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STORM-SCALE ENSEMBLE FORECASTS FOR THE 2015 NOAA HWT SPRING FORECASTING EXPERIMENT: COMPARISON BETWEEN CYCLED ENKF AND 3DVAR ENSEMBLES

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I. INTRODUCTION

The Center for Analysis and Prediction of Storms (CAPS) at the University of Oklahoma produces realtime storm-scale ensemble forecast (SSEF) each spring season since 2007 to support the NOAA Hazardous Weather Testbed (HWT) Spring Forecast Experiment (Kong et al. 2007; 2008; 2009; 2012; 2014a,b; Xue et al. 2007; 2008; 2009; 2010). The 2015 CAPS SSEF realtime forecast ran from April 20 to June 5, 2015, using WRF-ARW with a domain covering the full continental United States (CONUS) with convection-allowing resolution at 3-km horizontal grid spacing. CAPS SSEF members were configured with a hybrid of initial/lateral boundary condition (IC/LBC) perturbations extracted from the operational NCEP Short-Range Ensemble Forecast (SREF) ensemble members (at 16 km grid spacing) and various combinations of physics options in microphysics, PBL and land-surface model. Up to 140 WSR-88D Doppler weather radar data over the CONUS, with both radial wind and reflectivity, and other observation data were analysed into the SSEF members in realtime using the ARPS 3DVAR and Complex Cloud Analysis system (Gao et al. 2004; Hu et al. 2006).

For the first time, an experimental EnKF-based ensemble was able to run in realtime, produced from a one hour EnKF cycles at 15 min interval from 2300 to 0000 UTC with all available radar and other observation data.

II. CAPS 2015 SSEF OVERVIEW

Each spring in the past nine years from 2007 to 2015, the Center for Analysis and Prediction of Storms (CAPS), in collaboration with the Storm Prediction Center (SPC) and the National Severe Storm Laboratory (NSSL) and funded by the NOAA Collaborative Science, Technology, and Applied Research (CSTAR) program, had conducted highly successful real-time storm-scale ensemble forecast (SSEF) experiment to support the NOAA Hazardous Weather Testbed (HWT) Spring Forecast Experiment (Xue et al. 2007, 2008, 2009, 2010; Kong et al. 2007, 2008, 2009, 2012, 2014a,b).

The CAPS 2015 Storm-Scale Ensemble Forecast (SSEF) started on 20 April through 5 June 2015, encompassing the NOAA HWT 2015 Spring Forecast Experiment that is officially between 4 May and 5 June. Different from past years, the 2015 SSEF CONUS domain is changed from 4-km to 3-km horizontal grid spacing, resulting in 2.1 times more grid points and covering 18% more area than in the 2014 season. The migration to a 3-km grid spacing makes CAPS SSEF more consistent with the operational HRRR setting. As in previous years, the forecasts are produced Monday through Friday, initialized at 0000 UTC (1900 CDT) each day and made available in early morning for evaluation at HWT.

There are two suites of SSEF runs. One is the ordinary 0000 UTC 3-km ensembles consist of 20 WRF-ARW members initialized with a onetime 3DVAR analysis, with the forecast lead time of 60 hours. The ensemble is configured with a combination of IC/LBC perturbations and physics variations. For the perturbed members, 3-hourly forecasts from consistent NCEP SREF members were used to provide the lateral boundary conditions. The second suite is a newly implemented realtime EnKF based forecasting that includes a one hour EnKF cycling DA at 15 min interval from 2300 UTC to 0000 UTC following a 5-h 40-member ensemble forecast initiated from 1800 UTC, over the same CONUS domain as the ordinary SSEF.

In order to provide an ensemble background for EnKF, a separate 3-km ensemble of 5-h forecasts, starting at 1800 UTC, with 40 WRF-ARW members is produced over the same CONUS domain. 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 in rain and graupel number concentration and graupel density. No radar data is analysed for this set of runs. All members also include random perturbations with recursive filtering of ~20 km horizontal correlations scales, with relatively small perturbations (0.5K for potential temperature and 5% for relative humidity). EnKF analysis (cycling), with radar data and other conventional data, is performed from 2300 to 0000 UTC every 15 min, using as background the 40-member ensemble. An 11-member ensemble forecast of 60 h follows using the 0000 UTC EnKF analyses. In addition, four deterministic forecasts, two (one with Thompson and another with WSM6 microphysics) from the ensemble mean analysis and another two (Thompson, WSM6) from 3DVAR cycling, are also produced. Ensemble products from both suites are available to HWT participants in the morning.

