

#### **4A.4 NCEP Short Range Ensemble Forecast (SREF) System Upgrade in 2009**

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##### **1. Introduction**

Current NCEP Short Range Ensemble Forecast (SREF) system is an ensemble of ensembles. It was started to be developed around 1995 (Tracton *et. al.*, 1998; Stensrud *et. al.*, 1999) followed a special workshop (Brooks *et. al.*, 1995) and operationally implemented in May 2001 initially as a 10-member Eta (with BMJ convective scheme)/RSM based multi-model regional ensemble prediction system (Du and Tracton, 2001). Five members of another version of Eta (with K-F convective scheme) were added in 2003 (Du *et. al.*, 2003). In August 2004, more convective schemes were applied to the models to further address physics uncertainty (Du *et. al.*, 2004). The last major upgrade to the system occurred in December 2005 when six WRF members (3 NMM and 3 ARW) were added to then 15-member Eta/RSM-based SREF as an example of fast transition from research to operation in terms of WRF community model (Du *et. al.*, 2006). As model improves, computing power increases and more user requests are received, it's time to upgrade the system again. This paper is a brief description of the incoming SREF upgrade in late 2009.

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## 2. Upgrades

There are mainly two aspects being upgraded: one in ensemble system including models and another in products. In the aspect related to ensemble system, the changes can be seen by comparing Table 2 (upgraded system) with Table 1 (current system) and are highlighted in Table 2. First, the model version has been upgraded for three models: NMM from v2.0 to v2.2, ARW from v2.0 to v2.2 and RSM from v2003 to v2008. Model horizontal resolution of the same three models has also been increased from 40kmish to a uniformly 32km (ARW is 35km). To increase physics diversity, the Zhao microphysics has been replaced by Ferrier

Table 1: December 2005 SREF System (21 members)

Model	Membership	Resolution	Forecast Hours	IC/IC perturbation	LBC/LBC perturbation	Output Frequency for pgrb files	Output Frequency for bufr soundings
Eta_BMJ	3 (ctl1, n1, p1)	32km	87hr	ndas/regional bred	GFS/GEFS	3hrly	3hrly
Eta_SAT	2 (n3, p3)	32km	87hr	ndas/regional bred	GFS/GEFS	3hrly	3hrly
Eta_KF	3 (ctl2, n2, p2)	32km	87hr	ndas/regional bred	GFS/GEFS	3hrly	3hrly
Eta_DET	2 (n4, p4)	32km	87hr	ndas/regional bred	GFS/GEFS	3hrly	3hrly
RSM_SAS (Zhao MP)	3 (ctl1, n1, p1)	45km	87hr	GFS 3hr fcst/regional bred	GFS/GEFS	3hrly	3hrly
RSM_RAS (Zhao MP)	2 (n2, p2)	45km	87hr	GFS 3hr fcst/regional bred	GFS/GEFS	3hrly	3hrly
NMM	3 (ctl, n1, p1)	40km	87hr	GFS 3hr fcst/regional bred	GFS/GEFS	3hrly	3hrly
ARW	3 (ctl, n1, p1)	45km	87hr	GFS 3hr fcst/regional bred	GFS/GEFS	3hrly	3hrly

scheme for the three RSM\_SAS members given the fact that the difference between SAS (Simplified Alakawa-Shubert scheme) and RAS (Relaxed Alakawa-Shubert scheme) convective schemes is small. Since the NCEP global ensemble forecast system (GEFS) uses

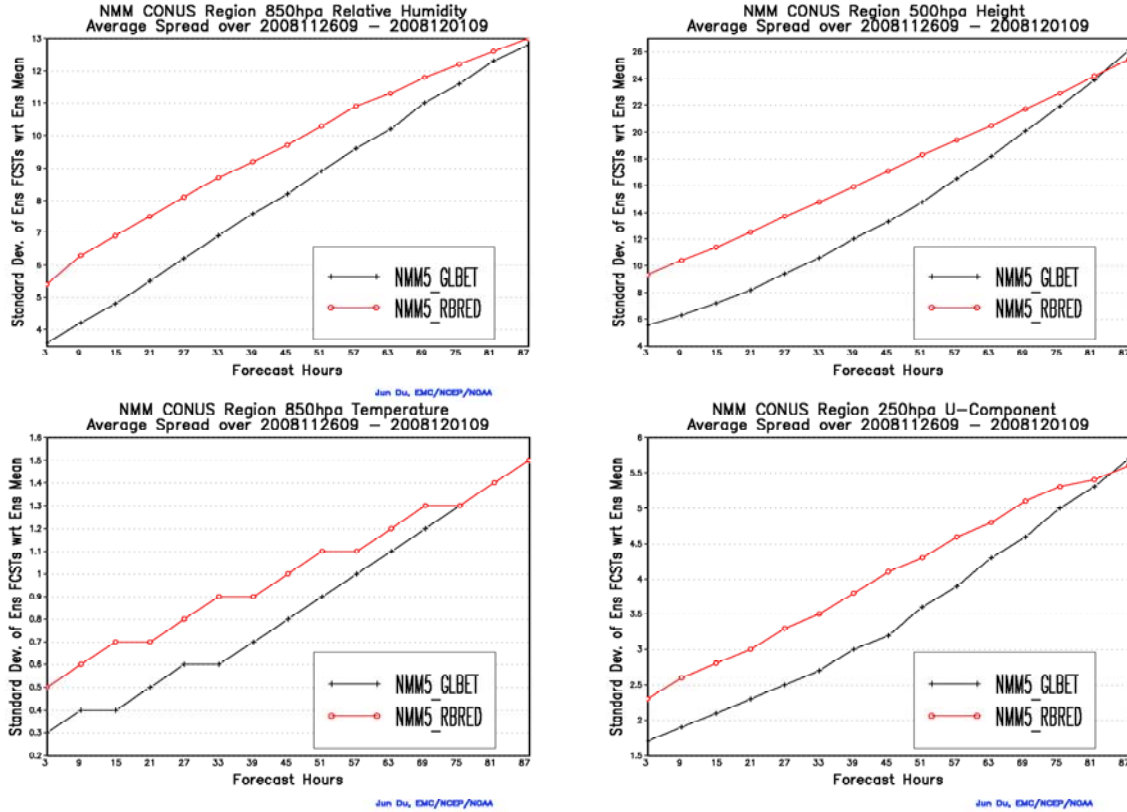
Table 2: Late 2009 SREF System (21 members)

