New Dimension of NCEP Short-Range Ensemble Forecasting (SREF) System: Inclusion of WRF Members

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1 History of NCEP SREF

Encouraged by the success of global medium-range ensemble practice at NCEP (Tracton and Kalnay, 1993; Toth and Kalnay, 1993) and ECMWF (Mureau *et. al.*, 2003), a few pioneer efforts were also given to regional model based short-range ensemble research in early 1990s such as Mullen and Du (1994) and Du *et. al.* (1997). The first workshop focusing on short-range ensemble forecasting was held at NCEP (then NMC) from 25-27, July 2004 (Brooks et. al., 1995). Following the recommendation from this earlier workshop, a prototype regional-model based ensemble system was setup and run at NCEP in 1995-1996 (DiMego, Rogers, Tracton, Toth and Du) on weather event basis (roughly once per week) and the output was shipped to NSSL for archive and evaluation (Stensrud et. al., 2000). Based on the promising results seen from an early-version of this prototype system (Stensrud et. al., 2000; Hamill and Colucci, 1997 and 1998) as well as from an improved version later on (Tracton et. al. 1998; Tracton and Du, 2001a, 2001b; Hou et. al., 2001), a 10-member Short-Range Ensemble Forecasting (SREF) system started to run daily (but in a delayed mode) from April 2000 for case studies and systematic evaluation. Ironically, due mainly to a majoy snowstorm forecast bust (known as Jan. 24-26 2000 Blizzard over Washington DC and North Carolina region, see Zhang *et. al.*, 2002) – missed by then operational deterministic models (Eta and AVN) but a clear heads-up signal given by the experimental SREF system (about 20-30% chance of being heavy snow event 24hr ahead of time, see Tracton and Du, 2001a, 2001b), this 10-member system was then operationally implemented and used real-time at NCEP in May 2001 with an accelerated pace (Du and Tracton, 2001). This was the first real-time, operational regional ensemble prediction system in the world.

From the very beginning of its development stage, the NCEP SREF system has emphasized **both** initial condition (IC) and model physics uncertainties by using multi-analysis (edas and gdas), multi-LBCs (using NCEP global ensemble members), multi-model (Eta and RSM) and perturbed ICs (breeding method, see Toth and Kalnay, 1997) mixed approaches (Tracton et. al. 1998). In September 2003, another set of 5 Eta members but with a different version of convective scheme (Kain-Fritch) was added (For a total of 15 members) to further address physics uncertainty (Du et. al. 2003). The date of August 17, 2004 marks a new level of addressing physics diversity by implementing a total of 6 various convective schemes to the syetem besides perturbing ICs in 12 out of its 15 members (Du et. al. 2004; McQueen et. al. 2005).

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This report describes another important milestone which was achieved recently at NCEP. Six Weather-Research-Forecast (WRF) model based members were operationally implemented as part of the NCEP SREF system on December 6, 2005. Three members use NCEP NMM core, while other 3 members use NCAR ARW core (Table 1). Now, there are a total of 21 members in NCEP SREF system in each cycle (two cycles per day to 87 hours, holizontal resolution varies among members from 32 to 45 km, Table 1). This implementation marks the beginning of transition of NCEP SREF into WRF era. Numerous real-time NCEP SREF forecast products are avialable twice per day at http://wwwt.emc.ncep.noaa.gov/mmb/SREF/SREF.html.

The NCEP SREF has been playing an important role in both weather forecasting operation and ensemble development and research since the operational implementation in 2001. Now, the NCEP SREF is an integrated and crucial part of daily weather forecasting process in the US National Weather Service. Many and generally positive feedbacks have been received from fields forecasters on a regular basis especially following severe or rare weather events (Richard Grumm, http://eyewall.met.psu.edu/). The NCEP SREF system and its developement experiences and lessens learnt such as significant impact of LBC on ensemble spread (Du and Tracton, 1999) also served as a model and valuable asset for many other regional ensemble prediction systems during their planning and development stage around the world. IC's and LBC's perturbations generated by NCEP SREF were also directly used to initiate other region ensemble systems in some US universities (Jones and Colle, 2005). In the past, many published research work have also directly based on NCEP SREF outputs.

