Geophysical Research Abstracts
Vol. 19, EGU2017-14170, 2017
EGU General Assembly 2017

Efficient linear inversion of poststack seismic data with 3-D uncertainties

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Large amounts of reflection seismic data are routinely collected to investigate the subsurface. This demands for fast and reliable algorithms to invert the seismic data for desired properties, such as acoustic impedance or other physical properties. The algorithm for inversion, in case of linear forward model and Gaussian uncertainties, based on the so-called least squares criterion, is well known. However, when the amount of data to be inverted is large, the size of the matrices involved grows so much that it may become impossible even to store them on disk and so calculations become impractical. Usually, to circumvent this problem, some assumptions are made, such as that of uncorrelated uncertainties both on data and model parameters, which lead to diagonal covariance matrices, and that of spatial invariance of the system, and thus the convolution approach. These simplifications alleviate the computational burden and decrease tremendously the size of arrays to be stored in memory/disk. Nevertheless, lateral and vertical correlated uncertainties both on data and model parameters are disregarded with this strategy, as well as potential spatial variance of the forward operator, often resulting in "noisy" images of the subsurface because each seismic trace is treated independently.

In this study, we propose a methodology which, based on the assumption of separability and taking advantage of some properties of Kronecker products, it formulates the linear inverse problem with taking into account 3-D uncertainties through an algorithm which requires a very low memory/storage capability and is computationally very efficient compared to the classical approach. The result is a complete characterization of the so-called posterior distribution in terms of mean model and covariance. With this strategy, we can take into account the 3-D, vertical and horizontal correlation of uncertainties both on the model parameters and on the observed data, improving the final result of inversion. Large data sets can thus be inverted all together, with all seismic traces contributing simultaneously to the final result. This algorithm is also easily parallelizable.

We show an application of the methodology to a 3-D seismic reflection data set. Nevertheless, this algorithm is general and can thus be applied to any linear (or linearizable) inverse problem fulfilling the initial assumptions.