase shift corrections simultaneously using nonlinear optimisation techniques. However, to derive a unique solution it is necessary to add extra constraints which in this case can be “network constraints” as described in Zabihi Naeini et al. (2010). In addition it is useful to limit the variation along the sail-line and the amount of correction required.

It is also possible to decompose different elements in equation (1) and create individual cost functions for amplitude and time shift corrections i.e. in the case of amplitude

$$\text{cost function } A(g_{(i)}, a_{g_{(j)}}) = \left\| a_{g_{(j)}} T_i - a_{g_{(j)}} T_j \right\|^2 \rightarrow \min$$

(2)

where $a$ is now the amplitude scalar correction. A similar argument is also valid for the time shift correction. This is a different way to address the acquisition guided destriping problem with a new quadratic type cost function that can be solved using appropriate solvers. Again it is necessary to add some linear constraints to achieve a unique and physically acceptable solution.

To choose one of these algorithms is a matter of data quality and convenience as the main difference between the above proposed algorithms is that the NRMS based method is data-driven which means the input is seismic data while for minimizing equation (2) we need amplitude or time horizon maps (that can be time consuming to pick precisely). In the next section the application of both methods is demonstrated on two different data examples.

**Examples**

Figure 1 shows the application of the NRMS based algorithm as in equation (1) on a time-lapse dataset from the UK Continental Shelf (UKCS) with 2 acquisition vintages. It can be observed that there is a significant improvement in removing the acquisition footprint from both amplitude ratio and time shift maps which leads to an improved NRMS map as highlighted by the ellipses.

**Figure 1** NRMS, time shift and RMS ratio before (a)-(b)-(c) and after (d)-(e)-(f) footprint removal.
The second example is another time-lapse dataset from UK continental Shelf. Figure 2 compares RMS amplitude ratio maps and 4D difference sections before and after acquisition footprint removal using the algorithm in equation (2). This algorithm also successfully corrected for stripes on the map and significantly improved the time-lapse repeatability as is clearly visible on the 4D difference section (the stripe marked by the ellipse is well removed after applying the algorithm).

**Figure 2** Full stack 4D difference section and RMS amplitude ratio maps before (top) and after (bottom) acquisition footprint removal. Note the significant removal of stripes from the map. The 4D difference section also clearly shows the improvement in the repeatability as marked by the ellipse.
In the case of change in water velocity, the corrections derived from a near offset cube are not sufficient for far offsets and there may well be residual time shifts present. This problem requires a dynamic type correction. The methodology introduced in this paper can be extended for this application by using the calculated statics to approximate the water velocity for each sail-line and replacing the water layer with a constant velocity (MacKay et al., 2003) for both vintages. This was applied on some deep water datasets with significant improvement on the repeatability. Obviously the result of dynamic correction has most impact on the far stack.

Conclusions

In this paper two different acquisition guided inversion-based algorithms were proposed to correct for amplitude and time shift acquisition footprints in time-lapse seismic data. Successful application of these methods was shown on two real data examples. It is also possible to extend the application of these techniques to water layer replacement for dynamic correction when there are water velocity variations.

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References