2 Results

Reader is referred to the captions of Figures 1-6 for the description of results. All results are evaluated against the NCEP global analysis (GDAS) and averaged over the 212 AWIPS grid domain (40km CONUS) during the period Aug. 25 to Sept. 17, 2005. Improvements are shown in all fileds and can be attributed to increased model diversity by including WRF members.

3 Looking Forward

Bias correction is an immediate need for this 21-member system to be more robust (Figs. 6-7). The NCEP SREF is planned to be transfered from a multi-model based system to a unified WRF-based one (but still having various dynamic cores and physics packages within the umbrella of WRF modeling framework) in near future. Therefore, it is also desired to investigate if a WRF-member only SREF system will have similar quality comparing to the current multi-model based system, i.e. comparable accuracy in both ensemble mean and probabilistic forecasts and simi-

model/Dyn Core	Physics	Res	Configuration	Membership	base IC	LBC	LSM
Eta	BMJ	32km/L60	N America/hydro	3 (1 ctl, 2 bred)	NDAS	glb ens	NOAH
Eta	BMJ-SAT	32km/L60	N America/hydro	2 (2 bred)	NDAS	glb ens	NOAH
Eta	KF	32km/L60	N America/hydro	3 (1 ctl, 2 bred)	NDAS	glb ens	NOAH
Eta	KF-DET	32km/L60	N America/hydro	2 (2 bred)	NDAS	glb ens	NOAH
RSM	SAS	45km/L28	N America/hydro	3 (1 ctl, 2 bred)	GDAS	glb ens	NOAH
RSM	RAS	45km/L28	N America/hydro	2 (2 bred)	GDAS	glb ens	NOAH
WRF NMM	NCEP/BMJ	40km/L52	N America/non-hydro	3 (1 ctl, 2 bred)	GDAS	glb ens	NOAH
WRF ARW	NCAR/KF	45km/L36	N America/non-hydro	3 (1 ctl, 2 bred)	GDAS	glb ens	NOAH

Table 1: Configuration of the 21-member NCEP SREF system. The last two rows are the setup of the 6 WRF members.

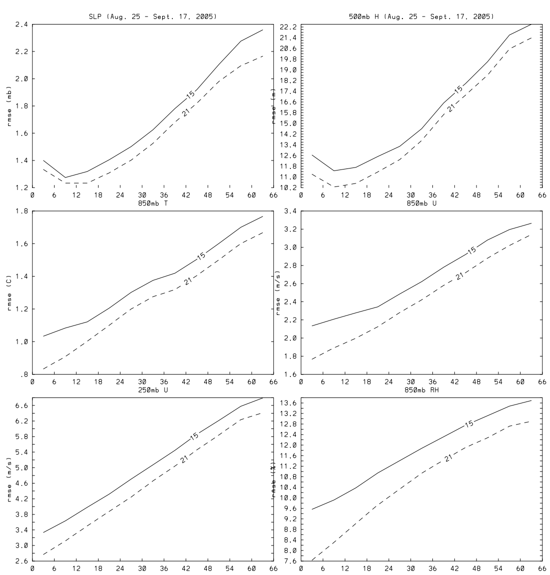

Figure 1: RMSE of the 21-member based ensemble mean forecast is largely reduced over that of the 15-member based for six selected fields: SLP, 500mb H, 850mb T, 850mb U, 250mb U and 850mb RH.

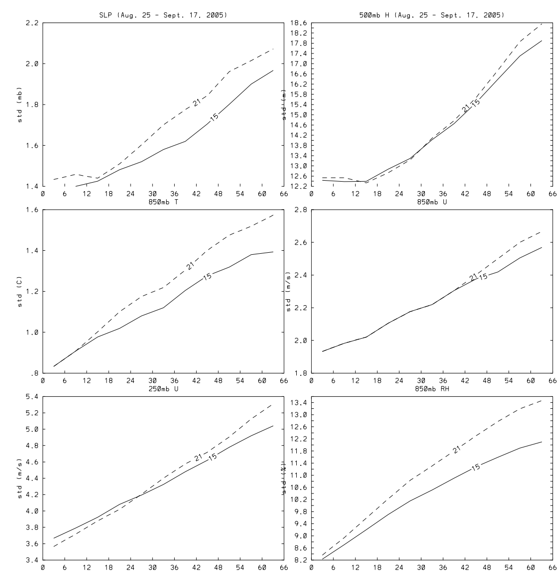

Figure 2: The ensemble spread is increased from the 15-member based to the 21-member based SREF system with a larger growth rate too!