Model	Membership	Resolution	Forecast Hours	IC/IC perturbation	LBC/LBC perturbation	Output Frequency for pgrb files	Output Frequency for bufr soundings
Eta_BMJ	3 (ctl1, n1, p1)	32km	87hr	ndas/regional bred	GFS/GEFS	<u>1hrly to 39hr</u> , 3hrly afterward	<u>1hrly and breakdown</u>
Eta_KF	3 (ctl2, n2, p2)	32km	87hr	ndas/regional bred	GFS/GEFS	<u>1hrly to 39hr</u> , 3hrly afterward	<u>1hrly and breakdown</u>
<b>RSM_SAS</b> ( <b>Ferrier MP</b> )	3 (ctl1, n1, p1)	<u>32km</u>	87hr	GFS 3hr fcst/regional bred	GFS/GEFS	<u>1hrly to 39hr</u> , 3hrly afterward	<u>1hrly and breakdown</u>
<b>RSM_RAS</b> (Zhao MP)	2 (n2, p2)	<u>32km</u>	87hr	GFS 3hr fcst/regional bred	GFS/GEFS	<u>1hrly to 39hr</u> , 3hrly afterward	<u>1hrly and breakdown</u>
<b>NMM</b>	<u>5</u> (ctl, n1, p1, <u>n2, p2</u> )	<u>32km</u>	87hr	GFS 3hr fcst/ <u>global ET</u>	GFS/GEFS	<u>1hrly to 39hr</u> , 3hrly afterward	<u>1hrly and breakdown</u>
<b>ARW</b>	<u>5</u> (ctl, n1, p1, <u>n2, p2</u> )	<u>35km</u>	87hr	GFS 3hr fcst/ <u>global ET</u>	GFS/GEFS	<u>1hrly to 39hr</u> , 3hrly afterward	<u>1hrly and breakdown</u>

Ensemble Transform (ET, Wei *et. al.*, 2008) technique to generate its IC perturbations, to take advantage of this new technique as well as to be consistent between perturbations in ICs and LBCs (from GEFS), the eight perturbed WRF members (4 NMM and 4 ARW) use ET perturbations directly from GEFS in stead of generating its own regional bred vectors (Toth and Kalnay, 1993) as their IC perturbations. By doing so, the ensemble spread growth rate seems to become larger and, therefore, be improved (Fig. 1). Finally, ensemble membership has been adjusted to have a more balanced diversity in model - about 5 members for each model - by reducing Eta membership from 10 to 6 and increasing WRF membership from 6 to 10. Two modified BMJ members (so-called SAT/Saturation) and two modified KF members (so-called DET/Full Detrainment) were eliminated based on their relatively poor

performance. For each of NMM and ARW models, a pair of perturbed members were added respectively.

