EMS Annual Meeting Abstracts
Vol. 11, EMS2014-446, 2014
14th EMS / 10th ECAC

Spectral Ensemble Kalman Filters

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Low rank approximation of the forecast covariance matrix by sample covariance is an obstacle to a better skill in the applications of the ensemble Kalman filter (EnKF) for data assimilation, and it can contribute to filter divergence. Localization, such as tapering, improves the approximation, but relatively large ensembles are still needed, and localization significantly increases the computational cost of the analysis step.

We propose a modified version of the EnKF, where the forecast covariance is estimated from the ensemble by the diagonal and, optionally, a low frequency part of the sample covariance in spectral space (wavelet or Fourier), which also provides a natural localization of the covariance. Rigorous algebraic estimates of the error of the spectral covariance approximation are developed. In the base variant of the method, the state consists of a single random field and the whole state is observed, which allows an efficient implementation by algebraic operations on diagonal and small dense matrices, and the use of very small ensembles. We extend the method to general states consisting of multiple random fields, spectral approximation of cross covariances, and observations at a small number of points or a part of the spatial domain.

It is well known that a random field with diagonal covariance in the Fourier space must be covariance stationary, but the use of wavelets allows the covariance function to vary spatially. We evaluate the use of Fourier bases as well as several types of wavelets, including orthogonal wavelets (tensor product Coiflets) and redundant frames (near shift-invariant dual-tree complex wavelets).

The method is tested on the Lorenz 96 dynamical system, shallow water equations, and numerical weather forecasting using WRF.

This research is supported by GACR grant 13-34856S and NSF grant DMS-1216481.