4D-REPEATABILITY OF RESERVOIR ILLUMINATION: NEW QUALITY INDICATORS FOR MARINE ACQUISITION

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Summary

A target-oriented approach is developed to provide support for in-fill and re-shoot decisions during time-lapse (4D) marine seismic acquisitions. Repeatability quality of surveys positioning is determined from their respective illumination on selected reservoir horizons.

Quality control of seismic repeatability is carried out from processing standpoint, through the check of 4D differences in target illumination fold and shifts in reflection-points.

Corresponding support to re-shoot decisions is provided onboard from a dedicated indicator. It is defined as the similarity between time-lapse illumination of individual shots or navigation lines, evaluated from an adapted image registration metric. This indicator provides a user-friendly tool to qualify the acquisition, or identify and rank any re-shoot options.

Evaluation of 4D mismatches at target depth enables to derive re-shoot decisions driven from the repeatability of reservoir illumination. At the end of acquisition, monitor data are delivered that have been validated in terms of seismic illumination repeatability with respect to base data.

Introduction

Time-lapse or 4D seismic surveys are carried out to reveal production changes in the sub-surface reservoir. Ensuring optimal repeatability between the different vintage surveys provides a direct way to minimize 4D noise unrelated to reservoir changes.

Positioning repeatability is one of the main issues in 4D towed-streamers acquisition. It is primarily addressed with steering the vessel, source and streamers. 4D onboard quality control of positioning relies conventionally on maximal admissible mismatch. Mismatches on source and receiver positions must not exceed a contractual geometrical value, defined with respect to monitor pre-plot navigation lines and displayed in terms of spatial source mismatch DS and receiver mismatch DR. For seismic traces 4D positioning mismatches are therefore often evaluated in terms of spatial shifts of the associated surface midpoints.

However in laterally heterogeneous media or for dipping reflectors, midpoint does not stand anymore for reflection point. Whenever knowledge about the sub-surface velocity model is available, relevant mapping should therefore be carried out to determine where seismic reflections actually occur in depth. Several authors have suggested restoring sub-surface coverage maps for seismic coverage analysis [Winbow et al, 2004] [Pramik et al, 2005] [Monk, 2009], where hit-count of illumination is computed from ray theory on depth horizons.

In this paper, we address 4D repeatability during the acquisition with onboard monitoring of target illumination. The surface geometrical mismatch is converted into a subsurface target illumination mismatch, unraveling for distortions due both to the overburden lateral heterogeneity and reservoir horizon local dip. Then the illumination mismatches are appraised through various indicators.

A first class of indicators provides quality control of data for processing. Some authors [Lacombe et al, 2006] [Cantillo, 2012] have outlined the role of reflection point in seismic data repeatability. Here, differences in target illumination full-fold and shifts in reflection-point are examined for asymptotic hit-count or within Fresnel zone.

A second class of indicators is designed to provide support for re-shoot decisions during the acquisition. Correspondence between subsurface illumination mismatches on full fold map and associated shooting positions at the surface is no more obvious, impeding localization of corrective re-shoots. We build a complementary indicator to assess repeatability at finer discrimination scales, ranging from set of lines down to individual shots. Similarity between base and monitor individual shots (or shot-lines) is evaluated from comparison of associated illumination imprints on target. Similarity value is derived from Partitioned Intensity Uniformity metric, which is a matching measure used in medical image registration [Wood et al, 1993].

Such analysis is carried out onboard so that, at the end of acquisition, monitor data are delivered which have been validated in terms of seismic illumination repeatability with respect to base data.

Illumination imprints

The proposed indicators rely on the determination of sub-surface illumination, assuming a known velocity model. For a given target point, illumination is defined as the weighted occurrence of reflection impacts, that is basically, the number of source-receiver couples for which asymptotic reflection takes place at that point.

Given a source-receiver pair and a depth horizon $\mathcal{H}$, determination of reflection point $\mathbf{x}_r \in \mathcal{H}$ can be achieved under asymptotic ray theory using Fermat's principle and stationary phase analysis. Various methods can be used, such as iterative shooting or bending two-point ray tracing [Cerveny, 2001] or optimization from travel time maps provided by any modeler [Herrman and Bousquié, 2003].

Seismic sources carry band-limited frequency content and a single reflection point actually consists in a whole vicinity of reflection points which is the normal cross-section to $\mathcal{H}$ between incident and reflected ray beams. Therefore, each source-receiver pair is associated with a trace illumination spread which contour is delimited from Fresnel zone.

Shot imprint and shot-line imprint

A shot imprint is defined as the target illumination associated to a single acquisition shot. It is the summation of illumination spreads obtained from one source and all receivers from towed streamers. A shot-line imprint is defined as the summation of shots imprints from all shots (including starboard and portside) belonging to the same navigation line. Hence it represents the depth fold map associated to one navigation shot-line.

