2.2 UTILIZING THE ETA MODEL WITH TWO DIFFERENT CONVECTIVE PARAMETERIZATIONS TO PREDICT CONVECTIVE INITIATION AND EVOLUTION AT THE SPC

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1. INTRODUCTION

Since NCEP's Storm Prediction Center (SPC) moved into the National Severe Storms Laboratory (NSSL) facility in 1997, close proximity and a mutual interest in operationally relevant research problems have cultivated numerous collaborative research projects. One prominent area of research has been the development and evaluation of an experimental version of the NCEP's operational Eta model (Black 1994). This experimental version contains a modified version of the Kain-Fritsch convective parameterization (Kain and Fritsch 1993 - herafter KF) in place of the operational Betts-Miller-Janjic scheme (Betts 1986; Janjic 1994 - hereafter BMJ). It also uses 4th order horizontal diffusion, with a relatively small diffusion coefficient, whereas the operational model is configured with 2nd order horizontal diffusion. Both the higher order diffusion and the KF convective scheme favor the development of smaller-scale atmospheric structures compared to the operational configuration. This configuration of the model (hereafter Etakf) has been run in a semi-operational (1-2 times daily) mode, using the same initial conditions as the operational model, since February of 1998. Since that time, we have made the same updates to the model that have been introduced operationally at the Environmental Modeling Center (EMC), but no other changes have been made.

The two versions of the Eta model have been compared extensively. This comparison has been done informally on a daily basis, most frequently by SPC forecasters who rely on both versions of the model when formulating severe weather forecasts. In addition, the two versions of the model have been compared more formally during organized programs of model evaluation and experimental forecasting in the spring of 2000 and again in the spring of 2001 (Janish et al., this issue). In this article, selected examples of comparative model forecasts are presented, showing that each version of the model has distinct advantages and disadvantages. These results suggest that this two member ensemble provides valuable information to forecasters that would not be available if either version was presented alone.

2. COMPARING THE TWO CONVECTIVE SCHEMES

Due to limitations of space, it is not possible to provide a detailed description of the BMJ and KF convective schemes here. Below we provide a brief description of the elements of each scheme that most strongly contribute to their different behaviors.

2.1 *The Betts-Miller-Janjic Scheme*

This scheme introduces a deep convective adjustment, along with convective rainfall, at a model grid point whenever CAPE exists and deep-tropospheric moisture exceeds a specified, temperature-dependent threshold. The adjustment is imposed over the layer from the LCL to the level of neutral buoyancy. If CAPE exists, but the cloud-layer moisture is insufficient (or the CAPE layer is too shallow), the scheme switches to non-precipitating "shallow" convection, with the cloud top now specified as the layer above cloud base with the strongest vertical gradient in relative humidity (maximum depth of shallow cloud ~ 200 mb).

Both deep and shallow convection nudge the grid-point environment toward specified temperature and dewpoint profiles when they are activated. The "adjusted" temperature profile for deep convection is similar to a moist virtual adiabat, while for shallow convection it is close to a mixing line between air from just below cloud base and just above cloud top (Betts 1986). Specified dewpoint profiles are somewhat more complex. For the purposes of this article, it suffices say that, for deep convection, the relative humidity corresponding to the moisture profile is about 75-80% near cloud base and the gap between the dewpoint and temperature profiles (on a skew-T/log P diagram) grows slowly up to the freezing level, then shrinks again towards cloud top. The two curves are nearly parallel. For shallow convection, the gap between the two profiles depends on the relative humidity when the scheme is called (integrated cloud-layer moisture does not change) and this gap increases towards cloud top.

The shallow convection component of this scheme is critically important because it effectively mixes moisture upward, favoring the eventual activation of deep convection. Neither deep nor shallow convection are suppressed by a convective inhibition (CIN) layer (i.e., a stable layer just above the LCL). Thus, as long as CAPE exists *at some level* for parcels lifted from the lowest ~ 200 mb, the BMJ scheme will activate (except in rare limiting circumstances - see Janjic 1994). If the cloud layer is too dry, parameterized convective activity will be shallow (non-precipitating), transporting moisture upward and heat downward

2.2 *The Kain-Fritsch Scheme*

Unlike the BMJ scheme, the KF parameterization is a mass flux scheme, meaning that it uses a cloud model to characterize the vertical redistribution (or flux) of mass in a column. Convective initiation is strongly tied to parcel theory, thus it is modulated by CIN.

