USING THE SPATIAL COVERAGE OF FAVORABLE SEVERE WEATHER PARAMETERS IN FORECASTS OF SEVERE CONVECTION

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I. INTRODUCTION

Severe storm forecasters have recognized that most major tornado outbreaks occur on days with the collocation of favorable vertical wind shear and buoyant instability spanning a large region (e.g., Hamill et al. 2005). However, this notion has not been tested on a large sample of cases, largely owing to the exceedingly rare occurrence of such events and the absence of a universally accepted definition for severe weather outbreaks. Doswell et al. (2006) developed a technique to identify *prototypical* tornado outbreaks and primarily nontornadic outbreaks in the conterminous United States (CONUS). Shafer and Doswell (2010; 2011) expanded this technique to include outbreaks of any type, with the intention of ranking the events by their relative severity. The ranking scheme used a linear-weighted formula with multiple severe weather report variables to compute an index score (e.g., N15 in Fig. 1). The cases were ranked based on the magnitudes of the index score, with the highest ranked (i.e., lowest rank number) cases primarily major tornado outbreaks.

Shafer and Doswell (2011 – hereafter SD11) used kernel density estimation (KDE; Bowman and Azzalini 1998) to identify severe weather outbreaks based on the density of severe weather reports in separate 24-h intervals. A threshold value of the approximated probability density function was used to identify the region associated with the outbreak. This permitted the designation of multiple outbreaks on a given day (spatially separate clusters of reports, associated with distinct synoptic-scale systems), and increased the sample of cases available for discrimination analyses (>6000 cases identified by SD11 from 1960-2008).

SD11 found that the rankings of the most significant (least significant) outbreaks were subject to little (substantial) variability when modifying the variable weights used to compute the index score. Therefore, the diagnosis and forecast of the index scores is unreasonable, based on the uncertainties associated with the severe weather report variables, whereas the discrimination of major and minor severe weather outbreaks is more feasible.

The definition of major and minor outbreaks is subject to considerable controversy (see Doswell et al. 2006). The characteristics of the index scores used to rank the cases confirm this (Fig. 1). Specifically, the scores exhibit a rapid decrease with increasing rank number and then level off for less significant events. Ideally, the ranking index scores would exhibit neutral slopes for the highest- and lowest-ranked cases with a large negative slope between the two classes (i.e., a "logit" curve). As there appears to be no clear distinction between major and minor outbreaks, we instead determine the threshold index score in which the objective techniques proposed here and Storm Prediction Center (SPC) convective outlooks (Section 2) distinguish major and minor outbreaks most skilfully (Section 3).

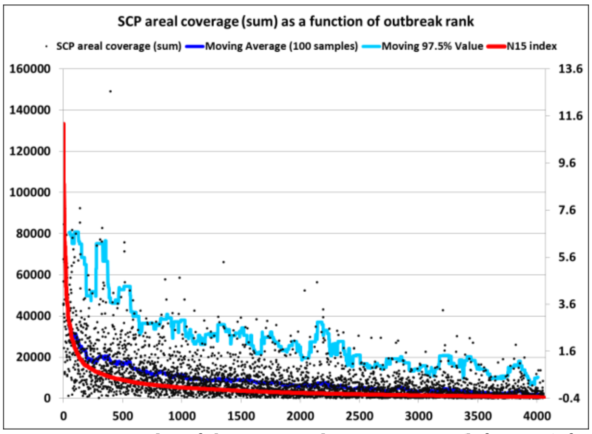

FIG. 1: Scatter plot of the SCP areal coverage sum (left *y*-axis) for each of 4057 outbreaks as a function of rank (*x*-axis). The 100-sample moving average (dark blue) and 97.5% value (cyan) are indicated. The N15 index scores (red; right *y*-axis) are shown.

II. PRESENTATION OF RESEARCH

Shafer et al. (2009) attempted to discriminate tornado and primarily nontornadic outbreak model simulations using subjective techniques. A consistent finding was the relatively large regions of favorable magnitudes of severe weather variables in tornado outbreak simulations. Shafer et al. (2010) tested the so-called areal coverage of these variables on 840 severe weather outbreaks from 1979-2006, using North American Regional Reanalysis (NARR; Mesinger et al. 2006) data available at the event valid times. They found that areal coverage of a subset of these variables was skillful in discriminating major and minor severe weather outbreaks. However, the results were subject to considerable uncertainty owing to the limited sample of cases available for testing. With the availability of the new

