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Hydrology and Earth System Sciences Discussions

Interactive comment on "Groundwater flow inverse modeling in non-MultiGaussian media: performance assessment of the normal-score Ensemble Kalman Filter" *by* L. Li et al.

Anonymous Referee #2

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Title: Groundwater Flow Inverse Modeling in non-MultiGaussian Media: Performance Assessment of the Normal-Score Ensemble Kalman Filter MS No.: hess-2011-182

General Comments

In this paper, the authors evaluate the performance of the ensemble Kalman filter with a normal-score transformation of variables on a data assimilation problem for which the distribution of model parameters to be estimated is bimodal. The normal score transformation transforms the variables such that the resulting variables are marginally gaussian and thus are more amenable to updating using the EnKF.

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Interactive Discussion
Discussion Paper

The current paper can be considered as a follow-up to the previous paper by the same authors (An approach to handling non-Gaussianity of parameters and state variables in ensemble Kalman filtering, Advances in Water Resources, 34(7) 844-864, 2011, Zhou, Gmez-Hernndez, Hendricks Franssen and Li). The primary difference in the methodology of this paper from the previous paper is the addition of a distance-based taper function for localization. The authors examine a number of cases that are of interest, including several in whch the initial ensemble is generated from a different stochastic model than the one used to generate the true conductivity field. They also investigate the effect of localization on the quality of the estimate. The use of a normal-score transform is clearly beneficial for estimation and simulation of the conductivity fields in their examples.

The question that is being addressed by the authors "Can the normal score EnKF proposed by Zhou et al identify a highly channelized aquifer . . . " is an odd question. It is not clear if the authors are investigating the information content of the data on the ability to identify channels, or if the authors are investigating the inherent limitations of the EnKF for nongaussian parameter distributions. If the paper is about the ability of the normal-score EnKF to identify channels, then section 4.4 is quite important as the amount of data is reduced so the importance of the prior information becomes more important. These scenarios test the limitations of the methodology. In Scenarios 1-12, the piezometric heads were observed on a lattice with spacings between observations of approximately 25 m, compared to channel width of approximately 35 m. In these cases, it is highly unlikely for a channel to be "missed" by well observations and one might expect connectivity estimates to be relatively good if the observations are sensitive to the conductivity at the measurement location. In Scenarios 13 and 14, the well spacing is increased to nearly 50 m, so the channels are less likely to always be sampled. The repeated statements that the NS-EnKF can identify structures makes me cringe. Apparently, the data in most of the scenarios are sufficient to allow identification of the channels even when prior information on the log-permeability fields is poor. The NS-EnKF seems to do a reasonably good job of approximating the

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It is a bit misleading to claim that the data assimilation method which couples the EnKF with a normal-score transformation of variables "has been recently developed by Zhou et al (2011)". The methodologyy has been discussed in the literature a number of times before being adopted by the authors. I believe that it was originally presented by Bertino, Hollard, Evensen, Wackernagel (An ensemble Kalman filter for non-gaussian variables, EGS - AGU - EUG Joint Assembly, April 2003). Gu and Oliver (J Energy Resources Technology 2006) used a normal score transform of water saturation before updating the transformed variables and Simon and Bertino (Ocean Science 2009) applied the normal-score transform (which they called gaussian anamorphosis) to the problem of updating plankton concentration in an ocean model. It is also evaluated in a paper by David Beal, Brasseur, Brankart, Ourmieres, Verron (Ocean Science, 2010).

Specific Comments

Page 6751, line 22: I am not sure what the authors mean when they state that the EnKF is a "continuous implementation of the Bayes update rule". Bayes rule explains how to update probabilities, but the EnKF updates variables. These seem to be much different.

Page 6752, line 15: The statement that "most studies applying the EnKF assume that the hydraulic conductivities follow a multiGaussian distribution" is not completely correct. In fact, most studies assume that the log-conductivities follow a multiGaussian distribution.

Page 6752, line 27: Since the authors use univariate transformations to make the marginal distributions gaussian, it would be useful to discuss the impact on the multivariate distributions and the consequences for nonlinearity.

Page 6754, line 20: K is described as a symmetric positive-definite rank-two tensor but is treated as a scalar throughout the paper.

Page 6758, line 14: After the facies are generated, the facies are populated with real-

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izations of conductivity fields generated using sequential gaussian simulation.

Page 6759, line 6: The sampled head data are said to be error-free. Consistency in the stochastic model requires that the sampled head data should have noise added to it.

Page 6762, line 8: Although Chen and Zhang (2006) did discuss the use of the ensemble spread and the root-mean-square-error for evaluation of methodology, I could not find a discussion of the fact that when "RMSE and ES have a similar magnitude filter inbreeding is avoided" which seems to imply causality.

Page 6763, line 1: Provide a reference to CONNEC3D.Page 6766, line 19: Why do you state here that "Regarding sand connectivity it is not clear whether localization improves its characterization" but in the conclusions section state that "Coupling the NS-EnKF with a distance-dependent localization function improves both the characterization of conductivity and the prediction of groundwater flow"? These two statements are inconsistent.

Page 6765, Section 4.2: It is not clear why the estimation of channel connectivity, which has long ranges in the examples, should be improved when localization with a relatively short range is used in model updating. Most investigations of the optimal range for taper functions conclude that they should be similar in length to the range of the correlation in the prior covariance (or greater than this if the measurements are nonlocal). If it is related to the spacing between observations, then it would make sense to use a different localization for several of the scenarios.

Page 6768, Section 4.4: Need to provide information about connectivity of realizations after data assimilation such as plots similar to those in Fig. 8.

Page 6768, line 13: The authors state that "assimilating piezometric head data with the NS-EnKF allows the detection of channels structures" yet at the end of the previous section, they conclude that "the number of piezometers is important for the characteri-

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zation of log-conductivity."

Technical comments

Page 6773, line 31: List of authors is incorrect. G.B. F. S. R. M. -> Bauser, G; Stauffer, F; Muller, R

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