Progress Report

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A Partnership to Develop, Conduct, and Evaluate Realtime High-Resolution Ensemble and Deterministic Forecasts for Convective-scale Hazardous Weather: Moving to the Next Level

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1. Project scientific objectives

The realtime forecasts performed under this NOAA CSTAR project, together with retrospective analyses using the real time data, aim to address the scientific issues including:

- the values and cost-benefit of convection-allowing-resolution ensemble versus coarser-resolution short-range ensembles and even-higher-resolution convection-resolving deterministic forecast;
- optimal design of a storm-scale ensemble system including the initial condition perturbation methods, physics perturbations, and the use of multiple models;
- proper handling and use of lateral and lower boundary perturbations;
- the value and impact of assimilating high-resolution data including those from WSR-88D radars;
- the most effective ensemble post-processing and forecast products for the convective storm scales, including ensemble calibration; and
- the value and impact of such unique products for forecasting guidance and warning.

2. Progress for this reporting period

The primary activity in this reporting period is the configuration, code development, and test of the storm-scale ensemble forecast system (SSEF) for the 2014 Spring Experiment season.

For the spring 2014, the CAPS SSEF system has the following major changes:

- The total number of ensemble members initiated at 0000 UTC is set to 24, consisting of two NWP modeling systems (WRF-ARW, and the Navy COAMPS), running at NICS. Forecast lead time is further increased to 60 h. The CONUS domain is the same as in 2013 (1200x768 horizontal grid points, 51 vertical levels);
- WRF version is upgraded to V3.5.1 from V3.4.1;
- The 1200 UTC initiated SSEF (8-member), running on local (University of Oklahoma) computer system, are with forecast lead time of 24 h and covering the same CONUS domain as in 00 UTC runs;
- HAILCAST products, developed by AFWA, are included for all ARW members.
- Synthetic GOES IR channel brightness temperature at 3.9, 6.48 and 10.7 μm products using CRTM, are produced (for GOES-R Proving Ground);
- Simulated dual polarmetric radar variables (REF, ZDR, KDP) are produced using CAPS dual-pol radar simulator;
- An experimental EnKF ensemble forecast system is setup with 40-member storm-scale ensemble background, a one hour EnKF cycling at 15 min interval, and a 12-member ensemble forecast of 24-h starting at 0000 UTC, running on the same CONUS domain as regular SSEF;

The CAPS 2014 spring forecast experiment started on 21 April 2013 and end on 06 June, encompassing the HWT 2014 Spring Experiment that is officially between 05 May and 06 June. As in previous years, the forecasts are produced Monday through Friday, initialized at 0000 UTC (1900 CDT) of each day and made available early morning for evaluation at HWT. A 1200 UTC 8-member ensemble forecast is produced the same way but run on local computer system, the University of Oklahoma's Boomer system. The 00 UTC 4-km ensembles consist of 20 ARW and 4 COAMPS members for a total of 24 members. The 12 UTC ensembles are a subset of 00 UTC members. For the perturbed boundary members, 3-hourly forecasts from consistent NCEP SREF members are used to provide the lateral boundary conditions.

As in previous years, level-2 radial velocity and reflectivity data from over 140 operational WSR-88D radars are analyzed using the ARPS 3DVAR together with its cloud analysis package (Gao et al. 2003; Hu et al. 2006). Other high-resolution (e.g., Oklahoma Mesonet) data are also analyzed. The results serve as the control initial conditions for the four models. Sixty-hour forecasts are produced for the 00 UTC runs and twenty-four-hour for the 12 UTC runs.

The Cray XC30 supercomputer operated by National Institute for Computational Science (NICS) at the University of Tennessee, ***Darter***, with 12,000+ CPU cores, is utilized for about 8 hours a day for producing the 00 UTC 4-km SSEF forecasts, the experimental EnKF analysis and forecast, and for post-processing data output. A Linux cluster supercomputer operated by the Oklahoma Supercomputing Center for Education and Research (OSCER) at the University of Oklahoma, ***Boomer***, is used for producing the 12 UTC ensemble forecasts. Hourly 3D model outputs are produced and archived while some fields are output every 6 minutes for high-frequency animations.

