13A.1 UTILITY OF SHORT-RANGE ENSEMBLE FORECAST (SREF) GUIDANCE FOR FORECASTING THE DEVELOPMENT OF SEVERE CONVECTION

Jared L. Guyer* and David R. Bright
NOAA/NWS Storm Prediction Center, Norman, Oklahoma

1. INTRODUCTION

The NOAA/NWS Storm Prediction Center (SPC) is tasked with providing specific forecasts regarding the location and likelihood of severe convective storms for the protection of life and property. The SPC issues both deterministic and probabilistic outlooks of thunderstorms and severe thunderstorms (a severe thunderstorm is a thunderstorm with large hail ($\geq$ 0.75”), damaging wind ($\geq$ 58 mph), and/or one or more tornadoes) for the contiguous United States. These convective outlooks are issued for time periods covering the next one to eight days. On shorter timescales, the SPC (collaboratively with WFOs) issues convective watches (tornado and severe thunderstorm), as well as Mesoscale Discussions (MDs) that provide 1-6 hour guidance for hazardous mesoscale phenomena including severe thunderstorms.

Although great meteorological and technological strides have been made in severe convective forecasting over the past few decades, forecasting the development and coverage of deep moist convection remains an especially difficult challenge for operational forecasters. As a complement to observational meteorological data and traditional deterministic numerical model guidance, forecast guidance derived from the National Centers for Environmental Prediction (NCEP) Short-Range Ensemble Forecast (SREF - Du et al. 2006) has come into increasing use at the SPC over the past five years. SPC forecasters have found much benefit from utilizing post-processed fields from the SREF to provide guidance for the operational forecasting of severe convective storms, and some of those benefits will be discussed herein.

2. OVERVIEW OF NCEP SHORT-RANGE ENSEMBLE FORECAST (SREF) SYSTEM

The National Centers for Environmental Prediction (NCEP) Short-Range Ensemble Forecast (SREF) system is used to account for both model and initial condition uncertainty of environmental parameters considered important to the development of hazardous, high-impact weather including severe convective storms. The SPC's version of the SREF is constructed by post-processing all 21 members of the NCEP SREF (Table 1), plus the 3-hour time lagged operational WRF-NAM, for a total of 22 members each 6 hours (0300, 0900, 1500, and 2100 UTC). Output is available at 3 hour intervals out to 87 hours on a national 40 km grid. The SPC ensemble post-processing focuses on diagnostics relevant to the prediction of SPC mission-critical high-impact, mesoscale weather such as thunderstorms, severe thunderstorms, excessive convective precipitation, hazardous winter weather, and critical fire weather conditions. For more detailed information on the SPC version of the NCEP SREF, please see: http://www.spc.noaa.gov/exper/sref or http://www.emc.ncep.noaa.gov/mmb/SREF/SREF.html

Model	Convective Param	Resolution	Configuration	Membership	Initial Cond
ETA	BMJ	32km/L60	NOAM/Hydrostatic	3 (1 control, 2 bred)	NDAS
ETA	BMJ-SAT	32km/L60	NOAM/Hydrostatic	2 (2 bred)	NDAS
ETA	KF	32km/L60	NOAM/Hydrostatic	3 (1 control, 2 bred)	NDAS
ETA	KF-DET	32km/L60	NOAM/Hydrostatic	2 (2 bred)	NDAS
RSM	SAS	45km/L28	NOAM/Hydrostatic	3 (1 control, 2 bred)	GDAS
RSM	RAS	45km/L28	NOAM/Hydrostatic	2 (2 bred)	GDAS
WRF-NMM	NCEP BMJ	40km/L52	NOAM/Non-Hydrostatic	3 (1 control, 2 bred)	GDAS
WRF-ARW	NCAR KF	45km/L36	NOAM/Non-Hydrostatic	3 (1 control, 2 bred)	GDAS

Table 1. Configuration of the 21 member NCEP SREF system, adapted from Du et al. 2006. BMJ=Betts-Miller-Janjic; BMJ-SAT=BMJ with saturated moisture profiles; KF=Kain-Fritsch; KF-DET= KF with full detrainment; SAS=Simplified Arakawa-Shubert; RAS=Relaxed Arakawa-Schubert; NOAM=North America; NDAS=NAM Data Assimilation System; GDAS=GFS Data Assimilation System.

3. SREF APPLICATIONS TO SEVERE THUNDERSTORM FORECASTING

SREF derived forecast guidance has come into increased use over the past several years as related to the prediction of severe convective storms and related environments (e.g., Bright et al. 2004, Bright and Nutter 2004, Bright and Grumm 2006, Korotky and Grumm 2006, Weiss et al. 2007). Recent work at the SPC has focused on calibrating probabilistic output from the NCEP SREF using an "ingredients-based approach" for predicting thunderstorms and severe convective storms. Bright et al. (2005) discussed the development of the Cloud Physics Thunder Parameter (CPTP) as derived from the SREF. When combined with SREF forecasts of convective precipitation, the CPTP has proven to be valuable output for delineating potential thunderstorm areas by determining if sufficient instability and the appropriate thermodynamics considerations will exist for the charge separation needed to produce

* *Corresponding author address*: Jared L. Guyer NOAA/NWS Storm Prediction Center, National Weather Center, 120 David L. Boren Blvd, Suite 2300, Norman, OK 73072; e-mail: Jared.Guyer@noaa.gov

cloud-to-ground lightning. Building on the thunderstorm probabilistic guidance derived from the SREF, Bright and Wandishin (2006) discussed a post-processing method for producing calibrated probabilistic severe thunderstorm guidance. Its development parallels the SPC approach of examining environmental parameters to guide the forecasting of severe convective weather, especially as it relates to SPC's Convective Outlook (Day 1-3) scales. Serving as a complimentary follow-up to the aforementioned probabilistic-based guidance, this paper will focus on the application and utility of examining individual ensemble members from the SREF, as related to the development and areal coverage of potentially severe deep moist convection.

