A Hybrid Ensemble Kalman Filter Approach to Data Assimilation in WRF/DART

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Introduction

The ensemble Kalman filter (EnKF) has become a popular data assimilation method after it was first proposed by Evensen (1994). The background error covariances in the EnKF are computed from an ensemble forecast, and then the EnKF is able to provide a flow-dependent estimate of the background error covariances for use in data assimilation.

However, the EnKF, as an intermittent data assimilation, may have discontinuities / error spikes around the observations times. It may also lead to dynamic imbalances and high-frequency adjustment processes in the model dynamics. We hypothesize that if the EnKF is able to be applied continuously in time, analyses can be improved by reducing the discontinuities or bursts.

Therefore, the hybrid EnKF proposed by Lei and Stauffer (2007; 2009) combines the EnKF and nudging by applying the EnKF gradually in time via nudging-type terms. This hybrid EnKF was tested and showed added value in the Lorenz three-variable model (Lei and Stauffer 2007) and a two-dimensional shallow water model (Lei and Stauffer 2009). It is further investigated here in a three-dimensional mesoscale model, WRF-ARW, and the Data Assimilation Research Testbed (DART, Anderson et al. 2009). The analyses of the data assimilation methods are used to drive an atmospheric transport and dispersion model (SCIPUFF), and the predictions of atmospheric tracer concentration for CAPTEX-83 (Deng et al. 2004) serve as an independent verification of the data assimilation approaches.

Methodology

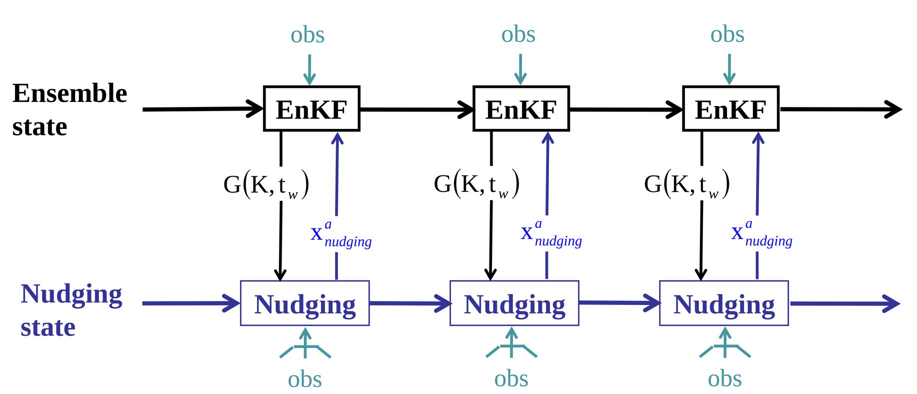

Figure 1. Schematic showing the procedures of the hybrid EnKF approach.

Experimental Design for WRF/DART and SCIPUFF

Exp. Name	Exp. Description
CTRL	Assimilate no observations
FDDA	Assimilate observations by observation nudging with nudging coefficients of 4×10^{-4} s^{-1}
EnKFIC24	Assimilate observations by EnKF with initial condition (IC) ensemble and 24 ensemble members
EnKFIC48	Assimilate observations by EnKF with IC ensemble and 48 ensemble members
EnKFICPH24	Assimilate observations by EnKF with initial condition and multi-physics (ICPH) ensemble and 24 ensemble members
EnKFICPH48	Assimilate observations by EnKF with ICPH ensemble and 48 ensemble members
HEnKFIC24	Assimilate observations by hybrid EnKF with IC ensemble and 24 ensemble members
HEnKFIC48	Assimilate observations by hybrid EnKF with IC ensemble and 48 ensemble members
HEnKFICPH24	Assimilate observations by hybrid EnKF with ICPH ensemble and 24 ensemble members
HEnKFICPH48	Assimilate observations by hybrid EnKF with ICPH ensemble and 48 ensemble members

