11.3 SEVERE STORM FORECAST GUIDANCE BASED ON EXPLICIT IDENTIFICATION OF CONVECTIVE PHENOMENA IN WRF-MODEL FORECASTS.

Ryan Sobash*[1], D. R. Bright[2], A. R. Dean[2], J. S. Kain[3], M. Coniglio[3], S. J. Weiss[2], and J. J. Levit[2]

[1]University of Oklahoma, School of Meteorology, Norman, OK
[2]NOAA/NCEP/Storm Prediction Center, Norman, OK
[3]NOAA/OAR/National Severe Storms Laboratory, Norman, OK

1. INTRODUCTION

Convection-allowing numerical models are providing operational forecasters with many new forms of forecast guidance. In addition to predicting traditional environmental parameters, convection-allowing models are capable of providing guidance related to convective mode, intensity and storm motion (Done et al. 2004; Kain et al. 2006; Weisman et al. 2008). Specific guidance for the convective organizational mode of storms can be particularly valuable because mode is often associated with the likelihood of different severe weather phenomena (e.g. tornadoes, large hail, damaging winds). Forecasters at the Storm Prediction Center (SPC) routinely use high-resolution output fields such as simulated reflectivity to infer model predictions of convective mode and they use this information to assess the potential for severe weather threats (Weiss et al. 2007; Kain et al. 2008).

While such inferences are certainly useful, we have the potential to dig much deeper in our interrogation of output from convection-allowing models. In particular, since these models explicitly resolve convective circulations, it seems likely that extreme convective phenomena in the models could have a direct correspondence to severe phenomena in the real atmosphere. Since convective circulations are rather coarsely resolved in the convection-allowing models that are currently available to operational forecasters, convective-scale details are certainly lacking in these models. For example, explicit realtime prediction of tornadoes is many years away. Yet, subjective assessments suggest that models with grid spacing as coarse as 4 km have skill in predicting the occurrence of supercells (e.g., Kain et al 2008), which are associated with a disproportionate share of severe weather, including tornadoes. If the correspondence between extreme phenomena predicted by the models, such as strong mesocyclones (supercells), and observations of severe weather can be quantified, the relationship could be developed as a tool for using output from convection-allowing models in unique ways as guidance for the forecasting of severe weather.

The purpose of this study is to introduce and explore this concept. The approach is to identify a set of extreme phenomena in model forecasts and determine their correspondence to observations of severe weather. The goal is to find which predicted features have the strongest correspondence to severe weather and to develop a diagnostic tool that can be used as a guidance product for operational forecasting. It is important to emphasize the uniqueness of this approach: Automated assessments of model output have been used for years to characterize convective *environments* for the purpose of assessing the likelihood of severe convection, but this is the first time (to our knowledge) that such an assessment has been based on the actual development of severe convective phenomena in models.

* *Corresponding author address: Ryan Sobash, University of Oklahoma, School of Meteorology, 120 David L. Boren Blvd. Suite 5642, Norman, OK 73072; E-mail: rsobash@ou.edu*

2. A PRELIMINARY PROOF OF CONCEPT

A proof of concept for this approach was developed during the 2008 NOAA HWT Spring Experiment[1] (hereafter SE2008). In this initial application, extreme phenomena were identified in output from a 10-member convection-allowing ensemble (see Xue et al. 2008 for details on the ensemble). In particular, model output was mined for the presence of low-to-mid level mesocyclones, very strong low-level winds, and moderately strong low-level winds associated with linear and/or bowing reflectivity structures. These phenomena were selected in an ad hoc manner, based on subjective assessments that suggested their association with observed severe convection. Their locations were marked with "surrogate severe reports" and a Gaussian smoother, as described by Brooks et al. (1996), was used to create a surrogate-severe density (SSD) field from the aggregate surrogate reports. These density fields were created on a daily basis and compared to experimental probabilistic forecasts for severe weather and to corresponding report-density fields based on observed reports. On many days, the agreement between the SSD and observations was remarkably good. For example, Fig. 1 compares observed severe-weather reports from 3 June 2008 (and the corresponding observed-severe density field – hereafter OSD) to the corresponding SSD field derived from the 10-member ensemble, in addition to the SPC 1300 UTC Day 1 Outlook from this day. The SSD field corresponded quite well with both the OSD and the human forecast on this day and on many others during the experiment, providing motivation for a more detailed and quantitative exploration of this concept.