The potential for initiation is assessed using a multi-step process. Beginning at the surface, vertically adjacent model layers are mixed until the depth of the mixture is at least 50 mb. This combination of adjacent model layers comprises the first potential updraft source layer (USL). The mean thermodynamic characteristics of this mixture are computed, along with the temperature and height of this "parcel" at its lifting condensation level (LCL). The parcel is given an upward-motion perturbation (magnitude based on background low-level convergence, but not greater than 3 ms^{-1}; see Kain and Fritsch 1992) and the parcel buoyancy equation is used to determine whether it can reach its level of free convection (LFC), subject to incremental dilution with environmental air in each model layer. If it can reach the LFC and continue to rise beyond a specified minimum depth (typically 3-4 km), deep convection is activated. If the parcel

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rises at least one model layer, but not high enough for deep convection, this layer is marked as a possible source for shallow convection, but additional layers overhead (lowest 300 mb) are first checked in a similar way to see if deep convection can be activated. If not, the layer that produces the tallest "shallow" cloud is identified as the USL and shallow convective is activated.

With the KF scheme, convective adjustment is not imposed by specified profiles. Instead, the scheme uses simple models of updrafts, downdrafts (deep convection only), and local vertical compensating motions (necessary for mass conservation in every layer) to rearrange a vertical column to a more stable structure. In practice, the temperature and moisture changes that it imposes in a column are characterized typically by three distinctive characteristics: 1.) between the LCL and the equilibrium-temperature layer, warming and drying are imposed as a result of parameterized compensating subsidence; 2.) above the equilibrium layer parameterized updrafts overshoot and detrain, resulting in a net cooling feedback; 3.) in the case of deep convection, the subcloud layer is cooled and (usually) moistened by parameterized convective downdrafts.

3. A SAMPLING OF INTERESTING RESULTS

3.1 *Shallow Convection*

Forecasters at the SPC are responsible for issuing watches for severe thunderstorms and tornadoes, in addition to other guidance products that hinge on accurate prediction of convection initiation. Among other things, these forecasters frequently examine model-forecast soundings to help them assess the potential for initiation. Model soundings derived from both the BMJ scheme and the KF scheme can be strongly influenced by parameterized shallow convection, yet the BMJ scheme activates shallow convection typically over a much larger area than the KF scheme. For example, Fig. 1 depicts the areal coverage in terms of shallow convective effects on (shallow) cloud-layer moisture for 21 h Eta and Etakf forecasts, valid 2100 UTC, 11 May 2000. The active area in the Eta is larger because the BMJ scheme imposes fewer constraints on activation. Most significantly, it does not require parcel buoyancy in the vicinity of cloud base (the LCL), only buoyancy at some level in the column. In contrast, the KF scheme will not activate convection (deep or shallow) if more than 9 J kg^{-1} of CIN is present in a sounding. In fact, this maximum value (corresponding directly to the maximum upward perturbation of 3 ms^{-1}) can only be realized if low-level convergence is significant.

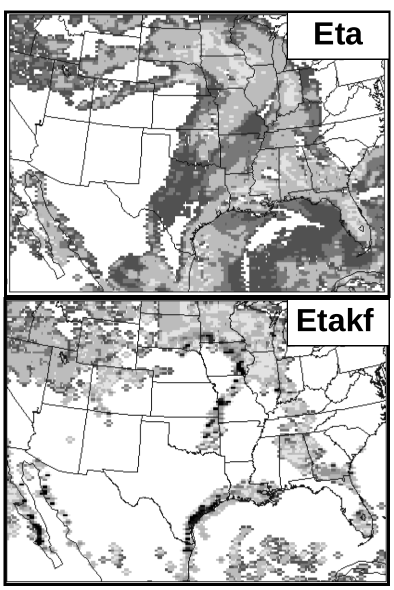

Fig. 1. Areal coverage of parameterized shallow convection from 21 h Eta and Etakf forecasts, valid 2100 UTC 11 May 2000.

