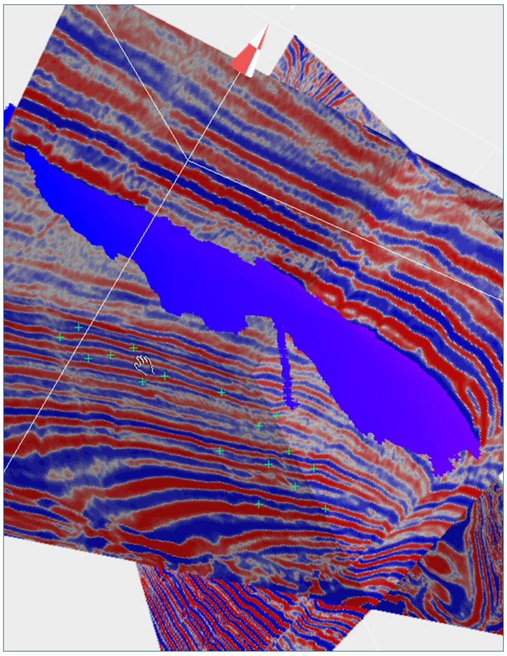
White Paper



Seismic Filtering

Geostatistical methods to filter out seismic noise and artifacts without modifying the signal

SEISMIC FILTERING

Geostatistical methods to filter out seismic noise and artifacts without modifying the signal.

Use your available data to inform your velocity model and support your drilling decisions.

The quality of seismic volumes is critical in building reliable reservoir models. Seismic data are often polluted by acquisition or processing artifacts which may have strong impact on subsequent seismic processing or interpretation. Geostatistics allows filtering efficiently seismic noise and artifacts without modifying the signal.

Geovariances provides solutions from seismic data quality control and filtering to reservoir characterization. This technology is based on geostatistics and all algorithms are available in Isatis, leader in geostatistical software solutions.

Filtering

Filtering is used in seismic data processing to enhance the signal quality by suppressing undesirable acquisition or processing noise or artifacts which can alter seismic data (i.e. seismic attributes such as velocities or amplitudes).

Geostatistics allows assessing the presence and magnitude of artifacts.

This filtering step in seismic processing can be critical in budget planning for project development as mediocre seismic data may alter the quality of subsequent processing or interpretation. Indeed, improving the data quality facilitates interpretation and the many processes that results and so save time. Also filtering improves greatly 4D studies interpretation, attribute cubes building or seismic surveys merging.

The use of geostatistical filtering methods, where seismic cube contains aliasing effect or production effect, is recommended as best practice for the industry.

Benefits

Filtering is frequently required in order to remove undesirable structures (acquisition footprint, patterns due to oriented processing windows, random noise) on various seismic attributes (e.g. velocities, amplitudes). In comparison with standard geophysical filters such as Wiener, Median or F-k, factorial kriging (Matheron, 1982) allows removing efficiently artifacts that are spatially correlated.

Independent quality control

Geostatistics provides consistent methods for modeling the reality and the uncertainty of its representation.

Controlling data quality is compulsory in order to identify artifacts or anomalies. Geostatistics is particularly well suited for this task, allowing an independent review of the data quality that can be achieved at any step in your process. Geostatistics enables quantifying the magnitude of artifacts and subsequently the quality of the processing. Geostatistical tools allow a control of spatial coherence. Therefore it helps characterizing the spatial distribution of events related to seismic velocities.

Setting statistical evidence of anomalies

Directional statistics allow highlighting zones with special characteristics or the presence of test lines. The principal benefit is to emphasize inconsistencies as seismic fold during acquisition (around the wells). Geological effects can also be highlighted like salt bodies, strong slopes and important thickness differences. Experimental variogram is an essential tool for the structural interpretation of the data. It gives quantitative and qualitative information on major spatial data structures.

Filtering based on the characterization of spatial continuity

Geostatistical filtering aims at removing noise and artifacts on seismic volumes by decomposing a signal into spatially independent structures (signal + artifact(s) + noise) and filtering out the undesirable one(s).

Geostatistics allows analyzing seismic data through a probabilistic approach based on a spatial variability analysis. Geostatistics characterizes the intrinsic structure of the parameter in order to:

- Take into account the continuity of your data,
- Introduce the geology by capturing the geological structures.

The approach allows the removal of acquisition footprints, patterns due to oriented picking, white or coherent noise on velocities or amplitudes.

