Multi-Scale Ensemble Kalman Filter Data Assimilation and Forecasts in Central United States

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INTRODUCTION

The parallel ensemble square-root Kalman filter (EnSRF) algorithm [1] developed recently at the Center for Analysis and Prediction of Storms (CAPS), capable of assimilating multi-scale observations is applied to the May 10, 2010, Oklahoma-Kansas tornado outbreak (Figure 1) that spawned more than 60 tornadoes with up to EF4 intensities [2]. To properly initialize both the synoptic and meso-scale environment and the convective scale features, a nesting strategy is used, with the storm-scale analyses at 4 km horizontal grid spacing nested inside the continuously cycled regional analyses at a 40 km grid spacing. The former includes all observations used by the operational Rapid Refresh (RAP) system.

The 4 km storm-scale domain uses the Advanced Regional Prediction System (ARPS) as the prediction model. Conventional (sounding, profiler, surface station, and mesonet) observations and data from more than 40 WSR-88D radars are assimilated every hour, while during the last hour before the free forecasts the data are assimilated every 10 minutes (Figure 2). Ensemble and deterministic forecasts are launched several times during the assimilation cycles.

For real-time implementation, the performance of the parallel scheme has been investigated, and has been found to have good scalability for dense radar observations. One EnKF DA assimilating surface and radar DA could be completed within a DA interval on a Cray XT5 system (called Kraken) at the National Institute for Computational Sciences (NICS) at the University of Tennessee. Better performance could be achieved through the optimization of configurations and domain decomposition.

During the 2013 NOAA Hazardous Weather Testbed (HWT) Spring Experiment (SE), an experimental one-time EnKF analysis employing the above EnKF system interfaced with the Weather Research and Forecasting (WRF) model was performed at 0000 UTC over the central US domain, which is an approximately 1/4 CONUS domain. The ensemble consisted of 40 WRF-ARW members, started at 1800 UTC over the CONUS domain (http://www.caps.ou.edu/wx/enkf/). This ensemble is configured with initial perturbations, and mixed physics options to provide input for EnKF analysis. Each member uses WSM6 microphysics with different parameter settings (http://forecast.caps.ou.edu/SpringProgram2013_Plan-CAPS.pdf). A parallel 3DVAR/cloud analysis over the same central US domain was carried out for purposes of comparison.

A pair of deterministic forecasts was launched from the EnKF ensemble mean analysis and 3DVAR/cloud analysis on 12 days during 2013 HWT SE. Another pair of forecasts were run employing the Thompson microphysics scheme to examine the forecast skill dependency on the microphysics schemes during the post-season analysis.

OBJECTIVES

- Establish an efficient parallel EnKF system capable of assimilating multi-scale observations including surface, upper-air, profiler, satellite, and radar observations
- Preparing for a real-time CONUS-domain storm-scale EnKF DA and ensemble forecasts

CONFIGURATIONS FOR 10 MAY 2010 CASE STUDY

- Regional ensemble
  - Forecast model: WRF-ARW
  - DA scheme: GSI-based coupled EnKF-3DEnVAR hybrid system
  - Observations: Sounding, profiler, surface (land and ship), satellite wind, aircraft
  (Details in "A regional GSI-based coupled EnKF-3DEnVAR hybrid data assimilation system for the operational rapid refresh forecasting system", Tue. 4:45 pm)
- Storm-scale ensemble
  - Forecast model: ARPS
  - DA scheme: ARPS parallel EnSRF
  - Observations: conventional data (surface, sounding, and profiler), and radar data (radial velocity and reflectivity)
  - Microphysics scheme: LFO83 [3]
  - Grid configuration: nested grid (40 km -> 4 km) (Figure 3)
  - Model domain: 1750 × 1920 × 21 km³ (443 × 483 × 53 grid points)
- 40 ensemble members

Figure 1. SPC preliminary storm reports for 10 May 2010

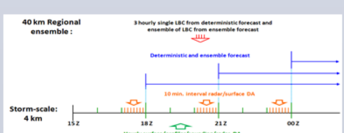

Figure 2. Flow diagram for the experiment

RESULTS FROM THE CASE STUDY

- EnKF analyses produced better prediction of storms in Kansas and Oklahoma than the CAPS real-time forecast that used 3DVAR/cloud analysis (Figure 3).
- The results showed that the parallel EnSRF algorithm exhibits good scalability for very dense radar observations.
- A line of strong, isolated storms in Oklahoma, Texas, Missouri, and Arkansas and a meso-scale convective system in the north were captured reasonably well by the ensemble forecasts throughout the forecast period (Figure 4).

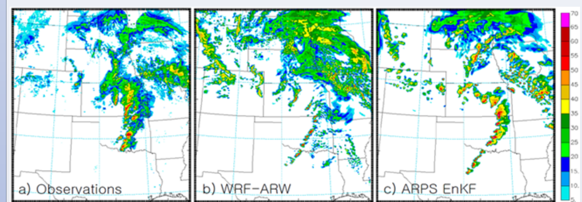

Figure 3. (a) The observed radar reflectivity mosaic; (b) CASP real-time WRF-ARW forecast; and (b) deterministic forecast from the EnKF ensemble mean analysis at model grid level 20 (about 3.6 km above mean sea level) for the central US domain, corresponding to 5-hour forecasts, valid at 2300 UTC, 10 May 2010.