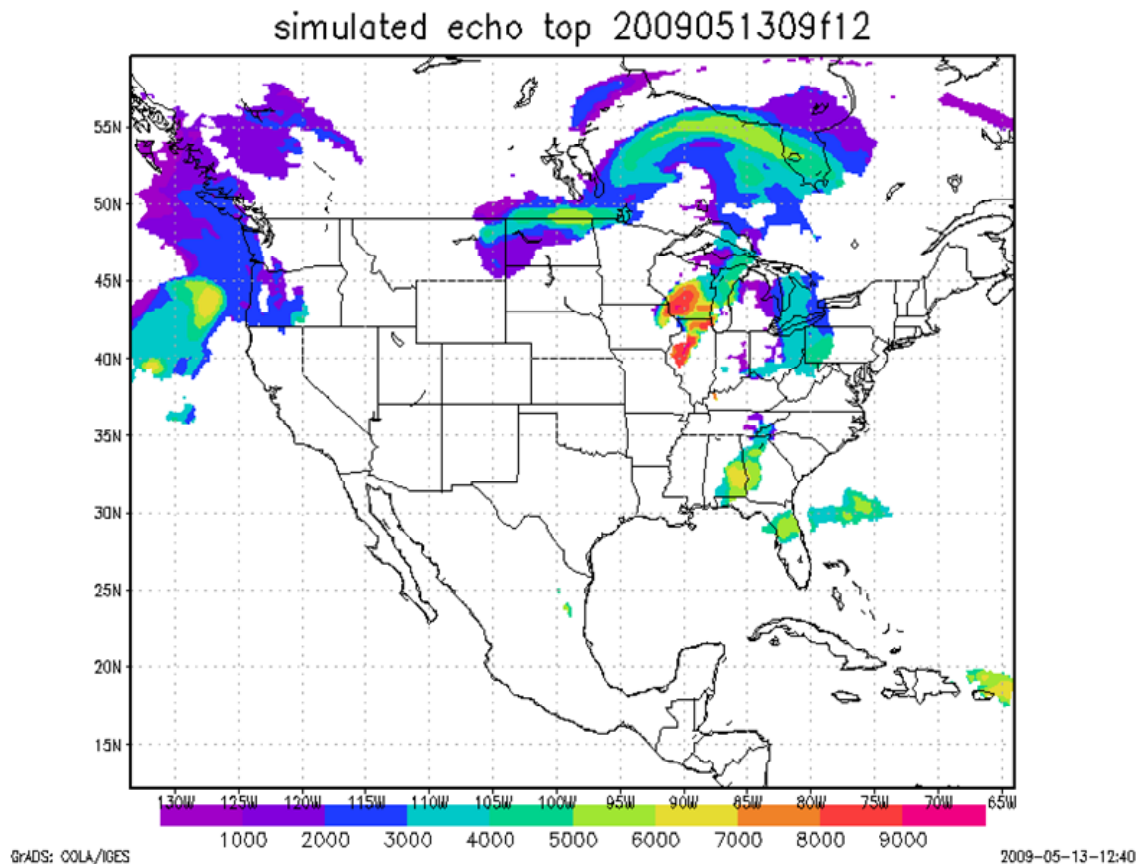
Fig. 1: Ensemble spread growth from 5-member NMM ensembles: one with global ET (GLBET) and another with regional Bred (RBRED) IC perturbations



To meet the requests from forecasters and other users, many changes and additions have been made to the forecast products in the upgraded SREF system. First of all, the frequency of forecast output has been increased from 3-hourly to 1-hourly (to 39hr for pressure-grib files and to 87hr for bufr sounding data) to meet requirements of convection and aviation forecasting. Bufr data was breakdown to one file per station for forecaster's convenience. Composite radar reflectivity and radar echo top/height (altitude convection penetrating vertically, an example is shown in Fig. 2) fields were also added to 10 WRF and 5 RSM members for convection and aviation users. Icing and Flight Restriction etc. products were

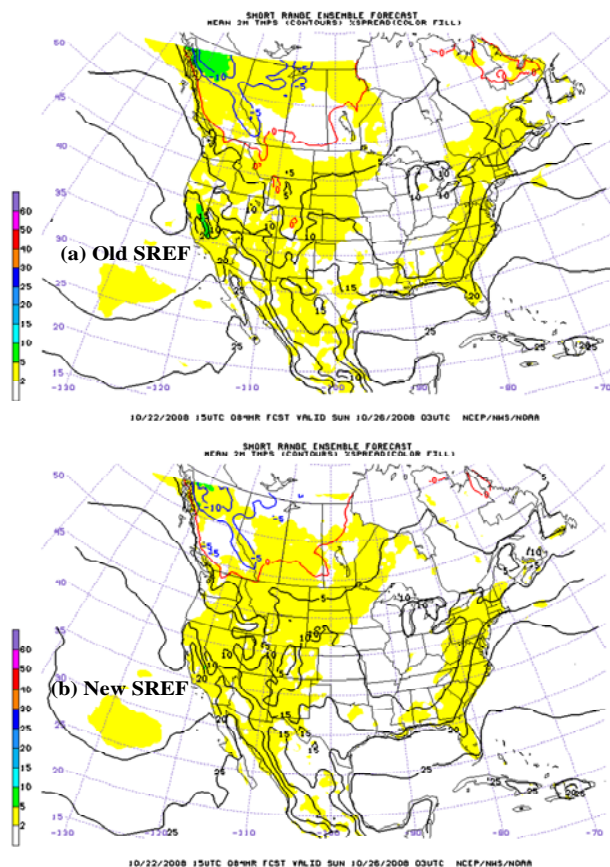
tailored to aviation users. Requested by air quality and dispersion modeling community, Richardson Number based planetary boundary layer (PBL) height was added for all 21 SREF members and wind variance field were calculated based on ensemble members. Given the good performance and positive feedback from forecasters about the SREF-based hurricane track forecasts during the last two hurricane seasons (2007 and 2008), a tropical cyclone tracker was added to produce hurricane track forecasts for individual member and ensemble mean forecasts for further evaluation and application. It could be part of EMC contribution to the on-going NOAA Hurricane Forecast Improvement Project (HFIP).