Taking into account non stationarity

Geostatistical tools can also deal with non-stationary such as vertical trends. The seismic provides a shape function with stationary residuals on top of it. The calibration of velocity functions and models takes into account wells and seismic data as well as geological features and velocity trends.

Can be applied for 2D/3D scattered or gridded data

Filtering and quality control are possible on 2D/3D gridded data but also on scattered data such as seismic picks.

Integration of various data

Merging several data sets (different acquisition techniques or vintages) in a single coherent velocity cube is possible using multivariate kriging techniques.

4D identification

The identification and filtering of non-relevant structures are essential to the evaluation of the reservoir. Filtering highlights the effect of production. On operated fields with available 4D seismic, it is ideal to identify prospect location and potential. An automatic extraction of common/different components from 4D surveys is used in Isatis Multi Acquisition Automatic Factorial Kriging (MAAFK) workflow.

Methodology

Quality control of seismic data

This step is essential when dealing with seismic data. Data control analysis allows detecting potential artifacts, problems of support, acquisition and interpolation during different processing steps.

Statistical tools offer great visibility in data and help quantifying artifacts accurately in order to take over the process or apply other processing such as filtering.

Spatial data analysis allows investigate seismic data thoroughly and identify anomalous and erroneous values in any seismic scattered or gridded datasets (seismic picks, velocities, acoustic impedance, etc.). It helps to understand data and optimize their use.

The following steps can be carried out for a proper data investigation:

- Display of a data basemap, in order to validate the data location.
- Compute an histogram to check the homogeneity of the statistical distribution (Figure 1.b).
- Calculate the statistical characteristics: the mean (or average tendency) and the variance that measures the dispersion of the values around the mean.
- Investigate correlation between several variables through the display of the scatter diagram (Figure 1.a).

How do you validate the absence of noise/artifacts in your seismic volume?

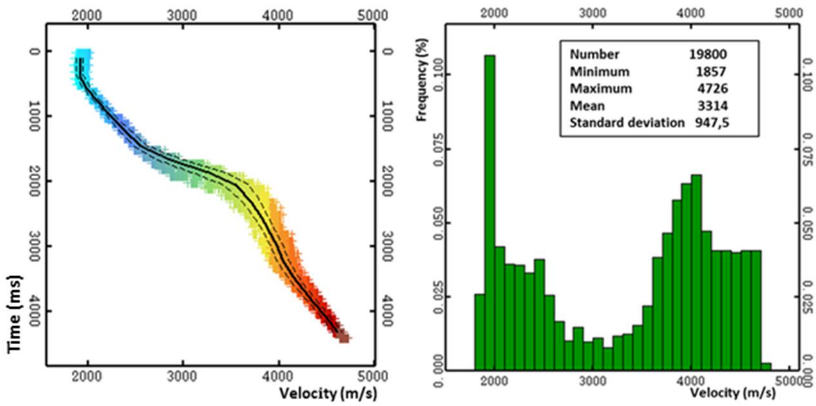


Figure 1: a) scatter diagram between time and velocity, b) histogram of raw velocity.

The benefit of statistics is to reinforce the geological interpretation but they have limitations (Figure 2), as several variables sharing the same statistical distribution may exhibit different spatial characteristics.

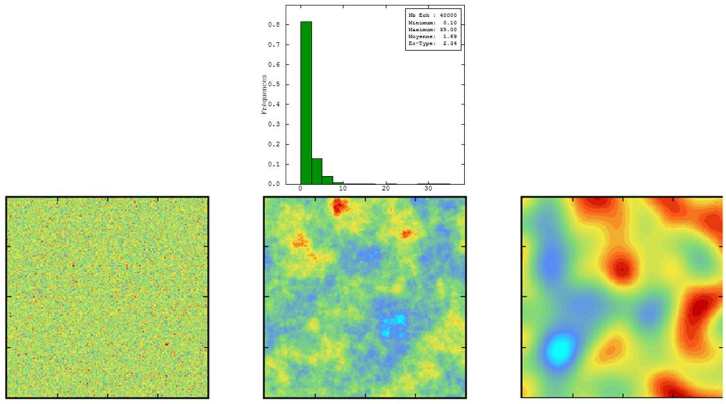


Figure 2: These three maps have the same statistical distribution but look very different.

Additional tools are therefore required to quantify this spatial variability:

- Trend estimation to know the spatial drift,
- Variogram analysis to interpret residual velocities.

