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Regional ensemble forecast systems at NCEP

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1. Acronyms of regional ensembles

Current independent systems (running separately from different modeling systems)

SREF = Short Range Ensemble Forecast (~16km, 00-87hr)

NARRE (TL) (should really be called SREF (RR, TL)) = Time-Lagged North America Rapid Refresh Ensemble (~12km, 00-12hr)

HREF (TL) = Time-Lagged High-Resolution Ensemble Forecast (~4km, 00-36hr)

HREF (RR, TL) = Time-Lagged High-Resolution Ensemble Forecast-Rapid Refresh (~3km, 00-12hr, *under construction*)

Planned unified systems (running as one with a same modeling system):

SREF = Standard Resolution Ensemble Forecast (~9-12km, 00-18/24hr: Rapid Refresh portion RR –*may not run*; 18/24-84/96hr: Extended portion EXT)

HREF = High-Resolution Ensemble Forecast (~3km, 00-18hr: Rapid Refresh portion RR; 18-48/60hr: Extended portion EXT)

2. Current regional ensemble prediction system: SREF

The NCEP Short Range Ensemble Forecast (SREF) system was operationally implemented in 2001 (Du and Tracton, 2001). It is currently a 16km, 26-member, multi-analysis, multi-model and multi-physics regional ensemble prediction system running 4 cycles (03, 09, 15, 21z) per day up to 87hr over North America domain (Tables 1 and 2). Besides 26 individual forecasts, it also produces many ensemble products including mean, spread, probability, range (min to max), percentiles, member ranking (Du and Zhou 2011) and clusters related to precipitation, convection, aviation, winter weather, hurricane and fire weather predictions (Table 3). Some forecast variables are also bias-corrected and/or downscaled to 5km NDGD (National digital guidance database) grid. The SREF has become an integral part of U.S. NWP modeling system by providing useful and critical info to forecasters and other users (private and academic) in their daily weather forecasting and research. The technical details of the 26 SREF members are listed in Tables 1a and 1b. This system was most recently upgraded in the summer of 2015, which is targeted to reduce surface cold and wet biases, increase ensemble spread and improve probabilistic forecasts in overall (Fig. 1).

Table 1: (a) 13 NMMB members

Mod-Mem	IC	IC pert	LBCs	Physics 1			Physics 2		GWD	Land Surface		
				Conv	PBL	Sfc layer	Microphys	LW, SW Rad	cleffamp	LSM	Initial	Soil pert?
nmmb_ctl	NDAS	Blending (GEFS + SREF)	GFS	BMJ old shal	MYJ	MYJ	Fer_hires	RRTM	cleffamp=1	Noah	NAM	no
nmmb_n1			GEFS 2	SAS	GFS	MYJ	WSM6	GFDL	cleffamp=0.6	Noah	NAM	no
nmmb_p1			GEFS 1	BMJ new shal	MYJ	MYJ	Fer_hires	RRTM	cleffamp=2	Noah	NAM	no
nmmb_n2			GEFS 4	SAS	GFS	MYJ	Fer_hires	GFDL	cleffamp=1	Noah	NAM	Drier soil
nmmb_p2			GEFS 3	BMJ old shal	MYJ	MYJ	WSM6	RRTM	cleffamp=0.6	Noah	NAM	Drier soil
nmmb_n3	GFS	Blending (GEFS + SREF)	GEFS 6	SAS	GFS	MYJ	Fer_hires	GFDL	cleffamp=2	Noah	NAM	Drier soil
nmmb_p3			GEFS 5	BMJ new shal	MYJ	MYJ	WSM6	RRTM	cleffamp=1	Noah	NAM	Drier soil
nmmb_n4			GEFS 8	SAS	GFS	MYJ	WSM6	RRTM	cleffamp=0.6	Noah	NAM	no
nmmb_p4			GEFS 7	BMJ old shal	MYJ	MYJ	Fer_hires	GFDL	cleffamp=2	Noah	NAM	no
nmmb_n5	RAP	Blending (GEFS + SREF)	GEFS 10	SAS	GFS	MYJ	WSM6	RRTM	cleffamp=1	Noah	NAM	Drier soil
nmmb_p5			GEFS 9	BMJ new shal	MYJ	MYJ	Fer_hires	RRTM	cleffamp=0.6	Noah	NAM	Drier soil
nmmb_n6			GEFS 12	SAS	GFS	MYJ	Fer_hires	GFDL	cleffamp=2	Noah	NAM	no
nmmb_p6			GEFS 11	BMJ old shal	MYJ	MYJ	WSM6	GFDL	cleffamp=1	Noah	NAM	no