4. VALUE OF SREF INDIVIDUAL MEMBER OUTPUT AS RELATED TO THE DEVELOPMENT OF SEVERE CONVECTIVE STORMS

Provided sufficient forcing for ascent and thermodynamic ingredients, the utilization of SREF individual member guidance may serve as a proxy for the areal extent and likelihood of deep convective development. SREF guidance can serve as an important compliment to observational data, standard deterministic operational numerical guidance (e.g., WRF-NAM, RUC, GFS, ECMWF), and experimental higher resolution model guidance (e.g., 4km WRF-NMM). Even with 3-hourly output and a coarser resolution compared to many operational deterministic models, the SREF can be very helpful for accessing the likelihood and timing of convective development and the potential areal coverage thereof. Aside from probabilistic and ingredients-based guidance as discussed in previous studies, SREF output such as spaghetti diagrams and postage stamps of convective precipitation (and individual ingredients) are helpful when deducing the prospects for severe convective development. The diverse 22-member approach of the SREF can be especially useful in more uncertain areas of convective initiation, such as when large scale forcing for ascent is limited and/or when convective inhibition or "capping" may be problematic. In particular, the model and physics diversity within the SREF, including three different convective parameterizations [Betts-Miller-Janjic (BMJ), Kain-Fritsch (KF), and Simplified Arakawa-Schubert (SAS)], encompass a wider range of numerical model performance characteristics. SPC forecasters have learned to take advantage of the differing characteristics of the parameterized convection schemes, especially between the BMJ and KF, to better understand the statistical properties of the SREF convective precipitation forecasts. As such, a detailed examination of SREF ensemble members can serve as a counter for known individual deterministic model biases or tendencies. The examination of individual SREF member output can compensate for perceived model biases, including both systematic "typical" biases and shorter-term variability or perceived incorrect trends. Baldwin et al. (2002) noted that "all convective parameterizations contain arbitrary parameter settings and have characteristic behaviors that are sometimes inconsistent with reality", and the SREF serves as an efficient means of examining diverse numerical model guidance with inherently different physics packages and convective parameterizations.

With inherent numerical model biases and tendencies in mind, ensemble member clustering (or the lack thereof) can at times imply a greater (or lesser) likelihood of convective development by proxy of convective precipitation forecasts. When viewing calibrated probabilistic guidance derived from the SREF (Bright et al. 2005; 2006), viewing individual member output in the form of spaghetti plots can help determine is there is a particular "biasing" of the probabilistic guidance toward a specific model's convective parameterization. Markedly diverse ensemble solutions can serve as both negative biases (detrimental to mean and probabilistic output) or potentially advantageous outlier guidance, pending what is deemed more realistic or likely by operational forecasters in a given situation.

Additionally, SREF output in terms of probabilistic and/or mean guidance can sometimes overly smooth potentially relevant details, such that the value to operational forecasters may be hindered without a fundamental examination of the individual components of the SREF. While time considerations for an operational forecaster may curb his or her ability to examine individual ensemble member output in finite detail, selective and/or efficient usage of individual ensemble output is beneficial. At least cursory examinations of individual SREF members should be used as a compliment to ensemble mean/probabilistic information, as a follow-up to observational data and standard deterministic model guidance (e.g., WRF-NAM, GFS, RUC). Case examples will be used to illustrate these concepts and reinforce the utility of examining individual SREF ensemble member output as it applies to forecasting the development and coverage of severe convective storms.

4.1 Case Examples

7 April 2008 - Dryline across Texas

Oftentimes during the warm season, determining the southward extent of thunderstorms can be a difficult challenge, especially across the Plains beneath an elevated mixed layer emanating from the Rockies. In general, this scenario is typically characterized by weaker large scale forcing for ascent and stronger convective inhibition with southward extent, often involving a surface dryline. This forecast dilemma is typically further complicated by an appreciable conditional potential for severe thunderstorms owing to ample available moisture and potential instability. It is suggested that the examination of individual ensemble member output is especially suited for such weakly forced scenarios and/or when capping may be problematic.

The afternoon and evening of 7 April 2008 serves as an example in which the southward extent of thunderstorms (including potentially severe storms) was in question across Texas. The 1630 UTC 7 April 2008

SPC Day 1 Convective Outlook indicated a categorical Slight Risk of severe thunderstorms as far south as far north Texas, with the potential for thunderstorms (≥10% probability) as far south as central Texas (Fig. 1). Ultimately, thunderstorms were confined to far north Texas along the Red River, where large hail and a tornado was reported (Fig. 1). Thunderstorms did not occur farther south across central Texas, although SREF post-processed probabilities of severe thunderstorms (Bright and Wandishin 2006) supported a modest potential for severe thunderstorms in central Texas (Fig. 2). However, as a compliment to the probabilistic guidance, it is important to note that these severe thunderstorm probabilities appeared to be largely driven by the SREF's RSM and WRF-ARW members, while the majority of SREF members did not develop convective precipitation during the late afternoon/evening hours based on 3-hourly spaghetti plot forecasts of convective precipitation (Fig. 3). By examining the individual member output from the SREF, in conjunction with additional forecast guidance and observational data, operational forecasters can become better informed about any potential biases in probabilistic output, while factoring in a subjectively higher or lower weighting to thunderstorm probabilities by accounting for any perceived model biases on a given day.