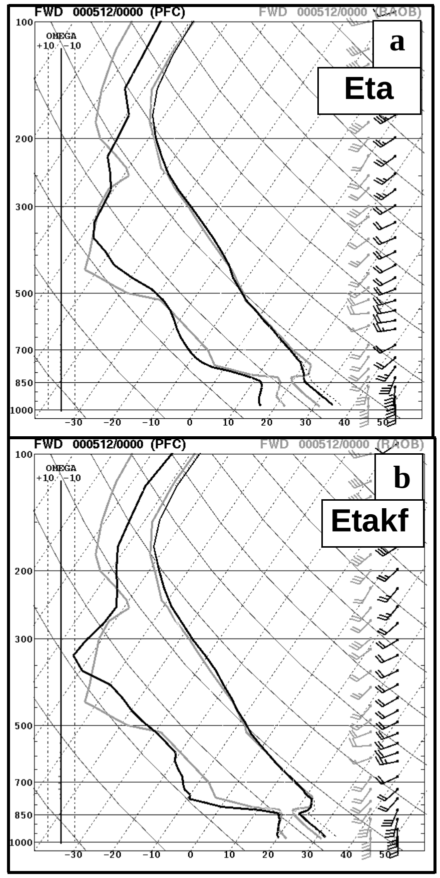

Fig. 2. Model forecast soundings from 24 h (a) Eta and (b) Etakf forecasts, valid 0000 UTC 12 May 2000 at the grid point nearest FWD, with observed FWD sounding in lighter shading.

In many environments, it appears that BMJ shallow convection causes Eta model soundings to deviate from observations. For example, consider a point where the BMJ scheme has been active, but the KF scheme has not. The model-forecast sounding from the Etakf run for Fort Worth (FWD), valid 0000 UTC 12 May 2000, shows a much better agreement with the observed sounding than does the forecast sounding from the Eta (Fig. 2). The Eta profile shows a relatively weak cap along with a warm and dry boundary layer (BL), a characteristic bias associated with BMJ shallow convection.

In this case, the Etakf run produced a more realistic sounding at FWD *by not activating shallow convection*, but remaining inactive is not always so favorable for the KF scheme. Indeed, we also note that the Etakf run has a tendency to overpredict BL moisture in some situations, apparently because shallow convection does not activate. Inactive shallow convection can lead to anomalously moist and cool BLs in the Eta model because parameterized shallow convection can be very effective at coupling the BL with the "free" atmosphere, exchanging moist air within the BL for drier air aloft.

Of course, it is also interesting to compare soundings at a grid point where *both* schemes are actively parameterizing the effects of shallow convection. Fig. 3 shows soundings over Birmingham, AL (BMX) from both model runs, with the observed 0000 UTC 12 May 2000 sounding in the background. Again, the Eta forecast weakens the cap while the Etakf forecast retains a better representation of the CIN in the environment.

3.2 *Deep Convection*

Overall, the Eta and Etakf forecasts have scored very similarly during the spring season on traditional measures of skill in predicting precipitation. For equitable threat scores, for example, the operational Eta has averaged slightly higher for precipitation thresholds below ~ 0.5 in./ 24h, while the Etakf averages a bit higher for higher thresholds. However, these two forecasts can be very different on any given day.

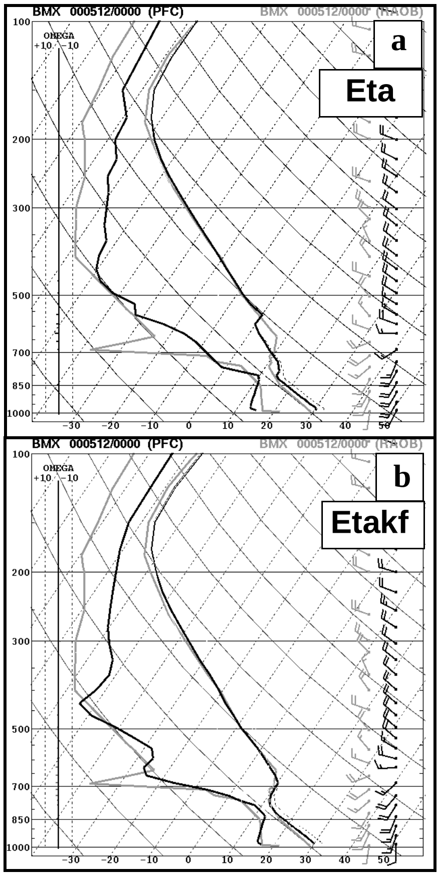

Fig. 3. *Model forecast soundings from 24 h (a) Eta and (b) Etakf forecasts, valid 0000 UTC 12 May 2000 at the grid point*

3.2.1 a bow-echo environment

One systematic bias that has frustrated developers of the KF scheme is a tendency for the Eta to provide superior predictions of MCS propagation in some environments. Given the well-known role of downdraft outflow in MCS propagation, and fact that the KF scheme explicitly parameterizes downdraft effects, whereas the BMJ approach does not, one would intuitively think that the Etakf should perform better in these situations. A detailed comparison of scheme behavior in a bow-echo environment sheds some light on this paradoxical behavior.

