Joint Bayesian spatial inversion of lithology/fluid classes, petrophysical properties and elastic attributes – A Norwegian Sea gas discovery

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A Bayesian model for prediction and uncertainty quantification of subsurface lithology/fluid classes, petrophysical properties and elastic material properties conditional on seismic amplitude-versus-offset measurements is defined. We demonstrate the proposed methodology on a real Norwegian Sea gas discovery in 3D in a seismic inversion framework.

The likelihood model is assumed to be Gaussian, and it is constructed in two steps. First, the reflectivity coefficients of the elastic material properties are computed based on the linear Aki Richards approximation valid for weak contrasts. The reflectivity coefficients are then convolved in depth with a wavelet. We assume a Markov random field prior model for the lithology/fluid classes with a first order neighborhood system to ensure spatial coupling. Conditional on the lithology/fluid classes we define a Gauss-linear petrophysical and rock physics model. The marginal prior spatial model for the petrophysical properties and elastic attributes is then a multivariate Gaussian mixture random field.

The convolution kernel in the likelihood model restricts analytic assessment of the posterior model since the neighborhood system of the lithology/fluid classes is no longer a simple first order neighborhood. We propose a recursive algorithm that translates the Gibbs formulation into a set of vertical Markov chains. The vertical posterior model is approximated by a higher order Markov chain, which is computationally tractable. Finally, the approximate posterior model is used as a proposal model in a Markov chain Monte Carlo algorithm. It can be verified that the Gaussian mixture model is a conjugate prior with respect to the Gauss-linear likelihood model; thus, the posterior density for petrophysical properties and elastic attributes is also a Gaussian mixture random field.

We compare the proposed spatially coupled 3D model to a set of independent vertical 1D inversions. We obtain an increase of the average acceptance rate of 13.6 percentage points in the Markov chain Monte Carlo algorithm compared to a simpler model without lateral spatial coupling. At a blind well location we obtain a reduction of at most 60 % in mean absolute error and root mean square error for the proposed spatially coupled 3D model.