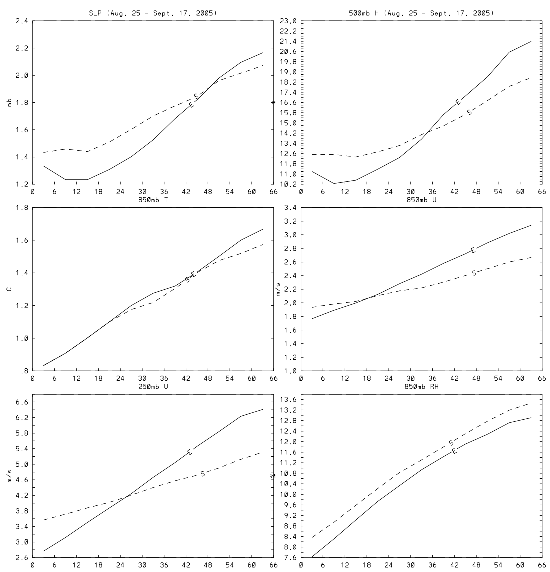

Figure 3: Due to the reduction of forecast error and the increase of ensemble spread, the spread-skill relationship is improved, i.e. the ensemble spread (lable "S") is now closer to the error of ensemble mean forecast (labled "E") for an originally underdispersive ensemble system.

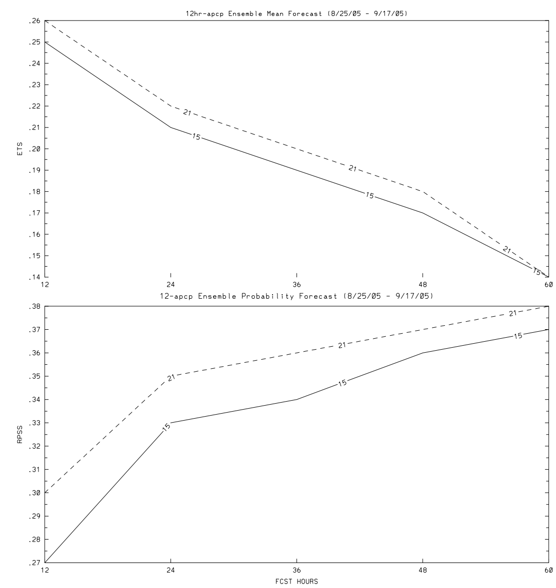

Figure 4: Similar improvements are also seen for ensemble mean precipitation forecasts in terms of Equitable Threat Score (upper panel) and for probabilistic precipitation forecasts measured by Ranked Probability Skill Score (here, the accuracy of 12km-NAM forecast is used as a reference in calculating the skill) (lower panel).

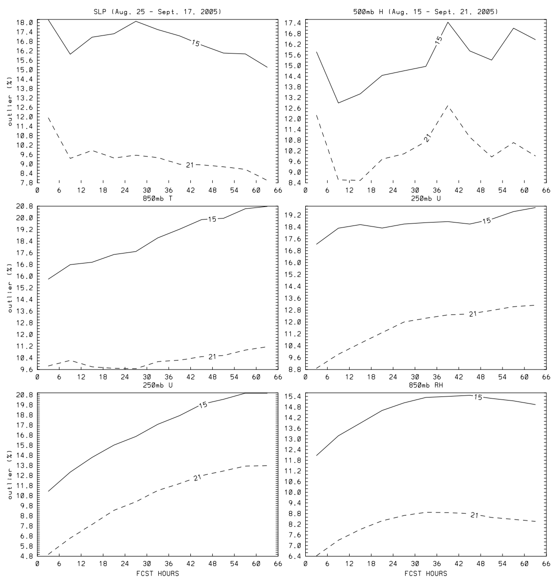

Figure 5: Outlier is decreased, i.e., the chance that truth to be left outside a forecast range predicted by the ensemble becomes much less after the 6 WRF members are added.