[1] See <http://hwt.nssl.noaa.gov/Spring_2008/opsplan/Spring_Experiment_2008_ops_plan_v6_6May.pdf> for information on this experiment.

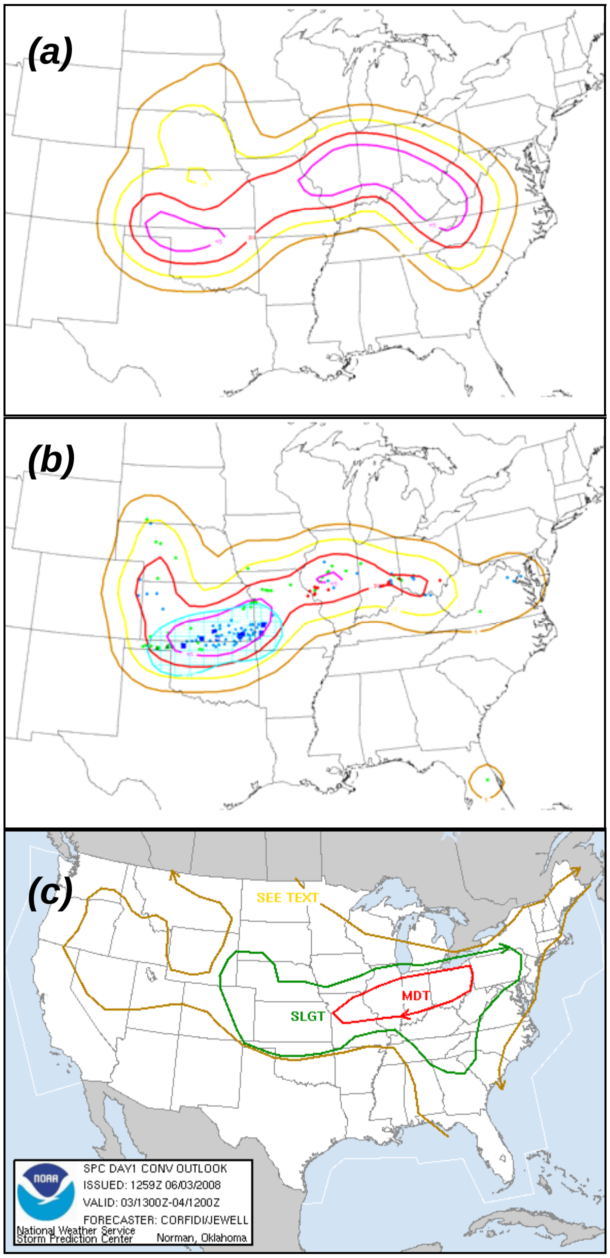


Fig. 1: (a) *Surrogate-severe density field, (b) storm reports and practically-perfect forecast, and (c) 13 UTC SPC Day 1 outlook, all for 3 June 2008. The contours for (a) and (b) are 5, 15, 30, 45%; the hatched area in (b) across southern Kansas indicates > 10% density of significant severe reports.*