The CAPTEX-83 Case

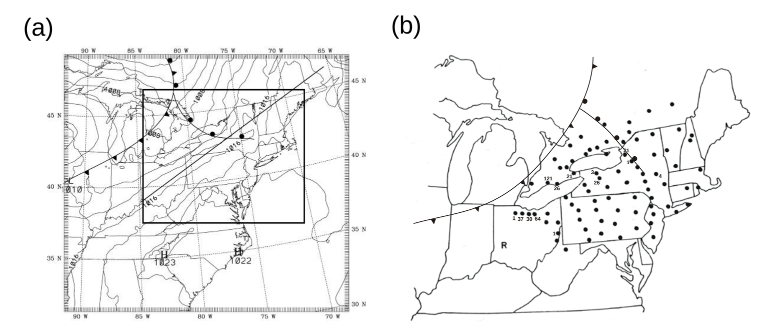

Figure 2. Model domains and surface tracer network for CAPTEX-83. (a) the sea level pressure (hPa) at 0000 UTC 19 September 1983 on the WRF 12-km domain, and (b) the observed surface tracer concentrations (parts of perflurocarbon per 10^{15} parts of air by volume, or femtoliters/liter) at the surface sampling sites at 0040 UTC 19 September 1983. The black frame in (a) denotes the domain of the SCIPUFF model. The R in (b) is the tracer release site near Dayton, OH.

- All data assimilation experiments produce lower RMS errors than the CTRL, except for the wind direction priors (three-hourly forecasts) of the EnKF experiments (Figs. 3-5).
- For the IC ensemble, Figs. 3-4 show that the HEnKFIC24 improves the posteriors (fit-to-observation statistics) compared to the EnKFIC24, although both experiments have larger posterior RMS errors than the FDDA.
- The HEnKFIC24 produces similar or better priors than the FDDA and EnKFIC24 (Fig. 5).
- Figure 6 shows that the HEnKFIC24 produces better statistics than the EnKFIC24 for hits, misses and false alarms from the independent tracer concentration data.
- The analysis of surface pressure tendency (Fig. 7) shows that the HEnKFIC24 has much lower noise levels than the EnKFIC24.
- Figures 4-5 show that the ICPH ensemble improves the posteriors and slightly improves the priors of the mass field compared to the IC ensemble for the EnKF and HEnKF with 24 ensemble members, and especially for the EnKF. The wind field posteriors and priors are very similar for the IC and ICPH ensembles.
- The ICPH ensemble with 24 ensemble members degrades all three tracer statistics for the EnKF, and increases the hits and decreases the misses with no changes of the false alarms for the HEnKF, compared to the IC ensemble results (Fig. 6).

