Hydrol. Earth Syst. Sci. Discuss., 9, C5573–C5576, 2012
www.hydrol-earth-syst-sci-discuss.net/9/C5573/2012/

Hydrology and Earth System Sciences Discussions

Interactive comment on "Ensemble Kalman filter versus ensemble smoother for assessing hydraulic conductivity via tracer test data assimilation" *by* E. Crestani et al.

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Received and published: 30 November 2012

We thank you the referee for his/her comments. Please find below the detailed responses to each issue.

"The authors present a comparison of the ensemble Kalman filter (EnKF) and the ensemble smoother (ES) applied to a low variability hydraulic conductivity field in a very idealistic case study for which concentration measurements are exhaustively know and measured at each simulation step. The authors compare different scenarios

in which the state variable on which the EnKF and ES are applied are univariate transforms of the concentration."
Response: we have chosen to perform our analysis on a simple synthetic test case, in which the "true" system state is perfectly known, in order to highlight the advantages and disadvantages of the two methods being compared, thereby avoiding that other factors and uncertainties, certainly present in real-world experiments, could blur the analysis results and conclusions.

"The authors describe the results, but fail to give a good insight of why they come out that way."
Response: we must have not conveyed our conclusions with sufficient clarity. The reasons of the worse performance of ES with respect to EnKF have been explained in Sections 3.2 and 3.3. In our tests, we did not make any prior assumption on the superiority of either of the two approaches. To address this comment, we will provide an amended discussion in section 3.3. Further details are provided in the following answers.

"Why EnKF and ES perform so differently?"
Response: Our tests suggest that this is due to the nonlinearity of the dispersion process and the development of non-Gaussian contributions in the statistical distribution for concentration. The EnKF copes well with these issues, due to its recursive procedure that (i) provides Gaussian updates eventually leading to an ensemble of members normally distributed around the true solution; and ii) progressively pulls each realization toward the true solution. The ES performs always worse than the EnKF as it does not involve recursive updates of the hydraulic conductivity fields. The consequences are two-fold: 1) the solute plumes are free to evolve in the prior fields without corrections, which produces significant differences from the evolution of the true plume and a more dispersed ensemble; 2) non-Gaussian contributions in the

pdf's of concentration cannot be kept under control as well as in the EnKF.

"Did you try an iterative ES?"
Response: This is an idea that we already considered during the preparation of our manuscript. However, we elected not to follow such an approach, since applying the ES iteratively would lead to losing one of the main advantages of the scheme, that is, its off-line, one-time application at the end of the simulation period. Still, we value this suggestion, which will be worth investigating in a future study.

"What about the sensitivity of the results to measurement error?"
Response: Both schemes are sensitive to the measurement error. However, the scope of this work is to compare the two methods in identical conditions, using a reasonable value to represent the measurement errors.

"Why is the modified normal score performing better than the unmodified one?"
Response: The classic NST, computed independently for each node of the domain, is known to alter the structure of the spatial correlation between lnK and concentration. This correlation, which plays a crucial role in updating the hydraulic conductivity field based on concentration data, is not corrupted when the modified NST is applied. To highlight these aspects, we will add a paragraph to the Conclusions.

"Why did you choose such a low variability lnK field, for those cases the linearization of the state equations generally provides good approximations of the full equation, in which case you are filtering out the effect of a highly non-linear transfer function?"
Response: Nonlinear effects in Lagrangian transport have been observed even for $Y = lnK$ fields with low-variance values [e.g. Salandin & Fiorotto, 1998]. Therefore, our test case, although synthetic, is relevant because takes into account both the aspects of

non-linearity and non-Gaussianity that are inherent in the early travel time (non-Fickian) transport phenomena This is also confirmed by the difficulties of ES in retrieving the true spatial distribution of Y.

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., 9, 13083, 2012.