3. A MORE DETAILED APPROACH

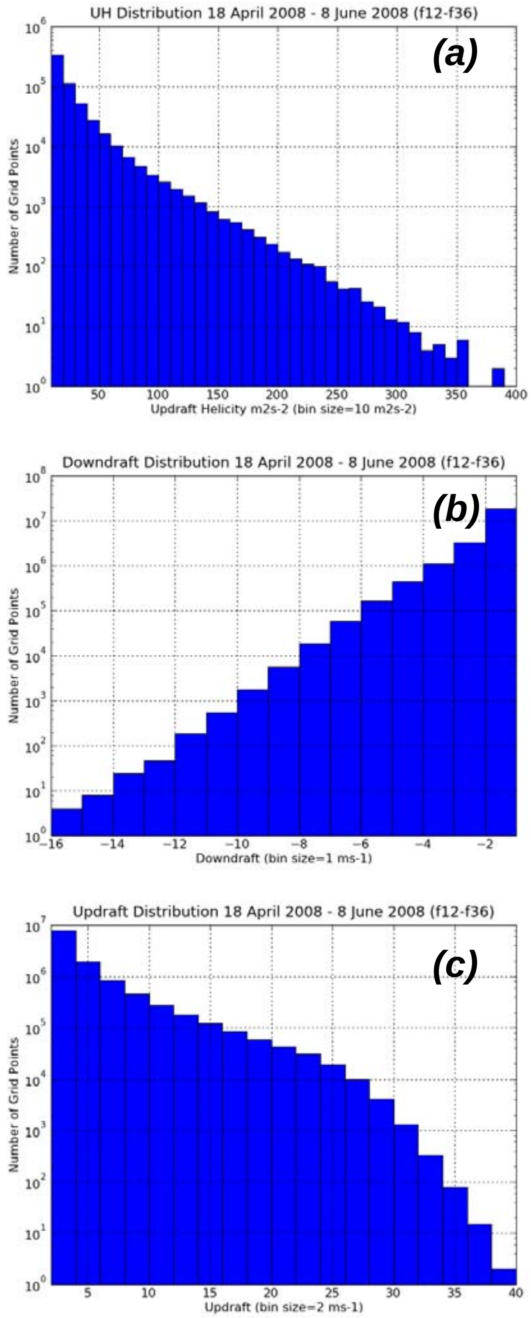
The proof of the surrogate-severe concept established during SE2008 motivated further exploration of this approach. The focus of this study is an investigation of the relevance of different simulated severe phenomena and a calibration of their correspondence to observed severe-weather reports. This study focuses on daily model forecasts from a single deterministic forecast system, rather than an ensemble, but in principle any number of convection-allowing model forecasts could be included. The forecast system will hereafter be referred to as the NSSL-WRF. This system uses the Advanced Research WRF (ARW – Skamarock et al. 2005) model to produce daily, 36-hr, 4 km forecasts at the NSSL (National Severe Storms Laboratory) over the eastern three-fourths of the CONUS (CONtinental U.S. – see Fig. 1). The model is initialized at 00 UTC and is run to 12 UTC the next day (36 h forecast), in a timely enough manner to be used as guidance for forecasts of the next day's convective cycle. The initial and lateral boundary conditions come from the operational North American Mesoscale (NAM) model. No convective parameterization is used; all precipitation originates from the microphysical scheme.

The configuration of the model is summarized in Table 1. This model configuration has remained frozen since early 2007 (~1.5 years). The NSSL-WRF system has been enhanced to supplement standard WRF output with five unique 2-D output fields (Kain et al. 2008). These five fields are hourly-maximum 10-meter wind speed (UU), 1 km AGL reflectivity (RF), maximum column upward vertical velocity (UP), maximum column downward vertical velocity (DN), and 2-5 km updraft helicity (UH). Each field represents the maximum that occurred in the previous hour (i.e. maximum at each of the model's timesteps in the past hour). This strategy permits the capture of storm-scale features in the model that have short lifetimes and might be missed using the hourly values. In addition, it allows one to track extreme phenomena in between output times.

As a first step, these five fields were used to identify surrogate-severe phenomena in the NSSL-WRF output rather than the three fields used during SE2008. At this preliminary stage it is not clear what model output fields (or diagnosed fields) would provide the best surrogates – that determination is a part of this effort. For now, working with these five fields, surrogate severe weather reports are placed at grid points where any of the five fields exceed specified field threshold values. Initially, field threshold values were determined by subjective assessments based on examination of model output during SE2008. Later, the frequency distributions of each of these fields (Fig. 2) were examined and it was found that the 99.995th percentile of each distribution corresponded roughly to the subjectively determined threshold values. Accordingly,

NSSL-WRF Configuration	
Horizontal Grid	4.0 km
Vertical Levels	35
PBL/Turb. Param.	MYJ
Microphysics	WSM6
Radiation (SW/LW)	Dudhia/RRTM
Init. Conditions	40 km NAM