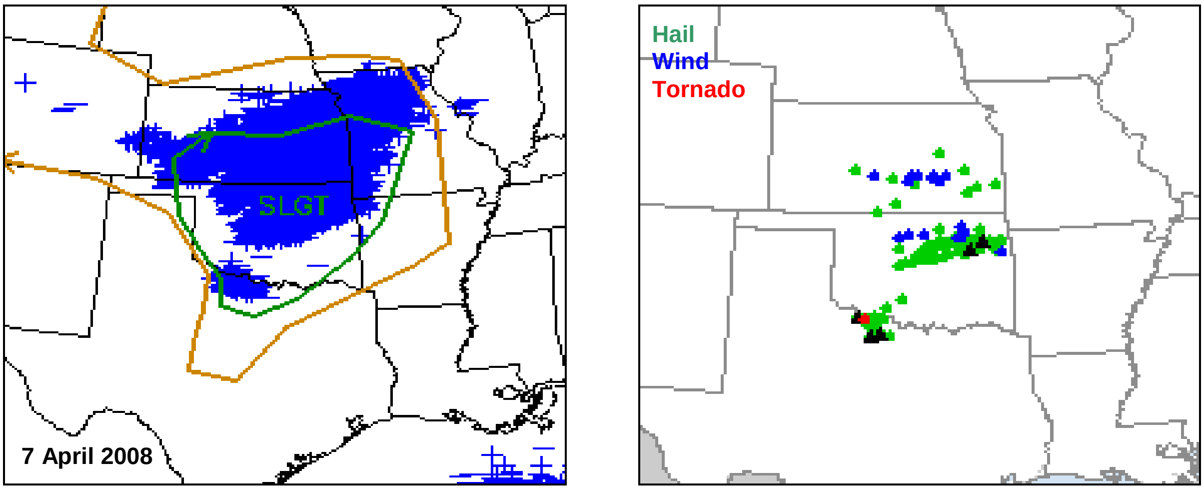

Fig. 1. (Left) SPC Day 1 Convective Outlook issued 1630 UTC 7 April 2008 with cloud-to-ground lightning (blue). Green line denotes an SPC Slight Risk (SLGT) of severe weather, with brown lines (to the right thereof) denoting 10% and greater thunderstorm probabilities. (Right) SPC preliminary severe reports for 1200 UTC 7 April 2008 to 1200 UTC 8 April 2008, with severe hail (> 0.75") as green dots, damaging wind (> 58 mph) in blue dots, and tornadoes as red dots.

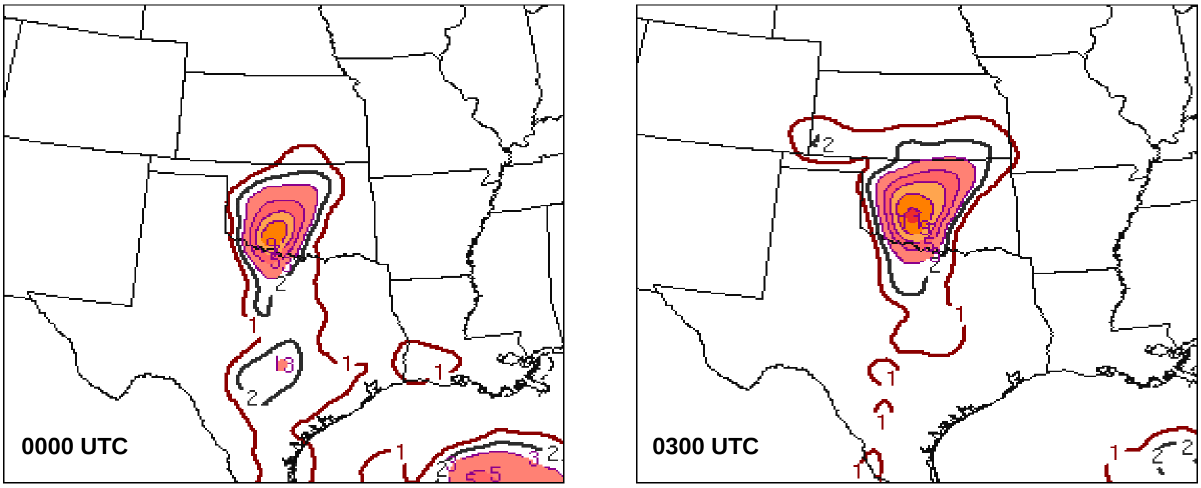

Fig. 2. 0900 UTC 7 April 2008 NCEP SREF 3-hourly calibrated probability of severe thunderstorms, with 15-hr (left) and 18-hr (right) forecasts valid 0000 UTC and 0300 UTC 8 April 2008, respectively.

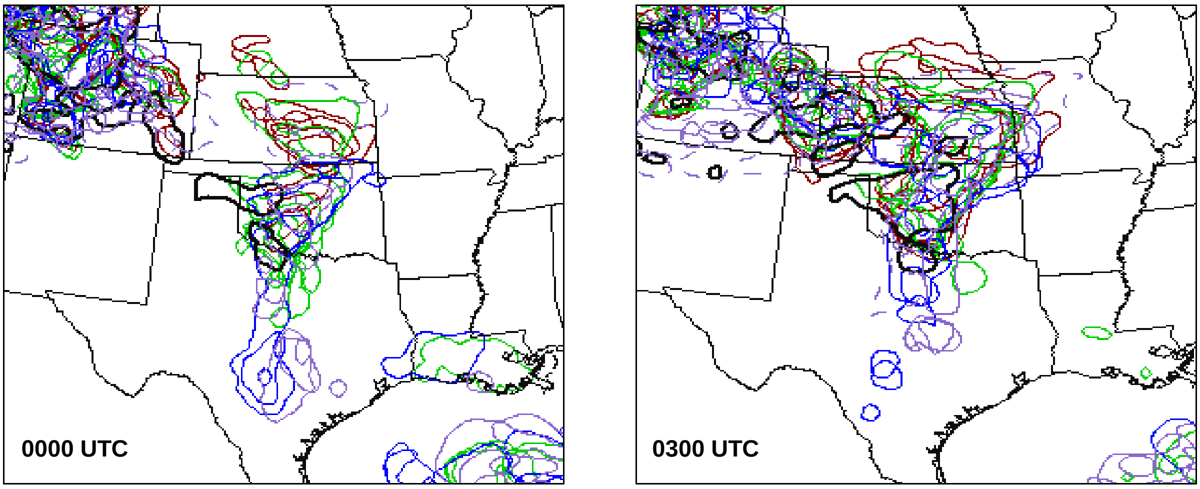

Fig. 3. 0900 UTC 7 April 2008 NCEP SREF 3-hourly spaghetti plots of convective precipitation, with 15-hr (left) and 18-hr (right) forecasts valid 0000 UTC and 0300 UTC 8 April 2008, respectively (ETA=red, EtaKF=green, RSM=blue, Operational NAM=black, WRF-ARW=solid purple, WRF-NMM=dashed purple).