Fig. 2: An example of 12-hour forecast of Radar Echo Top from new SREF NMM\_ctl member



### 3. Verification

Verification was performed by both NCEP EMC developers and other service centers' forecasters over several extensive periods of time including Jun. - Jul., 2008, Sept. - Nov. 2008, Feb. - May 2009 as well as retrospective runs of four cold-season cases in 2008 selected by HPC and SPC forecasters (covering 20 days). Both statistical scores (deterministic and probabilistic) and case studies were examined. The main results are summarized below: (a) a known strong cold bias of low-level temperature fields (especially NMM members) was much reduced using new model version. An example is given in Fig. 3 where the old SREF (Fig. 3a) predicted way too cold especially over northwest region (10 deg too cold), while the new SREF (Fig. 3b) greatly reduced this cold bias by about 5 deg although it's still too cold comparing to the analysis (Fig. 3c) in this particular case.



**Fig. 3: 84hr T2m SREF mean forecasts from the old SREF (a) and new SREF (b). (c) is the analysis.**

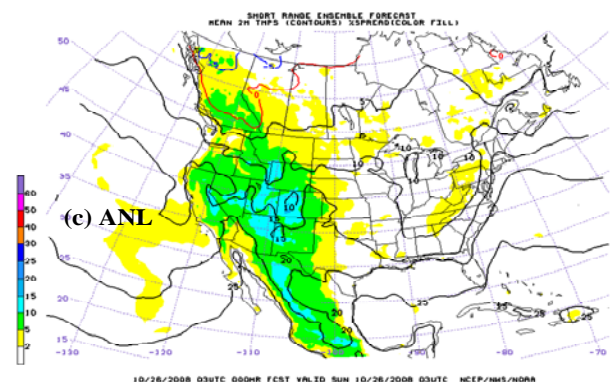


Fig.4: Talagrand Distribution of 87hr 500hpa-height forecast over CONUS during a two week period of time: old SREF is in red and new SREF in black

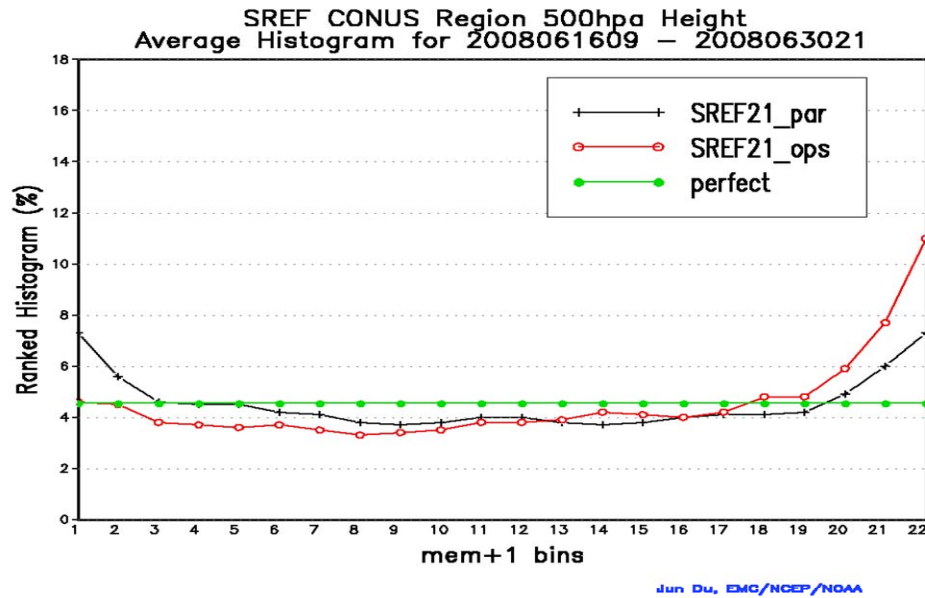
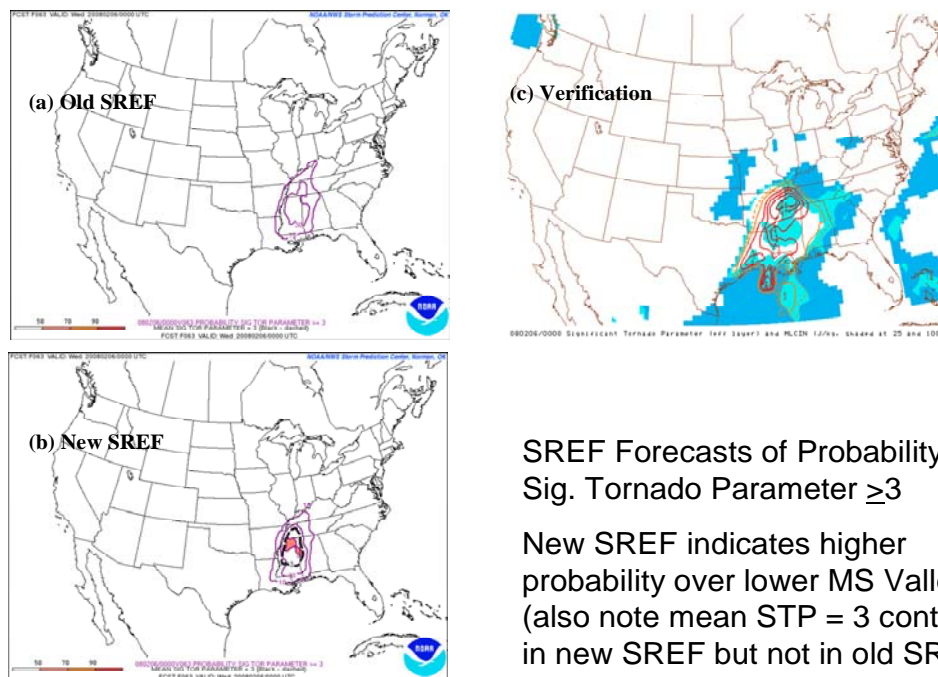


