OVERVIEW OF THE NOAA/NWS/NCEP Short Range Ensemble Forecast (SREF) system

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March, 2004

1. INTRODUCTION

The NCEP multi-Initial Condition (multi-IC) and multi-model Short Range Ensemble Forecasting (SREF) system has been operationally running since May 2001 (Du et al. 2003). This system is run twice per day (09 and 21 UTC) at 48 km with 15 model members. Forecasts are output at 3 hour intervals out to 63 hours. Recent studies have shown the benefits of adding physics perturbation members to an ensemble system (Stensrud et al. 2000). Also, ensemble members clustering by model is a main concern of field forecasters. Therefore, a new physics ensemble system has been developed and evaluated. This paper summarizes the NCEP SREF system and reports on some of our findings from a comparison study between a multi-IC and multi-physics ensemble approach for short range forecasts (1-3 days).

The SREF system was developed to provide a multi-regional model, short-range (0-3 days) ensemble prediction system to provide operationally relevant and useful guidance on the probability distribution of weather elements or events. The probabilistic information provided by SREF will help meet the NWS FY05 strategic goal of providing probabilistic gridded products to the NWS/WFOs, service centers and other users.

In September, 2003, NCEP added 5 Eta-KF (With Kain-Fritsch Convective parameterization) to the routine production and evaluation of a regional model based ensemble system and product suite (Du, et al., 2003). The system consisted of 5 ETA-KF, 5 Eta-BMJ (With Betts-Miller-Janjic Convective parameterization) plus 5 RSM multi-model members (15 members total) at 48 km horizontal resolution. SREF is run twice per day (09z and 21z) to 63hr and output available every 3h with regional bred initial state perturbations.

Previous studies have shown the importance of multi-physics ensemble forecasts to improve a SREF diversity. This implementation incorporates an additional physics diversity by running various convective and cloud microphysics parameterizations along with single pair breeding to improve system diversity and forecast spread information, especially for quantitative precipitation forecasts.

The 32 km experimental SREF breeding (I) and physics perturbation (II) experiments were run to support the New England High Resolution Temperature Program (NEHRT) during the Summer, 2003. (Wilczak et al. 2004). Thinned GRIB files and BUFR files from all SREF members were provided to NOAA/OAR to perform bias-corrected forecasts at several locations in New England. A subset of probabilistic products is sent to the NCEP SREF web page for forecaster use. For more information, see http://highrestemp.noaa.gov. Results from this study showed the value of enhanced physics diversity (Du, et al., 2004). This bulletin describes the SREF system and presents an evaluation of the SREF-X enhanced physics diversity system.

1.1 SREF Goals

1. Improve the forecast by ensemble averaging.
2. Provide an indication of confidence in the forecast.
3. Provide quantitative probabilistic forecasts.

The primary measure of success is to provide improved forecasts of upper level fields (Z, T, Winds) and low-level fields such as T, V and last but not least QPF.

2. EXPERIMENTAL SREF CONFIGURATION.

During the Summer, 2003, the 32 km (60 levels) SREF was run twice per day, producing 3 hourly forecasts out to 63 hours. NCEP Global Forecast System (GFS) outputs were used for boundary conditions. The domain covers most of North America. Table 1 summarizes the SREF Multi-IC (SREF-I) membership. This system was similar to the operational SREF system except for higher horizontal and vertical resolutions. All runs used lateral boundary conditions from the GFS ensembles. For the SREF-I configuration, each model is run with 1 control run plus 2 initial condition breeding pairs (n1, p1, n2, p2). Each pair is perturbed positively and negatively using the NCEP breeding technique described by Toth and Kalney (1997). Figure 1 outlines the SREF forecast system run process. Table 2 summarizes the members used for SREF Multi-physics perturbation (SREF-II) model configuration. Table 3 describes a modified SREF-II system that was run beginning in November 2003 for the Experminental SREF system (SREF-X). The SREF-X configuration will be implemented operationally at NCEP in January, 2004.

Table 1. Description of NCEP experimental SREF Multi-IC (SREF-I) system run for the Summer, 2003 NEHRT Program.

Members	Model	ΔX	# levels	Members	Cloud physics	PBL, Sfc physics
5	Eta-BMJ	32 km	60	Ctl,n1,n2,p1p2 *	Bett-Miller-Janic (BMJ) convection Ferrier microphysics	Mellor-Yamada TKE NOAH-LSM
5	RSM-SAS	32 km	28	Ctl,n1,n2,p1,p2	Simple Arakawa-Shubert (SAS) convection	MRF K theory NOAH-LSM
5	Eta-KF	32 km	60	Ctl,n1,n2,p1,p2	Kain-Fritsch(KF) convection Operational Ferrier microphysics	Mellor-Yamada TKE NOAH-LSM

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Table 2. Description of the multi-physics experimental SREF configuration (SREF_II). * and

# Members	Model	Δx	# levels	Members	Cloud physics	*Convective parameterization*
3	RSM-SAS	32 km	28	Ctl, n1,p1	GFS physics	Simple Arakawa-Shubert
2	*RSM-RAS*	*32 km*	*28*	*n1,p1*	*GFS Physics*	*Relaxed-Arakawa - Shubert*
3	Eta-BMJ	32 km	60	Ctl,n1,p1	Op. Ferrier microphysics	Betts-Miller-Janic
1	*Eta-RAS-Mic*	*32 km*	*60*	*p2*	*Exp. Ferrier microphysics (more mixed-phased processes)*	*Relaxed-Arakawa - Shubert*
1	*Eta-RAS*	*32 km*	*60*	*n2*	*Op. Ferrier microphysics*	*Relaxed Arakawa-Shubert*
2	Eta-KF	32 km	60	n1,p1	Op. Ferrier microphysics	Kain-Fritsch
1	*Eta-FER*	*32 km*	*60*	*Ctl*	*Op. Ferrier Microphysics*	*Ferrier Shallow Convection*
1	*Eta-KF-DET*	*32 km*	*60*	*n2*	*Op. Ferrier microphysics*	*Kain-Fritsch w/full detrainment*
1	*Eta-KF-CON*	*32 km*	*60*	*p2*	*Exp. Ferrier microphysics w/ more freq. calls to cloud water condensation & ice deposition*	*Kain-Fritsch*

italisized members are unique runs from the multi-IC breeding SREF-I experiment, and are used to make up the SREF-II configuration.

2.1 Description of SREF-X model system.

The SREF-X system was made up of members from the NCEP Eta model (Rogers et al. 1996; Ferrier, et al. 2003) and Regional Spectral Model (RSM, Juang et al. 1997). The various convective parameterizations and cloud microphysics chosen for the SREF-II multi-physics system are described in more detail in Ferrier (2004). Changes to the operational SREF system are summarized below:

- Increase horizontal resolution of all 15 ensemble members (11 Eta and 4 RSM). A horizontal resolution increase from 48 km to between 32 and 40 km.
- Increase vertical resolution to 60 levels in the Eta members.
- Upgrade Eta members to software version level the same as the 12 km North American Eta run (pre March 6, 2004).

- Upgrade the Regional Spectral Model (RSM) with improved physics and computational schemes.
- Enhance the SREF system physics diversity by running several members with different cloud physics and convective parameterization schemes. Six different model physics systems were tested. All of the model configurations will have one initialization breeding pair. A description of physics configuration for each member is summarized in Table 3 below:

Table 3. Configuration of the SREF-X enhanced physics diversity sytem.