WRF-ARW V3.6.1 was used, with different microphysics and PBL schemes assigned for different members. In addition to Thompson, Milbrandt-Yau, and Morrison microphysics schemes, two newly developed P3 (Predicted Particle Properties) microphysics by Morrison and Milbrandt, one with a single ice category and another with two ice categories (Personal communications), are implemented and included in 2015 SSEF ARW ensemble members. A Thompson scheme addressing fractional cloudiness is also included. PBL schemes used include MYJ, MYNN, QNSE, YSU, as well as a modified YSU by Greg Thompson in an attempt to correct the overly dry and warm PBL issue of YSU.

The 3DVAR initiated SSEF forecasts were performed on Stampede, a Dell C8220 supercomputer system with over 6400 Intel Xeon Phi computing nodes at Texas Advanced Computing Center (TACC) at the University of Texas at Austin, utilizing 950 computing nodes each day in the overnight hours. The EnKF ensemble forecasts were performed on Darter, a Cray XC30 supercomputer system with 12,000 computing cores, at the National Institute of Computational Sciences (NICS) at the University of Tennessee. Both TACC and NICS are the National Sciences Foundation (NSF) sponsored.

A total of 33 days of complete ensemble forecasts from the 0000 UTC 3DVAR initialized SSEF runs, and 25 days of mostly complete EnKF-based SSEF runs were produced during the experiment period. Using the NSSL 1-km resolution Multi-Radar/Multi-Sensor (MRMS) QPE data (Zhang et al. 2011) as a verification dataset, the SSEF QPF and probabilistic QPF performance has been evaluated using various traditional verification metrics.

The more detail description on the SSEF system, including membership configuration, and on the 2015 Spring Experiment can be found in the CAPS 2015 Plan Document (Kong, 2015)[1] and Kong et al. (2015).

III. ENKF VS 3DVAR ENSEMBLES

FIG.1 shows the 1-h accumulated precipitation forecast from a sample case of 9 May 2015, valid at 0100 UTC 9 May 2015. Forecasts from EnKF mean and cycled 3DVAR analysis, and one EnKF-based ensemble member (enkf_cn) are compared to the QPE plot. It can be seen that the 3DVAR initiated forecast over-predicted the area of light rainfall in central Texas and under-predicted the heavier rainfall band in Oklahoma.

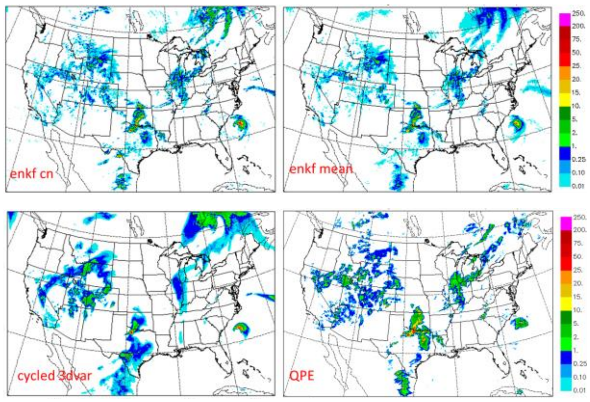

FIG. 1: 1-h accumulated precipitation from one member (enkf_cn) and two deterministic forecasts with Thompson microphysics (enkf_mean, enkf_3dvar). They are valid at 0100 UTC, 9 May 2015, corresponding to 1 h forecast lead time.

The ETS scores of the EnKF-based ensemble forecasts starting at 0000 UTC are evaluated, along with its ensemble mean and PM, and four deterministic runs initiated using the EnKF mean and cycled 3DVAR analysis. There are 25 dates of mostly complete runs.

FIG 2 plots the ETS scores of 1-h accumulated precipitation averaged over 25 days. Only the values up to 48 h are drawn since there are incomplete data beyond 48 h in some dates. Between the two sets of deterministic forecasts, those initiated from EnKF mean (blue lines) outperform those from cycled 3DVAR, in particular in the early forecast hours. The EnKF-based ensemble members also outperform 3DVAR runs most of the forecast period.