WRF/DART Results

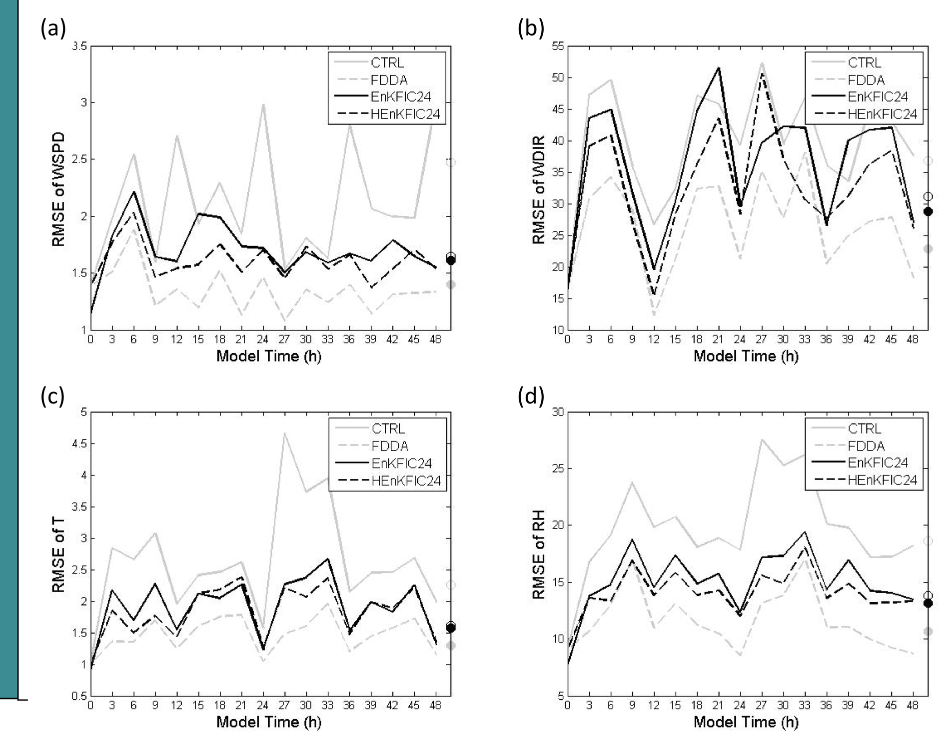

Figure 3. The time series of RMS errors of the posteriors of CTRL, FDDA, EnKFIC24 and HEnKFIC24 for (a) wind speed (ms^{-1}), (b) wind direction (deg), (c) temperature (K) and (d) relative humidity (percent). The light gray open circle (CTRL), light gray solid circle (FDDA), black open circle (EnKFIC24) and black solid circle (HEnKFIC24) on the right y-axis denote the average RMS errors through the 48-h period.

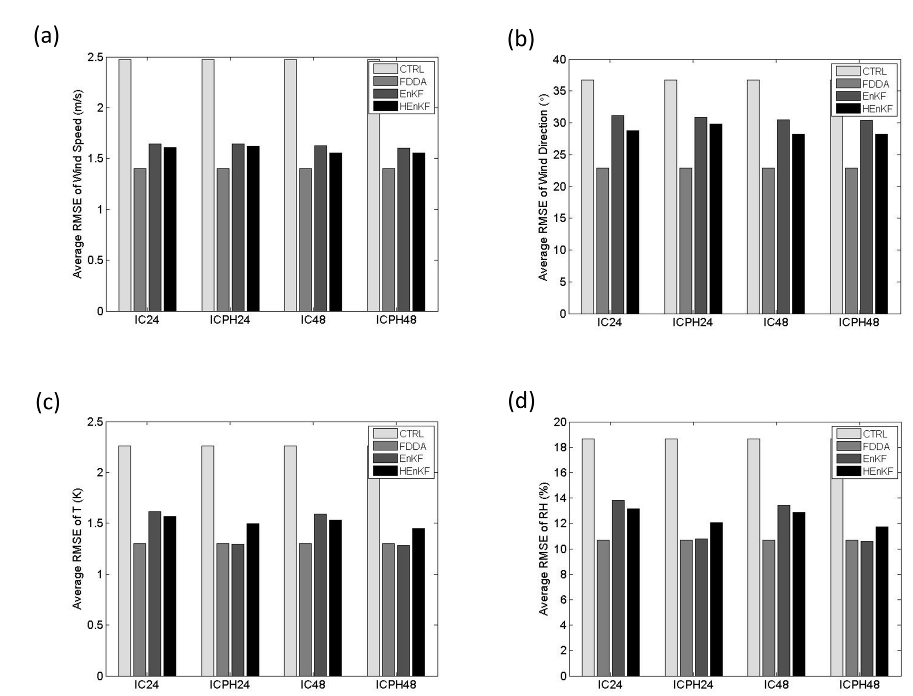

Figure 4. The average RMS errors of the posteriors for (a) wind speed (ms^{-1}), (b) wind direction (deg), (c) temperature (K) and (d) relative humidity (percent) from each experiment through the 48-h period.