Table 1: (b) 13 ARW members

Mod-Mem	IC	IC pert	LBCs	Physics 1			Physics 2				Land surface		
				Conv	PBL	Sfc layer	Microphy	LW Rad	SW Rad	Stochastic	LSM	Initial	Soil pert
arw_ctl	RAP	Blending (GEFS + SREF)	GFS	KF	YSU	MM5	WSM6	RRTMG	RRTMG	no	Noah	NAM	no
arw_n1			GEFS 14	BMJ	MYJ	MYJ	Fer	GFDL	GFDL	no	Noah	NAM	Drier soil
arw_p1			GEFS 13	Grell	MYNN	MYNN	Thompson	Old RRTM	GSFC	no	Noah	NAM	no
arw_n2			GEFS 16	KF	YSU	MM5	Fer	GFDL	GFDL	no	Noah	NAM	Drier soil
arw_p2			GEFS 15	BMJ	MYJ	MYJ	Thompson	RRTMG	RRTMG	no	Noah	NAM	no
arw_n3	GFS	Blending (GEFS + SREF)	GEFS 18	Grell	MYNN	MYNN	WSM6	RRTMG	RRTMG	no	Noah	NAM	Drier soil
arw_p3			GEFS 17	KF	YSU	MM5	Thompson	Old RRTM	GSFC	no	Noah	NAM	no
arw_n4			GEFS 20	BMJ	MYJ	MYJ	WSM6	RRTMG	RRTMG	no	Noah	NAM	no
arw_p4			GEFS 19	KF	YSU	MM5	Fer	GFDL	GFDL	no	Noah	NAM	Drier soil
arw_n5	NDAS	Blending (GEFS + SREF)	GEFS 2	Grell	MYNN	MYNN	Fer	GFDL	GFDL	no	Noah	NAM	no
arw_p5			GEFS 1	KF	YSU	MM5	WSM6	RRTMG	RRTMG	no	Noah	NAM	Drier soil
arw_n6			GEFS 4	BMJ	MYJ	MYJ	Thompson	Old RRTM	GSFC	no	Noah	NAM	Drier soil
arw_p6			GEFS 3	Grell	MYNN	MYNN	Thompson	RRTMG	RRTMG	no	Noah	NAM	no

Table 2: a summary of SREF

- **Configuration**: 16km, L40, 26 members, 0-87hr, North America domain, 4 cycles per day (03, 09, 15 and 21z)
- **IC uncertainty**: multi-analysis (ndas, GFS, RR), blended perturbation (regional Breeding + global EnKF), multi-LBCs from GEFS (updated 3hrly)
- **Physics uncertainty**: multi-model (nmmb and arw), multi-physics, quasi-stochastic physics
- **Post-processing**: bias correction and downscaling
- **Products**: individual members, mean, spread, probability, percentiles, range, member ranking, clusters

SREF provides useful and sometimes critical information to forecasters in high-impact weather prediction. Fig. 2 show the SREF probabilistic forecasts of the record-breaking Boulder, CO extreme precipitation event of September 12, 2013, which was the only operational model consistently and correctly predicting this extreme event (Hamill, 2014). The flash flood brought by the extreme heavy rainfall caused enormous property damages and life losses during this event. Fig. 3 shows another successful story of SREF probabilistic forecasts indicating the January 21, 2014 major snow-storm impacting Northeast U.S. two days ahead of time in the 09z 1/19/14 SREF run, which is half a day earlier than other operational model guidance. The increasing trend of the SREF-based probability with time is obvious when it is closer to the event, which provides extra confidence to forecasters to issue a warning. This snow-storm was a sudden event with short predictability and caused major distraction to people's life in Northeast U.S. resulting from flight cancellation and school and government closures etc.

Fig. 1: Verification results (Oct. 2014 – Mar. 2015, red=new, blue=old)

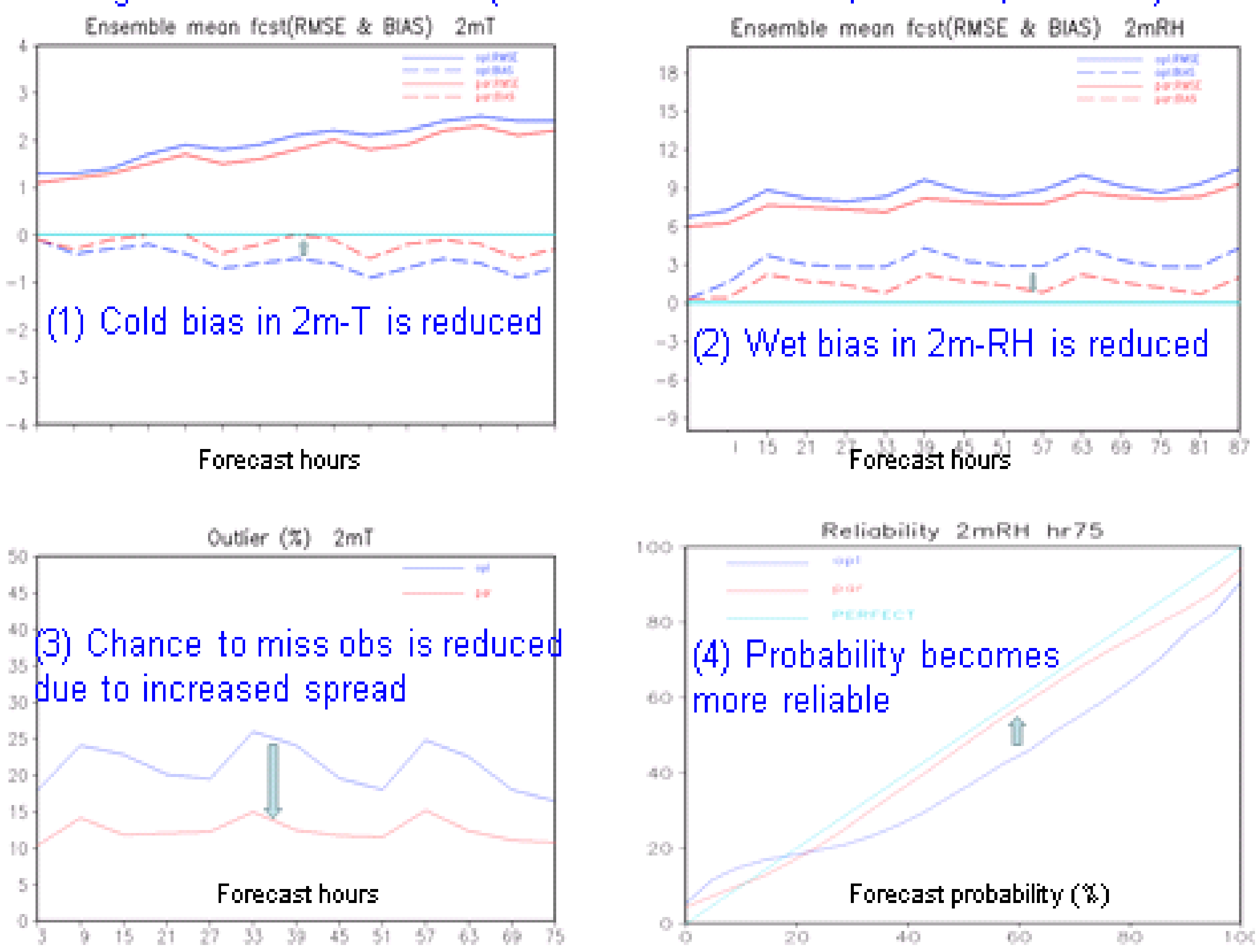
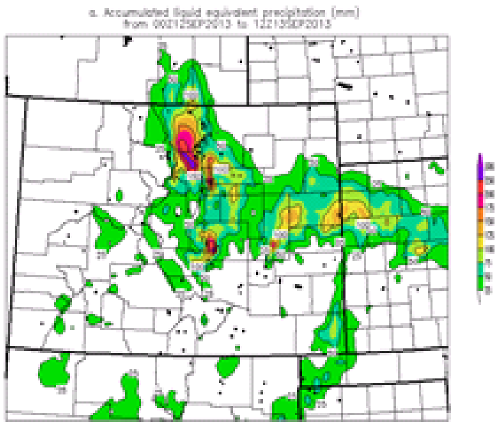