On 31 May 2000, a quasi-stationary surface boundary ran west to east across the Upper Midwest (details of this case can be found under URL http://www.spc.noaa.gov/exper/Spring_2000/calendar/ may.html). South of the boundary convective activity was strongly capped. North of the boundary, however, moisture was deep, elevated instability was substantial and relatively uncapped, and winds aloft were nearly unidirectional, parallel to the low-level boundary with a deep-layer shear of ~ 30 m s^{-1}. These conditions are characteristic of a warm-season bow-echo environment (Johns 1993). Numerous intense MCSs formed just north of the boundary and propagated rapidly eastward, nearly parallel to the surface front. The Eta model did well in predicting this general behavior. However, the Etakf struggled with the timing of initiation and tended to underestimate the forward propagation speed of convective systems.

Examination of Eta model soundings and the behavior of the KF and BMJ schemes in this environment provide insight into this disparity. For example, a 15 h Eta forecast sounding for Slater, IA, valid 1500 UTC 31 May 2000 (Fig. 4a), shows a moist atmosphere aloft with high lapse rates in the 400 - 600 mb layer. The path taken by a surface-layer parcel (as determined by the KF scheme) reveals a deep layer of CIN in the lower troposphere, consequently the KF scheme does not activate at this point. In contrast, the BMJ scheme finds that CAPE exists for this parcel and that deep layer moisture exceeds the threshold for initiation, so it does activate. It nudges the environment towards a moist virtual adiabat between cloud base (950 mb) and cloud top (200 mb). In so doing, it bisects the high lapse rate air in the mid-troposphere, producing warming aloft and a deep layer of cooling in the lower to middle troposphere (Fig. 4b).

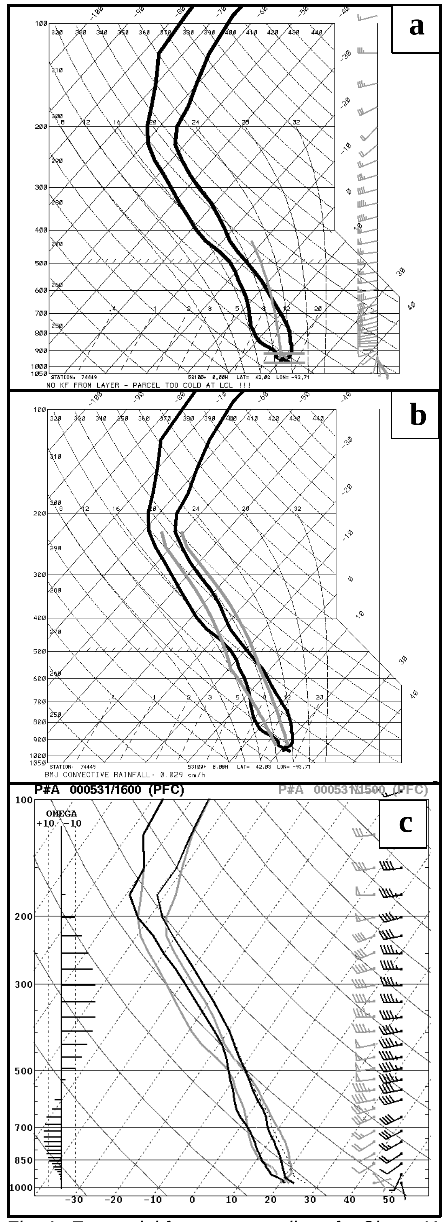

Fig. 4. Eta model forecast soundings for Slater, IA from the 0000 UTC 31 May 2000 initialization. (a) 15 h forecast, with parcel path computed by the KF scheme in shaded curve. (b) Same as in (a), except temperature and dewpoint profiles imposed by BMJ scheme shown in shaded curves. (c) 16 h forecast, with previous hour in shaded curve and model predicted vertical velocity profile (µb/s) indi-

