

## An Adjoint-Based Adaptive Ensemble Kalman Filter

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We introduce a new hybrid EnKF (ensemble Kalman filter)/4D-VAR (four-dimensional variational) approach to mitigate background covariance limitations in the EnKF. The work is based on the adaptive EnKF (AEnKF) method which bears a strong resemblance to the hybrid EnKF/3D-VAR (three-dimensional variational) method. In the AEnKF, the representativeness of the EnKF ensemble is regularly enhanced with new members generated after back projection of the EnKF analysis residuals to state space using a 3D-VAR (or OI - optimal interpolation) scheme with a preselected background covariance matrix. The idea here is to reformulate the transformation of the residuals as a 4D-VAR problem, constraining the new member with model dynamics and the previous observations. This should provide more information for the estimation of the new member and reduce dependence of the AEnKF on the assumed stationary background covariance matrix. This is done by integrating the analysis residuals backward in time with the adjoint model.

Numerical experiments are performed with the Lorenz-96 model under different scenarios to test the new approach and to evaluate its performance with respect to the EnKF and the hybrid EnKF/3D-VAR. The new method leads to the least root-mean-squared estimation errors as long as the linear assumption guaranteeing the stability of the adjoint model holds. It is also found to be less sensitive to choices of the assimilation system inputs and parameters.