Fig. 1 shows the coverage area of the model domains, which is the same as in 2012 seasons.

Special software codes that were developed at CAPS to handle interface among the two NWP model systems and between ARPS 3DVAR/Cloud Analysis and non-ARPS models are upgraded to be compatible with the new WRF version (V3.5.1) used in the 2013 season.

In addition to the four existing two-moment microphysics schemes that are included, Thompson, Milbrandt-Yau, Morrison, and WDM6, a newly developed P3 (Predicted Particle Properties) microphysics by Morrison and Milbrandt is implemented and included in 2014 SSEF ARW ensemble members. A modified Milbrandt-Yau scheme addressing overly prediction of ice cloud anvil is also included. Model simulated radar reflectivity is computed within each individual microphysics algorithm.

Tables 1-2 list the configurations for each individual members of each model group (arw, coamps). cn refers to the control member, with radar data analysis, c0 is the same as cn except for no radar data is analyzed in. m3 – m20 are members with either initial perturbation or physics perturbation or both added on top of cn initial condition. NAMa and NAMf refer to 12-km NAM analysis and forecast, respectively. ARPSa refers to ARPS 3DVAR and cloud analysis using

NAMa as the background. For the perturbed members arw_m3~m13 and, the ensemble initial conditions consist of a mixture of bred and Ensemble Transform (ET) perturbations coming from the 21Z SREF perturbed members and physics variations (grid-scale microphysics, land-surface model (LSM), and PBL physics).

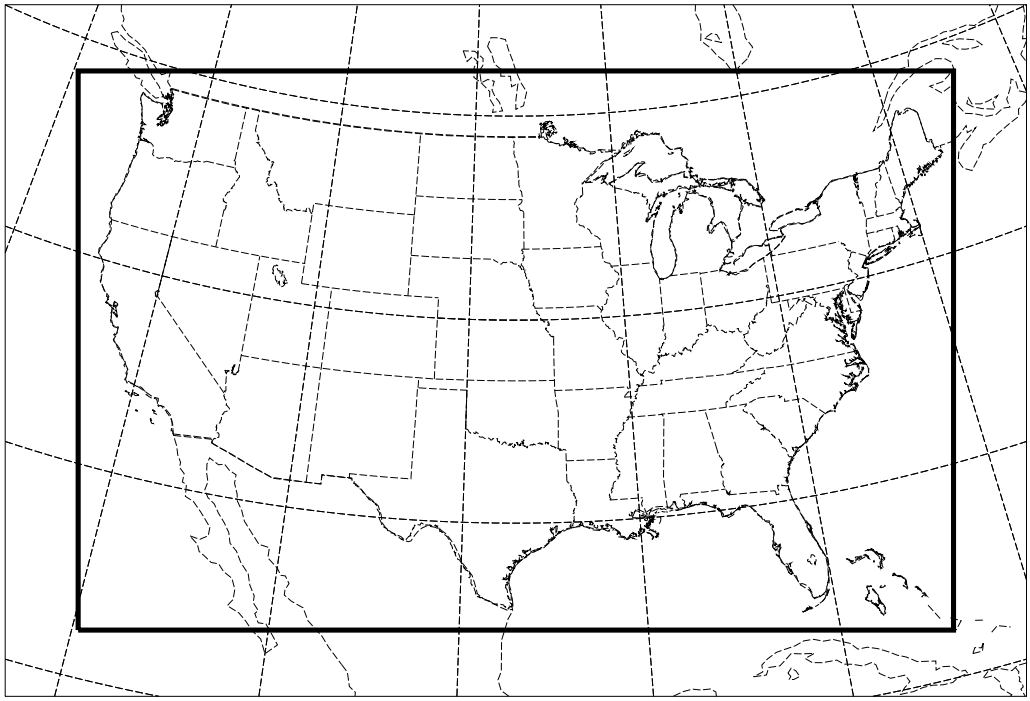

Figure 1. The 2014 CAPS Spring Forecast Experiment domain, thick inner box (1200x768 horizontal grid points) for the SSEF runs.