One hour later, the Eta forecast sounding from the same grid point overlaid on the previous sounding shows that the model environment has conformed to the BMJ profile (Fig. 4c). More significantly, a vertical motion profile reveals that the deep layer of cooling has induced strong subsidence in the model below 600 mb. Stepping back to look at a mesoscale area, we see that BMJ adjustments over a mesoscale region has induced a large area of subsidence (Fig. 5). In turn, outflow from this *mesoscale downdraft* has enhanced low-level convergence on its periphery, particularly to the south and east where a low-

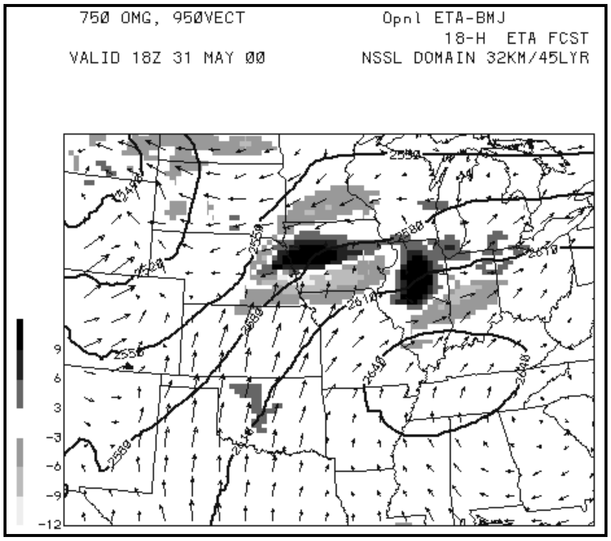

Fig. 5. 18 h forecast from the Eta model, valid 1800 UTC 31 May 2000, showing ω (μb/s - shaded) and geopotential height (30 m interval) at 750 mb, along with wind vectors at 950 mb. Darker shades represent subsidence.

level jet provides an opposing flow and source of high-θ_e air. The vertical motion field is consistent with our conceptual models of organized MCSs, and a similar pattern just downstream reflects the Eta model's production of a series of simulated MCSs in this environment. The deep-layer cooling produced by the BMJ scheme appears to play a critical role helping the Eta model to move these MCSs along with a realistic phase speed consistent with forward propagation.

In comparison, the KF scheme struggles with initiation in this environment. Once it does activate over a mesoscale area, it generates a cool pool at the surface through parameterized convective downdrafts. Yet, this cool pool is initially static, can only propagate horizontally, and is quickly modified through contact with the underlying surface. In contrast, the BMJ-generated cold pocket is generated aloft, induces a deep and broad mesoscale circulation as it begins to sink, and eventually produces sustained mesoscale outflow and convergence on the leading edge of the parameterized convection. The operative mechanism of the BMJ cooling process appears to be much more effective at promoting system propagation in this environment, in spite of the fact that this scheme has no explicit procedure for generating *convective-scale* downdrafts.

3.2.2 a potential supercell environment

In the derecho environment discussed above, the BMJ scheme correctly activated in grid-point columns with abundant moisture aloft but limited moisture and instability in lower levels. That case exemplifies a characteristic and favorable response by the BMJ scheme to organized deep-layer moistening and destabilizing processes. However, this characteristic behavior is not perfectly calibrated and can be problematic. As an example we present data from a potential supercell environment from 20 April 2001. On this day, broad southwesterly flow over the Southern Plains was associated with an upper level trough lifting out of the Southwest. SPC forecasters were carefully evaluating the potential for severe convection over the Southern Plains, where instability and shear profiles were favorable for supercells. Over south-central Oklahoma, both the Eta and Etakf forecasts were predicting CAPE values of 2500-3500 J kg^{-1}, but surface-based air parcels were strongly capped.

By late afternoon on the 20th however, a deep plume of middle and upper level-subtropical moisture was flowing over this area, moistening the local atmosphere from aloft. In the Eta model, the combination of this process and BMJ shallow convection pumping BL moisture upward eventually moistened grid columns to the point where threshold moisture values for BMJ initiation were exceeded and the scheme activated deep convection. Feedbacks from this scheme eliminated an elevated mixed layer that had provided CIN in this environment so that CAPE actually increased after activation, producing an uncapped forecast sounding with CAPE value over 4000 J kg^{-1} over Ardmore (ADM) OK at 2300 UTC (Fig. 6a). In contrast, the Etakf run maintained the elevated mixed layer and strong CIN, in good agreement with the nearest raob (FWD) at 0000 UTC 21 April (Fig. 6b). SPC forecasters examined forecast soundings over this area from both the Eta and Etakf models during the midnight to 8 a.m. shift on 20 April. They recognized and understood the behavior of both the BMJ and KF schemes and predicted a very low probability of convective initiation (Rich Thompson, personal communication). Convection never developed over this part of Oklahoma during this event.