Fig. 2: Success story 1 on high-impact weather

SREF is the only operational model consistently indicating a historical heavy rain event over Boulder, CO region days ahead (Hamill 2014; plots from Rich Grumm)



Observed 36hr (00z, Sept. 12 – 12z, Sept. 13, 2013) accumulated precipitation.

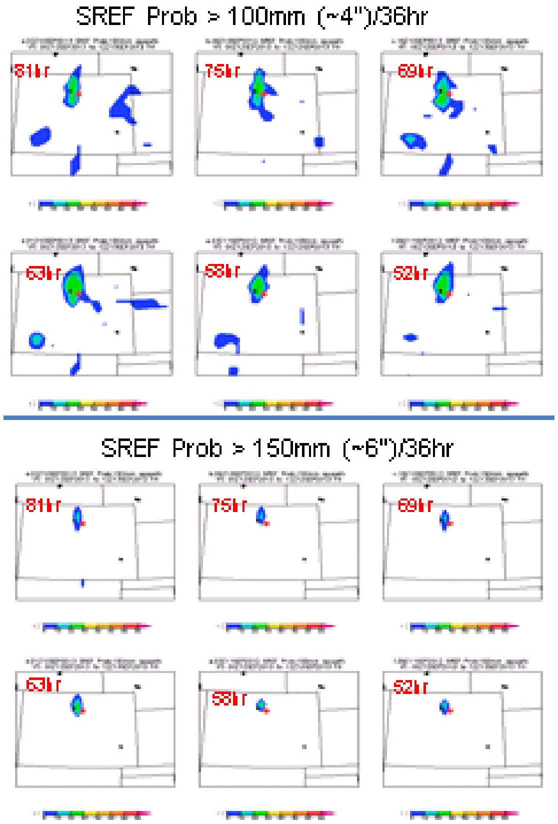
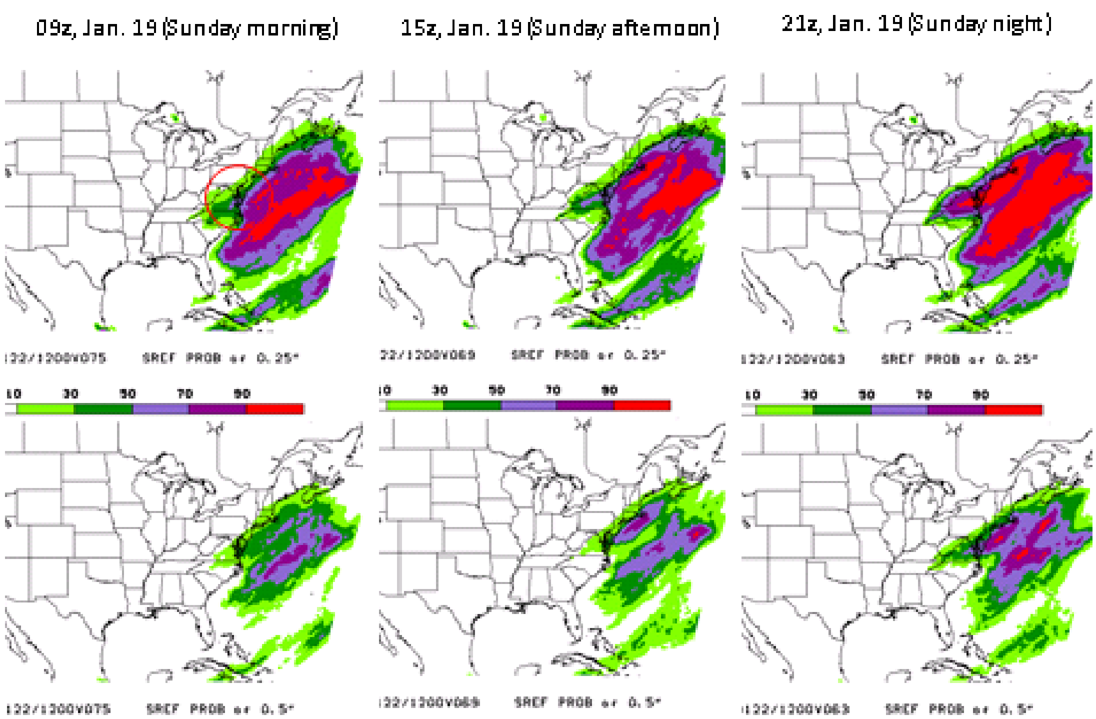


