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Markov random field modeling for fluid distributions in the mantle wedge beneath the Japan Island

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Recent advances in methodologies of geophysical observations, such as seismic tomography, seismic reflection method and geomagnetic method, provide us a large amount and a wide variety of data sets for physical rock properties in a crust and upper mantle (e.g. Matsubara et al. (2008)). However, it has still been difficult to interpret these data geologically (i.e. specify a rock type and its physical conditions), mainly because (1) available data usually have large noise and uncertainty, and (2) physical properties of rocks depend on several factors, such as temperature, pressure and the shape and the volume fraction of the fluid-filled pores. Therefore, the statistical analyses of geophysical data sets are essential for the objective and quantitative geological interpretation.
We propose the use of Markov random field (MRF) model to geophysical data as an alternative to classical deterministic approaches. The MRF model is a statistical model using a generalized form of Markov Chains, and is often applied to the analysis of images, particularly in the detection of visual patterns or textures. The MRF model assumes that the spatial gradients of physical properties are relatively small compared to the measurement noise and analytical uncertainty. It acts practically as a low-pass filter to extract the accurate spatial variations of physical properties. By Bayesian approach, this model can determine the appropriate bandwidth from the statistical property of the observed data. Additionally, it has the potential advantage of incorporation of prior geophysical and geological information through the evaluation function.
In this study, the MRF model is applied to the P- and S- wave velocity (Vp and Vs) structures beneath the Japan Island to image the fluid distributions in the mantle wedge. Recently, Takei (20 02) proposed the unified formulation of Vp and Vs as a function of the effective aspect ratio and the volume fraction (porosity) of the fluid-filled pores. Moreover, Nakajima et al. (2005) clarified that the thermal heterogeneity alone cannot account for the observed low-velocity anomalies in the mantle wedge beneath the NE Japan, and they evaluated roughly the effective aspect ratio and the porosity by using the formulation by Takei (2002). Because of the highly noised data, however, the quantitative and detailed spatial mapping of the fluid distributions has not yet been made. Here, we develop a Gaussian MRF model to formulate the evaluation function based on Takei (20 02). At first, the effective aspect ratio is assumed to be constant for sake of simplicity. Application to synthesized data shows that the spatial distributions of porosity can be reliably estimated, which suggests the effectiveness of the MRF model. In the presentation, we will introduce the application to the observed data sets and discuss the fluid distributions and their dynamics in the mantle wedge.

Keywords: Bayesian statistics, seismic tomography, fluid, mantle wedge