Model	**Convection**	**Microphysics**	**GFS ensemble 6hrly LBC**	**IC Breeding**
Eta-32 (60 lvls)	Betts-Miller-Janic (BMJ)	Operational Ferrier	Ctl, N1, P1	Ctl1 + 1 pair (N1, P1)
Eta-32	Kain-Fritsch (KF)	Operational Ferrier	Ctl, N2, P2	Ctl2+ N2, P2
RSM-32 (28 lvls)	Simple Arakawa Shubert (SAS)	Zhou GFS	Ctl, N1,P1	Ctl1 + N1, P1
RSM-40	Relaxed Arakawa-Shubert (RAS)	Zhou GFS	N2, P2	N2, P2
Eta-32	BMJ-SAT (Saturated moisture profiles)	Operational Ferrier	N1, P1	N3, P3
Eta-32	KF-DET (Full cloud detrainment)	Experimental Ferrier*	N2, P2	N4, P4

** Experimental Ferrier Microphysics are related to changes in parameters controlling the liquid water glaciation, ice nucleation, cloud formation, vapor deposition and cloud water collection by precipitation. More information on the various microphysics and convective parameterization can be found in Ferrier (2004) and Ferrier, et al. (2002).*

EMC ran a near real-time parallel system (SREF-X) beginning in November 2003. These parallel runs can be accessed at:
http://wwwt.emc.ncep.noaa.gov/mmb/SREF/PARA.html

The SREF production runs can be found in a similar format to the parallel runs at:
http://wwwt.emc.ncep.noaa.gov/mmb/SREF/SREF.html

Modified SREF physics diversity configuration

The experimental SREF system with enhanced physics diversity has been undergoing testing since early December, 2003. During the evaluation phase, the system has shown unrealistically high spread for some cases. An error in the initial condition breeding has recently been uncovered and corrections are being made. Therefore, the system will not be implemented as originally scheduled for the end of January, 2004. Further system testing will be required to reduce the over-dispersive character of the system by reducing the initial condition perturbation amplitude and also possibly reducing the convective parameterization physics diversity. For example, it appears the Eta members with Bett-Miller-Janjic saturated profiles are not contributing positively and will likely be replaced by control runs of more well tested convective parameterizations (e.g.: Betts-Miller-Janjic and Kain-Fritsch). A modified experimental SREF configuration is summarized in the table below. This system then underwent more robust testing with implementation by NCO. Other changes to the implementation, including updated Eta and RSM model physics and increased horizontal and vertical resolution will remain on target.

Model	**Convection**	**Microphysics**	**GFS 6hrly LBC**	**IC Breeding**
Eta-32	Betts-Miller-Janic (BMJ)	Experimental Ferrier	Ctl, P1, N1	Ctl + 1 pair (pos & neg)
Eta-32	Kain-Fritsch (KF)	Operational Ferrier	Ctl, P2, N2	Ctl + 1 pair
RSM-40	Simple Arakawa Shubert (SAS)	Zhou GFS	Ctl, P1, N1	Ctl + 1 pair
RSM-40	Relaxed Arakawa Shubert (RAS)	Zhou GFS	Ctl, P2, N2	Ctl + 1 pair
Eta-32	Relaxed Arakawa-Shubert (RAS)	Operational Ferrier	Ctl	Ctl
Eta-32	BMJ-SAT (Saturated vapor pressure profile)	Operational Ferrier	Ctl	Ctl
Eta-32	KF-DET (Full cloud detrainment)	Operational Ferrier	Ctl	Ctl

** Experimental Ferrier Microphysics are related to changes in parameters controlling the liquid water glaciation, ice nucleation, cloud formation, vapor deposition and cloud water collection by precipitation. More information on the various microphysics and convective parameterization can be found in Ferrier (2004) and Ferrier, et al. (2002).*

2.1.2 Upgraded Eta Model

There was a desire to increase the spread and diversity between various model runs of the NCEP SREFs. The current operational SREF is running five Eta model runs using the BMJ convective scheme, five Eta runs using the KF convective scheme, and five runs of the Regional Spectral Model (RSM) at a horizontal resolution of 48 km. During this past summer, each of these runs were made at a horizontal resolution of 32 km in the same configuration as the operational SREF, and their results were compared against a modified system with greater physics diversity. The experiment showed improved forecast spread using physics diversity (Du *et al*., 2004). After extensive discussions, it was decided to add more physics diversity to the Eta model and the RSM members, together with diversity in initial conditions using symmetric breeding cycles. This section will briefly describe aspects of the expanded physics diversity used in the SREF-X system. 11 Eta members are run for the SREF-X sytem. The SREF-X system uses the latest version of the NCEP Eta system as described in Ferrier, et al. 2003 and Ferrier (2004).

This implementation of SREF will use a version of Eta implemented operationally in July, 2003 (See NCEP/TPB, Ferrier et al., 2003):
http://www.emc.ncep.noaa.gov/mmb/tpb.spring03/tpb.htm.

A list of Eta changes are available at:
http://www.emc.ncep.noaa.gov/mmb/research/eta.log.html.

2.1.2.1 Convective Parameterization Diversity

In order to promote greater physics diversity in the Eta model runs, changes were also made in the grid-scale microphysics to compliment the use of different convective schemes. The final configurations of the Eta model members are summarized in Table 3. Along with the operational BMJ convection (labeled BMJ in the table), a modified BMJ_SAT scheme has been included in the SREF system because of its superior performance in the 00Z 30 August 2003 forecast as well as the diversity it exhibits with respect to the operational BMJ. Based on a series of sensitivity experiments, the following modifications to the BMJ scheme resulted in improved convective initiation and QPF (BMJ-SAT).

- For explicit triggering of convection, limiting the amount of lifting of air parcels from their source level to their condensation level to no more than 25 hPa, and further lifting to their level of free convection to no more than 50 hPa.
- Candidate parcels are searched over the lower half of the atmosphere, whereas this is limited to the lowest 1/5 of the atmosphere in the BMJ.
- Updated lookup tables and refined calculations of equivalent potential temperature use the algorithm of Bolton (1980).
- Including the effects of ice in calculating the cloud updraft parcel characteristics, as well as in the enthalpy conservation and the entropy evaluation steps. The isobaric freezing of cloud water to ice is included in the parcel calculations following Saunders (1957). The greatest impacts from these changes are higher estimated cloud-top heights due to the increased diabatic heating effects, and drier moisture profiles aloft due to the lower saturation mixing ratios with respect to ice.
- The BMJ scheme, which adjusts towards reference profiles of temperature and moisture, will be delayed in triggering deep convection when moister profiles are assumed. *In this regard, the reference moisture profiles behave as implicit triggers of convection.* In the absence of grid-scale ascent, the reference moisture profiles were modified to be near water saturation at temperatures warmer than -15 C, decreasing linearly with temperature to ice saturation below -40 C. Drier reference moisture profiles are assumed In the presence of grid-scale ascent following eq. (10) in Betts (1986), which prevents supersaturated conditions from forming in the

convective column and reduces the occurrence of spuriously large and rapid rates of grid-scale precipitation.

