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Feature scale and identifiability: quantifying the information that point hydraulic measurements provide about heterogeneous head and conductivity fields

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We consider the optimal inference of spatially heterogeneous hydraulic conductivity and head fields based on three kinds of point measurements that may be available at monitoring wells: of head, permeability, and groundwater speed. We have developed a general, zonation-free technique for Monte Carlo (MC) study of field recovery problems, based on Karhunen-Loève (K-L) expansions of the unknown fields, whose coefficients are recovered by an analytical adjoint-state technique. This allows unbiased sampling from the space of all possible fields with a given correlation structure and efficient, automated gradient-descent calibration. The K-L basis functions have a straightforward notion of period, revealing the relationship between feature scale and reconstruction fidelity, and they have an *a priori* known spectrum, allowing for a non-subjective regularization term to be defined. We have performed automated MC calibration on over 1100 conductivity-head field pairs, employing a variety of point measurement geometries and quantified the mean-squared field reconstruction accuracy, both globally and as a function of feature scale.

We present heuristics for feature scale identification, examine global reconstruction error, and explore the value added by both groundwater speed measurements and by two different types of regularization. We show that significant feature identification becomes possible as feature scale exceeds four times measurement spacing and identification reliability subsequently improves in a power law fashion with increasing feature scale.