Fig. 5: Day 3 SREF 09z 3 Feb 2008: 63-hr forecasts valid at 00 UTC 6 Feb 2008 (Super Tuesday Tornado case, provided by David Bright of SPC)



SREF Forecasts of Probability of Sig. Tornado Parameter  $\geq 3$

New SREF indicates higher probability over lower MS Valley (also note mean STP = 3 contour in new SREF but not in old SREF)

(b) Due to model upgrade, the performance of individual ensemble members was seen improved in general (not shown), which results in a higher-confidence SREF system with ensemble spread reduced slightly in magnitude but better in quality (*e.g.* Fig. 4), higher-probability values and improved forecasts. Fig. 5 is an example provided by SPC showing higher probability of “Significant Tornado Parameter” exceeding a threshold from the upgraded SREF. Fig. 6 shows an improved ensemble forecast by the new SREF over the

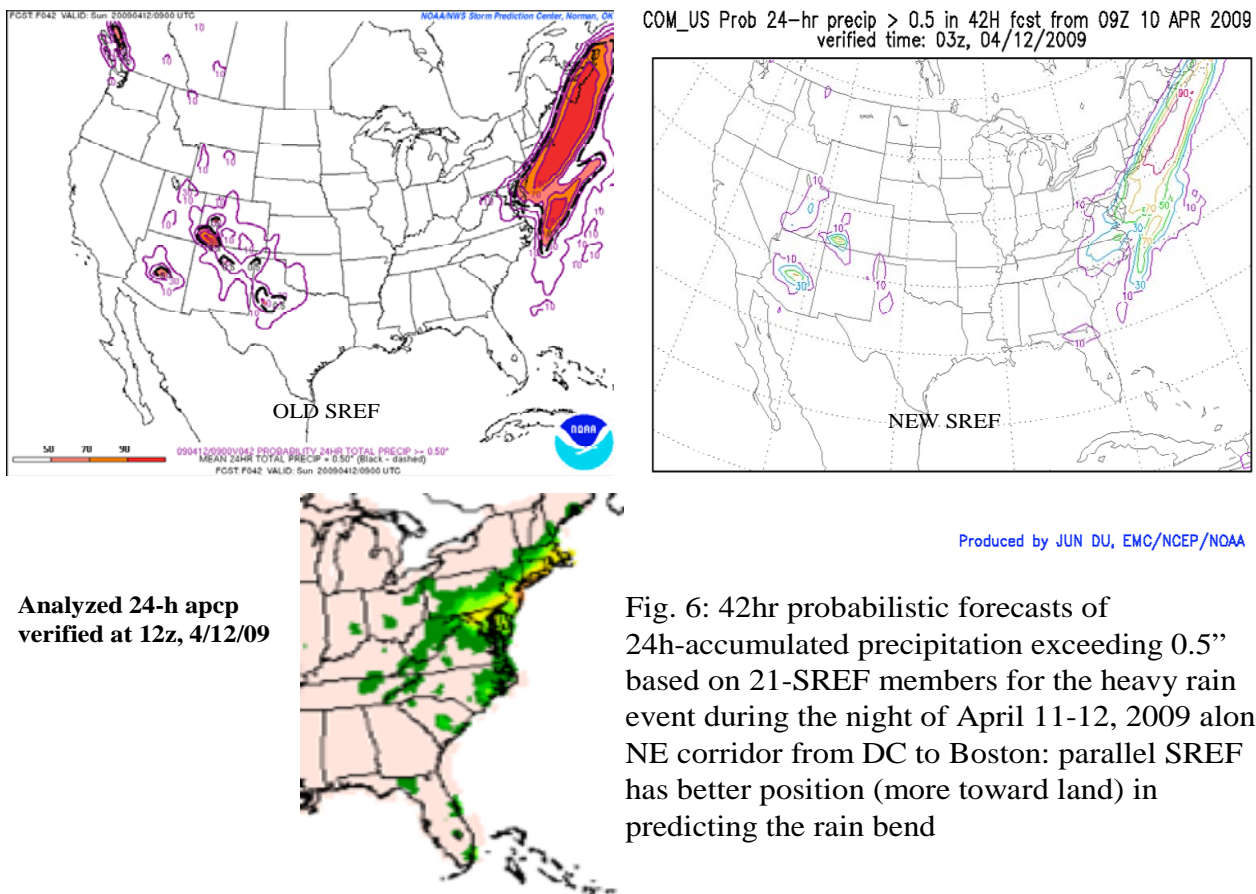
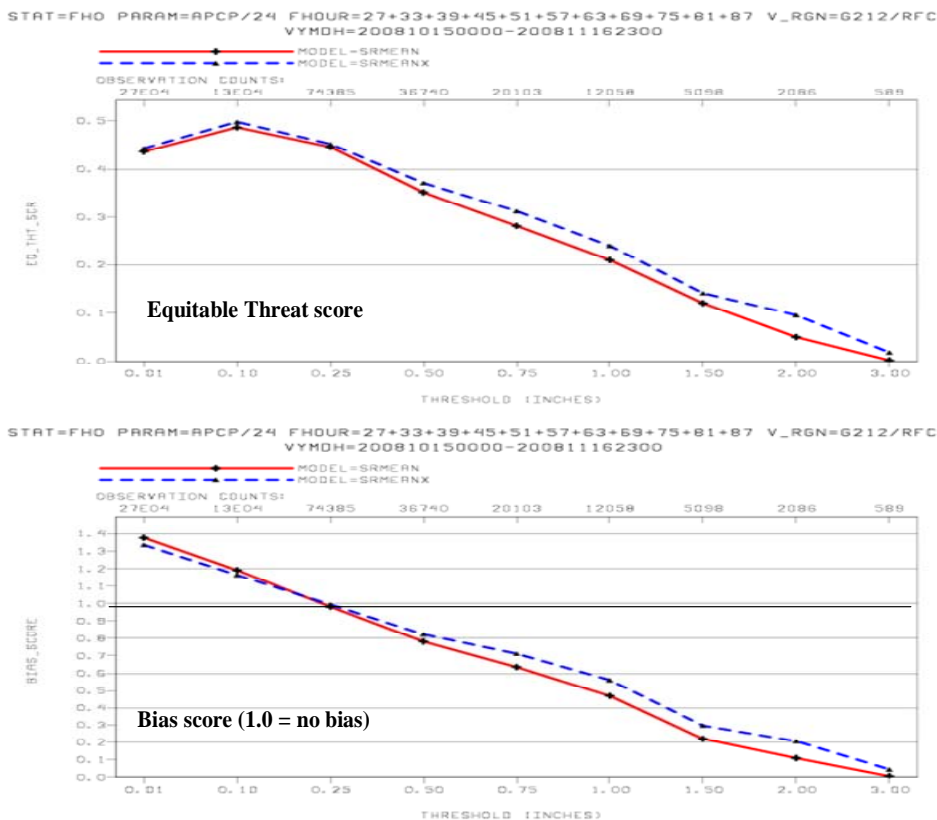


Fig. 6: 42hr probabilistic forecasts of 24h-accumulated precipitation exceeding 0.5” based on 21-SREF members for the heavy rain event during the night of April 11-12, 2009 along NE corridor from DC to Boston: parallel SREF has better position (more toward land) in predicting the rain bend

old SREF for a major precipitation event ( $>0.5$ ”) over Northeast corridor (from Washington DC to Boston) in the night of April 11, 2009. The event wasn’t predicted well by operational models by putting the rain bend too little over land (HPC SOO David Novak, personal communication). Comparing with the operational SREF, the upgraded parallel SREF predicted a better position by correctly moving the rain bend toward inland.

(c) Statistically, the overall performance of the upgraded SREF forecasts has been improved which includes more accurate ensemble mean forecasts (Fig. 7) and more skillful (Fig. 8) and more reliable (Fig. 9) probabilistic forecasts. (d) Finally, due to the increase of model horizontal resolution, more detailed spatial features of many fields such as precipitation and surface temperature can now be revealed (Fig. 10).