Since convective triggering will be substantially delayed with respect to the original BMJ scheme, a greater potential exists for grid-scale instabilities to form. The cloud efficiency functionality in Janjic (1994) is therefore removed in order to make the convection respond rapidly when triggered. Together with the KF convective scheme, the full detrainment of precipitation back onto the grid (labeled KF-DET in table 3) is included in the physics suite

The Relaxed Arakawa-Schubert (RAS) convective scheme (Moorthi and Suarez, 1992; 1999) was used in both the Eta and RSM members. We have relatively little experience with this scheme in the Eta model compared to the RSM and the GFS model. The RAS exhibits encouraging skill when simulating strong convective events and more organized synoptic systems. Compared to the other convective schemes, the Eta-RAS seems to produce a dearth of shallow convection, along with widespread areas of light precipitation falling from the transient triggering of deep convection. In fairness, this model behavior may be a result or byproduct of the scheme being run with a suite of physics parameterizations used in the RSM and GFS that are quite different from those used in the Eta. More tuning of the RAS is probably needed for it to achieve better performance in the Eta modeling system.

The BMJ, KFc, and RAS convective schemes are run using the operational grid-scale microphysics (Rogers *et al*., 2001; Ferrier *et al*., 2002) as labeled in Table 3. The BMJ_SAT and KFc-DET are run using an experimental version of the same grid-scale microphysics, labeled "Exp" in the Table, will be described later.

2.1.3 Upgraded RSM model

For SREF, the hydrostatic version of the RSM will be implemented with upgraded Global Forecast System (GFS) physics and improved parallel processing. More information on the RSM upgrades can be found on the NCEP RSM page at:
http://wwwt.emc.ncep.noaa.gov/mmb/RSM/

4 RSM members contributed to the 15 member SREF-X system. The NCEP RSM used in the SREF is a hydrostatic version of RSM(Juang and Kanamitsu, 1994, Juang et al 1997). The uniquenes of NCEP RSM is its perturbation for spectral computation. The definition of the perturbation is the difference between value obtained from the regional model and value obtained from the global model. The time integration comprises linear and nonlinear computations. Linear computation is all perturbation on spectral space, including all numerical treatments such as semi-implicit, horizontal diffusion, and time-filter; and nonlinear computation is full value on physical space, including all dynamical forcing, model physics and lateral boundary relaxation. The model physics includes long-wave and short-wave radiations with aerosol, ozone and cloud interaction, simple soil model with three layers, surface physics with non-local PBL, gravity-wave drag, Simplified Arakawa-Schubert convective scheme, shallow convection and large-scale precipitation, and a simple hydrological cycle such as snow depth and water run-off.

Preliminary results have shown that the addition of the improved physics diversity SREF system at 32 km provide more accuracy mean forecasts as well as ensemble diversity and forecast spread to the SREF (See description of testing and statistical summaries, below).

2.2 SREF Breeding Initialization System

This change was implemented to control unrealistically high initial conditions perturbations noted with the previous technique. The initial condition perturbations are now scaled by a factor inversely proportional to the difference between the previous 12 hour perturbed 850 mb temperature forecasts.

3. SREF OUTPUT PRODUCTS

Output fields from the SREF post-processor are available for the AWIPS 40-km Lambert conformal grid over the CONUS (Grid 212). following output grids on a 3-hourly basis out to 63 hours Contingent upon available resources on the NCEP server, these grids will be accessible via anonymous ftp from this server. There are currently no SREF model outputs available on AWIPS.

Graphical plots of various SREF products from the combined 15 member 48 km system can be found at: http://wwwt.emc.ncep.noaa.gov/mmb/SREF/SREF.html Grib outputs of the 32 km SREF mean, spread and probabilistic output will be found at:
ftp://ftpprd.ncep.noaa.gov/pub/data/nccf/com/sref/prod/
Bufr outputs of individual Eta members from the SREF 32 km system will be found at :
ftp://ftpprd.ncep.noaa.gov/pub/data/nccf/com/sref/prod/

Additional changes were made recently to the SREF output products and are described below:

3.1 *Use of Grib extensions for combined probabilistic outputs*

To improve output standardization, the grib information of all SREF ensemble combined products (mean, spread and probabilistic fields) are being corrected to follow the NCEP standard for ensemble extensions. All probabilistic products will be contained in one file , rather than 5 as previously done. This change was implemented in December, 2003. A list of mean, spread and probabilistic products are available in Table 4 and 5 or at :
http://wwwt.emc.ncep.noaa.gov/mmb/SREF-Docs/

Table 4. SREF Grib File Statistical Products

Mean/Spread Parameter (3 hrly)	**Units**	**Levels**
2 m Temperature	K	Sfc
10 m U, V wind	m/s	Sfc
Total Precipitation (3, 6, 12, 24 hrly)	kg/m^2	Sfc
CAPE	J/kg	
Convective Inhibition (CIN)	J/kg	
Storm Relative Helicity (SREH)	m^2/s^2	0-3000 m
Lifted Index		0-30mb AGL
MSLP	Pa	Sfc

Categorical rain *	Y/N	Sfc
Dominant Precip Type (3hrly) *	1-7	Sfc
Large-scale snowfall (12 hrly)*	kg/m^2	Sfc
Snow depth (12hry)*	kg/m^2	Sfc
Accumulated snowfall (12 hrly)*	kg/m^2	Sfc
Pressure	Pa	1000-50 mb
Absolute Vorticity*	/s	1000-50 mb
Geopotential Height	gpm	1000-50 mb
U, V wind	m/s	1000-50 mb
Temperature	K	1000-50 mb
Thickness	gpm	1000-50 mb
Relative Humidity	%	1000-50 mb

**=means computed only*

Table 5. SREF Grib File Probabilistic Threshold Products.

Field	Unit	Levels	Probability of occurance
Temperature	F	2m	>75,80,85,90,95 F
Winds	m/s	10m, 850, 700 mb	> 5, 10, 15, 20, 25 m/s
Precipitation	kg/m^2	3, 6, 12, 24 hrly	>0.1, 0.25, 0.5, 1.0, 2.0 inches
Dominant Precip	1-7	3 hrly	Probability of precip type
Snowfall	kg/m^2	3, 6, 12, 24 hrly + min, max	>1, 2.5, 5, 10, 20 inches
CAPE	J/kg		>500, 1k, 2k, 3k, 4k
Lifted Index	K		< 0, -4, -8

3.2 *Additional Grib outputs for individual members*

In September, 2003, at the request of NWS field forecasters and NCEP service centers, additional Grib outputs from each SREF Eta and RSM member and combined mean, spread and probabilistic products were added to the SREF Grib files. For Eta, additional cloud and convective fields were added. For RSM, additional convective fields and 2 m dew point temperature are added. In addition, the number of pressure levels are increased from 20 to 40 (25 mb intervals from 1000 mb to 25 mb). Updated on-line inventories of output grids from individual members are available for Eta at: http://www.nco.ncep.noaa.gov/pmb/products/eta/

Future implementations of AWIPS will carry additional SREF products. Currently SREF graphical products are available at the NCEP SREF web page and Gridded data are available on the NCEP ftp site.

3.3 Eta member Bufr outputs

At the request of NWS field forecasters and NCEP service centers, BUFR sounding output for individual Eta SREF members are created and have been available since September, 2003 at:
ftp://ftpprd.ncep.noaa.gov/pub/data/nccf/com/sref/prod/
A list of outputs from Eta member Bufr soundings are available at:
http://www.nws.noaa.gov/om/ord/iob/NOAAPORT/resources/noaaport_links.shtml

In addition, mean and spread output products from the NCEP operational and experimental SREF systems are summarized in Table 4. Spread is defined as the standard deviation of ensemble members from the ensemble mean. All outputs are produced on AWIPS Grid 212 (Lambert Conformal 40 km, 185x129, CONUS grid). Probabilistic output products are summarized in Table 4. Probability estimates are defined as the percentage of predictions out of the total (15) that meet or exceed the specified criterion.

