# Geostatistical filtering of 4D seismic data: methods and benefits

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## Abstract

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). Multivariate methods allow the identification of common spatial behavior between different seismic volumes, as time-lapse seismic. This paper shows the methodology and benefits of using geostatistical filtering on 4D vintages.

## Introduction

During seismic processing, 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.

Factorial co-kriging extends this approach to the case of multiple seismic volumes allowing for instance to retain the common part and to filter out the volume dependent residuals. 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 two examples are presented in this paper.

## Methodology

Factorial kriging is a variogram-based filtering technique relying on a simple additive model where the spatial variable under study is modeled a random function, Z(x), which is decomposed into spatially independent factors (Matheron, 1982):

$$Z(x) = S_1(x) + S_2(x) + \ldots$$

When the noise part of a data set is considered independent of the complementary signal part, factorial kriging, by estimating $S_{SIGNAL}(x)$, allows filtering out the noisy component of a data set:

$$Z(x) = S_{SIGNAL}(x) + S_{NOISE}(x)$$

Factorial co-kriging extends this approach to several variables or sets of data. 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.

In variogram terms:

$\gamma_1(h) = \gamma_s(h) + \gamma_{r1}(h)$

$\gamma_2(h) = \gamma_s(h) + \gamma_{r2}(h)$ and

$\gamma_{12}(h) = \gamma_s(h)$

In these equations $\gamma_1(h)$ and $\gamma_2(h)$ are the simple variograms and $\gamma_{12}(h)$ the cross-variogram between variable 1 and 2 which coincides with $\gamma_s(h)$.

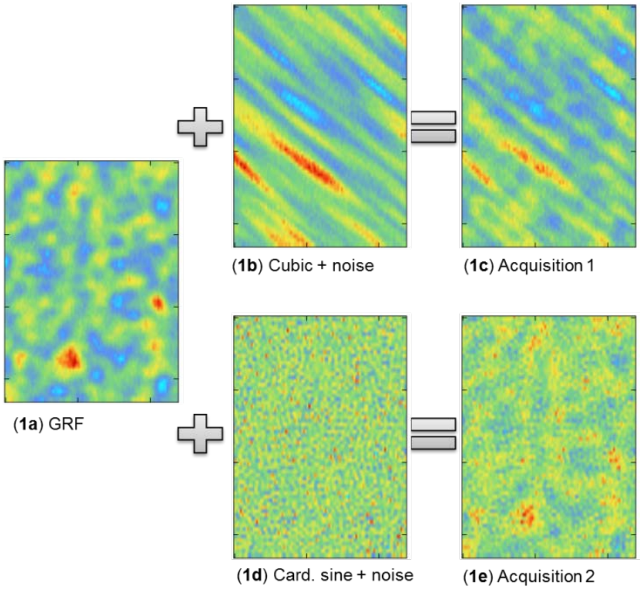
Coléou (2002) introduced an automatic factorial co-kriging technique (AFACK), by computing simple experimental variograms $\gamma_1(h)$ and $\gamma_2(h)$ and the cross-variogram $\gamma_{12}(h)$. It is then possible to retrieve the residual structures $\gamma_{r1}(h)$ and $\gamma_{r2}(h)$ by simple subtraction. In practice, for efficiency, variogram maps are computed instead of experimental variograms. For regularly sampled data such as seismic attributes, variogram maps can be computed using fast Fourier transform method (Marcotte, 1996). Finally, factorial co-kriging is done using these experimental variograms to decompose the input volumes into a common part and residuals.

A slightly different approach is implemented here, as variogram models are automatically fitted on variogram maps using the approach developed by Desassis and Renard (2013). The automatic variogram modeling is performed through iterative least squares fitting which minimize the error between an experimental variogram (or variogram map) and the model defined in term of parametric equations. Variograms can be estimated globally or locally using local variogram parameters to account for non-stationary components such as vertically-varying noise (Magneron et al., 2009). The resulting approach, called MAAFK (Multi-Acquisition Automatic Factorial Kriging) is developed in the latest ISATIS 2013 version (Geovariances, 2013).