Table 1. Configurations for ARW members. NAMa and NAMf refer to 12 km NAM analysis and forecast, respectively. ARPSa refers to ARPS 3DVAR and cloud analysis

Member	IC	BC	Radar data	Microphy	LSM	PBL
*arw_cn	00Z ARPSa	00Z NAMf	yes	Thompson	Noah	MYJ
arw_c0	00Z ARPSa	00Z NAMf	no	Thompson	Noah	MYJ
arw_m3	arw_cn + em-p1_pert	21Z SREF em-p1	yes	Morrison	RUC	YSU
*arw_m4	arw_cn + em-n2_pert	21Z SREF em-n2	yes	Thompson	Noah	QNSE
*arw_m5	arw_cn + nmm-p1_pert	21Z SREF nmm-p1	yes	Morrison	Noah	MYNN

*arw_m6	arw_cn + nmmb-n1_pert	21Z SREF nmmb-n1	yes	MY2	RUC	MYJ
arw_m7	arw_cn – nmmb-p1_pert	21Z SREF nmmb-p1	yes	WDM6	Noah	YSU
*arw_m8	arw_cn + em-n1_pert	21Z SREF em-n1	yes	WDM6	Noah	QNSE
arw_m9	arw_cn – em-p2_pert	21Z SREF em-p2	yes	MY2	Noah	MYNN
*arw_m10	arw_cn – nmmb-n3_pert	21Z SREF nmmb-n3	yes	Morrison	Noah	YSU
*arw_m11	arw_cn – nmmb-p3_pert	21Z SREF nmmb-p3	yes	Thompson	RUC	YSU
*arw_m12	arw_cn – em-p3_pert	21Z SREF em-p3	yes	Thompson	Noah	MYNN
arw_m13	arw_cn – nmm-p2_pert	21Z SREF nmm-p2	yes	Morrison	Noah	QNSE
arw_m14	00Z ARPSa	00Z NAMf	yes	Thompson	Noah	MYNN
arw_m15	00Z ARPSa	00Z NAMf	yes	Thompson	Noah	YSU-T
arw_m16	00Z ARPSa	00Z NAMf	yes	Thompson	Noah	YSU
arw_m17	00Z ARPSa	00Z NAMf	yes	MY2	Noah	MYJ
arw_m18	00Z ARPSa	00Z NAMf	yes	MY	Noah	MYJ
arw_m19	00Z ARPSa	00Z NAMf	yes	Milbrant-Morrison	Noah	MYJ
arw_m20	00Z ARPSa	00Z NAMf	yes	Morrison	Noah	MYJ

Note 1: For all members: *ra_lw_physics*= RRTMG; *ra_sw_physics*=RRTMG; *cu_physics*=none
Note 2: MY2 is a modified version of Milbrandt-Yau microphysics scheme; YSU-T is the Thompson modified YSU PBL scheme
Note 3: m19 uses the newly developed P3 (Morrison-Milbrandt) microphysics

Table 2. Configurations for each individual member with COAMPS

Member	IC	BC	Radar data	Microphy.	PBL
cmps_cn	00Z ARPSa	00Z NAMf	yes	Hobbs-Rutledge	Mellor-Yamada
cmps_c1	00Z ARPSa	00Z NAMf	yes	Thompson	Mellor-Yamada

cmps_c2	00Z ARPSa	00Z NAMf	yes	M-Y	Mellor-Yamada
cmps_c3	00Z ARPSa	00Z NAMf	yes	Thompson	YSU

* For all members: no cumulus parameterization

The lateral boundary conditions come from the corresponding 21Z SREF forecasts directly for those perturbed members and from the 00Z 12-km NAM forecast for the non-SREF-perturbed members.

All ensemble-derived products of 2014 are based on the 12 ARW members highlighted in red in Table 1. They exclude members without radar data, and members that had physics perturbations only.

An eight-member ensemble initiated at 12 UTC, consisting of selected WRF-ARW members in Table 1 marked with "*" (cn, m4, m5, m6, m8, m10, m11, m12), is produced for 2014 Spring Experiment. This small ensemble is run locally on Boomer at the Oklahoma Supercomputing Center for Education and Research (OSCER) at University of Oklahoma, producing twenty-four-hour forecasts daily.

