

Inter-comparison and Coupling of Ensemble and Variational Data Assimilation Approaches for Regional-Scale Modeling

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Ensemble, variational, and hybrid data assimilation systems are compared using the WRF model for a set of regional and storm-scale data assimilation experiments. Five different data assimilation schemes are considered, including standard three-/four-dimensional variational methods (3D/4DVar), an ensemble Kalman filter (EnKF), and coupled ensemble-variational methods (E3DVar and E4DVar). The hybrid methods require that EnKF and 3D/4DVar run independent of one another with two coupling steps; the variational component uses the ensemble forecast mean and perturbations at the beginning of the observation time window, and the minimizing solution replaces the posterior EnKF mean after assimilating the available data. The coupled approach uses the ensemble-estimated error covariance to incorporate flow-dependent information into the variational analysis, while considering a full-rank climatological covariance estimate. Among the tested data assimilation methods, E4DVar is the most flexible. This approach can assimilate high volumes of asynchronous observations during the analysis, while taking into account flow-dependent information from the ensemble perturbations and adjoint model. These benefits provide E4DVar with theoretical advantages over the other tested data assimilation methods, especially at the mesoscale.

In a month-long coarse-resolution cycling data assimilation experiment over the continental US, E4DVar significantly outperforms all other data assimilation methods in terms of 48-h root-mean square forecast error [1,2]. Most of the forecast improvements are observed in the lower-model levels for both dynamic and thermodynamic variables. E3DVar proved to be the second most effective method, followed by EnKF, 4DVar, and 3DVar over the month-long study. The EnKF, 4DVar, and E4DVar methods are also compared in a weeklong convection-permitting experiment that uses the WRF model to simulate the genesis and rapid intensification of Hurricane Karl (2010). Routinely collected observations are assimilated, as well as dropsondes from the Pre-Depression Investigation of Cloud Systems in the Tropics field campaign. The E4DVar method produces significantly more accurate 12 – 72 h forecasts in the vicinity of the developing tropical wave, when compared to the benchmark systems. Improvements in the wind and moisture fields translate into more accurate forecasts for the timing and location of genesis for this event. Furthermore, the hybrid variational scheme reduces the number of inner-loop iterations by about 30% for multi-incremental 4DVar, owing to the smooth first guess and ensemble estimation of background error covariance. This study demonstrates the effectiveness of coupled ensemble-variational data assimilation methods at the synoptic and mesoscale, while considering possible computational cost savings in the new system.

References

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