Fig. 3: Success story 2 on high-impact weather

SREF is the earliest operational model indicating the Jan. 21, 2014 major but sudden (short-predictability) Northeast snow storm (about half a day earlier than other models)



3. Interim systems: Time-lagged NARRE, HREF

Due to the limitation of computing power, there is no rapid refresh (hourly update cycle) or convection-allowing scale (<5km) ensemble system currently running at NCEP. Instead, two interim time-lagged ensembles (NARRE and HREF) have been developed based on multiple existing high-resolution deterministic models as a prelude of the future planed Rapid Refresh SREF and HREF, respectively. A third time-lagged ensemble Rapid Refresh HREF is under development to mimic the future HREF (RR). NARRE (TL) is a 12km, 10-member, multi-model and hourly updated system with forecast length of 12hr over North America (see Fig. 4 for details), HREF (TL) is a 4km, 11 (9)-member and multi-model system with forecast length of 36hr, updated every 12 hours over CONUS, AK etc. domains (Fig. 5), and HREF (RR, TL) is a 3km, 27-member and multi-model system with forecast length of 12hr, updated every hour over CONUS, AK etc. domains (Fig. 6). The ensemble products of NARRE (TL) and HREF (TL) are co-listed with those of SREF in Table 3.

Fig. 4: Time-Lagged North America Rapid Refresh Ensemble (NARRE, TL) to mimic future SREF (Rapid Refresh)

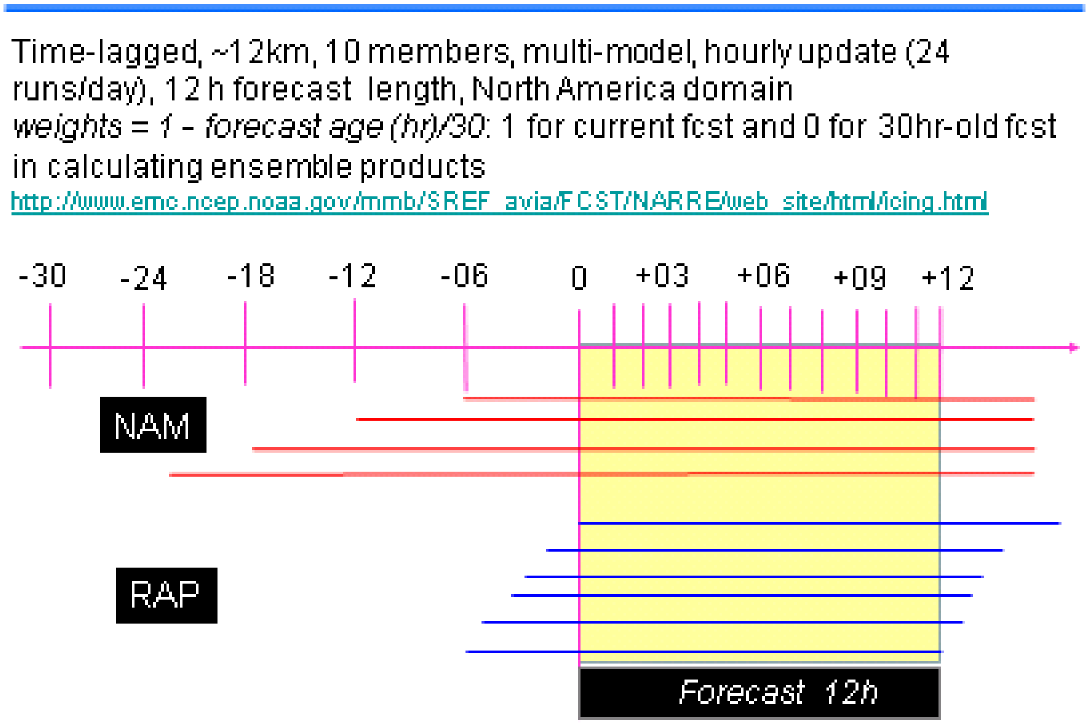


Fig. 5: Time-lagged High Resolution Ensemble Forecast (HREF) to mimic future HREF (Extended)

Time-lagged, ~4km, 9-11 members, multi-model, 12-hourly update (2 runs/day), 36h forecast length, CONUS (AK, HI, PR, Guam) domains
weights = 1 - forecast age (hr)/30: 1 for current fcst and 0 for 30hr-old fcst in calculating ensemble products

http://www.emc.ncep.noaa.gov/mmb/SREF_avia/FCST/NSSE/web_site/html/storm.html
http://www.emc.ncep.noaa.gov/mmb/SREF_avia/FCST/HREF/web_site/html/ffair.html