Additionally, the current NCEP SREF system products are displayed on the NCEP web page athttp://wwwt.emc.ncep.noaa.gov/mmb/SREF/SREF.html. An example of a SREF mean and spread diagram for total precipitation is shown in Fig. 2. An example of probability of occurrence for specific values for precipitation is shown in Fig 3.

3.4 Additional Experimental Products

Additional specialized graphical ensemble products are made from the 15 member ensemble runs for Aviation and Hydrological applications. Two basic graphical charts are produced:

- Mean and Spread plots for SREF system output fields.
- Probability of occurrence for SREF system output fields.

These graphics are produced for the combined 15 members.

Aviation

The following aviation products are produced twice/day from the SREF predictions. More information about SREF-Aviation products can be found at: http:////////////////////////

Table 6. Graphics produced every 3 forecast hours to 63 hours for Aviation applications.

Field	Levels	Mean/Spread	Probability of occurrence
Wind Threshold (m/s)	850 mb 500 mb 250 mb	Wind barb means	>10, 20, 30 m/s >30, 40, 50 m/s > 30, 40, 50 m/s
Icing (only Eta)	850-500, +50 mb		Probability of occurrence
Tropopause (only Eta)	Trop	Height (mb), Temp (C)	
Freezing Level (only Eta)		Height (m)	
Visibility (only Eta)			
Turbulence Intensity	500-450 mb 450-400 mb 400-350 mb 350-300 mb		Probability of occurrence for: Lgt/Moderare Moderate

Field	Levels	Mean/Spread	Probability of occurrence
	300-250 mb 250- 200 mb		Severe
Vertical Wind shear (m/s per km)	1000-950 mb 950-900 mb 900-850 mb	Mean/spreads	
Clouds (Eta only)	All	Total Cloud Fraction, + max and min	10-30%, 40-70%, 80-100 cloud fraction probability

Hydrological
Probability of occurrence of flash flood conditions are plotted for +12, +24, +36 and +48 hour forecasts on the NCEP/HPC web page from the SREF outputs:
http://www.hpc.ncep.noaa.gov/newrpp/rpp_ens.shtml

4. SREF MEAN AND SPREAD EVALUATION

Standard error time-series of the grid domain mean, average and standard deviations for the SREF-I & II systems (Summer 2003) and SREF-X (Fall-Winter, 2004) of various products (listed below) are computed at the standard evaluation times for each run as part of SREF system processing. These evaluations are produced for the following fields:

- MSLP
- 500 mb Heights
- 850 mb Temperature, RH, U and V-wind components and wind speed
- 250 mb Temperature, U and V-wind components and wind speed.

The following standard error plots are computed:

- Root Mean Square Error (RMSE)
- Correlation Coefficient (%)
- Bias
- Equitable Threat Scores (ETS).

Three error time-series are usually plotted:
Mean: mean of all ensemble members
Best: The best ensemble member as computed from the evaluation statistic
OPR: Eta-12 operational forecast error.

An example of the mean and spread plots are shown on the SREF evaluation web page (http://wwwt.emc.ncep.noaa.gov/mmb/SREF/VERIFICATION/2003.htm).

Preliminary results have shown that the spread is increased with the SREF-II system, however, the mean accuracy results are similar for key fields (not shown). Wilczak et al. (2004) also showed that the mean 2 m temperature accuracies were similar between both SREF approaches during the Summer 2003 NEHRT experiment.

5. SREF PROBABILISTIC EVALUATION

The following probabilistic plots were produced by the NCEP SREF system to summarize the SREF system statistical characteristics. More information on probabilistic verification is summarized by Toth et al. (2002).

Talagrand Analysis Ranked Histogram plots are produced by binning each of the 15 members into equal ranges for the forecast fields. Fields for each member are compared to the operational analysis at corresponding grid points. The numbers of ensemble members at each grid point that agree with the analysis value range bin are then summed and plotted. Currently 16 bins (membership plus 1) are used. For example, for MSLP 16 bins are created ranging from min pressure to max pressure in the analysis. The results yield the percentage of the ensemble system that encompasses the analysis. (Figs. 4 and 5).
Talagrand Equal Likelihood Frequency Plots yield the percent chance that an individual member is closest to the analysis. 15 members are currently analyzed. (See SREF web page, for examples)

In addition, probabilistic error time-series of the 3 SREF composites are produced for 3, 6, 12 and 24 hour precipitation forecasts for the following error statistics:

· Brier Skill Scores: 0.1, 0.5, 1.0 inch precipitation thresholds used. Operational Eta-12 forecast is the reference forecast that skill is based upon.

· Ranked Probability Skill Scores (RPSS): Operational Eta-12 forecast is the reference forecast that skill is based upon.

· Skillful area (%) from RPSS statistics

5.1 Summer 2003 Evaluation

A conference paper was written (Du, et al. 2004) that evaluation statistics from the July 2003 physics diversity experiment. This paper can be found at:
http://wwwt.emc.ncep.noaa.gov/mmb/SREF-Docs/SREF_16thNWP2004.pdf
The Analysis Rank Histogram plots for several fields from the SREF-I and II systems (Summer 2003 evaluation) are shown in Fig. 4 and 5, respectively. The U-shaped distribution indicates that both SREF-I and II are under-dispersive; however, error for the SREF-II system is more equally spread among all value ranges. The amplitude of the outlier ranges (bins 1 and 16) are also reduced for the SREF-II system, implying a better chance that the verifying analysis falls within the ensemble forecast ranges than in SREF-I. The MSLP histograms (Fig. 4 and 5 a), for example, show that 24% of the SREF-I member forecasts lie outside of the verifying analysis as compared to 19% for SREF-II. Both systems, however, still underestimate the the true uncertainty in the forecast.

A spaghetti diagram of the MSLP 1004 mb contour for SREF-I and SREF-II systems is shown in Fig. 6 for 06 UTC July 9, 2003 SREF runs. A wider diversity of contours is shown in the SREF-II system, indicating more spread predicted than for the SREF-I system for this forecast.

5.2 Winter 2003-2004 Evaluation

A full series of probabilistic verification plots are shown on the SREF verification web page.

6. SUMMARY AND FUTURE PLANS

This document overviewed the current NCEP SREF system that includes breeding initialization, member configuration, postprocessed products and ensemble based verification tools. The preliminary results show that adding physics diversity improves the SREF system's ability to capture more forecast uncertainty. This SREF system product directly supports NCEP's strategic goal of delivering improved probabilistic products and services. This upgrade to the operational SREF system capability will be part of a larger plan to gradually increase the forecast accuracy and provide improved confidence information over the next several years. This project, which will increase ensemble diversity information and add forecast products, is planned to expand in the following years to include more and higher resolution ensemble members, improved member physics, model core and initialization diversity, and additional ensemble post-processed products.

In the near term, a SREF system similar to SREF-II will be implemented this coming winter. Specific improvements include the development of post-processed bias correction and calibration techniques, extension of the SREF runs to 4 times per day, improved initial and lateral boundary condition generation, and the addition of energy, hydrological and aviation related products and ensemble mean meteograms.