Fig. 7: Equitable Threat score (ETS) and Bias score of 24h-accumulated precipitation forecasts of ensemble mean over CONUS, averaged over the period of Oct. 15 – Nov. 16, 2008. New SREF is in dash line and old SREF in solid line. Both ETS and Bias score improved, smaller bias and larger ETS for all thresholds especially heavier precipitation, for the new SREF (against Stage-II precip analysis)



#### 4. Plans

The next major upgrade to the SREF system is planned within 2-3 years after this upgrade is operationally implemented (probably around September 2009). In the next upgrade system, it is ambitiously planned to replace the current four-model (Eta, RSM,

Fig 8: Probabilistic forecast measured by RPSS: large improvement for all fields (Feb. 5 – Apr. 14, 2009)

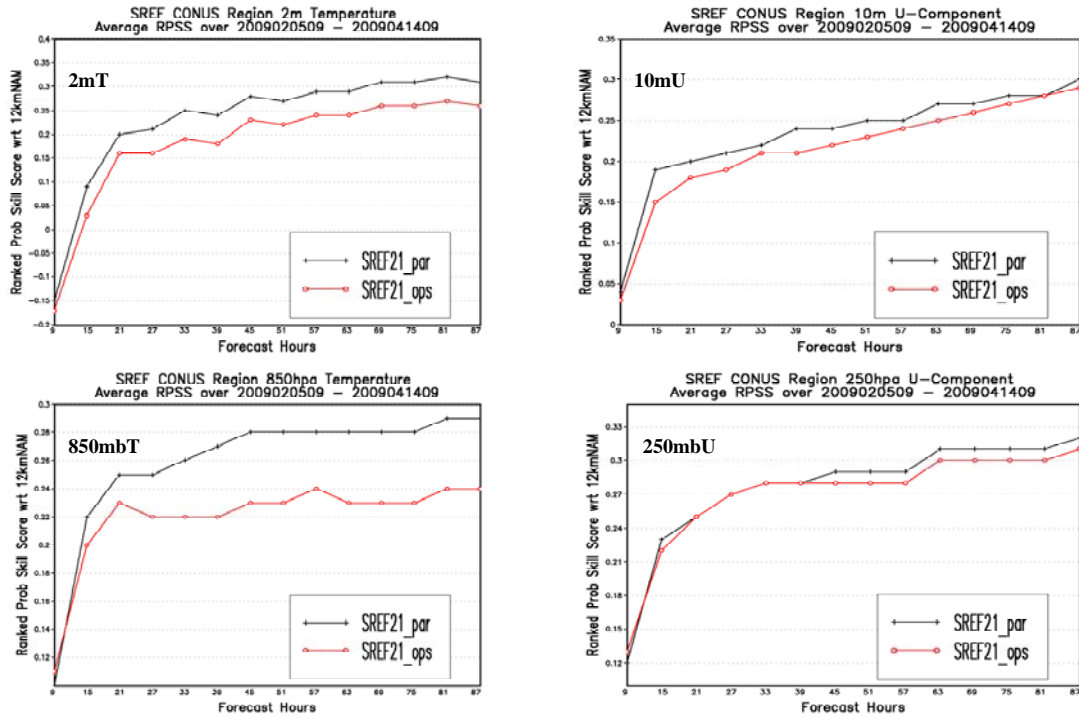
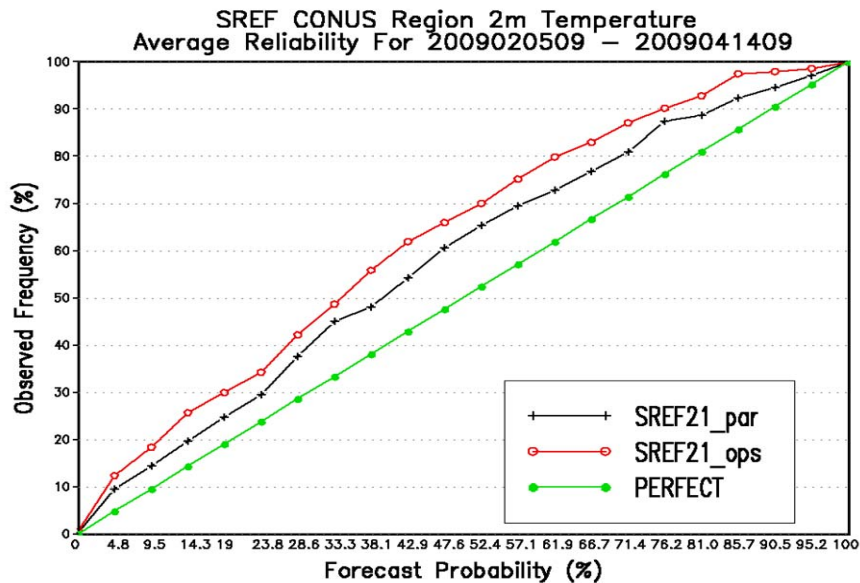
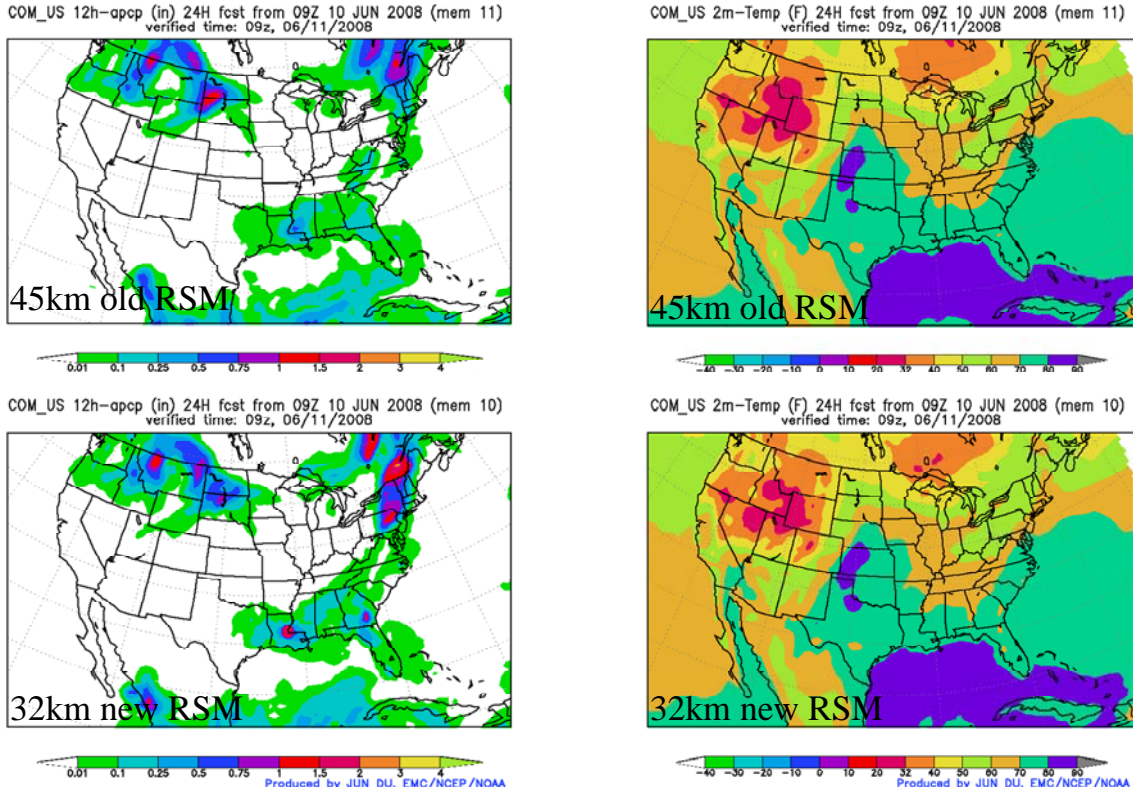