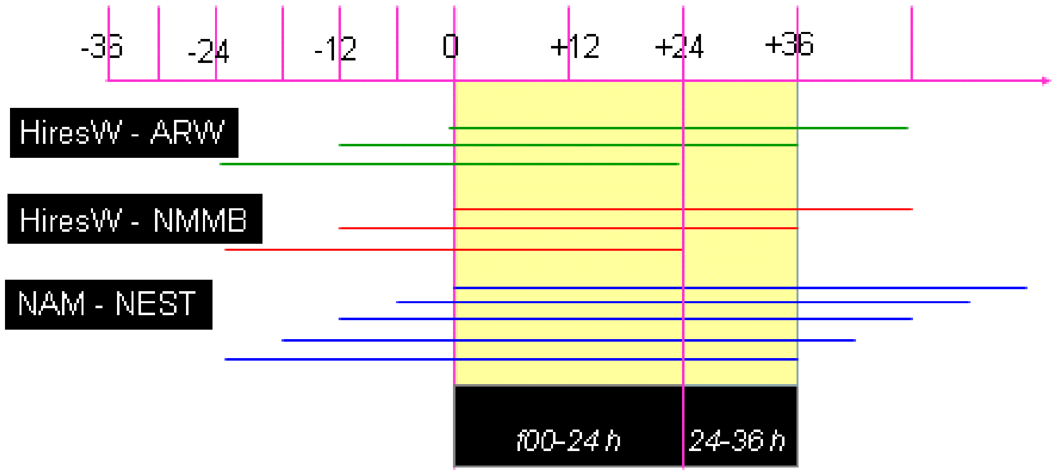
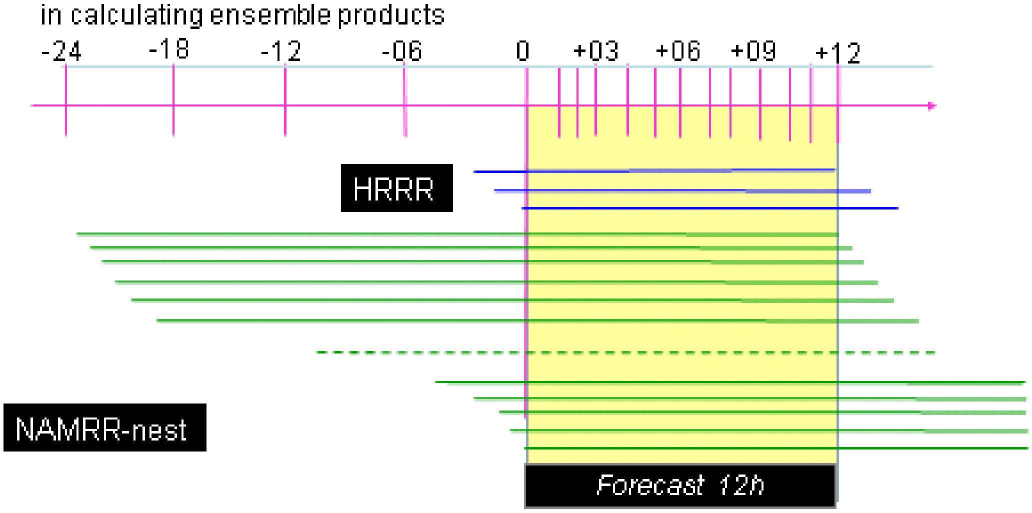


Fig. 6: Time-Lagged High Resolution Ensemble Forecast Rapid Refresh HREF to mimic future HREF (Rapid Refresh)

Time-lagged, ~3km, 27(?) members from multi-model (3 HRRR and 24 NAMRR-nest), hourly update (24 runs/day), 12 hour forecast length, CONUS, (AK) domain
weights = 1 - forecast age (hr)/30: 1 for current fcst and 0 for 30hr-old fcst in calculating ensemble products



The products from NARRE (TL) and HREF (TL) are available online and used by field forecasters in real time. Positive feedbacks have been received from operational forecasters. Fig. 7 is an example of NARRE-LT based probabilistic forecast in successfully predicting January 15, 2014 major east coast dense fog event 12-hour ahead of time while some of other operational models including MOS failed to predict. Two positive comments from the eastern region forecasters are also recorded in Fig. 7. For low visibility events, the NARRE (TL) is found to be more skillful than its base models RAP and NAM in both deterministic (Fig. 8a) and probabilistic (Fig. 8b) forecasts. Fig. 9 shows an example of HREF (TL) based 27-h probabilistic forecast of composite radar reflectivity exceeding 30dBZ.

Table 3: (a) Aviation ensemble products list

Field	Ensemble product	SREF	NARRE (TL)	HREF (TL)
Ceiling	Mean/spread/prob of 6 height thresholds	Y	Y	Y
Visibility	Mean/spread/prob of 6 VIS thresholds	Y	Y	Y
Low level wind shear	Mean/spread/occurrence probability	Y	Y	Y
Surface wind	Mean/spread/prob 3 speed thresholds	Y	Y	Y
Fog	Probability of dense fog and light fog	Y	Y	N
Precipitation type	Prob of rain, snow, freezing rain	Y	Y	Y
Accumulate Precip	Prob of 1, 3 and 6hr accumulated precip	Y	Y	Y
Icing	Occurrence prob on 8 Flight levels (FLs)	Y	Y	Y
Turbulence (CAT)	3 severity occurrence Prob on 9 FLs	Y	Y	Y
Freezing height	Mean/spread	Y	Y	N
Jet stream	Prob on 3 heights & 3 speed thresholds	Y	Y	N
Radar reflectivity	Probability of 5 thresholds of dBZ	Y	Y	Y
Echo-top	Probability of 5 height thresholds	Y	N	Y
Mountain obscuration	Probability (to be added)	N	N	N