Table 1: *Configuration of the NSSL-WRF.*



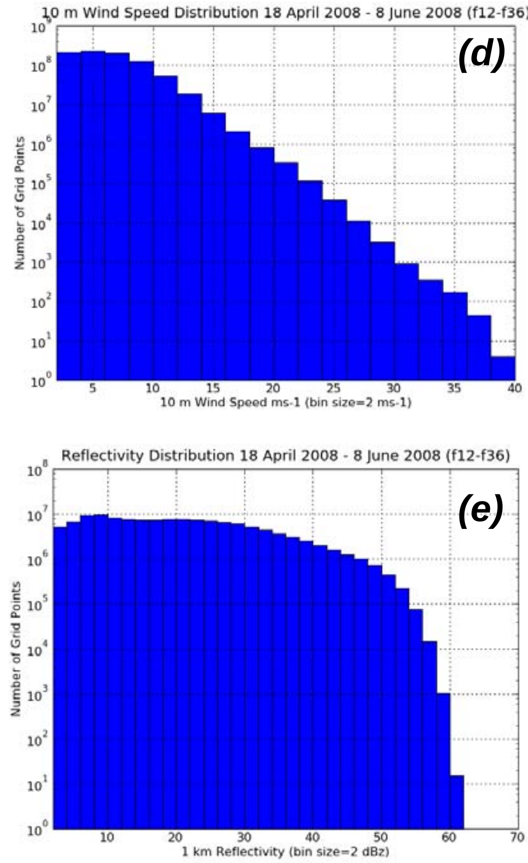


Fig. 2: *Distributions of the (a) UH (b) DN (c) UP (d) UU and (e) RF fields over the 51-day experiment. All plots are log-linear. The bin including zero is not shown.*

this percentile was used to set a benchmark value for all thresholds (Table 2). Preliminary results shown below are based on these thresholds.

For the SE2008 period, surrogate severe reports were generated for each day, based on the 24-hour period from 12 UTC to 12 UTC, the 13-36 hour forecasts. That is, surrogate reports were placed on the model grid at points where one or more of the five field thresholds was exceeded at any output time in the 24-hour period. The 12 UTC to 12 UTC period was chosen to allow for direct comparison to the SPC's archive of preliminary observed daily storm reports (see http://www.spc.noaa.gov/climo/). These observed reports (based on tornadoes, hail > ¾ in., wind gusts > 50 knots) were also mapped to the NSSL-WRF's 4 km grid for each day in the experiment. SSD and OSD fields are generated following Brooks et al. (1996). Specifically, the initial report field is first expanded by marking all grid points within 40 km of a report point as a "hit". This is roughly consistent with the SPC's operational probabilistic forecasts, which are based on the likelihood of severe weather within 25 miles of a point. Then, a spatial smoother with a Gaussian kernel is applied to the expanded report field. Specifically, at each grid point, the SSD is given by

	Field	**First-guess threshold**	**99.995^{th} percentile threshold**
UH	Updraft helicity ($m^2 s^{-2}$)	75	54
UU	10 m wind speed ($m s^{-1}$)	25	24.45
UP	Maximum column upward vertical motion ($m s^{-1}$)	30	23.35
DN	Maximum column downward vertical motion ($m s^{-1}$)	-6	-6.54
RF	1 km AGL reflectivity (dBz)	58	54.875

Table 2: *First-guess and percentile thresholds for the five fields.*

$$SSD = \sum_{n=1}^{N} \frac{1}{2\pi\sigma^2} \exp\left(-\frac{d_n^{\ 2}}{2\sigma^2} \right)$$

where d_n is the distance from the grid point to the point marking the nth report, N is the total number of reports, and sigma is the spatial smoothing parameter, which is the same in both the x and y directions (i.e. isotropic smoothing). For the preliminary results shown below, σ = 120 km. OSD is defined in a directly analogous manner for observed reports. This describes the default application of SSD and OSD, although other variations are possible, as described below.