ACKNOWLEDGEMENTS

The views expressed are those of the authors and do not necessarily represent those of the National Weather Service or NOAA. This work was partially supported by the North East High Resolution Temperature Program grant.

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Appendix A. Software Description and Output files

A1. Software and Scripts

The SREF software and scripts are located on:

/nwprod/sorc & /scripts: Production code & scripts
or
/nfsuser/g01/wx20jd/OPT/{ETA or RSM} : Development scripts

All scripts are driven by autotrigger_{ETA or RSM}.{09 or 21}.ll

Operational scripts are divided into the following components:

exsref_prelim: Data preparation and truncation software
exsref_{MDL}_fcst:[MDL] forecast run software where [MDL] is either ETA, ETAKF or RSM
exsref_{MDL}_post:[MDL] post-processing (vertical interpolation, additional fields)
exsref_post: Probablistic product generation (i.e.: mean, spreads, etc)

/nfsuser/g01/wx20jd/prod/web: Development scripts dir to create Grads GIF files and copy to web e.g.: para_com15mem.3hrly: creates Grads gifs for combined parallel 15 member runs.

/nfsuser/g01/wx20jd/prod/ver: Development scripts dir to creates verification statistics

A1.1 Breeding Perturbation software

exsref_prelim.sh (Development: runeta_data.sh ,runeta_edas.sh, runeta_pert.sh):
- Gets all data needed to initialize and provide LBCs for the members (GFS and Eta)
- Truncates the GFS spectral fields for RSM ensembles
- Converts global data to Eta format
- Truncates the Eta fields to Eta ensemble member resolution
- Create regional breeding perturbations (With programs: PERT_INIT.x, PERT_CONT.x, PERT_COMB.x, IT.x)

Input Files are located on /nwges/prod/sref.YYYYMMDD
(Development: /gpfstmp/wx20jd/ETA/datain3260)

The following input files are needed to run the breeding codes:

1. For Eta:
- EDAS ground and static files: edas.t09z.nhb4845, edas.t21z.nhb4845
- Each of the following control and perturbation initialization and boundary condition (ctl, p1, n1, p2, n2) files for both t09z and t21z:
  - Eta: (Output from prelim programs): nhb4845.t09z_(ctl,p1,n1,p2,n2), nbcout.t09z_* , init.t09z.* , restrt12.t09z.*
  - KF-Eta: kf_init.t09z.* , kf_restrt12.t09z.*

2. For RSM:
sfc.init.t09z.* , sig.init.t09z.* , rsm_sig12.t09z.*, BC files from the GFS ensemble archive.

A1.2 Model Execution software

execsref_MDL_fcst.sh(dev: runeta,rsm_fcst.sh_all): Drives each MDL member's forecast

3.3 Post-processing software

execsref_{ETA or RSM}_post: Runs {ETA or RSM}post.x and product generator. Calls Bufr sounding generator. Also creates GEMPAK files:

- *runeta_post0.sh* --- Creates Eta BUFR sounding files (currently Eta only)
  Output: /ptmp/wd20jd/ETA/run3260/holdprofil/*BMJ_ctl.2004032409.profilm.c1.tm00*

- *{ETA or RSM}post.*sh or .x – Creates GRIB file on pressure surfaces
  Also Calls *prdgen* to interpolate eta post files to AWIPS212 grid
  Output*: /emc2/wx20jd/ETA/dataout3260/YYYYMMDDCC/DET_pgrb212.p6.fHH*

execsref_post: Probabilistic product generator (i.e.: mean, spreads, prob files)

/nfsuser/g01/wx20jd/prod/web: Create GRADS gif files and copies these to the web.
~ /prod/sorc/SREFCOM_GRIB: SREF-post source code (grib2ascii2grib.f)

3.4 Verification software
Scripts and software to compute SREF verification statistics are found at:
/nfsuser/g01/wx20jd/prod/ver
The main driving script is:
Verification.sh : SREF Verification driver script.

- Copies thinned member files, operational deterministic forecast and verifying analysis to verification working directory
- Runs score.15mem.f to compute std deterministic verification statistics against Eta, FNL and mean (Eta + FNL average) analysis of MSLP, H, T, U,V, RH,Q at standard levels. The following stats are computed:
  - Standard deviation among members (Ensemble Spread)
  - Compute difference between a pair of any two members (Perturbation Growth)
  - RMSE, anomaly correlation coefficients (subr correlation) as computed against analysis for ensemble mean, median
  - Talagrand Distribution (subr talagr) over 16 ordered bins (relative frequency, spread and position) and fixed members (score: ranked score and equally likely probababilities)
  - Output all statistics in ascii formatted file (temporary file data.out) for plotting

A1.2 Outputs

Operational 3hrly (to 63 hrs) Grib output files are written to the IBM Production side at /com/sref/prod/sref.yyyymmdd on the AWIPS 212 grid (40 km). Individual members have the following naming convention:
sref_MDL.tCCz.pgrb212.{p,n}{1,2].fHH
e.g.: sref_kfeta.t21z.pgrb212.p1.f63
where:
MDL = eta, kfeta, or rsm
CC = cycle time (09 or 21)
[p,n][1,2] = positive or negative breeding pair 1 or 2

HH= forecast hour

For SREF, all fields for each ensemble member are located in one file. For the Global ensembles, one field for all members are located in one file

Operational mean/spread and probability files have the following naming convention

sref.tCCz.pgrb212.mean (or spread or prob)
e.g.: serf.t09z.pgrb212.mean

Experimental mean/spread/prob GRIB products are located on the IBM-development at:
/ptmp/wx20jd/prod/grib/ens.YYYYMMDD

The raw experimental ensemble members are located on the IBM-development (snow) at:
/emc2/wx20jd/{ETA or RSM}/dataout/ens.YYYYMMDD