TAF products (yellow) En-route products (green) Y=yes, N=no

Table 3: (b) Storm/convection, flash flood, fire-weather, energy (wind) ensemble products list

Y=yes (available), N=no (not available)

Field	Ensemble product	SREF	NARRE(TL)	HREF(TL)
Convection	Probability	N	Y	Y
Lightning	Probability	Y	Y	N
Dry lightning	Probability	Y	Y	N
Severe thunderstorm	Probability	Y	Y	N
Max updraft helicity	Prob for certain thresholds	N	N	Y
Max down & updraft speed	Prob for certain thresholds	N	N	Y
Max 1km AGL radar reflectivity	> 40 dBZ probability	N	N	Y
Radar composite reflectivity	> 40 dBZ probability	N	N	Y
Max 10m wind	> 30 knots probability	N	N	Y
Fire weather	Probability of Hainse index	N	N	Y
Fire weather	Probability of Fosberg index	Y	N	N
80 m wind speed (for energy sector)	Mean/spread/probability	N	N	Y
Precipitation	Prob of 3-, 6-, 24-h rainfall > 1,2,3,5"	Y	Y	Y
Precipitable water	Prob of PWAT > 1, 1.5"	Y	Y	Y

Fig. 7: Positive feedbacks from WFOs about NARRE-TL:

(1) Dense fog is difficult to forecast as we all know. The Rapid Refresh Ensemble did very well with tonight's event - much better than traditional MOS. ... Jeff

(2) This product performed really well again tonight. As early as the 02z run, it showed the dense FG over PHL/NJ expanding N/NE into NYC/LI between 10-11z which matched satellite trends and the synoptic setup. Allowed for more confidence in the TAFs as there was big model discrepancy...NAM was also on the money, while GFS was out to lunch and completely dry in the low-levels. Adrienne referenced it in her AFD.

Jan. 15, 2014 (night-morning): Dense fog event in the east coast

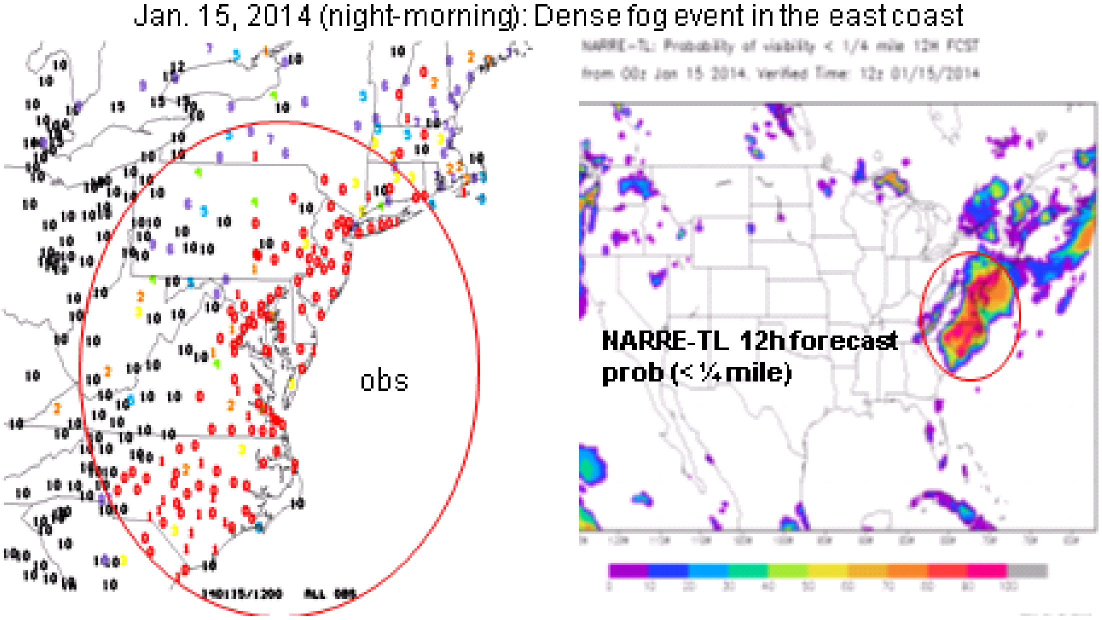
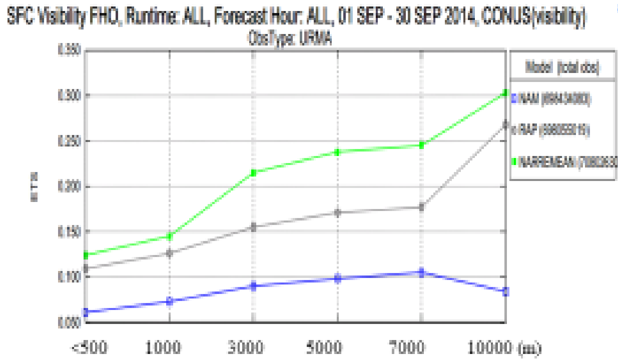
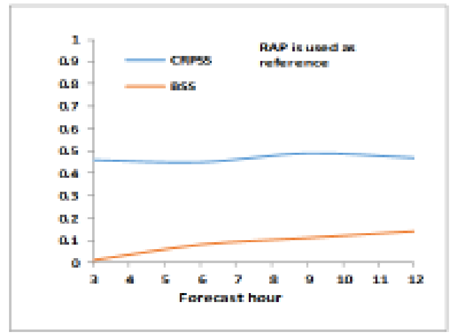