larly large and good spread. To improve more on public-sensitive weather elements *e.g.* clouds, fog, and surface variables such as T_2m, Td_2m, 10-m wind, visibility, and precipitaion type, a more wide range of physics diversity including cloud, radiation, PBL and land-surface model as well as Ensemble Transformation technique based alternative IC perturbation generating method will be tested and possibly incorporated in the system in future. Besides weather forecasting, application of the SREF to other areas such as aviation (Zhou et. al, 2004), energy industry (Stensrud and Yussouf, 2003), air quality, dispersion modeling and hydrology prediction (Yuan et. al, 2005, 2006) as well as to data assimilation and targeted observation is also under testing and consideration now. This new version of WRF-based NCEP SREF system will be used as part of the 2008 Beijing Olympic mesoscale ensemble project.

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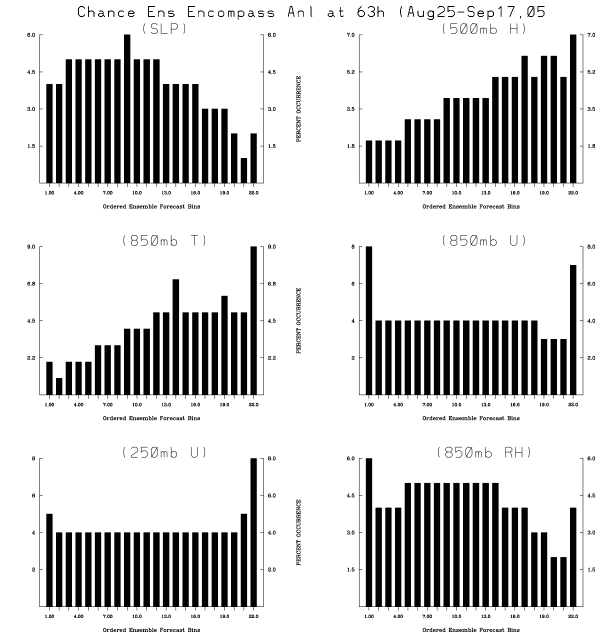

Figure 6: Talagrand Distribution or Rank Histogram shows that bias error is obviously possessed particularly for mass fields in the 21-member NCEP SREF system.

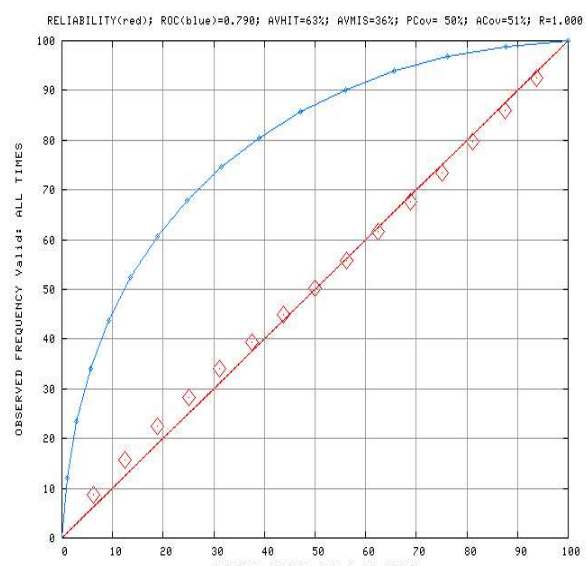

Figure 7: After bias correction, probabilistic forecasts of T2m from NCEP SREF at 00hr, 48hr and 84hr (shown) forecasts all show near-perfect reliability. Note: Another curve in the figure is the ROC. This result is based on 30-day 21-member SREF forecasts during December-January 2006 and a courtsey from Dr. David Bright at Storm Prediction Center of NCEP.

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