4. ANALYSIS OF NEW SSD GUIDANCE

The SSD field for 12 UTC May 29, 2008 through 12 UTC May 30, 2008 is shown in Figure 3a. The raw model surrogate reports, on which the density field is based, are also shown (cf. Fig 3b). These fields were produced using the thresholds at the 99.995th percentile of the distributions (Table 2). The SSD field resembles that of an SPC probabilistic outlook, while the field of raw surrogate reports reveals several swaths of activity in the model, produced by the paths of individual storms. It is also useful to display the raw storm reports from each of the five proxy fields (cf. Fig. 4). This will be discussed later. The placement of the SSD field agrees quite well with the density of observed reports (observed severe density – OSD) from this day (cf. Figs. 3a and 3d), especially in terms of focusing attention on eastern Nebraska. However, the amplitude of the SSD field is quite a bit higher than the OSD field. At this stage, the focus is mainly on location – trying to predict where severe convection will occur - but the disparity in raw numbers will have to be addressed eventually. The number of surrogate reports is determined by many factors, including the percentile used to determine the threshold values, the number of fields (or phenomena) considered, the number of models used for input, etc. The numbers of actual reports are also tied to many different factors, including population density, public awareness, and verification practices that can vary from one county warning area (CWA) to another (Weiss and Vescio, 1998). Calibration of the amplitude of the SSD field will be challenging. It is also worth noting that the pattern of the SSD field agreed quite well with the operational Day 1 Outlook from the SPC on this day (cf. Fig. 3c). As noted in Section 2, frequent similarity between operational outlooks from the SPC and the objectively generated SSD has inspired continued work on the SSD concept.

5. DISCUSSION AND VERIFICATION/CALIBRATION

Although the SSD product shows promise as the basis for a severe-weather guidance product, many factors must be taken into account in refining this product. Some of the uncertainties are highlighted below.

5.1 What are the Best Surrogate Fields/Phenomena?

It seems clear that WRF model configurations with ≤ 4 km grid spacing produce extreme convective phenomena in appropriate environments, but it is not clear which of these simulated phenomena correspond most strongly to observed severe-convective features. At this stage we are examining five different output fields/features, and two others were considered during SE2008, but there may be others that are equally relevant.

5.2 What are the Appropriate Threshold Values / Criteria for Identifying Surrogates?

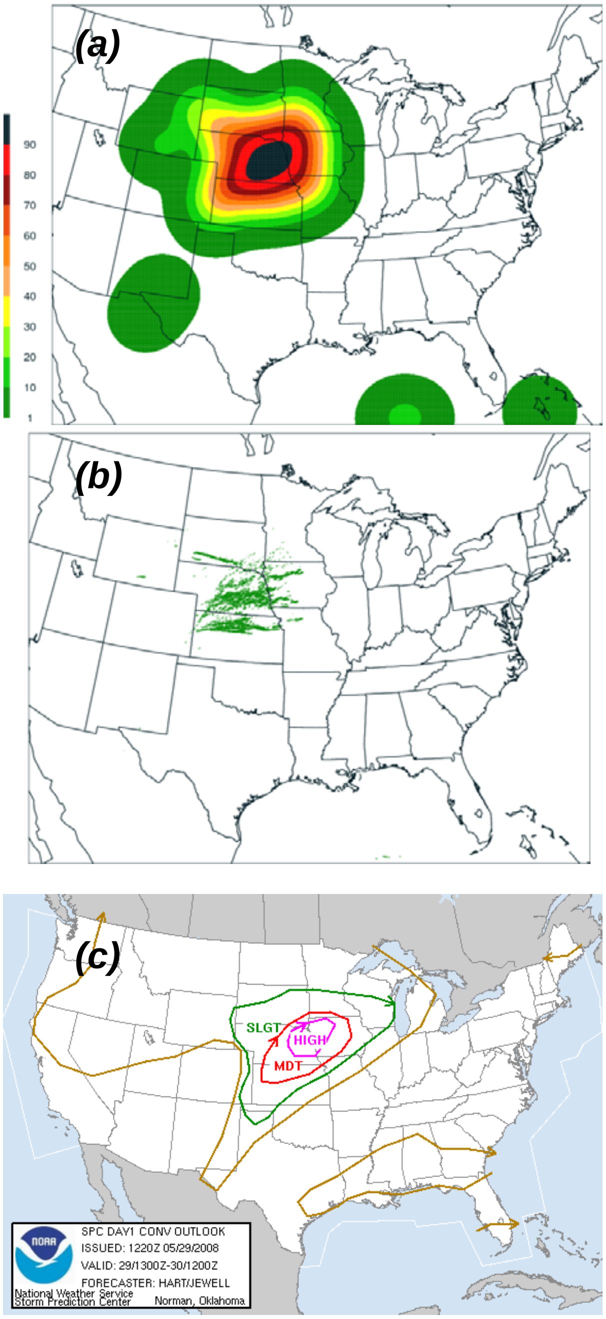
Currently, somewhat arbitrary threshold values are used to create surrogate-severe reports. Use of lower thresholds tends to increase the amplitude and coverage of the SSD field in a given region and activate surrogate reports in new areas, while the opposite occurs with higher thresholds. Optimal threshold values may depend on numerous factors, both meteorological and numerical. For example, any threshold based on the frequency distribution will vary as a function of season and perhaps geographical location. In addition, optimization is likely to be a function of model resolution and physical parameterizations.

