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A multi-timescale high-efficiency approximate EnKF for coupled model data assimilation

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Because it uses a set of model integrations to simulate the temporally varying background probability distribution function and implement Bayes' Theorem, the ensemble Kalman filter (EnKF), which produces an optimal data assimilation solution that coherently combines model dynamics and observational information, has been widely used in weather and climate studies. However, in practice, the EnKF has two limitations: 1) the insufficient representation of error statistics of low-frequency background flows due to its finite ensemble size and model integration over time, and 2) the high demand of computational power for ensemble model integrations in high-resolution coupled Earth system models. Given that background error statistics consist of stationary, slow-varying, and fast-varying parts, a multi-time scale, high-efficiency approximate EnKF (MSHea-EnKF) is designed to increase the representation of low-frequency background error statistics and enhance its computational efficiency. The MSHea-EnKF is a combination of multi-time scale filters implemented by regressions based on data sampled from the time series of a single model solution. Validation shows that with the improved representation of stationary and slow-varying background statistics, the MSHea-EnKF only requires a small fraction of computer resources and shows a comparable performance relative to a finite-size EnKF. Our experiments also show that the result can be further improved by using a small set of MSHea-EnKFs through second-stage EnKF filtering if sufficient computer resources are available. This new algorithm makes it practical to assimilate multisource observations into any high-resolution coupled Earth system model that is intractable with current computing power for weather-climate analysis and predictions.