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Computational efficient inverse groundwater modeling using Random Mixing and Whittaker-Shannon interpolation with application for the Lockyer Valley in Queensland (Australia)

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Geostatistical inverse modeling problems are often formulated as optimization problems. These can potentially be very high-dimensional and computationally expensive as large numbers of forward model runs might be required. Especially for complex problems, the number of required model runs is crucial thus reducing this number is desirable.
Random Mixing is a promising new geostatistical simulation technique that is applicable to inverse modeling. The method is an extension of the gradual deformation approach. It works by finding a field which preserves the covariance structure, the marginal distribution and honors observed hydraulic conductivities. This field is perturbed by mixing it with new fields that fulfill the homogeneous conditions. This mixing is expressed as an optimization problem which aims to minimize the difference between the observed and simulated hydraulic heads and/or concentration values. To preserve the spatial structure, the mixing weights must lie on the unit hyper-sphere. We present a modification to the Random Mixing algorithm which significantly reduces the number of required forward model runs by employing simple Whittaker-Shannon interpolations for all conditioning observations. The approach involves taking n equally spaced points on the unit circle as weights for mixing conditional random fields. Each of these mixtures provides a solution to the forward model at the conditioning locations. For each of the locations the solutions are then interpolated around the circle using Whittaker-Shannon interpolation to provide approximate solutions for additional mixing weights at very low computational cost. The interpolated solutions are used to search for a mixture which maximally reduces the objective function. This is in contrast to other approaches which evaluate the objective function for the n mixtures and then interpolate the obtained values. Keeping the mixture on the unit circle makes it easy to generate equidistant sampling points in the space; however, this means that only two fields are mixed at a time. Once the optimal mixture for two fields has been found, they are combined to form the input to the next iteration of the algorithm. This process is repeated until a threshold in the objective function is met or insufficient changes are produced in successive iterations. The procedure will be demonstrated using a model calibration case study for the Lockyer Valley alluvial aquifer system in Queensland, Australia. The Lockyer Valley is a sub-catchment of the Brisbane River and covers an area of around 2900 km2. It is a major vegetable and grain producing area supported by groundwater irrigation from the alluvial aquifer. In this case study, the groundwater model has to be calibrated to over 60000 hydraulic head measurements that have been recorded over a 20-year period.