5.3 Calibration Depends on the SSD Function.

The specific usage of the density function described in section 3 is based on Brooks et al. (1996). This approach was followed for preliminary tests, largely because it has been used informally at the SPC in recent years. As can be seen in Figs. 3a and 3d, this approach spreads the influence of individual reports over large areas, due partly to the step in which all points with 25 miles of a report are flagged and partly to the relatively large specified value of σ (120 km in initial tests). In general, the character of SSD and OSD fields can be changed rather dramatically by alternative approaches, involving modified parameters or different functions altogether. For example, the SSD field in Fig. 5 is derived from the same surrogate reports shown in Fig. 3a and application of the same Gaussian smoother, but without any expansion of the raw reports to adjacent points before application of the smoother and with σ = 40 km instead of 120 km. This alternative SSD field provides considerably more detail and highlights separate storm tracks in southern Nebraska and northern Kansas, where long-tracked supercells were observed on this day.

5.4 Verification/Calibration Strategies

Preliminary application of the concepts discussed herein show promise, but more rigorous usage requires verification of the SSD fields and calibration of a specific guidance product. This work



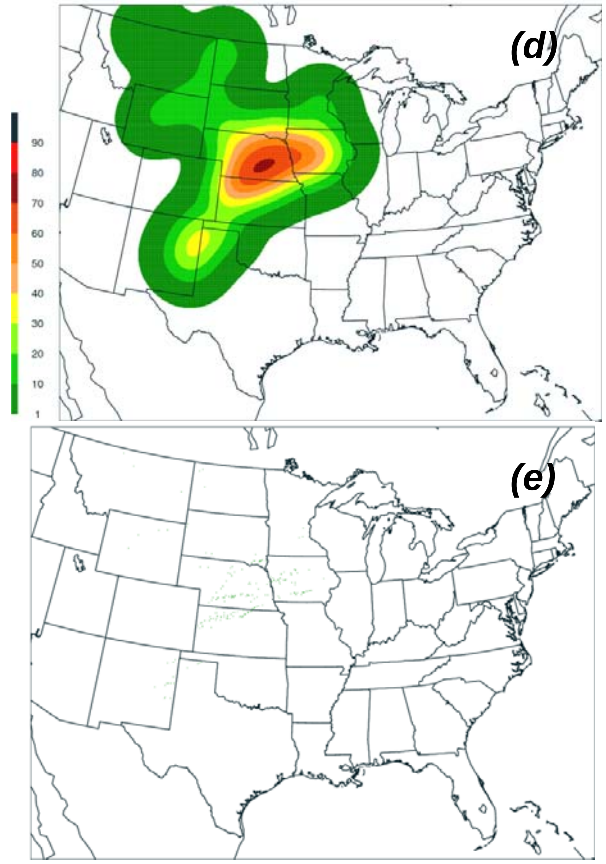


Fig. 3: (a) *SSD field, (b) surrogate storm reports, (c) 13 UTC SPC Day 1 outlook,* (d) *OSD field and (e) observed storm reports, all for 29 May 2008. For (a) and (d), filled contours plotted at 1%, 10%, and every 10% thereafter*

