A 4D-repeatability indicator based on similarity between shots illumination imprints

INTRODUCTION

Time-lapse 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 noises unrelated to reservoir changes.

Positioning repeatability is one of the main issues in 4D towed-streamers acquisition. Best matching of sources and receivers positions is sought between reference (pre-plot or base post-plot) and monitor survey. This is physically operated through vessel, source and receivers steering. Within the new acquisition features and current sea conditions, remaining positioning mismatches must be assessed to ensure the quality of acquisition.

Quality control of positioning relies conventionally on maximal admissible mis-positioning: mismatches on source and receiver positions between surveys must not exceed a contractual geometrical value. However for 4D surveys, we can take benefit from the knowledge of sub-surface velocity model (gained from processing of previous vintage surveys) to determine the actual impact of positioning mismatch on seismic features. Beyond surface geometrical criterion, we propose to evaluate positioning repeatability with a geophysical criterion based on repeatability of reservoir illumination. In this approach, 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.

Several authors have suggested calculation of subsurface illumination, for seismic coverage analysis (Winbow et al, 2004) (Pramik et al, 2005) (Monk, 2009). Reflection points are computed to build fold maps on depth-horizons for the full acquisition. Such maps can be used for quality control of acquisition, though may be insufficiently discriminant. Correspondence between sub-surface illumination mismatches and associated shooting positions at the surface is no more obvious, impeding easy localization for re-shoots.

In this paper, we propose to derive a complementary indicator to assess 4D 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) (Hill et al, 2001).

SUMMARY

A new 4D-repeatability indicator is proposed to appraise the quality of positioning during time-lapse marine surveys.

Repeatability of illumination between base and monitor surveys is assessed on selected reservoir horizons at fine discrimination scales, ranging from lines down to individual shots. Similarity between corresponding illumination imprints is evaluated from an adapted Partitioned Intensity Uniformity metric.

Such repeatability indicator can be used to assess jointly source and receivers positioning during 4D towed streamers surveys and under-shoots, or only source positioning over nodes surveys.

It provides a user-friendly tool to qualify the acquisition, or identify and rank preliminary re-shoots needs.

Key words: Marine acquisition, time-lapse, illumination, repeatability, positioning.

METHOD AND RESULTS

Shot and shot-line illumination imprints

Sub-surface targets are selected in the known velocity model (typically, top of reservoir horizon) where acquisition repeatability will be monitored and assessed. For each source-receiver couple, reflection point on the target is calculated through asymptotic ray theory. Reflection point can possibly be extended to a reflection spread taking count for the band-limited content of the source signal.

Within a defined acquisition subset and for a given target point, illumination is defined as the occurrence (hit-count) of reflection impacts, or the number of source-receiver couples for which reflection takes place at that point.

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.

**Similarity between time-lapse shots imprints**

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, that means, pixels (reflection points) with different intensities $I$ (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.

Reference imprint is partitioned into iso-intensity sets $b$, which are then mapped to the monitor imprint. The PIU metric is then defined as:

$$PIU = \sum_{b} \frac{n_b}{N} \mu_b$$

where $N$ is the total number of pixels in the imprints, $n_b$ is the number of base pixels within iso-intensity set $b$. Values $\mu_b$ and $\sigma_b$ are the mean and standard deviation measured on monitor imprint within each mapping $b'$ of set $b$:

$$\mu_b = \frac{1}{n_b} \sum_{x \in b} I(x)$$

$$\sigma_b^2 = \frac{1}{n_b} \sum_{x \in b} (I(x) - \mu_b)^2$$

**Applications**

First example is carried out on single shots from two vintage surveys, towing respectively 6 (base survey) and 10 (monitor survey) cables of 240 receivers. Illumination is computed on a plane subsurface horizon from a smooth velocity model. Shots imprints and 4D-similarity value are displayed on Figure 1.

![Figure 1. Shots illumination imprints (base versus monitor) and 4D similarity indicator](image)

Second example is carried out on shot-lines imprints from the two previous vintages surveys. Figure 2 shows the geometry of base and monitor navigation lines (zigzags due to alternate shooting of portside and starboard sources), corresponding target imprints and associated 4D-similarity value.

![Figure 2. Geometry of navigation lines (top), lines imprints (base versus monitor) and 4D similarity indicator](image)

**CONCLUSIONS**

We have introduced a new indicator to control the repeatability quality of 4D marine acquisition at fine discrimination scales, ranging from a set of shot-lines down to individual shots.

The indicator provides a geophysical assessment of positioning repeatability, determined from effective illumination induced on selected sub-surface target horizons. The approach converts a surface geometrical mismatch into a subsurface target illumination imprint mismatch, unraveling for overburden heterogeneity and reservoir horizon dip. Similarity is computed from an adaptation of Partitioned Intensity Uniformity metric. The combined impact of source and receiver deviations from base or reference positions can then be assessed simultaneously in the field.

The repeatability indicator provides a straightforward tool to validate shots/lines or identify necessary re-shoot areas during towed-streamer acquisitions. It can also be used to assess under-shoots or positioning in seafloor seismic surveys.

**REFERENCES**