During the variogram analysis, it is important to check the presence of potential anisotropies. Indeed, the target variable might present a more continuous behavior in a given direction, as for instance along a channel or more typically in IL/XL directions (Figure 3). Directional variograms are computed for this purpose. When data are densely sampled, one can compute a variogram map which plots experimental variograms in several categories of directions in the space. It is critical to analyze them and identify anisotropies or major directions of continuity.

In the case of seismic velocities, variogram analysis is typically performed on velocity residuals after the removal of a low frequency trend.

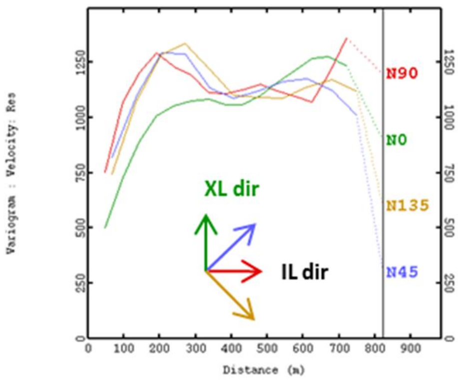


Figure 3: Example of a seismic variogram made of a nugget effect, a spherical model with anisotropic ranges and a spherical zonal component.

The experimental variogram (Figure 4) is modeled with mathematical functions defined by several parameters: range, sill, anisotropy. The anisotropy can be zonal (the sill varies with the direction), geometrical (the range varies with the direction) or a combination of both. Zonal anisotropy is most of the time the sign of acquisition footprints.

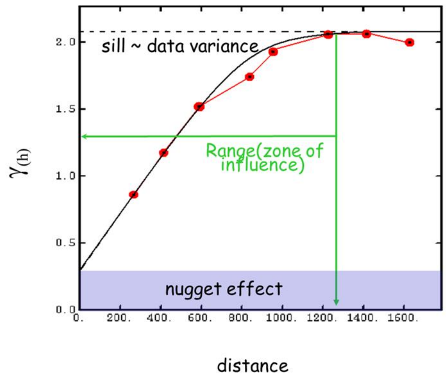


Figure 4: Example of a seismic variogram made of a nugget effect, a spherical model with anisotropic ranges and a spherical zonal component.

The spatial variability of the target parameter is characterized by the variogram model, sum of independent spatial components or structures.

Noise/artifacts removal

In seismic processing, a typical decomposition can be done between structure(s) corresponding to the signal and structure(s) corresponding to the noise. When dealing with nested variograms (i.e. variograms with several structures), each structure corresponds to a given scale of variability of the main variable. One interest is to map or remove the component corresponding to a given structure: this method is called factorial kriging (Matheron, 1982; Chilès and Delfiner, 2012).

The underlying assumption is that the variable of interest, Z(x), can be decomposed in several components:

$$Z(x) = Y_1(x) + \cdots + Y_n(x) + m(x),$$

where the $Y_i(x)$ $(i=1,\ldots,n)$ correspond to stationary and uncorrelated components of the phenomenon and m(x) represents the unknown mean (large scale trend). Once a variogram model is fitted, the efficiency of the filtering technique depends on the ability to interpret each variogram structure in terms of spatial component.

Gain time. Geostatistical filtering improving the data quality facilitates interpretation and the many processes that results.

The variogram of the variable Z(x) is decomposed in as many structures as Y_i components:

$$\gamma(h)=\gamma_1(h) + \gamma_2(h) + \cdots + \gamma_n(h).$$

Strictly speaking, factorial kriging consists in estimating, knowing the original data $Z(x_i)$ and the variogram model, one particular component $Y_i(x)$.

The general workflow applied on seismic data is described below (Figure 5). The velocity trend is obtained by a least square polynomial fit and residual velocities are the difference between raw velocity and this trend. Variogram analysis is performed on the residuals. In this case, three structures are identified and modeled, the ones corresponding to the nugget effect and the spherical with a large range vertically (corresponding to the artifact) signature are filtered out.

Success Stories

1. Experimental Hydrogeological Site (EHS) – University of Poitiers: an accurate delay map has been obtained from two sets of delay curves to map the top of a karstic reservoir and to point out corridor of fractures.
2. Geophysical Institute, University of Lausanne : Geostatistical filtering allowed detection of a furrow on a Bouguer anomaly dataset - Molasse basement at Aubonne (Switzerland).

