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Inversion for the lateral correlation structure of subsurface velocity heterogeneity from wave-based reflection images

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Estimation of the lateral correlation structure of subsurface velocity heterogeneity from backscattered reflection survey data is a topic of considerable interest in both seismic and ground-penetrating radar (GPR) research. In crustal seismic studies, such information may yield important information regarding the stochastic nature of the crystalline crust, which could then be employed to unravel the tectonic history and/or petrological nature of the probed regions. In exploration seismology, on the other hand, such information could provide critical constraints for the lateral geostatistical characterization of petroleum reservoirs between sparsely space wells. To date, such constraints are either unavailable or based on educated guess work and the resulting geostatistical models are correspondingly uncertain and error-prone. Finally, in GPR research, the velocity of electromagnetic (EM) waves in the subsurface depends largely on soil water content, which is related to key hydrological parameters both above and below the water table. Consequently, information regarding the correlation structure of EM-wave velocity in this case may be useful for constraining stochastic models of groundwater flow and contaminant transport.

Although research to date has identified the effects of a number of different phenomena (e.g., bandwidth, vertical differentiation of velocity to obtain reflection coefficients) on the correlation structure of a wave-based reflection image, and comparisons between the correlation structures of velocity and the corresponding reflection data

have shown that these two quantities are strongly related, an effective approach for estimating the correlation structure of subsurface velocity given a reflection image has not yet been presented. In this work, we attempt to address this issue by posing the estimation as an inverse problem. Using a simple convolution model for a wave-based reflection image, we first derive a forward operator relating the statistical structure of the image to that of the underlying velocity distribution. We then use this operator to invert for the spatial statistics of the velocity distribution, given the spatial statistics of the reflection image. This is done within a Bayesian Markov-chain-Monte-Carlo (McMC) framework, such that realistic statistical bounds can be placed on the information that is inferred. Results of applying our estimation technique to synthetic models are very positive and give us hope that, in many situations, reflection profile data can be used to constrain our knowledge of the stochastic nature of subsurface velocity heterogeneity.