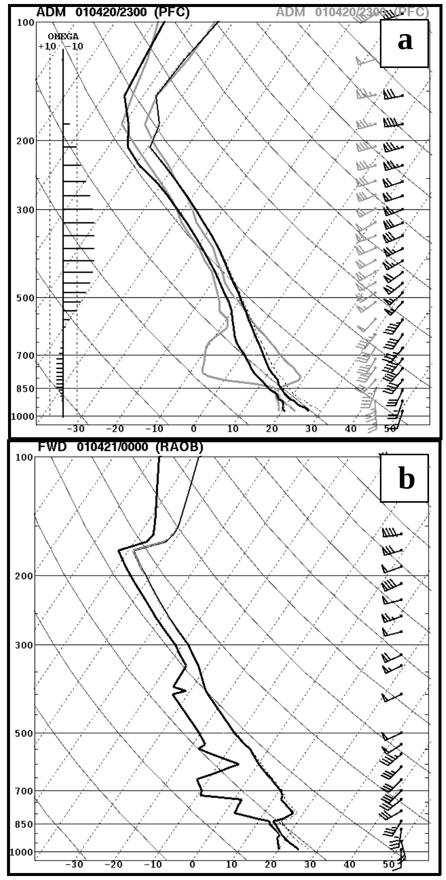

Fig. 6. (a) 23 h forecast soundings for ADM from the Eta (dark curves) and Etakf (faded curves), valid 2300 UTC 20 April 2001. (b) Observed sounding at FWD, valid 0000 UTC 21 April 2001.

4. SUMMARY AND DISCUSSION

The BMJ and KF convective schemes utilize fundamentally different approaches to parameterizing convection. Consequently, the operational and Etakf numerical solutions can be quite different. When averaged over many different events, however, these two versions of the Eta model produce very similar equitable-threat and bias scores, suggesting that forecasts from these two runs are about equally likely to be correct. This is consistent with the subjective impression of forecasters and research scientists at the NSSL and the SPC. Thus, experimental forecasts of the Etakf at the NSSL/SPC facility provide forecasters with a valuable complement to the operational Eta model, with each convective scheme tending to compensate for deficiencies in the other.

Experimental testing and evaluation of the Eta model at NSSL/SPC has been a core area of interaction between the two organizations. For example, NSSL scientists working on model development receive valuable feedback from SPC forecasters about the performance of experimental models, especially as they relate to the evolution of the pre-convective environment. This feedback is important, of course, but the real value of this close working relationship is our freedom to experiment with non-traditional output fields that can help SPC forecasters solve some of their specific forecast challenges. For example, forecasters are routinely provided displays of parameterized cloud-base updraft mass flux and updraft source level from the Etakf runs. The mass flux field has elicited very positive feedback from forecasters since it provides unique information about convective intensity (Kain and Baldwin 2000), while the USL is a valuable indicator of whether or not model convection is surface-based - a critically important consideration in severe thunderstorm forecasting.

We believe that subjective feedback from forecasters is essential if model developers are to proceed efficiently in improving model predictions. It has become increasingly clear to us that model development has been modulated too strongly by currently available objective verification measures. Compelling evidence for this argument is provided by the prominent status currently occupied by the equitable threat score. This score is enhanced by overforecasting and horizontal smoothing of precipitation fields, which seems to be distinctly at odds with our goal of providing more smaller-scale structure in numerical forecasts. Instead of being guided by this kind of measure, model development should be guided by measures that better reflect the value of numerical forecasts to the human forecasters.

One of the primary goals of the experimental-forecasting and model-evaluation programs at the NSSL/SPC is to develop subjective measures of the value that forecasters find in different kinds of model output. The information derived from these studies will be used to guide us in the development of objective "event-oriented" verification strategies that are based on verification of meteorological phenomena rather than grid-point by grid-point comparisons (Baldwin et al. this issue).

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