4-5 May 2008 - Nocturnal hail-producing thunderstorms in Kansas

Another perhaps optimal utilization of spaghetti output of individual SREF convective precipitation plots is when there is the potential for warm season nocturnal convection across the Plains. This convection is typically aided by a nocturnally strengthening low level jet and an associated warm advection/elevated moisture transport regime as parcels are isentropically lifted to their LFC. Oftentimes rooted atop a relatively stable boundary layer, the primary severe potential for such development is severe hail, provided sufficient elevated instability and shear through the cloud bearing layer exists. Such a scenario occurred late 4 May into early 5 May 2008 across Kansas. Before this late night development, the 0100 UTC SPC Day 1 Convective Outlook 5 May 2008 noted "FARTHER NORTH ACROSS WESTERN KS LATE TONIGHT...ISOLATED THUNDERSTORMS MAY DEVELOP TOWARD 09Z-12Z AMIDST A MODEST 35-40 KT LOW LEVEL JET AND ASSOCIATED ISENTROPIC LIFT/ELEVATED MOISTURE TRANSPORT REGIME. FORECAST SOUNDINGS SUGGEST THE DEVELOPMENT OF AS MUCH AS 750 J/KG ELEVATED MUCAPE… HOWEVER THE OVERALL RISK FOR SEVERE HAIL APPEARS MINIMAL."

Isolated thunderstorms did indeed occur late 4 May into 5 May across the central Plains, with 10 preliminary reports of severe hail across west central Kansas between 0930-1500 UTC 5 May 2008 (Fig. 4). While SREF calibrated probabilistic thunderstorm and severe thunderstorm guidance was not particularly robust (Fig. 5), 3-hourly spaghetti plots of convective precipitation reflected an increasing model clustering of convective precipitation through 0900-1200 UTC across western Kansas, with the majority of the SREF members supportive of at least isolated convective development across western Kansas overnight (Fig. 6).

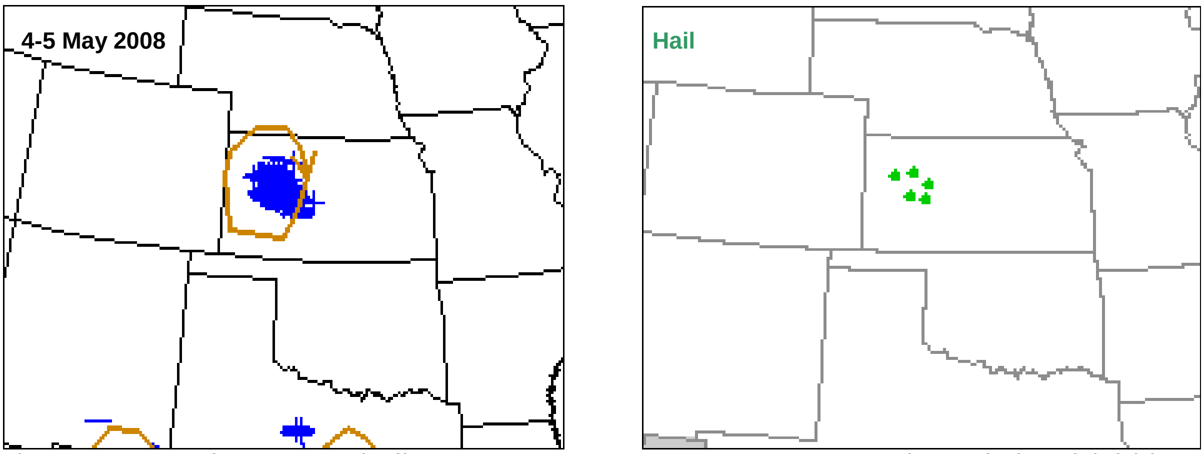

Fig. 4. Same as Fig. 1, except (*Left*) 0100 UTC 5 May 2008 SPC Day 1 Convective Outlook and (*Right*) SPC preliminary severe reports for 1200 UTC 4 May 2008 to 1200 UTC 5 May 2008. There were an additional 5 reports of severe hail across west-central Kansas between 1200-1500 UTC 5 May 2008 (not shown).