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. In this latter case the common part can be considered as being the geology and the residuals as containing the 4D signature (Lecerf and Coléou, 2002). The residuals might also contain vintage specific noise and acquisition imprints. These need to be filtered further using factorial kriging, but great care needs to be taken not to estimate these structures in areas affected by production. This workflow is illustrated in the section below.

### Example 1: 2D case

The first example is a 2D synthetic dataset where the acquisition variables are simulated as spatially independent Gaussian Random Function (GRF). The first acquisition variable (Figure 1c) is created by adding a GRF with an anisotropic cubic structure and a nugget (Figure 1b) to the reference GRF with a Gaussian variogram (Figure 1a) and the second acquisition variable (Figure 1e) by adding a GRF with an isotropic cardinal sine structure and a nugget effect (Figure 1d) to the same reference GRF. Therefore each acquisition variable is composed of a common part (Figure 1a), an artifact (cardinal sine or cubic) and a noise modeled as pure nugget. As expected MAAFK retrieves the structures of the different components and uses the two acquisition variables to derive the common part (Figure 2a), and the two residuals (Figures 2b and 2c) proving that MAAFK can be used to filter out volume specific noise and imprints.


**(1b)** Cubic + noise

**(1c)** Acquisition 1

**(1a)** GRF

**(1d)** Card. sine + noise

**(1e)** Acquisition 2

Figure 1: Acquisition 1 (1c) is created by adding an artifact (anisotropic cubic) and a noise (nugget effect) (1b) to a reference GRF (1a) and acquisition 2 (1e) by adding an artifact (isotropic cardinal sine) and a noise (nugget effect) (1d) to the same reference GRF (1a).

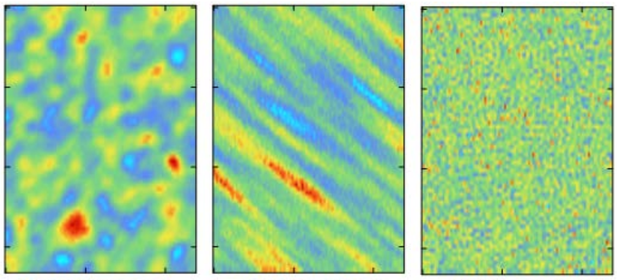

**(2a)** Common Part **(2b)** Residuals 1 **(2c)** Residuals 2

Figure 2: Common Part (2a), residuals 1 (2b) and 2 (2c) output from the MAAFK approach.

### Example 2: 3D case

The second example 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 3 shows the output of the MAAFK process applied to vintage 1 (3a) and vintage 2 (3b). The common part (3c) corresponds to the geology and each residual (3d and 3e) contains a fluid signature and acquisition imprints.

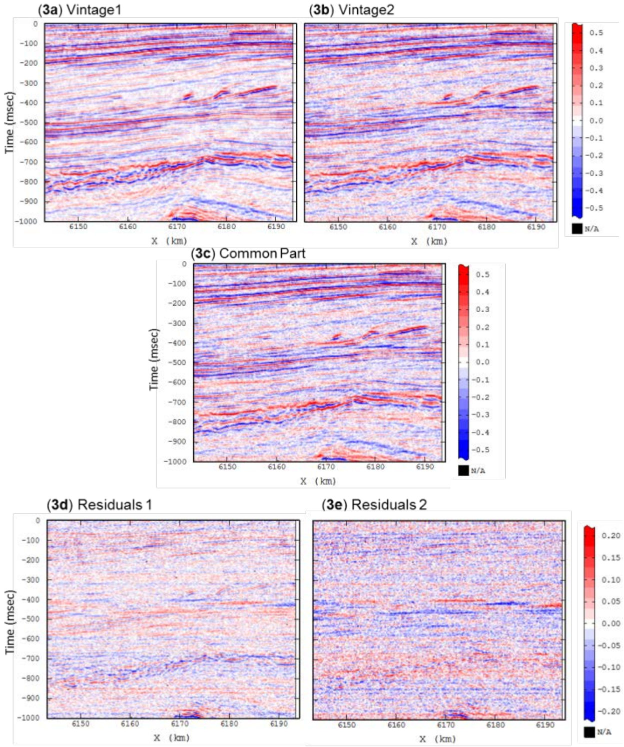


Figure 3: Cross-section of original input cubes (3a) and (3b). MAAFK output common part between the two inputs (3b), residuals between the common part and vintage 1 (3d) and vintage 2 (3e). Note that the residuals still contain noise and acquisition artifacts at this stage.

