Handling non-Gaussianity of state and observations in Ensemble Kalman Filters with refined Gaussian anamorphosis

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Sequential data assimilation schemes based on the Ensemble Kalman Filter are optimal in the sense of yielding the best linear unbiased estimate (BLUE) and the maximum a posteriori estimate (MAP) only if the involved error distributions are Gaussian. Nevertheless non-Gaussian error distributions are commonly encountered in geoscience.

Gaussian anamorphosis is one method to cope with non-Gaussianity in ensemble filters. It transforms the variables involved such that the distributions of the resulting variables are Gaussian and usually involves a back transformation after the filter has been applied. If only state variables are transformed, the inverse of the anamorphosis function applied to the posterior ensemble is sufficient as a back transformation and if only observations are transformed a back transformation might not be needed at all. If, however, state variables and observations are transformed, the posterior ensemble has to be corrected to yield the correct distribution of the original state variables. Otherwise a systematic error dependent on the derivative of the anamorphosis function is introduced.

We demonstrate this effect with illustrative examples based on distributions on the bounded interval $[0, 1]$ and a simplified case of assimilating albedo observations into a land surface model. In both cases direct observations are used and both, state variables and observations, are transformed to have Gaussian distributions on $[-\infty, \infty]$. The posterior ensembles are compared to the result of a Bayesian update of the bounded distributions for the toy examples and to a synthetically generated truth for the albedo example.