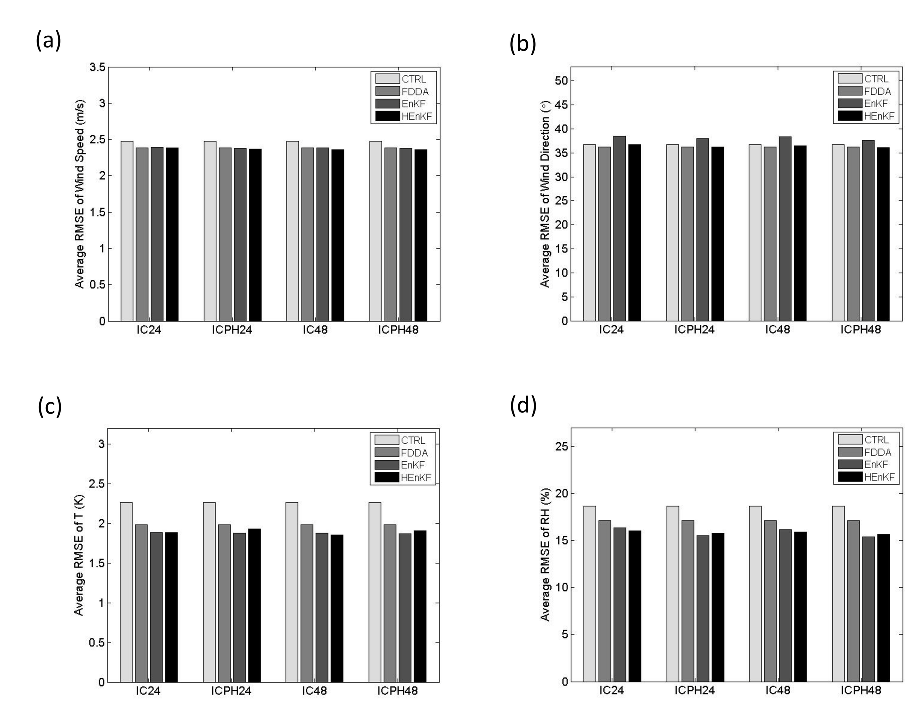

Figure 5. The same as Fig. 4, except for the priors.

- The increased noise levels in Fig. 8 for the EnKF using 24 members caused by including the multi-physics ensemble members may have contributed to the degradation of the tracer statistics.
- The increase of ensemble size from 24 to 48 slightly improves the posteriors and priors of the EnKF and HEnKF for both the IC and ICPH ensembles (Figs. 4-5).
- The comparative results (e.g., HEnKF vs. EnKF, IC vs. ICPH) from the 48 ensemble member experiments are consistent with those of the 24 ensemble member experiments.
- For the HEnKF, the ICPH ensemble with 48 ensemble members increases the hits, decreases the misses, and decreases the false alarms compared to the IC ensemble results (Fig. 6).