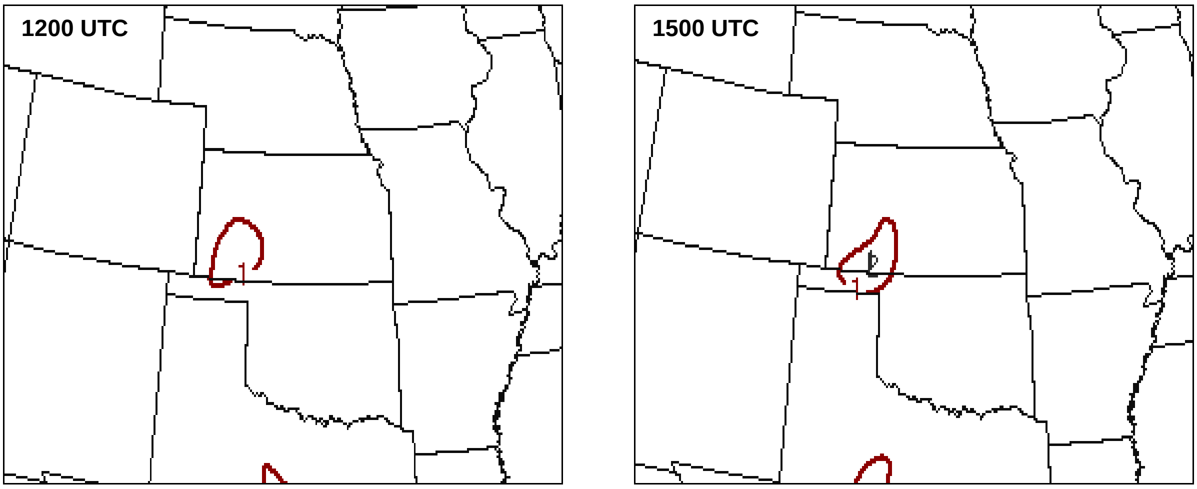

Fig. 5. 2100 UTC 4 May 2008 NCEP SREF 3-hourly calibrated probability of severe thunderstorms, with 15-hr (left) and 18-hr (right) forecasts valid 1200 UTC and 1500 UTC 5 May 2008, respectively.

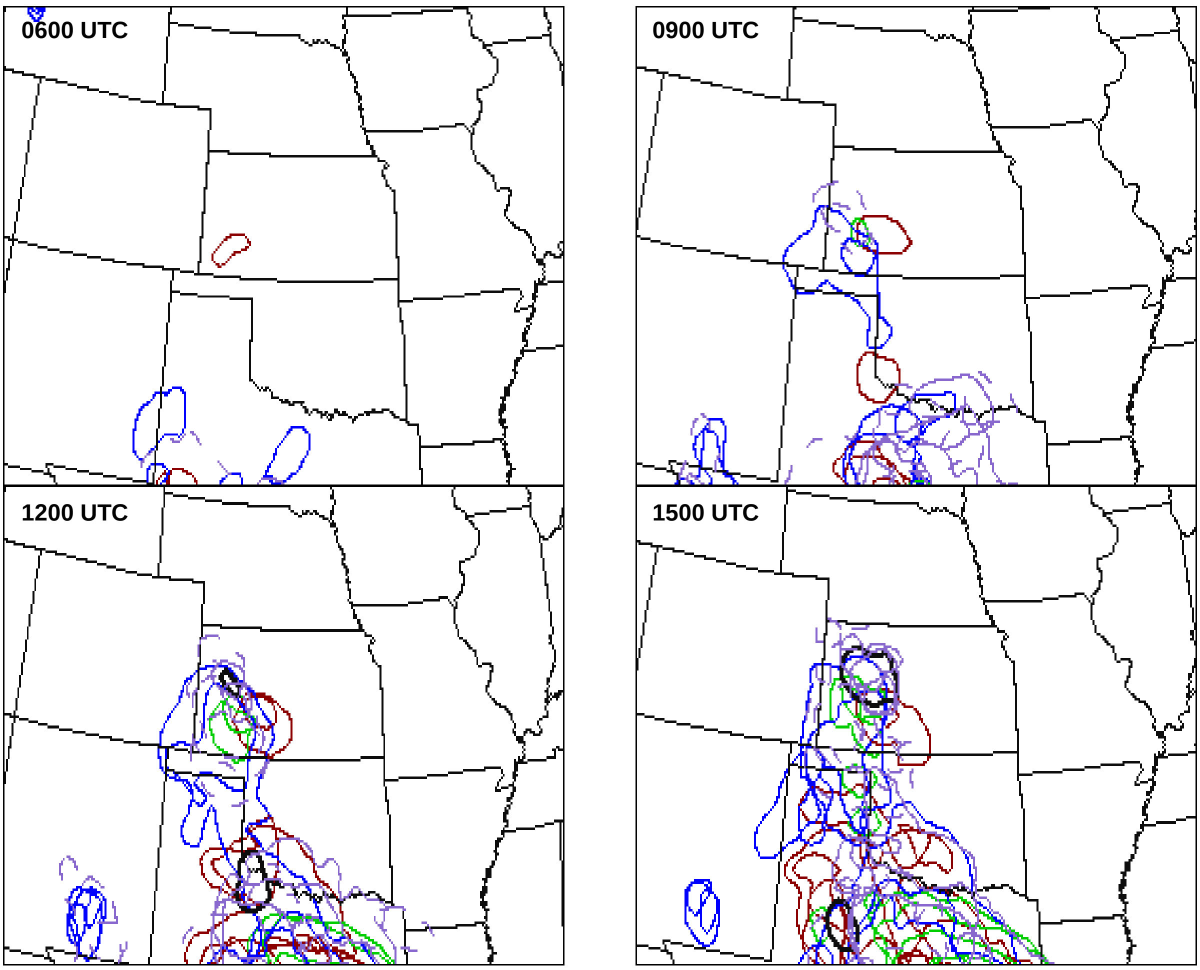

Fig. 6. 2100 UTC 4 May 2008 NCEP SREF 3-hourly spaghetti plots of convective precipitation with 09-hr, 12-hr, 15-hr, and 18-hr forecasts ending between 0600 UTC and 1500 UTC 5 May 2008 (ETA=red, EtaKF=green, RSM=blue, Operational NAM=black, WRF-ARW=solid purple, WRF-NMM=dashed purple).