Fig.9: Reliability diagram of 2m-temperature probabilistic forecast at 87hr over CONUS, averaged over the period of Feb. 5 – April 14, 2009: new SREF in black and old SREF in red, the closer to the green line, the better



NMM and ARW) based system with one single unified modeling framework (*i.e.* NOAA Environmental Modeling System, NEMS) based system. The Ensemble Transform (ET) technique is planned to replace the Breeding technique for generating IC perturbations to

Fig. 10: 45km RSM vs. 32km RSM (precip and T2m): more detailed spatial features revealed



be consistent with GEFS. To hopefully compensate the loss of diversity due to eliminating multiple models, stochastic physics will be used in the next system. Initial states of land surface variables such as soil moisture will also be perturbed in the next system. Surely, the replacement of the four-model SREF system with one-modeling framework SREF system will depend on the satisfaction in performance measures. In view of the benefit of fine-scale (about 4km) ensemble with a cloud-resolvable model (Clark *et. al*, 2009), it's desired to run operationally a high-resolution, relocatable or moving nest following storms and on-demand high-impact ensemble forecast (HIEF) system imbedded within the SREF (*i.e.*, IC

and LBC perturbations will be provided by the SREF). The HIEF idea will be explored at EMC. Another ongoing effort focusing on very short range (0-12hr) for aviation forecasting is the Very Short Range Ensemble Forecast (VSREF) system which is a time-lagged ensemble based on existing rapid-update-cycle forecasts. To provide better products and service to forecasters and users, it's always important and will be continuously emphasized to post calibrate and downscale raw ensemble forecasts as well as to design more and better ensemble-related products.

Due to the computer resource limitation, the SREF is currently running on 3hr-off time cycle (*i.e.*, 21/03/09/15z in stead of 00/06/12/18z cycles) to avoid competing computer resource with other models. This is a disadvantage for the SREF since it doesn't use the upper-air sounding data observed at 00z and 12z and also makes the SREF forecasts 3-hr older than the forecasts from other models. To overcome this disadvantage (also requested by many SREF users), a long term plan is to run the SREF on the normal cycles (00/06/12/18z) in near future when computer resource is allowed. Another long term strategic plan is that after the Canadian Meteorological Center (CMC)'s regional ensemble system becomes operational (expected to be so around 2011 or 2012, Martin Carron, personal communication), the current global-ensembles-only based North American Ensemble Forecast System (NAEFS) is planned to be expanded to include a limited-area model based ensemble component (NAEFS-LAM) by combining the NCEP SREF with the CMC's regional ensemble prediction system to have a multi-center regional ensemble prediction system. This potential joint regional ensemble system effort could allow each center to focus more on increasing model spatial resolution rather than increasing ensemble membership.

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