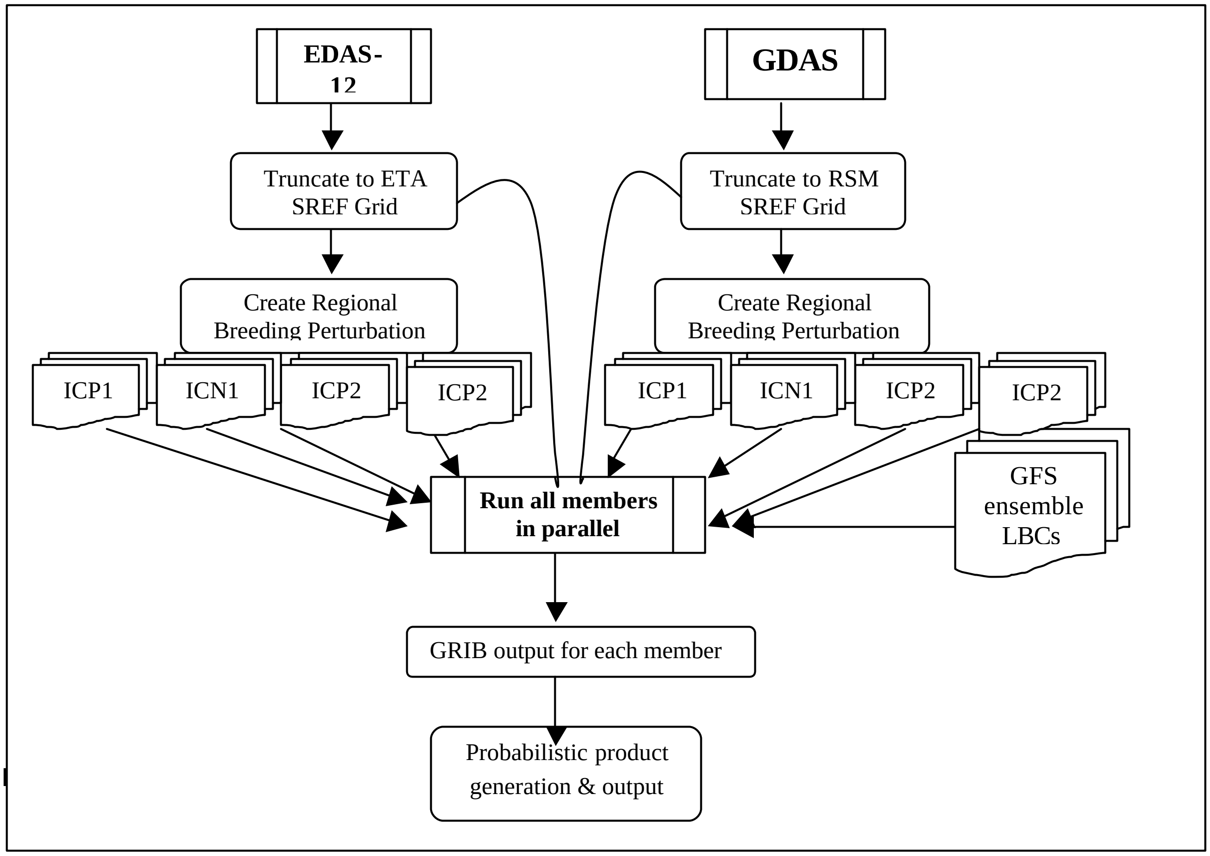


Figure 1. Outline of NCEP SREF Operational system run (Multi-IC) in 2003. ICP, ICN, I represent Initial Condition files for the Positive and Negatively perturbed runs, respectively. In addition, a control run was initialized with the truncated Initial condition grid (curved arrows). 2 perturbation pairs were run similar to the SREF-I configuration outlined in Table 1. In September, 2003, 5 additional members from the Eta run with Kain-Fritsch convection parameterization were added to the SREF Operational system.

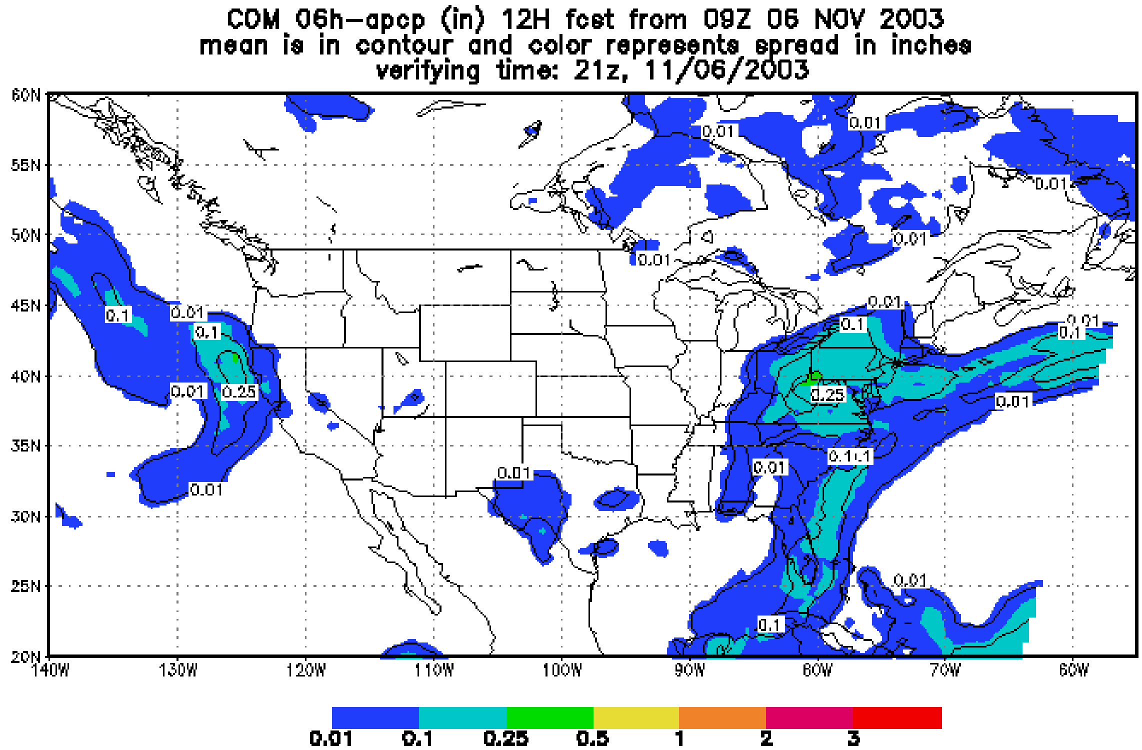


Figure 2. Example of a mean (solid lines. inches) and spread (standard deviations from all 15 members, color fill, inches) 6 hourly accumulated precipitation forecasts from NCEP SREF system.

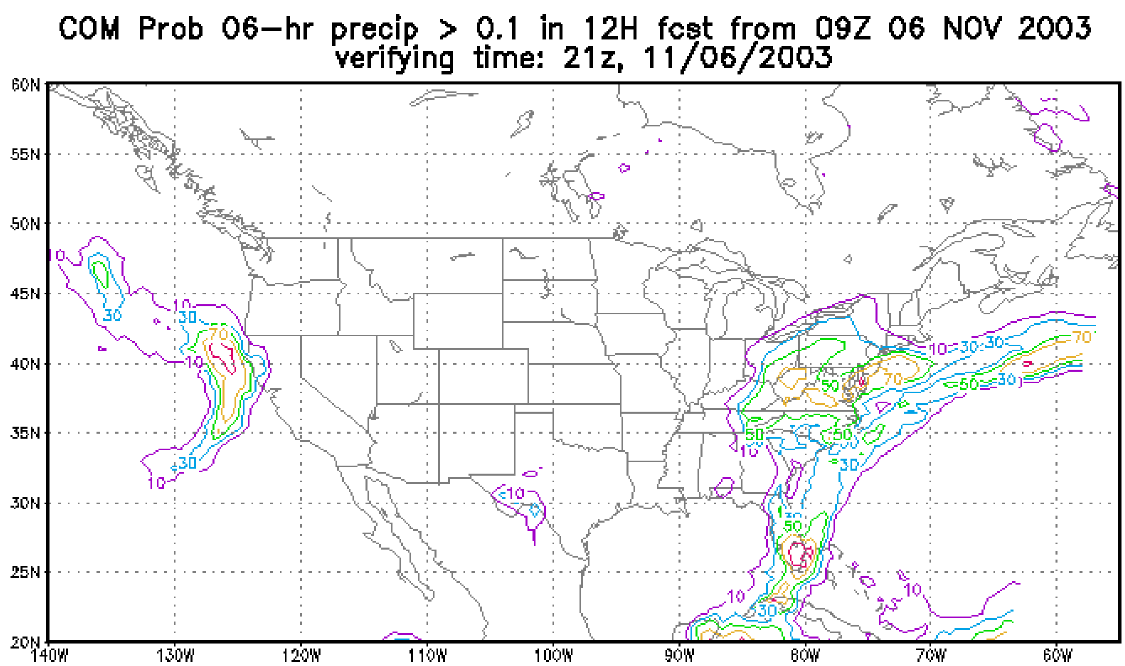


Figure 3. Example of 6 hourly accumulated precipitation probability of exceedence (%) of amounts greater than 0.1" in a 12 hour period. Highest probabilities are in orange and red.