9 May 2008 - Isolated severe thunderstorms across Texas amidst weak large scale forcing

On 9 May 2008, a conditional potential for severe thunderstorms, including supercells, was diagnosed for the late afternoon/early evening hours across portions of central Texas. Initial SPC Day 1 Convective Outlooks (0600 UTC/1300 UTC) discussed the uncertainties regarding the likelihood of deep convective development, with sub-Slight Risk ("See Text") 5% severe hail and wind probabilities issued for central Texas. By the 1630 UTC SPC 1 Convective Outlook, forecasters had become increasingly confident that a sufficient potential for at least isolated severe thunderstorms, including supercells, would develop later in the afternoon, warranting an upgrade to a categorical Slight Risk (Fig. 7). The 1630 UTC Day 1 Outlook text cited "CONSISTENT QPF SIGNAL IN A VARIETY OF MODEL GUIDANCE AND ENSEMBLE PROGS LEADS TO ADDITION OF HIGHER SEVERE STORM PROBABILITIES ACROSS PARTS OF TX HILL COUNTY ENEWD. RESIDUAL FRONTAL ZONE...AND POSSIBLE DRYLINE INTERSECTION...WILL COINCIDE WITH PRONOUNCED DIURNAL DESTABILIZATION WITH MUCAPE FORECAST TO CLIMB ABOVE 4000 J PER KG IN THE SAN ANTONIO/AUSTIN AREAS AND POINTS EAST THIS AFTERNOON. WHILE LARGE SCALE INFLUENCES SUPPORTING TSTM INITIATION AND MAINTENANCE ARE SUBTLE/WEAK...AND CAP WILL REMAIN QUITE STRONG MOST AREAS...ENOUGH MIXING AND HEATING INVOF RESIDUAL BOUNDARIES MAY BE ENOUGH TO OVERCOME THESE LIMITATIONS."

Utilizing 0900 UTC SPC SREF guidance, while relatively isolated in nature as confined to central Texas, there was an ample multi-model/convective precipitation overlap amongst the individual SREF convective members for 3-hourly output ending at 00 UTC and 03 UTC 10 May 2008 (Fig. 8). Even when calibrated guidance probabilities for thunderstorms and severe thunderstorms are modest, a relatively strong consensus of thunderstorm development within an environment potentially favorable for severe storms can serve to boost a forecaster's confidence in the likelihood of severe thunderstorm development. This is especially true when such development otherwise appears uncertain because of strong convective inhibition and/or limited forcing.

4.2 SREF Postage Stamps

In addition to the aforementioned spaghetti diagrams, "postage stamp" displays (Levit et al. 2004) are another way that individual SREF member information can be simultaneously displayed at the SPC, including output of fields such as 2m temperatures/dewpoints, MLCAPE/MUCAPE, 0-3 km Storm Relative Helicity, and convective precipitation (Fig. 9). For example, Fig. 9 shows all ensemble members develop precipitation over the central U.S. during the evening (0000 to 0300 UTC) of 7 October 2008; although, none of the Eta members (top row) extended the convective precipitation into southwest Texas. Knowing this provides additional information as to how the SREF system arrived at its probabilistic QPF and calibrated thunderstorm guidance. Postage stamps allow for the rapid visual assessment of the envelope of model solutions and the ability to check for clustering of solutions. This offers an experienced forecaster a simple tool to assess plausible scenarios from less likely or model biased outcomes. It is important to note that the purpose of postage stamps is not to view each solution deterministically or to "choose" a single or preferred model solution.

4.3 SREF Interactive Point Plume and Probability Products

One final tool available to view the contribution from individual members to the SREF is through the use of plume diagrams. Plume diagrams may be accessed at the following URL:
http://www.spc.noaa.gov/exper/sref/plume/

The plumes represent a collection of time series from each of the individual members. The SPC currently provides more than 15 parameters in the aforementioned interactive plume webpage. As a quick example, consider the most unstable CAPE (MUCAPE) from the SREF run initialized at 0900 UTC 21 October 2008 for Norman, Oklahoma (Fig. 10). Around 0900 UTC 22 October, the MUCAPE ranges from about 40 J/kg (in the WRF-ARW members) to 1500 J/kg (from one of the Eta members). The SREF mean is a little over 500 J/kg (the mean is the black line with large dots in Fig. 10). The RSM members also have low values of MUCAPE, but all the members indicate at least some potential instability during the overnight period. In addition to individual parameters, the web interface also allows for probabilistic interrogation (e.g., the probability of MUCAPE $\geq$ 500 J/kg) and combined parameter probabilities (e.g., the probability of MUCAPE $\geq$ 500 J/kg and convective precipitation $\geq$ 0.01").

5. SUMMARY

As a compliment to observational meteorological data, operational forecasters benefit from multifaceted numerical model guidance including deterministic operational models, experimental higher resolution explicit convection models, and the subject of this paper, the NCEP/SPC SREF. While SREF ensemble mean data and derived probabilistic output are valuable guidance, at least selective or situationally dependent examination of individual SREF member output can be an asset to anticipating the development of severe convection. As such, it is important to stress that individual ensemble data (such as spaghetti diagrams) should be used in concert with other ensemble fields (probabilities, means). As it relates to anticipating the development and likelihood of potentially severe thunderstorms, the utilization of convective precipitation spaghetti plots and other related fields can be beneficial, especially in situations when the general timing of deep convective development is in question and/or concerns exist regarding the degree of capping and/or forcing.

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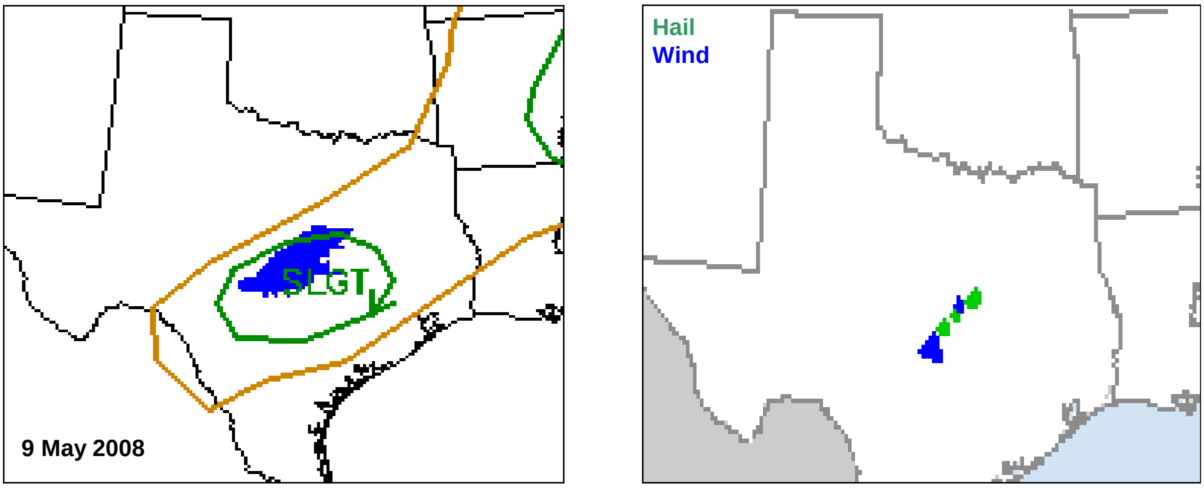

