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Identification and Simulation of Subsurface Soil patterns using hidden Markov random fields and remote sensing and geophysical EMI data sets

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Lateral and vertical spatial heterogeneity of subsurface properties such as soil texture and structure influences the available water and resource supply for crop growth. High-resolution mapping of subsurface structures using non-invasive geo-referenced geophysical measurements, like electromagnetic induction (EMI), enables a characterization of 3D soil structures, which have shown correlations to remote sensing information of the crop states. The benefit of EMI is that it can return 3D subsurface information, however the spatial dimensions are limited due to the labor intensive measurement procedure. Although active and passive sensors mounted on air- or space-borne platforms return 2D images, they have much larger spatial dimensions. Combining both approaches provides us with a potential pathway to extend the detailed 3D geophysical information to a larger area by using remote sensing information.

In this study, we aim at extracting and providing insights into the spatial and statistical correlation of the geophysical and remote sensing observations of the soil/vegetation continuum system. To this end, two key points need to be addressed: 1) how to detect and recognize the geometric patterns (i.e. spatial heterogeneity) from multiple data sets, and 2) how to quantitatively describe the statistical correlation between remote sensing information and geophysical measurements. In the current study, the spatial domain is restricted to shallow depths up to $\sim$3 meters, and the geostatistical database contains normalized difference vegetation index (NDVI) derived from RapidEye satellite images and apparent electrical conductivities (ECa) measured from multi-receiver EMI sensors for nine depths of exploration ranging from 0-2.7 m. The integrated data sets are mapped into both the physical space (i.e. the spatial domain) and feature space (i.e. a two-dimensional space framed by the NDVI and the ECa data). Hidden Markov Random Fields (HMRF) are employed to model the underlying heterogeneities in spatial domain and finite Gaussian mixture models are adopted to quantitatively describe the statistical patterns in terms of center vectors and covariance matrices in feature space. A recently developed parallel stochastic clustering algorithm is adopted to implement the HMRF models and the Markov chain Monte Carlo based Bayesian inference. Certain spatial patterns such as buried paleo-river channels covered by shallow sediments are investigated as typical examples. The results indicate that the geometric patterns of the subsurface heterogeneity can be represented and quantitatively characterized by HMRF. Furthermore, the statistical patterns of the NDVI and the EMI data from the soil/vegetation-continuum system can be inferred and analyzed in a quantitative manner.