Chances Ens Encompasses Anl at 60h (ini, July 03)

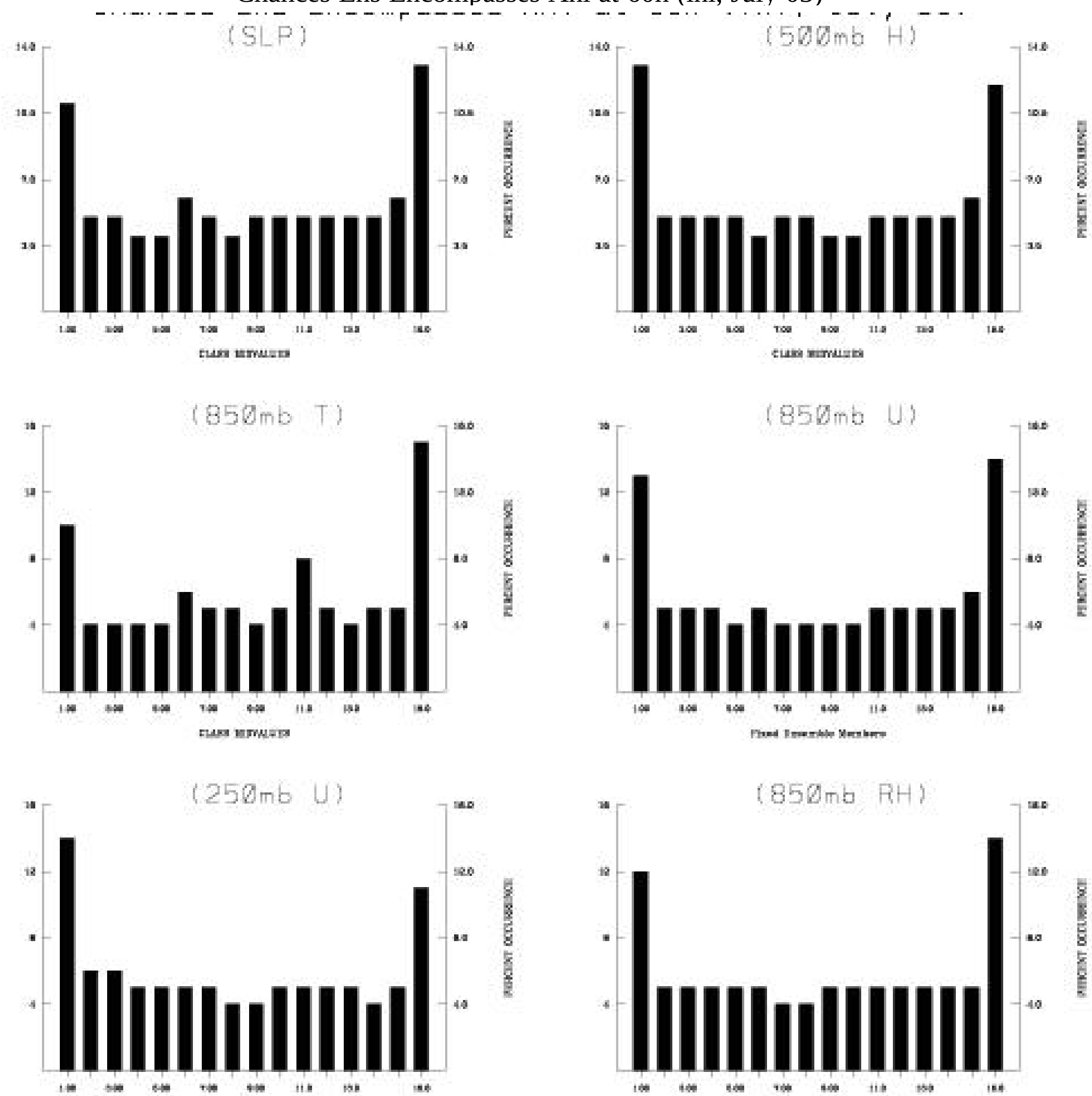


Figure 4. Talagrand Analysis Ranked Histogram diagrams for SREF-I multi-IC system for July 2003 from the SREF 06 and 18 UTC cycle 60 hour forecast. 16 ordered bins are shown representing equal value ranges for each variable from the variable minimum to maximum value. The leftmost and rightmost bins represent outliers. The y-axis represents the percent of the ensembles that lied within the analysis bin (0-16%) Talagrand diagrams are shown for a) MSLP, b) 500 mb height, c) 850 mb temperature, d) 850 mb Wind, e) 250 mb wind, f) 850 mb RH. See section 5 for a more detailed description of Talagrand diagrams