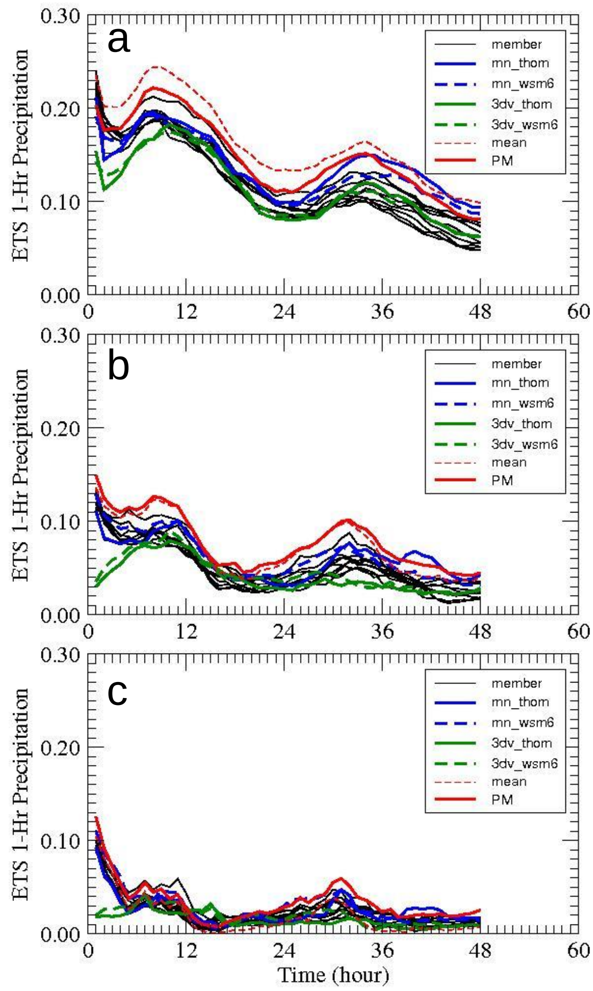

FIG. 2: ETS of 1-h accumulated precipitation (a) ≥0.01, (b) ≥0.10, (c) ≥0.25 inch, from the EnKF-based 0000 UTC ensemble members, mean, PM, and four deterministic forecasts.

The microphysics sensitivity between Thompson and WSM6 is less conclusive in FIG 2. WSM6 does show somewhat more skill early on but loss to Thompson beyond 24 h.

Comparison between the two ensemble suites is a bit harsh (and unfair?) since different NAM background data sets are used. FIG 3 plots the ETS curves of ensemble mean and the probability matched mean from the two ensemble forecasts, which shows that it is true that the EnKF-based ensemble, driven from 1800 UTC NAM background, scores lower in terms of QPF compared with the onetime 3DVAR initiated SSEF that is driven from 0000 UTC NAM background. The margins are quite large.

CAPS 2015 Spring SSEF Program features the first ever effort to perform streamlined EnKF DA and ensemble forecast system at 3-km horizontal grid spacing in a CONUS scale in realtime, with up to 140 Doppler radar data and other available observations. It is a success in that regard. More effort will be dedicated in off-season experiments and in the future studies to refining the EnKF system to optimize its performance in convection allowing NWP framework.

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[1] http://forecast.caps.ou.edu/SpringProgram2015_Plan-CAPS.pdf

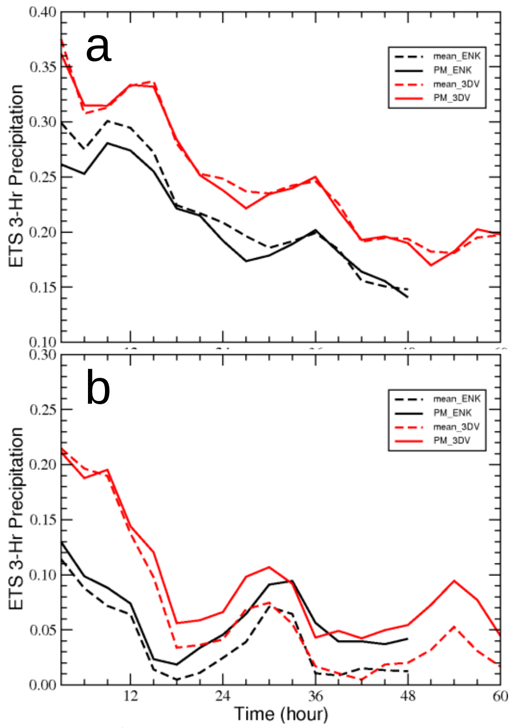

FIG. 3: ETS of ensemble mean and probability matched mean (PM) 3-h accumulated precipitation (a) ≥0.01 inch, (b) ≥0.5 inch, averaged over 25 days of 2015 SSEF runs..

IV. ACKNOWLEDGMENTS

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