Fig. 8: Verification of NARRE-TL-based visibility forecasts: ensemble mean and prob of vis < 1000m

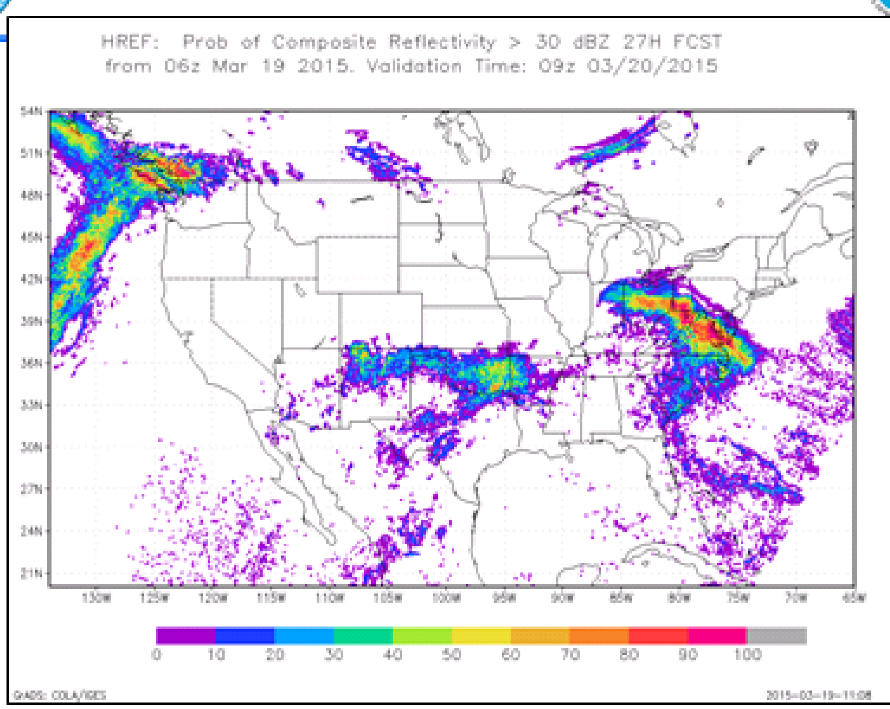


(a) Averaged *ETS* scores of surface visibility forecasts of NARRE-TL mean, 12km-NAM and 13km-RAP over various visibility thresholds, verified over all forecast times of all cycles and all grid points of the CONUS domain from September 1 to 30, 2014. The NCEP 2.5km gridded URMA visibility analysis is used as truth (URMA: unrestricted mesoscale analysis, a version of NCEP's Real Time Mesoscale Analysis, or RTMA). The numbers in ( ) in the legend indicate effective analysis grid points used in the verification.



(b) Averaged CRPSS and BSS scores of NARRE-TL (using the base model RAP as reference) over forecast hours, verified over all grid points of the CONUS domain from September 15, 2012 to March 15, 2013. The NCEP 2.5km gridded URMA visibility analysis is used as truth. The visibility threshold used in BSS is for fog range (< 1000 m).

Fig. 9: HREF (TL) example probability of exceedance, REFC > 30 dBZ



4. Future NCEP unified regional ensemble prediction systems: SREF and HREF

Fig. 10 and Table 4 below describe a strategic plan of future NCEP regional ensembles. Unlike the current regional ensembles which are independent to each other and running separately with different modeling systems, the future ones are in a unified framework and running together with a same modeling system. The current Short Range Ensemble Forecast (SREF) will be renamed to Standard Resolution Ensemble Forecast (SREF) and its initialization time will be switched from 03/09/15/21z to 00/06/12/18z.

The 1st tier is the 9-12km continental scale ensemble with parameterized physics covering North America for general weather forecasts. It includes an hourly-update rapid refresh portion (SREF (RR), 00-18/24hr, *this one might not be necessary given such coarse spatial resolution* to save computing resources) and an extension (SREF (EXT), 6-hourly update, 18/24-84/96hr). The 1st tier could be replaced by future global ensemble when the global ensemble can satisfy the end-users' requirements in spatial, temporal resolutions and various types of specific products. The 2nd tier is the 3km regional scale ensemble with convection-allowing physics covering four regional domains -- CONUS, Alaska, Hawaii and Puerto Rico for aviation and convection forecasts. The 2nd tier also includes an hourly-update rapid refresh portion (HREF (RR), 00-18hr) and an extension (HREF (EXT), 6-hourly update, 18-48/60hr). For the details, please see Fig. 10 and Table 4 although they are in constantly evolving progress and modification.]