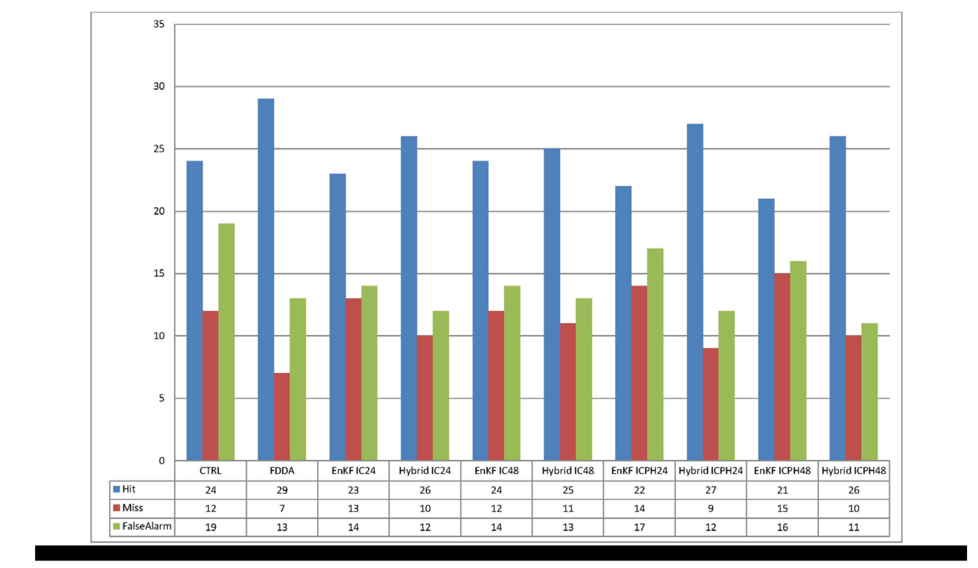

Figure 6. The statistics of the SCIPUFF-predicted surface tracer concentration driven by the analyses from each experiment and verified against the observed surface tracer concentration data.

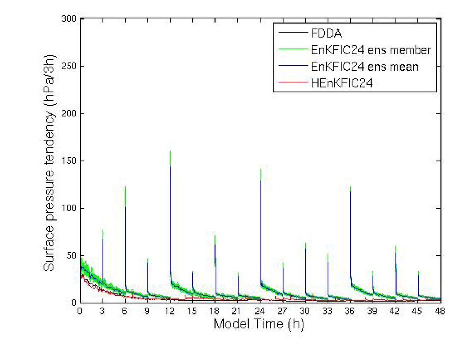

Figure 7. Comparison of the evolutions of the domain average absolute surface pressure tendency (noise) of the FDDA, each ensemble member of the EnKFIC24 and their ensemble mean, and the HEnKFIC24.

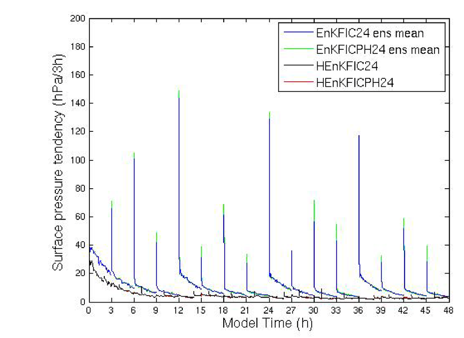

Figure 8. Comparison of the evolutions of the domain average surface pressure tendencies (noise) of the ensemble means of EnKFIC24 and EnKFICPH24, and the HEnKFIC24 and HEnKFICPH24.

Conclusions

A hybrid EnKF (HEnKF), combining the nudging and the EnKF, greatly reduces insertion noise in WRF/DART compared to the EnKF with the CAPTEX-83 case.

The increase in ensemble size from 24 to 48 members slightly improves the RMS errors for both the EnKF and HEnKF.

For the IC ensemble, the HEnKF has better posterior fit-to-observation statistics and three-hourly forecast priors than the EnKF for both 24 and 48 ensemble members. Moreover, the HEnKF analyses driving SCIPUFF produce better statistics of the independent tracer concentration data than the EnKF.

The ICPH ensemble improves the RMS errors of the EnKF and HEnKF in the mass field for both 24 and 48 ensemble members. It also improves the number of hits and misses without increasing the false alarms for the HEnKF. However, the ICPH ensemble degrades the tracer data statistics compared to the IC ensemble for the EnKF.

The analyses of surface pressure tendency demonstrate that the HEnKF is able to provide better temporal smoothness and dynamic consistency in the hourly analyses than the EnKF. Since the HEnKF produced better independent tracer predictions than the EnKF, there appear to be some advantages in the hourly dynamic analyses produced by the continuous HEnKF compared to the intermittent EnKF.

Acknowledgements

We acknowledge the Defense Threat Reduction Agency (DTRA) DTRA contract no. HDTRA1-07-C-0076 under the superviison of Dr. John Hannan. The authors thank Aijun Deng, Brian Reen, Brian Gaudet and Jeff Zielonka for technical support, and Jeff Anderson and Glen Romine for assistance with DART, and George S. Young and Sue Ellen Haupt for helpful discussions.