Fig. 7. Same as Fig. 1, except (*Left*) 1630 UTC 9 May 2008 SPC Day 1 Convective Outlook and (*Right*) SPC preliminary severe reports for 1200 UTC 9 May 2008 to 1200 UTC 10 May 2008.

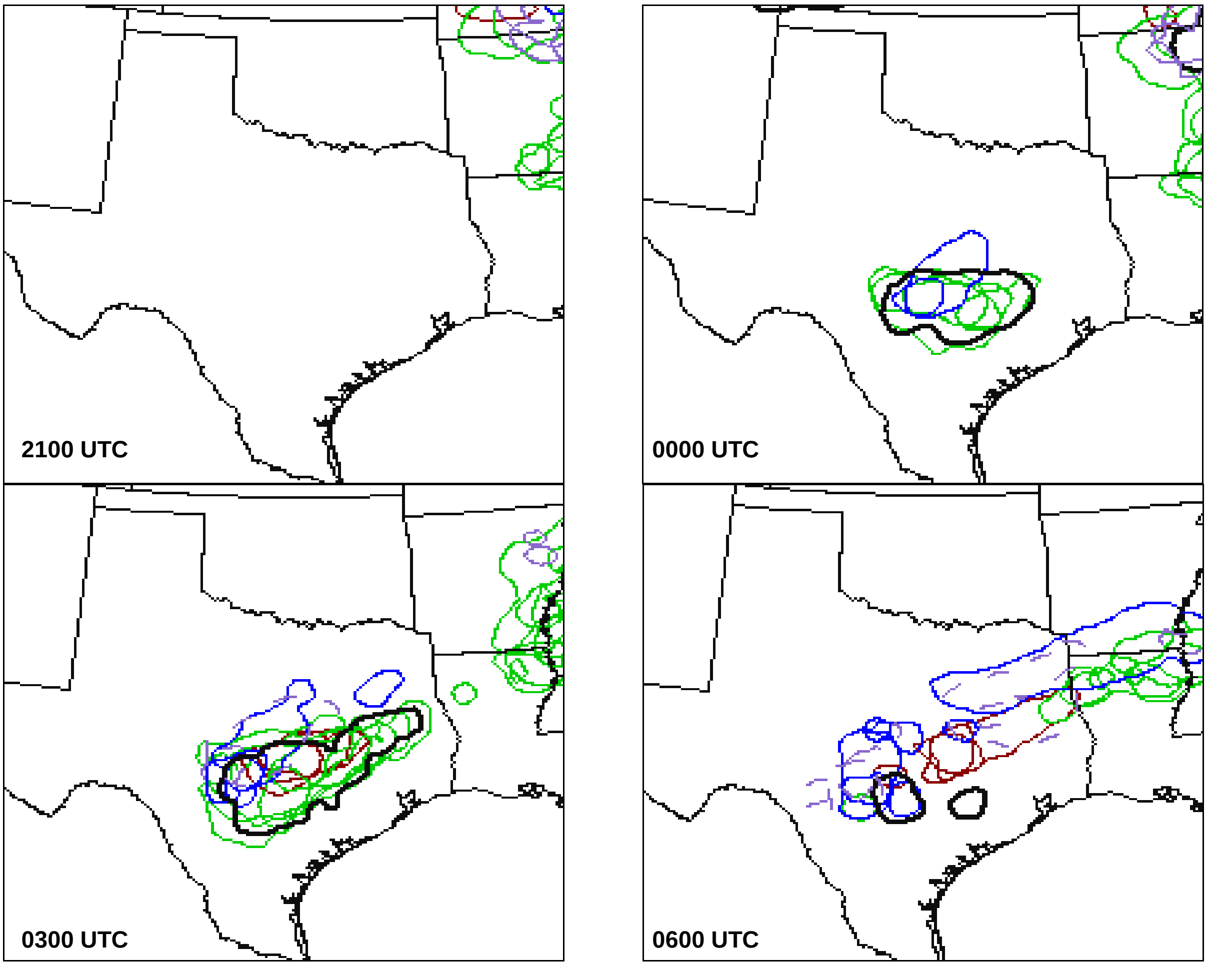

Fig. 8. 0900 UTC 9 May 2008 NCEP SREF 3-hourly spaghetti plots of convective precipitation with 12-hr, 15-hr, 18-hr, and 21-hr forecasts ending between 2100 UTC 9 May 2008 and 0600 UTC 10 May 2008 (ETA=red, EtaKF=green, RSM=blue, Operational NAM=black, WRF-ARW=solid purple, WRF-NMM=dashed purple).