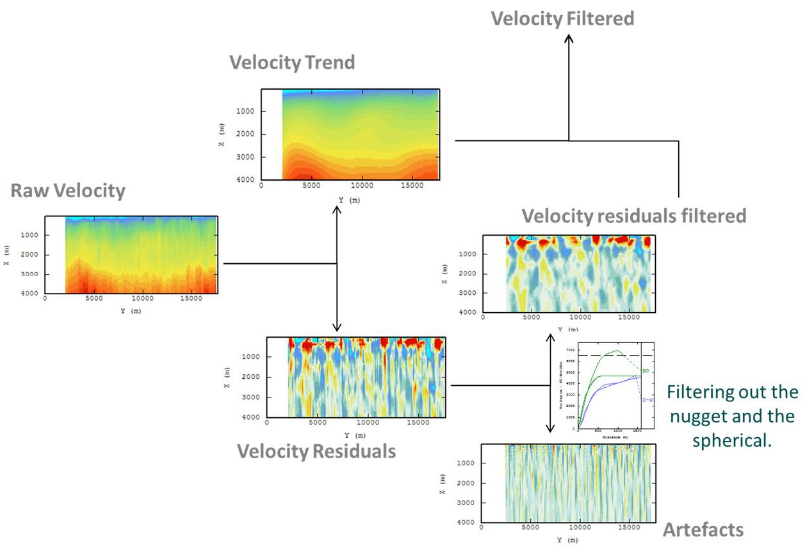


Figure 5: General workflow of velocity filtering.

One possible approach to QC the factorial kriging process is to compute the experimental variogram related to the filtered variable. The factorial kriging process is validated if structures related to the artifacts are no longer present on the experimental variogram.

Geostatistical filtering can be applied on two acquisitions of the same area. This process allows filtering the noise of two images and keeping the common part. This can be applied to 4D seismic analyses for common velocity cube estimation, repeatability measurement, 4D signature enhancement (Hoeber & Coléou, 2003). For some analyses, as 4D seismic enhancement, it is useful to combine several geostatistical filters. The underlying methodology and an example are presented below.

Factorial co-kriging extends the univariate approach to several variables or datasets. In the particular case of two seismic volumes, factorial co-kriging is designed to extract the common part between two datasets and the spatially independent residuals:

$Z_1(x) = S(x) + R_1(x)$ and

$Z_2(x) = S(x) + R_2(x)$

where $S(x)$ is the common part and $R_1(x)$ and $R_2(x)$ the spatially independent residuals.

Simple and cross variograms are then needed for the co-kriging. In practice, for efficiency, variogram maps are computed instead of experimental variograms.

Depending on the task requirement, the information to process is contained either in the common part as for common velocity cube estimation or in the residual part as for 4D signature enhancement.

The example below is a synthetic 4D dataset created from the Netherlands, Offshore North Sea, F3 Block. Acquisition imprints have been first removed from the initial survey, named vintage 1 hereafter. A fluid effect and a new acquisition imprint have been added to obtain the second seismic vintage.

Figure 6 shows vintage 1 and vintage 2 common part which corresponds to the geology, and each residual containing a fluid signature and acquisition imprints.