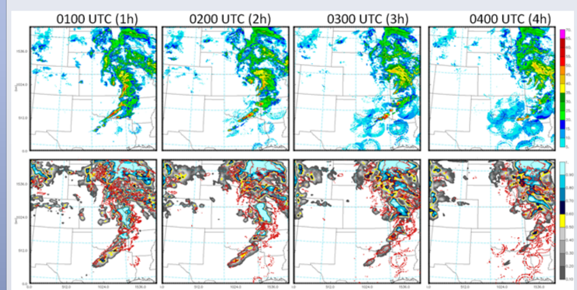

Figure 4. Observed reflectivity (top) and neighborhood (radius = 10 km) ensemble probability of forecast reflectivity exceeding 15 dBZ (bottom) at model grid level 20 at (left to right) 0100, 0200, 0300, and 0400 UTC, corresponding to 1-, 2-, 3-, and 4-hour forecast, valid at 0100, 0200, 0300, and 0400 UTC, 11 May 2010, respectively. The 15 dBZ radar reflectivity contour observed by the WSR-88Ds at the same time is in red contour.

CONFIGURATIONS FOR CAPS REAL-TIME EnKF DA AND FORECASTS

- Forecast model: WRF-ARW
- DA schemes: ARPS parallel EnSRF and ARPS 3DVAR/cloud analysis
- Microphysics scheme: WSM6 [4] and Thompson [5]
- Grid configuration: nested grid (CONUS -> central US) at 4 km (Figure 5)
- Observations: surface, sounding, profiler, and radar radial velocity and reflectivity
- 40 ensemble members
- Lateral boundary condition (LBC) for deterministic forecasts was provided by the CAPS HWT storm-scale ensemble forecast (SSEF) member 26.
- For a parallel experiment using a 3DVAR/cloud analysis, the ensemble mean forecast at 000 UTC was used as a background.

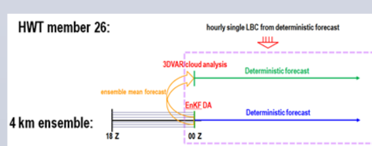

Figure 5. Flow diagram for the CAPS experimental 4 km EnKF and 3DVAR forecasts.

RESULTS

- Figure 6 shows the forecast composite reflectivity at 0400 UTC on 20 May 2013, corresponding to a 4 hour forecast, along with observed reflectivity. In general, both forecasts captured the convective line in Missouri-Kansas-Oklahoma, while the forecast from the EnKF analysis performed better in terms of location and structure. On the other hand, the convective line and stratiform rain in Illinois was predicted better with the forecast from the 3DVAR/cloud analysis.
- Equitable Threat Score (ETSs) of reflectivity averaged over 12 days show that a single EnKF outperformed 3DVAR/cloud analysis in general (Figure 7).
- The Thompson microphysics scheme produced more skillful forecasts than WSM6 scheme, mainly because a single-moment scheme tends to under-predict light precipitation region. When a higher threshold was used, the difference in ETSs utilizing different microphysics schemes was decreased (Figure 7).

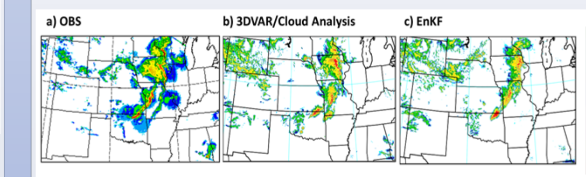

Figure 6. (a) Observed composite radar reflectivity and forecast reflectivity from (b) 3DVAR/cloud analysis and (c) EnKF ensemble mean analysis valid at 0400 UTC on 20 May 2013, corresponding to 4-hour forecasts

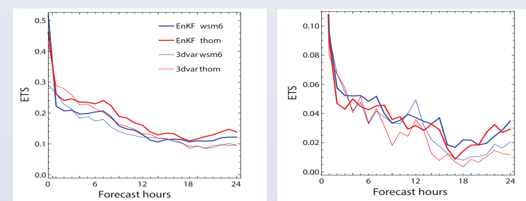

Figure 7. ETSs for reflectivity ≥ 20 dBZ (left) and ≥ 40 dBZ (right) averaged over 12 forecast days for deterministic forecasts starting from the EnKF mean analysis using WSM6 (think blue) and Thompson (thick red) microphysics schemes and parallel forecasts using 3DVAR/cloud analysis (thin blue and thin red)

FUTURE WORK

- Tune the EnKF and 3DVAR system to further improve analyses and forecasts.
- Perform cycled-EnKF and single-time and/or cycled 3DVAR/cloud analysis, and compare the forecast skill.

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