A major push in 2014 is that the experimental EnKF based forecasting is expanded to include a one hour EnKF cycling at 15 min interval from 2300 UTC to 0000 UTC following a 5-h 40-member ensemble forecast initiated from 1800 UTC, and over the same CONUS domain as other regular SSEF (Figure 1). In order to provide an ensemble background for EnKF, a separate 4-km ensemble of 5-h forecasts, starting at 1800 UTC, with 40 WRF-ARW members is produced over the 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 (see Table 3). No radar data is analyzed 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 23 to 00 UTC every 15 min over the CONUS domain, using as background the 40-member ensemble in Table 3. A 12- member ensemble forecast (24h) follows using the 00 UTC EnKF analyses (see Table 4. In addition, two deterministic forecasts, one from the ensemble mean analysis and another from 3DVAR analysis, are also produced.

Special code was developed to handle highly parallelized (MPI) EnKF analysis and the IC/LBC update for each cycle.

Table 3. Configuration for the EnKF background ensemble

Member	IC	BC	Microphy – WSM6 (N0r, N0g, ρg)*	LSM	PBL
enk_m1	18Z ARPSa	18Z NAMf	(8,6),(4,6),500	Noah	MYJ
enk_m2	arw_cn + em-p1_pert	18Z SREF em-p1	(8,6),(4,6),500	Noah	YSU
enk_m3	arw_cn + nmm-n2_pert	18Z SREF nmm-n2	(9.4,6),(5,4),673	Noah	MYJ
enk_m4	arw_cn + em-n2_pert	18Z SREF em-n2	(2.4,7),(5.7,4),666	Noah	ACM2
enk_m5	arw_cn + nmmb-p2_pert	18Z SREF nmmb-p2	(3.7,7),(6.3,4),659	Noah	ACM2
enk_m6	arw_cn + nmm-p1_pert	18Z SREF nmm-p1	(2.5,6),(8,4),652	Noah	MYNN
enk_m7	arw_cn + nmmb-n1_pert	18Z SREF nmmb-n1	(2.6,7),(9,4),645	Noah	MYJ
enk_m8	arw_cn – nmmb-p1_pert	18Z SREF nmmb-p1	(6.8,6),(1,5),638	Noah	YSU
enk_m9	arw_cn + em-n1_pert	18Z SREF em-n1	(3,6),(1.1,5),631	Noah	QNSE
enk_m10	arw_cn – em-p2_pert	18Z SREF em-p2	(8.4,6),(1.3,5),624	Noah	MYNN
enk_m11	arw_cn – nmmb-n3_pert	18Z SREF nmmb-n3	(1.5,7),(1.4,5),617	Noah	MYJ
enk_m12	arw_cn – nmmb-p3_pert	18Z SREF nmmb-p3	(3.1,6),(1.6,5),610	Noah	YSU
enk_m13	arw_cn – em-p3_pert	18Z SREF em-p3	(8.6,5),(1.8,5),603	Noah	ACM2
enk_m14	arw_cn – nmm-p2_pert	18Z SREF nmm-p2	(4.6,6),(2,5),596	Noah	QNSE
enk_m15	arw_cn + em-p1_pert	18Z SREF em-p1	(1.3,7),(2.2,5),589	Noah	MYNN
enk_m16	arw_cn + nmm-n2_pert	18Z SREF nmm-n2	(5.1,6),(2.5,5),582	Noah	ACM2
enk_m17	arw_cn + em-n2_pert	18Z SREF em-n2	(8.1,5),(2.8,5),575	Noah	MYJ
enk_m18	arw_cn + nmmb-p2_pert	18Z SREF nmmb-p2	(1.9,6),(3.2,5),568	Noah	ACM2
enk_m19	arw_cn + nmm-p1_pert	18Z SREF nmm-p1	(3.9,7),(3.6,5),561	Noah	MYJ