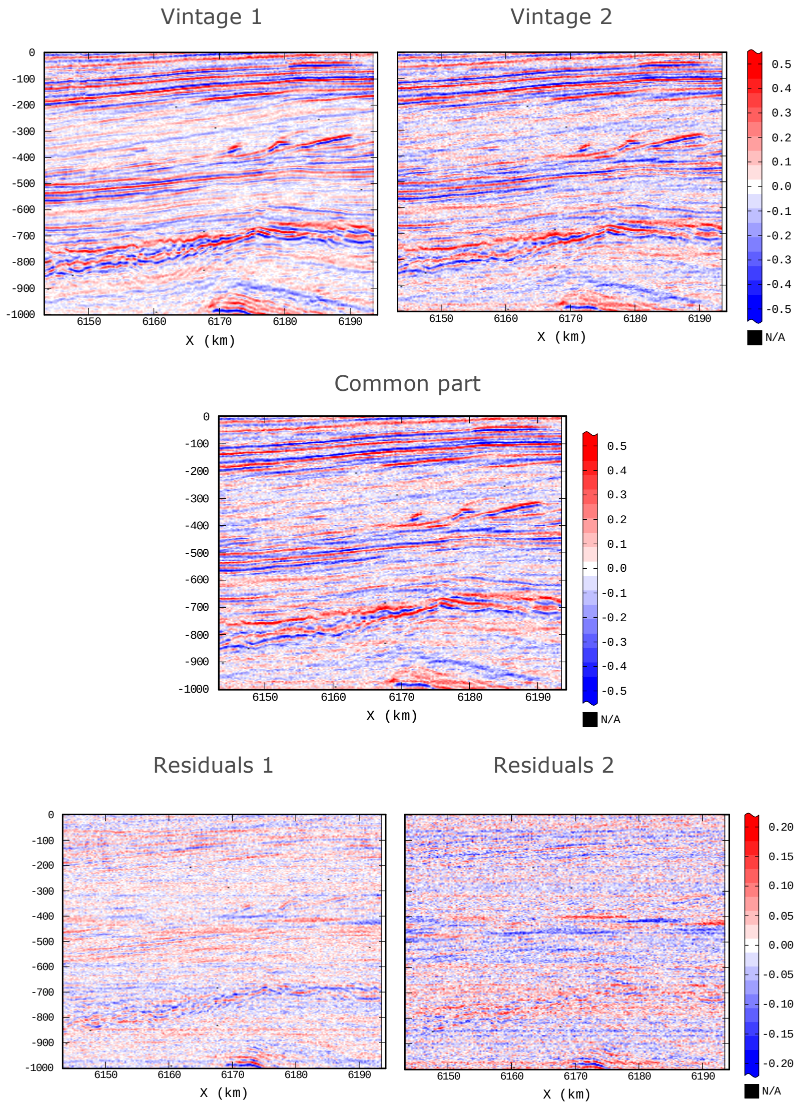


Figure 6: Cross-section of original input cubes (vintages). Common part between the two inputs, residuals between the common part and vintage 1 and vintage 2. Note that the residuals still contain noise and acquisition artifacts at this stage.

Figure 7 shows the benefit of applying a later geostatistical filter by factorial kriging to the original residuals in order to remove the acquisition imprints.

References:

- Deraisme J. and Bourges M., Geostatistical filtering of refraction data: methods and comparison of acquisition systems, EAGE 2010
- Mari J.L. and Jeannée N., Applying geostatistical filtering techniques to nearsurface geophysics: two examples for refraction surveying and gravimetry, EAGE 2008

Geovariances

Where no one has gone before

Who is Geovariances?

Geovariances is a specialist geostatistical software , consulting and training company. We have over 45 staff, including specialist oil consultants and statisticians.

Our software, Isatis, is the accomplishment of 25 years of dedicated experience in geostatistics. It is the global software solution for all geostatistical questions.

Other technical specialties

Geovariances are world leaders in developing and applying new and practical geostatistical solutions to oil operations. We have strong experience in applying geostatistics from seismic data QC to reservoir characterization and have gained trust from the biggest international companies.

Our expertise is in applying geostatistics to reservoir modeling. Our services are through consulting, training, and software.

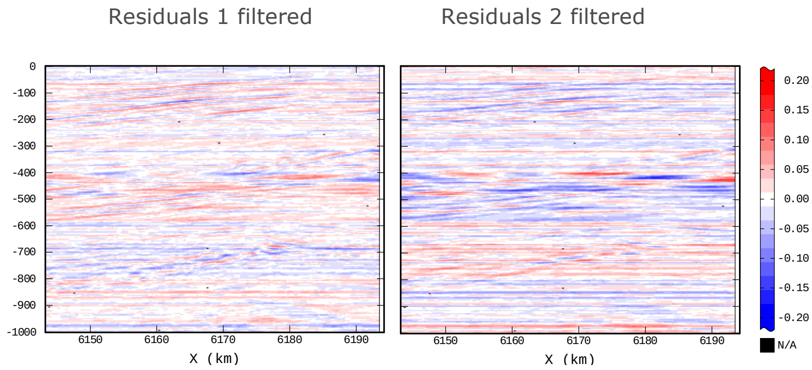


Figure 7: Cross-section of residuals after removal of the noise and artifact by factorial kriging. Results should be compared.

Our expertise

Isatis, the leading-edge geostatistical software solution by Geovariances, offers an original and efficient workflow called MAAFK (Multi-Acquisition Automatic Factorial Kriging) which implement the multivariate approach of factorial kriging.

MAAFK achieves automatic factorial kriging and applies the approach developed by Desassis and Renard (2013) to automatically fit variogram models.

Isatis also provides filtering model component feature in its standard kriging process.

Geovariances has more than 15 years' experience in geostatistical filtering projects. Numerous studies have been carried out for major Oil & Gas companies. We can provide a unique expertise through both our French and Australian offices.

For more information

Let us help you assess the quality of your seismic data and filter unexpected artifacts.

Contact our consultants at consult-oil@geovariances.com.

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