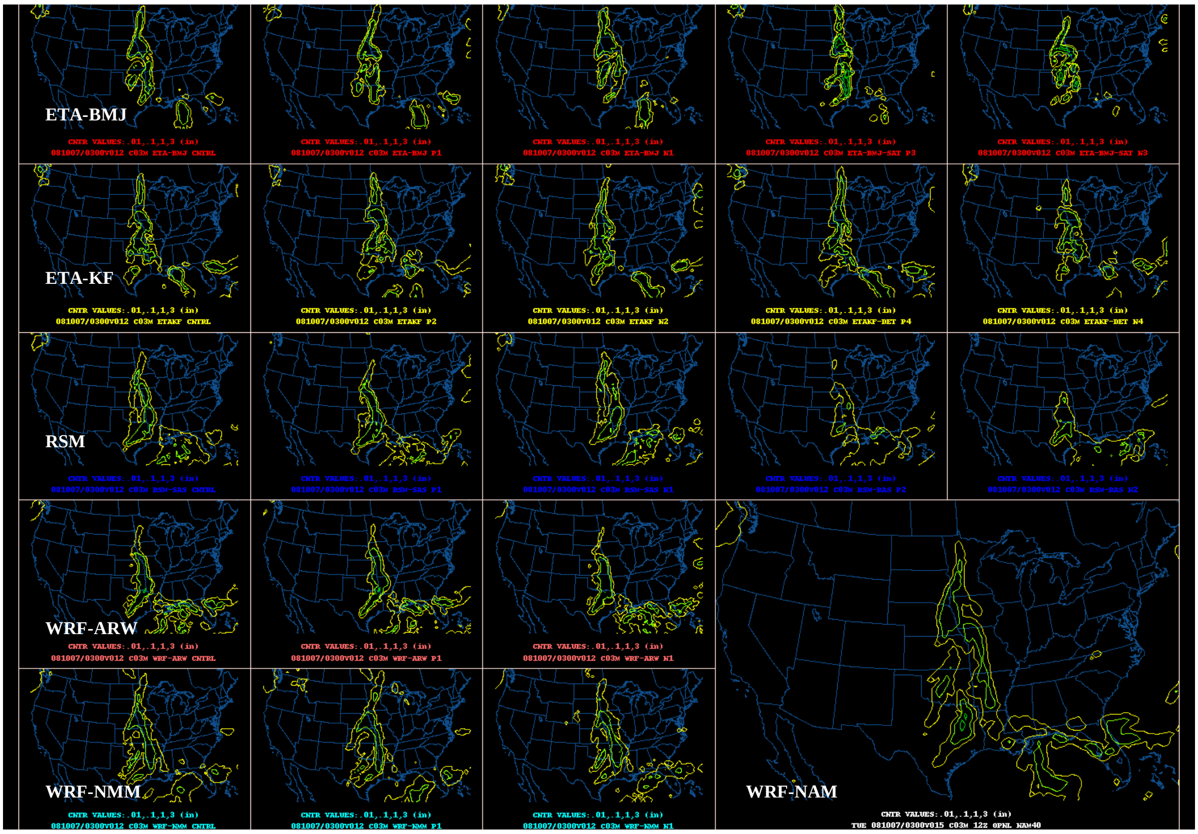

Fig. 9. Example postage stamp image (1500 UTC 6 October 2008 27-hr forecast valid 0300 UTC 7 October 2008) of individual SREF member output of 3-hourly convective precipitation, with the time-lagged operational WRF-NAM in the lower right.

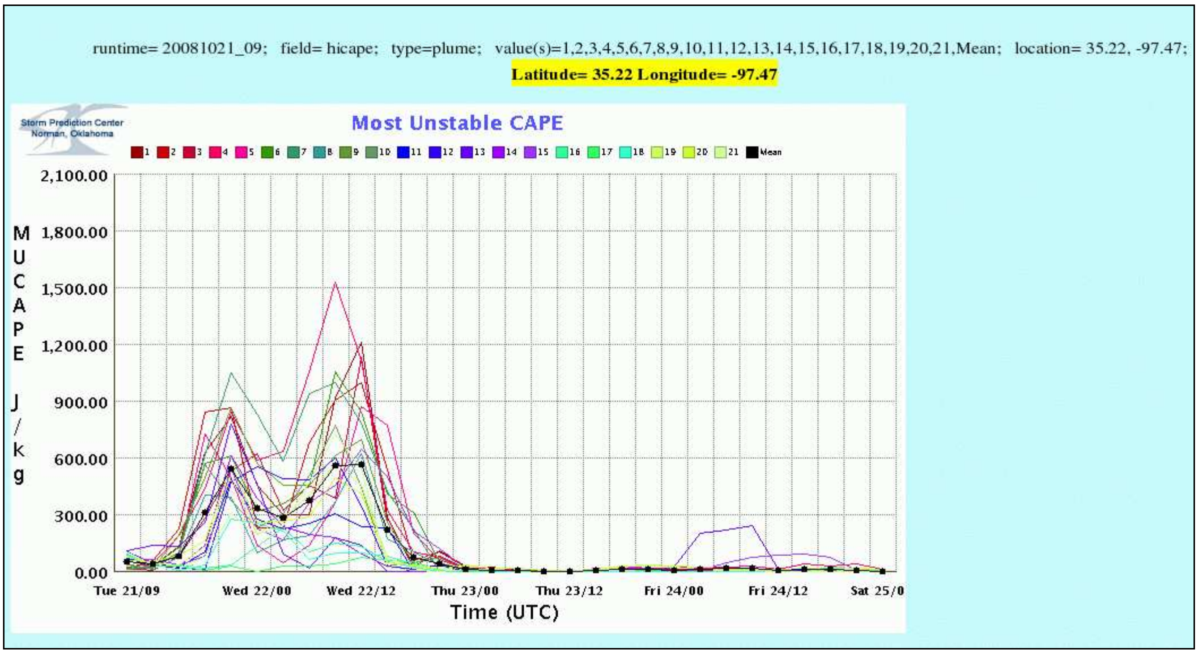

Fig. 10. A time series of MUCAPE (J/kg) from each member of the SREF (SREF "plumes"). The SREF run time was 0900 UTC 21 October 2008. Plumes are available at the SPC website: http://www.spc.noaa.gov/exper/sref/plume/