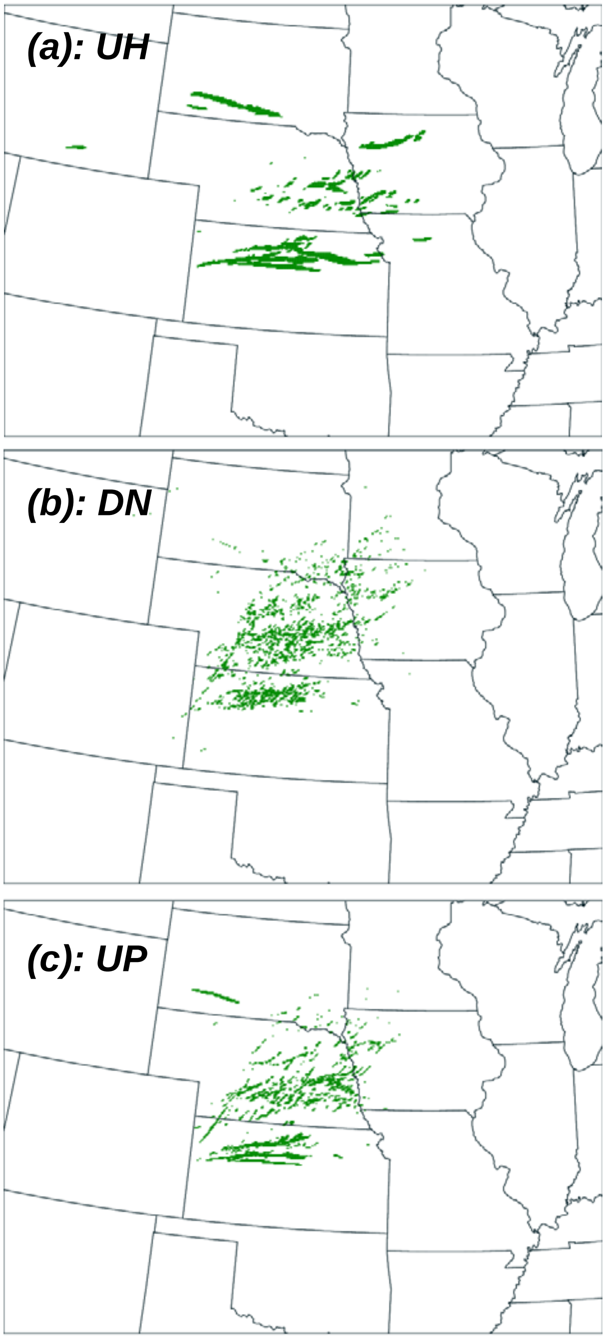
has just begun so only the general strategies can be discussed at this point.

Since our goal is to develop a tool that provides guidance for the expected location of severe convection, our general strategy is to identify predicted phenomena and parameters associated with these phenomena that will maximize the overlap between the SSD and OSD fields. Currently, the degree of overlap is being assessed using contingency-table based scores such as false alarm ratio, probability of detection, equitable threat score, etc. These scores can be computed by comparing overlap at a given density threshold. However, this comparison is complicated by the disparity in amplitude between the SSD and OSD fields, and the fact that the amplitude of the SSD field varies as a function of parameter threshold values and other factors. Thus, it might be more appropriate to compare the SSD field with the raw field of observations, i.e., map observations to the closest grid point on the surrogate report grid and create a contingency-table by selecting a density threshold for the yes/no forecast.

Verification against human forecasts is also desired. Although the SPC does not produce a Day 1 total severe probabilistic product, a threshold can be chosen from the SSD field to compare to the categorical risk areas (i.e. Slight, Moderate, High) in SPC outlooks.

6. CONCLUSIONS / FUTURE WORK

This paper serves to introduce the idea of surrogate severe reports and the guidance products that could be derived using this technique. Subjective verification of the SSD fields over a 51-day period demonstrates there is potentially considerable skill in