Quality control for processing

Indicators proposed for quality control are demonstrated on a 4D towed-streamer survey carried out in the Danish North Sea in 2012. The base survey was acquired in 2005 with 8 x 6km streamers (minimal seismic offset of 300m) versus the monitor survey acquired with 8 x 4km streamers (minimal offset of 100m). Illumination is computed on a constant time horizon corresponding to the average level of the reservoir.

Differences in full fold between base and monitor post-plots (Figure 1) are counted from hits on surface midpoints (top) versus hits on depth common reflection point (bottom). Maximal differences (in orange and blue) correspond to additional re-shoot line, borders and the platform vicinity where the two vintages do not overlap due to new surface obstructions, turn off distance and a different towing spread width. Both surface and depth illumination maps share the same global features due to small lateral variations in the overburden and a flat target horizon. However, differences can be noticed, showing that significant positioning mismatch on the surface does not necessarily induce significant illumination mismatch at depth, and vice-versa.

For each midpoint bin, the surface spatial shift $DS+DR$ is defined as the minimum value of all midpoints shifts from all traces within the offset class. For each common-reflection bin, the depth spatial shift $DCRP$ is defined as the minimum value of all reflection hit shifts from all traces within the offset class. Corresponding results are displayed in Figure 2 for 500-600m offset class. As previously, local disparities between $DS+DR$ and $DCRP$ maps (top and bottom left) show that significant positioning mismatch on the surface does not necessarily induce significant shift of reflection point at depth, and vice-versa.

From processing standpoint, the illumination of a depth point is satisfactorily repeated if shifted illumination point remains within the Fresnel zone of constructive reflection. For this particular example, our repeatability quality measure is evaluated for a 12.5m x 25m grid, as well as for a 25m x 50m grid. While there are some 4D differences observed in the denser grid (bottom left map), they disappear largely in the coarser one (bottom right map) which bin size is estimated to be within the Fresnel zone limits.

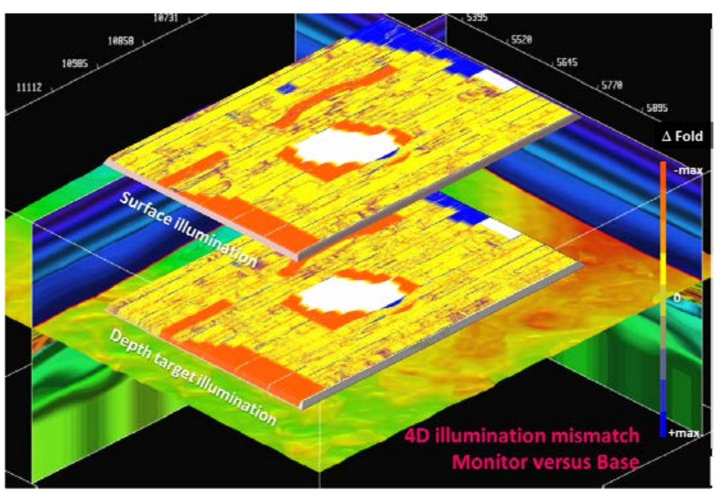

Figure 1. *4D differences in fold between base and monitor post-plots: Moving from common midpoint to common reflection point on target horizon*

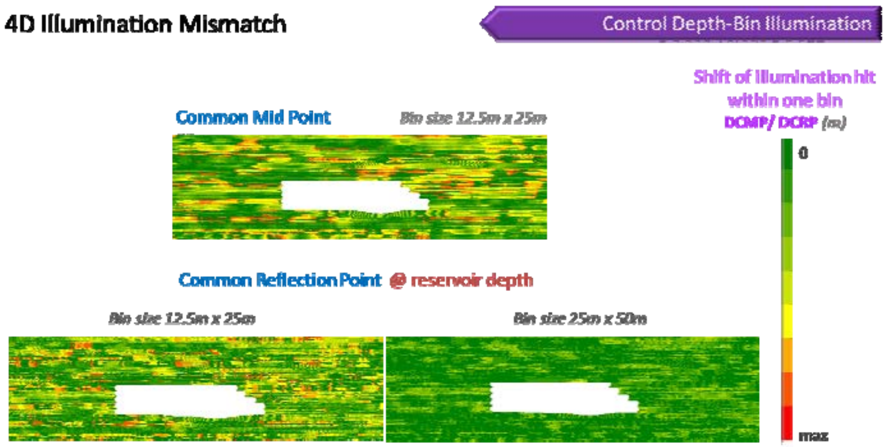

Figure 2. *Spatial shift in midpoint versus reflection point at reservoir depth between base and monitor*

Support to re-shoot decisions

Dedicated indicators are built to discriminate which shots lacked sufficient seismic repeatability (in reference to pre-plot or base survey) and which lines should consequently be re-acquired. We introduce a 4D repeatability indicator based on similarity between illumination imprints of current shot versus reference shot. This indicator assesses the seismic impact of both source and receivers spatial mismatches, possibly due to source deviation and streamers feathering from one vintage to another.