Figure 4 shows the benefit of applying geostatistical filter by factorial kriging (4a and 4b) to the original MAAFK residuals (3d and 3e) to remove the acquisition imprints

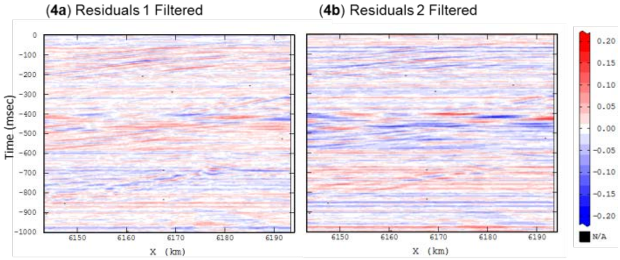


Figure 4: Cross-section of MAAFK residuals after removal of the noise and artifact by factorial kriging (4a) and (4b). Results should be compared with (3d) and (3e) respectively.

The 4D signature is obtained by subtraction of the residuals. Figure 5 shows the MAAFK residuals and 4D signature (5e) on a time horizon (X0Y section). Applying an extra geostatistical filtering step to the residuals, hence removing vintage acquisition imprints, enhances the 4D signature.

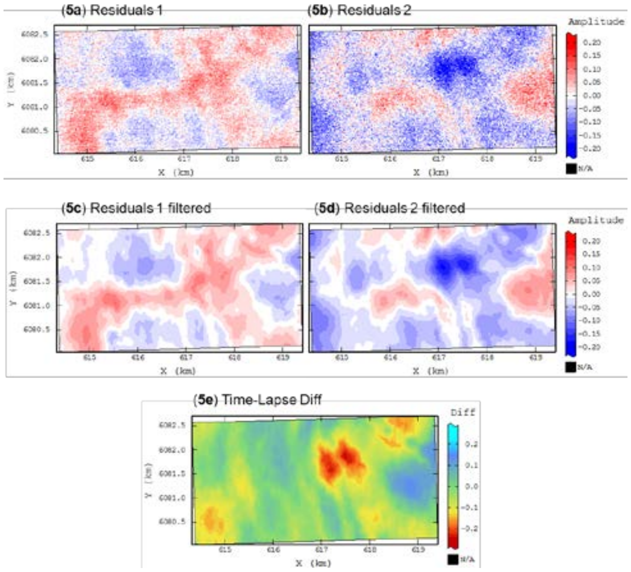


Figure 5: Attribute map of MAAFK residuals 1 and 2 before (5a, 5b) and after (5c, 5d) filtering showing that geostatistical filtering of the residuals can remove vintage specifics noise and artifacts. The 4D signature of the signal (5e) is the difference between the filtered residuals (5d-5c). The signature is enhanced after geostatistical filtering.

## Conclusions

The paper illustrated the benefit of applying geostatistical filtering approaches to 4D seismic analysis, in particular the MAAFK approach (Multi-Acquisition Automatic Factorial Kriging). Combining conventional geostatistical filters with MAAFK can extract the common part between seismic vintages, filter out vintage specific acquisition imprints, and enhance the 4D signature between vintages.

All these applications are based on the ability of geostatistics to analyze variables showing spatial continuity such as geological bodies, elastic property changes to fluid migration or acquisition imprints. In the case of seismic volume QC and filtering, artifacts or noise that are spatially independent from the signal can be discarded. Also geostatistical techniques can be applied in time or in depths, and therefore could be used after depth conversion of the seismic vintages.

## References

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