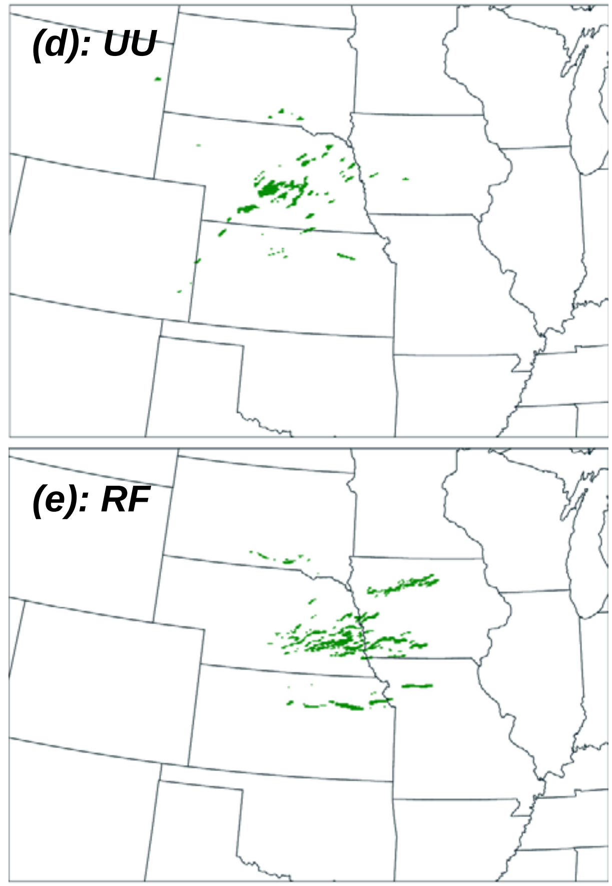


Fig. 4: *Surrogate reports from the (a) UH (b) DN (c) UP (d) UU and (e) RF fields from NSSL-WRF for 29 May 2008. Combined, these five fields make up Figure 3b.*

highlighting areas where severe convection is anticipated. Although this prototype product is based on a deterministic model run (NSSL-WRF), this technique can be extended to a collection of model runs (e.g. from an ensemble system).

The uncertainties discussed in the previous section will set the direction for future work on this topic. Of high priority is to examine the sensitivity of the SSD field by varying the field thresholds (by changing the field distribution percentile). Also, this study was restricted to the period from mid-April to early-June when severe convection was prevalent. A more robust examination of this technique over a longer time period is planned. An investigation of the five SSD fields is underway to determine what fields are most strongly correlated to severe weather reports using the verification techniques discussed in the previous section. This includes correlating forecast fields to different types of severe weather reports (hail, wind, tornadoes). In addition to the five fields, additional fields of potential interest include the hydrometeor mixing ratios from the NSSL-WRF microphysics scheme.

The Gaussian smoother parameter, σ, can be adjusted to produce an SSD field which retains more of the small-scale features of the surrogate report field. Such a product reflects less uncertainty in the model forecast and could prove to be valuable for forecasting the path and impacts of ongoing convection in the short-term, given that the predicted location has verified. The model accurately forecasted the path and location of individual storms on several days during the experiment. The ultimate goal of this work is to produce a guidance product which can be utilized in an operational forecasting environment, such as the SPC. Toward this end, real-time plots of proxy severe weather report

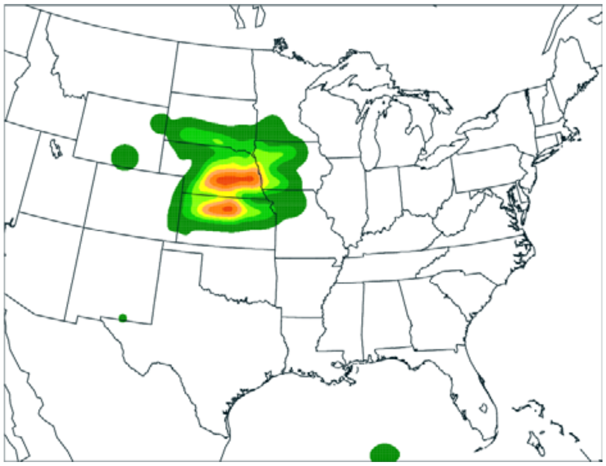


Fig. 5: *As in Fig. 3a, except with the Gaussian smoothing parameter, σ, set to 40 km.*

density are being produced in real-time using the NSSL-WRF. These are available online at http://www.nssl.noaa.gov/wrf.

7. ACKNOWLEDGEMENTS

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