Shots imprints are processed as images (Figure 3), that means, pixels (reflection points) with different intensities (illumination amplitude). Current and reference shots imprints are compared with an adapted Partitioned Intensity Uniformity metric (PIU), originally introduced by [Wood et al, 1993] in medical image registration. The PIU metric is adapted to provide a scalar percentage measure of similarity between reference and monitor imprints. This similarity indicator rates the seismic repeatability of illumination from current shot versus reference shot with a simple percentage value (left). In the same manner, it can be used to evaluate similarity of illumination between navigation shot-lines from different vintages (right).

This provides a user-friendly tool to validate or discard each shot or navigation line, together with a ranking of re-shoots requirements.

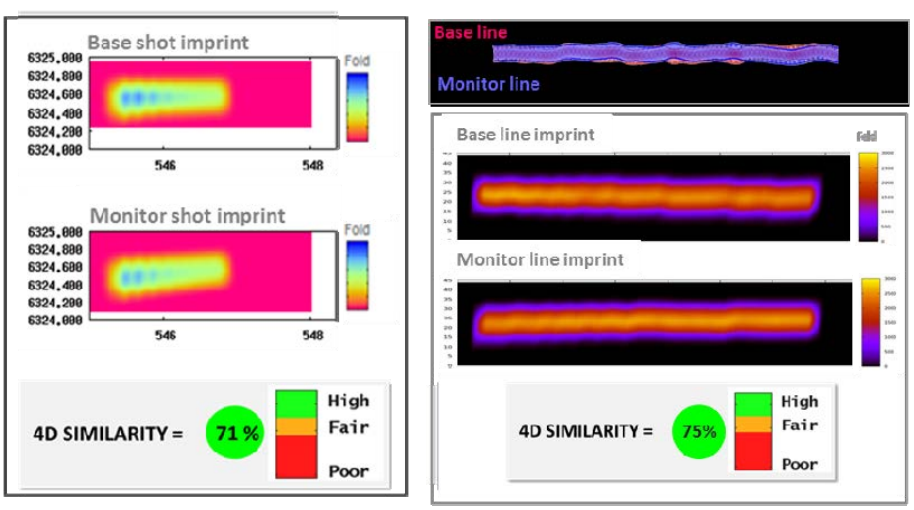

Figure 3. *Base versus monitor shots imprints (left) & lines imprints (right) with 4D similarity indicators*

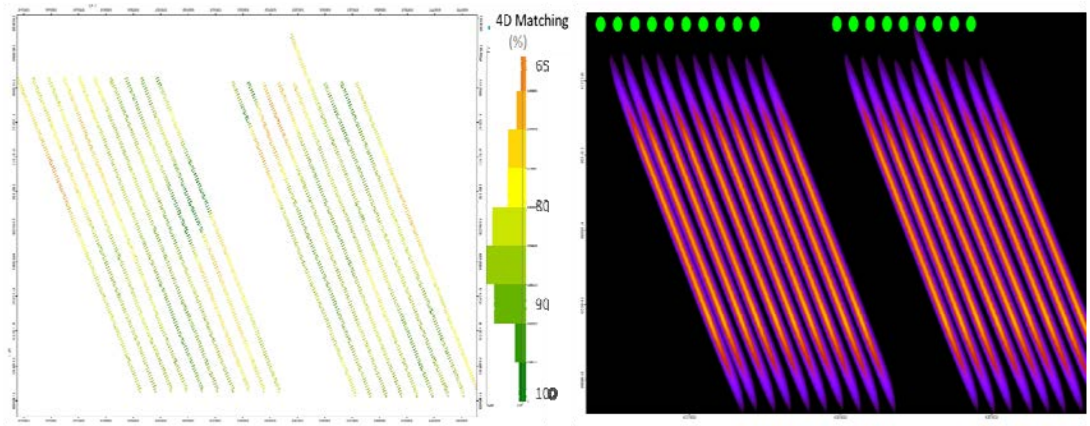

Figure 4. *Shot-by-shot 4D-similarity of illumination (left) displayed on survey map and shot-lines flagged with green-acceptable similarity (right)*

Conclusions

We propose to appraise the quality of positioning during 4D marine acquisitions from repeatability of illumination induced on reservoir horizon. The approach converts a surface geometrical mismatch into a subsurface target illumination mismatch, unraveling for overburden heterogeneity and reservoir horizon dip. Joint impact of source and receivers deviations from base positions can then be assessed simultaneously. Various geophysical repeatability indicators are designed to provide on-board quality control of data and real-time support to re-shoot decisions.

Spatial shifts of reflection points are determined between full base and monitor data within each target depth bin, to quality control that they do not exceed one processing bin size or at least corresponding Fresnel zone. Additive mismatches and constraints will be further investigated to ensure optimal 4D-repeatability from a processing standpoint.

Similarity between base and monitor illumination imprints is evaluated shot by shot (or navigation line by line) from an adapted image registration metric. This affords straightforward location of critical shots, providing a user-friendly tool to qualify the acquisition, or identify and rank preliminary re-shoots options.

Such onboard geophysical control enables us to deliver, at the end of acquisition, final monitor data which are validated in terms of seismic illumination repeatability with respect to base data.

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