enk_m20	arw_cn + nmmb-n1_pert	18Z SREF nmmb-n1	(2.2,6),(4,5),554	Noah	QNSE
enk_m21	arw_cn – nmmb-p1_pert	18Z SREF nmmb-p1	(8.5,6),(4.5,5),547	Noah	MYJ
enk_m22	arw_cn + em-n1_pert	18Z SREF em-n1	(1.1,7),(5,5),540	Noah	MYJ
enk_m23	arw_cn – em-p2_pert	18Z SREF em-p2	(8.1,5),(5.7,5),533	Noah	YSU
enk_m24	arw_cn – nmmb-n3_pert	18Z SREF nmmb-n3	(1,7),(6.4,5),526	Noah	QNSE
enk_m25	arw_cn – nmmb-p3_pert	18Z SREF nmmb-p3	(2.2,7),(7.1,5),519	Noah	MYNN
enk_m26	arw_cn – em-p3_pert	18Z SREF em-p3	(7.2,6),(8,5),512	Noah	MYJ
enk_m27	arw_cn – nmm-p2_pert	18Z SREF nmm-p2	(8.9,6),(9,5),505	Noah	YSU
enk_m28	arw_cn – nmmb-p3_pert	18Z SREF nmmb-p3	(2.9,7),(1,6),498	Noah	ACM2
enk_m29	arw_cn – em-p3_pert	18Z SREF em-p3	(1.1,7),(1.1,6),491	Noah	QNSE
enk_m30	arw_cn – nmm-p2_pert	18Z SREF nmm-p2	(9.6,6),(1.3,6),484	Noah	MYJ
enk_m31	arw_cn + em-p1_pert	18Z SREF em-p1	(3.1,6),(1.4,6),477	Noah	QNSE
enk_m32	arw_cn + nmm-n2_pert	18Z SREF nmm-n2	(1.3,6),(1.6,6),470	Noah	MYNN
enk_m33	arw_cn + em-n2_pert	18Z SREF em-n2	(2,6),(1.8,6),463	Noah	MYJ
enk_m34	arw_cn + nmmb-p2_pert	18Z SREF nmmb-p2	(4.4,6),(2,6),456	Noah	YSU
enk_m35	arw_cn + nmm-p1_pert	18Z SREF nmm-p1	(1.7,6),(2.2,6),449	Noah	ACM2
enk_m36	arw_cn + nmmb-n1_pert	18Z SREF nmmb-n1	(4.3,6),(2.5,6),442	Noah	QNSE
enk_m37	arw_cn – nmmb-p1_pert	18Z SREF nmmb-p1	(1.3,6),(2.8,6),435	Noah	MYNN
enk_m38	arw_cn + em-n1_pert	18Z SREF em-n1	(9.1,5),(3.2,6),428	Noah	MYJ
enk_m39	arw_cn – em-p2_pert	18Z SREF em-p2	(5,6),(3.6,6),421	Noah	YSU
enk_m40	arw_cn – nmmb-n3_pert	18Z SREF nmmb-n3	(6.1,6),(3.9,6),414	Noah	MYJ

* For N0r and N0h, (a, b) are coefficients of $a \times 10^b$.

Table 4. Configuration for the EnKF 12-member ensemble forecasts

Member	IC	BC	Microphysics	LSM	PBL
enkf_m1	enk_m1a	arw_cn	Thompson	Noah	MYJ
enkf_m2	enk_m2a	arw_m3	MY	Noah	MYJ
enkf_m3	enk_m3a	arw_m4	Morrison	Noah	MYJ
enkf_m6	enk_m6a	arw_m5	Thompson	Noah	MYNN
enkf_m7	enk_m7a	arw_m6	MY	Noah	YSU
enkf_m8	enk_m8a	arw_m7	Morrison	Noah	YSU
enkf_m9	enk_m9a	arw_m8	Thompson	Noah	QNSE
enkf_m10	enk_m10a	arw_m9	MY	Noah	MYNN
enkf_m11	enk_m11a	arw_m10	Thompson	Noah	YSU
enkf_m12	enk_m12a	arw_m11	WDM6	Noah	YSU
enkf_m15	enk_m15a	arw_m12	Morrison	Noah	MYNN
enkf_m16	enk_m16a	arw_m13	WDM6	Noah	MYJ

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