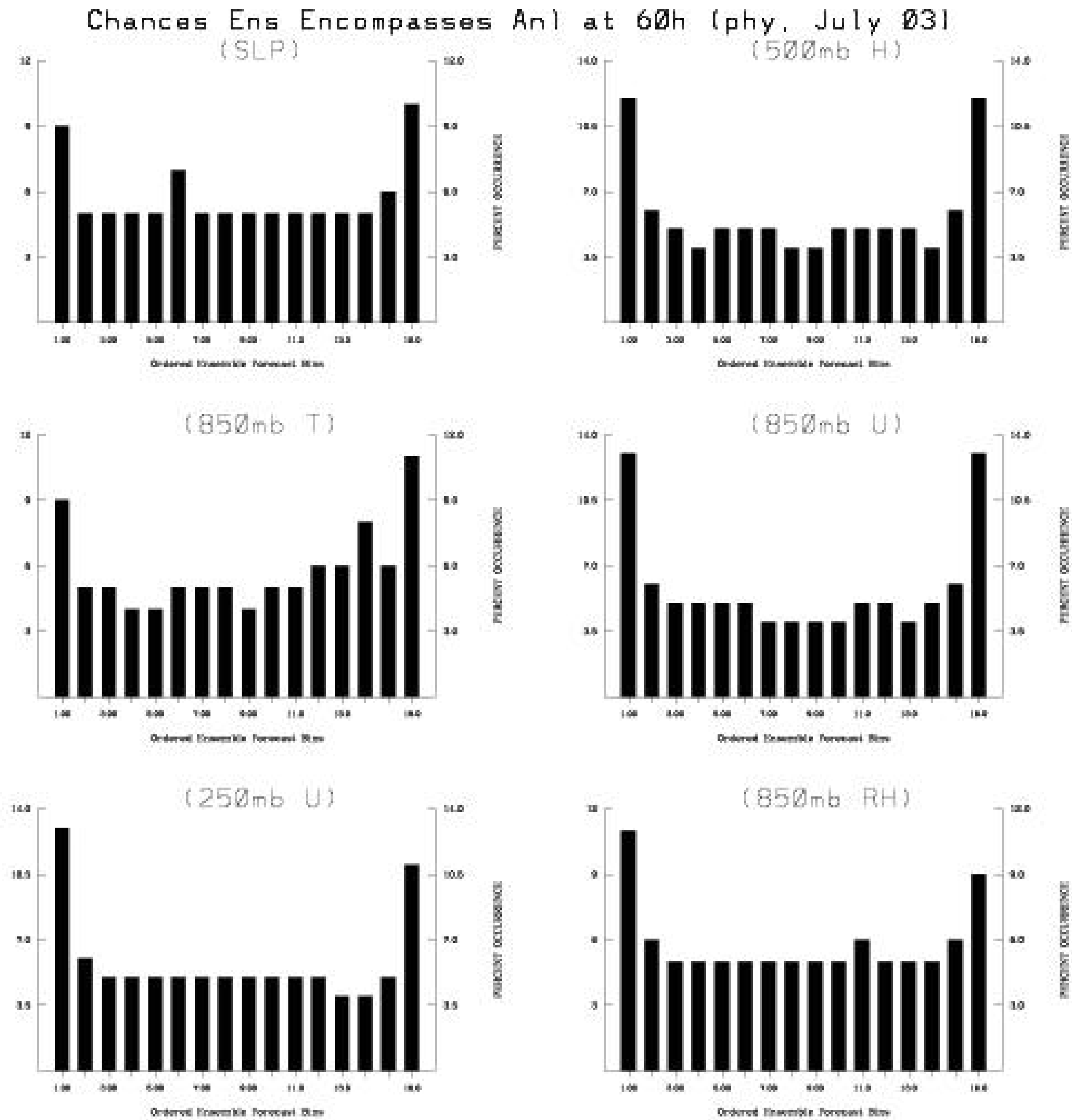
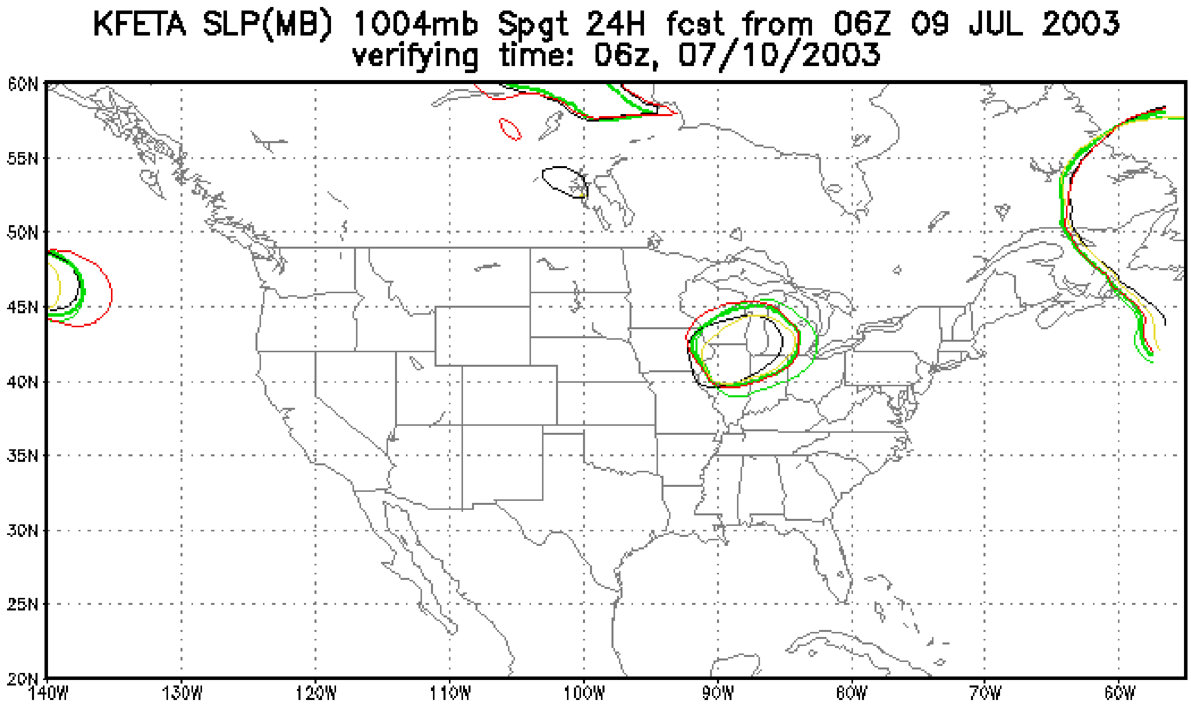


Fig. 5 Same as Figure 4 except for the SREF-II enhanced physics diversity system. Y-axis range is now 0-12%.



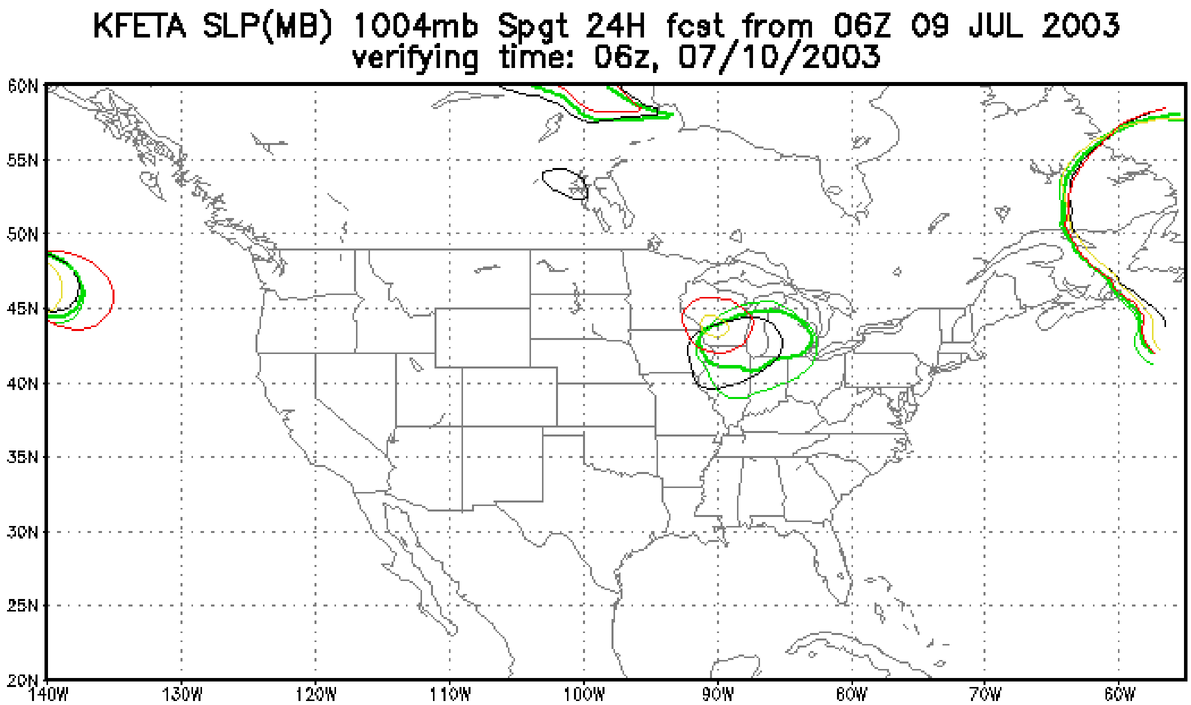


Figure 6. MSLP (mb) spaghetti diagram 24 h forecast of mslp contour 1004 mb valid July 10, 2003 at 0600 UTC for all a) SREF-I multi-IC members and b) SREF-II enhanced physics diversity members. (showing Eta-KF component only)