Fig. 10: Future unified regional ensemble systems (SREF & HREF)

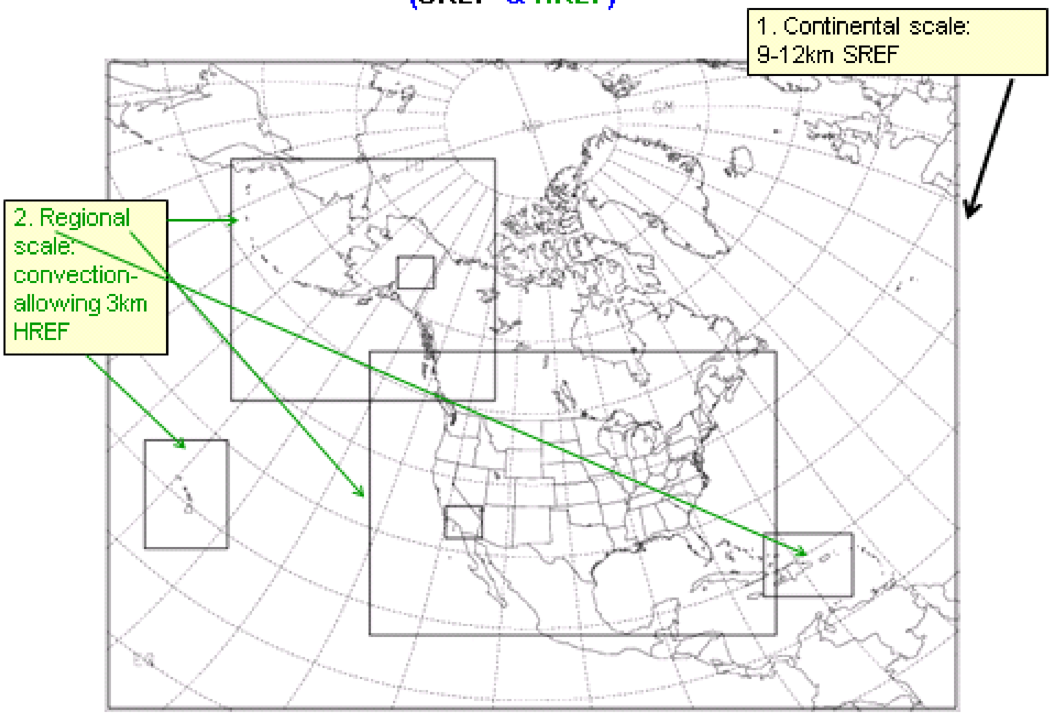


Table 4: Proposed future unified regional ensemble systems (SREF & HREF)

	1. Continental scale	*2. Regional scale*
	9-12km North America WRF-ARW, NMMB Parametrized physics	~3km CONUS, Alaska, HI, PR WRF-ARW & NMMB Convection-allowing physics
RR	SREF (NARRE, TL) "Standard-Resolution Ensemble Forecast" – Rapid Refresh ? members hourly update to 18/24hr	HREF (HREF, RR, TL) "High-Resolution Ensemble Forecast" – Rapid Refresh ? members hourly update to 18hr
EXT	SREF (SREF) "Standard-Resolution Ensemble Forecast" – Extended 26 members 6 hourly extended from 18/24 to 84/96hr	HREF (HREF, TL) "High-Resolution Ensemble Forecast" – Extended ? members 6 hourly extended from 18 to 48/60hr
	(May be replaced by global ensemble)	(Will be the focus)

5. Summary

The current NCEP state-of-the-art operational SREF is a 16km, 26-member, 3-analysis, 2-model and multi-physics regional ensemble prediction system running 4 times (03, 09, 15 and 21z) per day up to 87hr over North America domain, which is an integral part of U.S. NWP modeling system by providing useful and critical info to forecasters and other users in their daily weather forecasting and research. It was most recently upgraded in the summer 2015.

Due to the limitation of computing power, there is no rapid refresh (hourly update cycle) or convection-allowing scale (<5km) ensemble system currently running at NCEP. However, two interim time-lagged ensembles (NARRE and HREF) have been developed and a third time-lagged ensemble Rapid Refresh HREF is under development for aviation and severe convective storm forecasts. NARRE (TL) is a 12km, 10-member, multi-model and hourly updated system with forecast length of 12hr over North America, HREF (TL) is a 4km, 11 (9)-member and multi-model system with forecast length of 36hr, updated every 12 hours over CONUS, AK etc. regional domains, and HREF (RR, TL) is a 3km, 27-member and multi-model system with forecast length of 12hr, updated every hour over CONUS, AK etc. regional domains.

Rapid refresh (hourly update) parametrized-physics continental-scale (12km, SREF (RR), may not run) and convection-allowing scale (3km, HREF) ensembles are planned to be implemented at NCEP in next few years. The continental-scale SREF could be replaced by future global ensemble when the global ensemble can satisfy the end-users' requirements in spatial, temporal resolutions and various types of specific products.

Mesoscale ensembles will replace all current regional deterministic guidance (such as NAM, NAMnest, RAP, HRRR, NAMRR, HiresWindows) by strategically developing a unified regional modeling system at NCEP to better meet the requirements of NWS's Weather Ready Nation such as Warm on Forecast program (Stensrud et al. 2009).

6. References

Du, J., and M. S. Tracton, 2001: Implementation of a real-time short-range ensemble forecasting system at NCEP: an update. Preprints, 9th Conference on Mesoscale Processes, Ft. Lauderdale, Florida, Amer. Meteor. Soc., 355-356, available online at http://www.emc.ncep.noaa.gov/mmb/SREF/reference.html.

Du, J., and B. Zhou, 2011: A dynamical performance-ranking method for predicting individual ensemble member's performance and its application to ensemble averaging. *Mon. Wea. Rev.*, **129**(10), 3284-3303.

Hamill, T., 2014: Performance of operational model precipitation forecast guidance during the 2013 Colorado Front Range Floods, *Mon. Wea. Rev*, submitted, available online at http://www.esrl.noaa.gov/psd/people/tom.hamill/

Stensrud, D. J., and Coauthors, 2009: Convective-scale-warn-on-forecast system: A vision for 2020. *Bull. Amer. Meteor. Soc.*, **90**, 1487-1499.