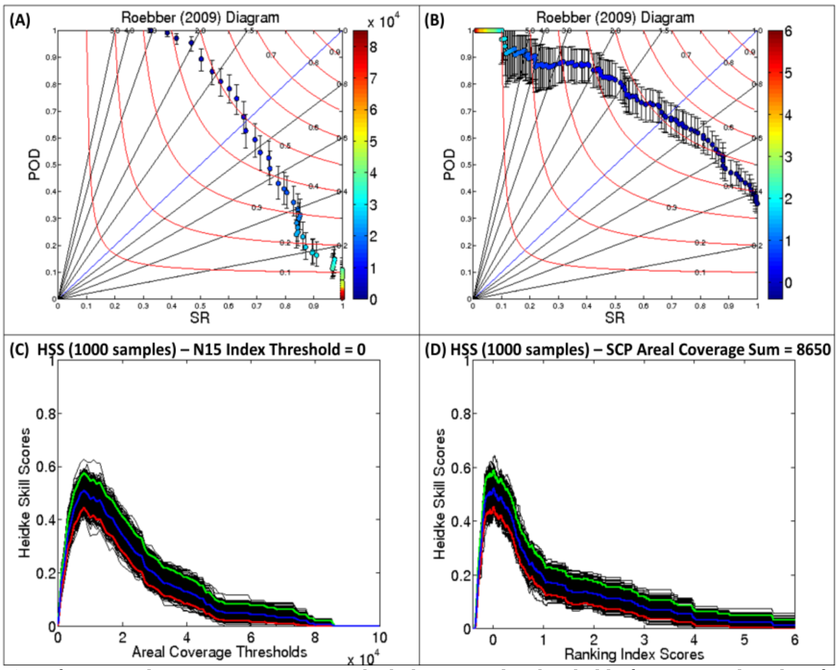

FIG. 2: (a) Roebber (2009) performance diagrams using SCP, in which the N15 index threshold of zero is used to classify events as major or minor outbreaks, with areal coverage sum values incremented from 0 to 80 000 (shaded points). Bootstrapped 95% confidence intervals of the POD for a given areal coverage value are shown. (b) As in (a), using an areal coverage sum value of 8650 to diagnose outbreak severity for incremented threshold N15 index scores from -0.4 to 6 (shaded points). (c) Bootstrap samples of the Heidke skill scores, with confidence intervals (red, 2.5%; green 97.5%) and the median (blue) indicated for each value of areal coverage tested using SCP, for the N15 index threshold of zero. (d) As in (c), but with areal coverage fixed at 8650 for each value of the N15 index scores tested.

ranking scheme introduced in SD11, the sample size increased to 4057 cases from 1979-2008.

The areal coverage of a severe weather variable is computed in three ways. The first method (referred to as the **KDE method**) initially identifies the region associated with each outbreak. The grid points in a 300x200 18-km horizontal grid encompassing the CONUS that are located within the region determined via KDE (see SD11) are identified. The magnitude of a severe weather variable of interest is computed at each of these grid points. If the sum of these values over all the identified grid points exceeds a specified threshold, the event is *diagnosed* as a major severe weather outbreak. The event is *classified* as a major outbreak if the index score (i.e., the N15 value in Fig. 1) used to rank the outbreaks exceeds a specified threshold.

The second method (the **intersect method**) uses the largest contiguous region in which a severe weather variable exceeds a specified threshold that also intersects the KDE region. The value of a severe weather variable is computed at each of the grid points, and the sum of the values is used for diagnosis, as in the KDE method. The third method (the **maximum method**) is the same as the intersect method, except that it does not require the contiguous favorable region to intersect the KDE region.

The accuracy and skill with which these techniques discriminate major and minor severe weather outbreaks are determined in two ways. The first method selects a particular threshold index score to classify outbreaks as major or minor (the value of zero is used in Figs. 2a,c). The areal coverage of a selected parameter (e.g., the supercell composite parameter, or SCP; Thompson et al. 2003) is incremented from zero to sufficiently high values to determine which threshold has the most skill in discriminating the outbreaks at the specified index score. The second method selects an areal coverage threshold to diagnose outbreaks as major or minor (the value of 8650 for the SCP areal coverage sum is used in Figs. 2b,d), and the N15 index score is incremented from the lowest to the highest scores to determine which threshold the selected areal coverage value most skillfully discriminates outbreaks.

In addition to an assessment of areal coverage for all 4057 events, SPC convective outlooks from 23 January 2003 to 31 December 2008 were assessed and compared directly to the areal coverage techniques for 727 cases, to determine how the objective techniques compare to present-day forecast skill in the diagnosis of major severe weather outbreaks. Outlooks with a "moderate" or "high" risk are assumed to be forecasts of major severe weather outbreaks.

III. RESULTS AND CONCLUSIONS

The areal coverage method demonstrates considerable (statistically significant) skill in the discrimination of major and minor severe weather outbreaks (Figs. 2 and 3). This skill exists for several severe weather variables, including the energy-helicity index (EHI; Hart and Korotky 1991), bulk shear, the product of CAPE and bulk shear, SCP, and the significant tornado parameter (STP; Thompson et al. 2003). As shown by Shafer et al. (2009; 2010), CAPE alone exhibits little to no skill in outbreak discrimination (not shown). The highest skill occurs over a broad range of values (e.g., Figs. 2c,d), and is generally between N15 index scores of 0 and 2. As expected, increased areal coverage values result in maximum skill at increased N15 index score thresholds; however, at higher thresholds, uncertainty increases because of the smaller fraction of cases exceeding the specified values.

SPC convective outlooks issued at 0600 UTC on the nominal date of the outbreak are compared to Weather Research and Forecasting (WRF; Skamarock et al. 2008) model simulations initialized with NARR data at 0000 UTC on the nominal date of the event to determine the utility of the areal coverage technique in an operational setting (e.g.,

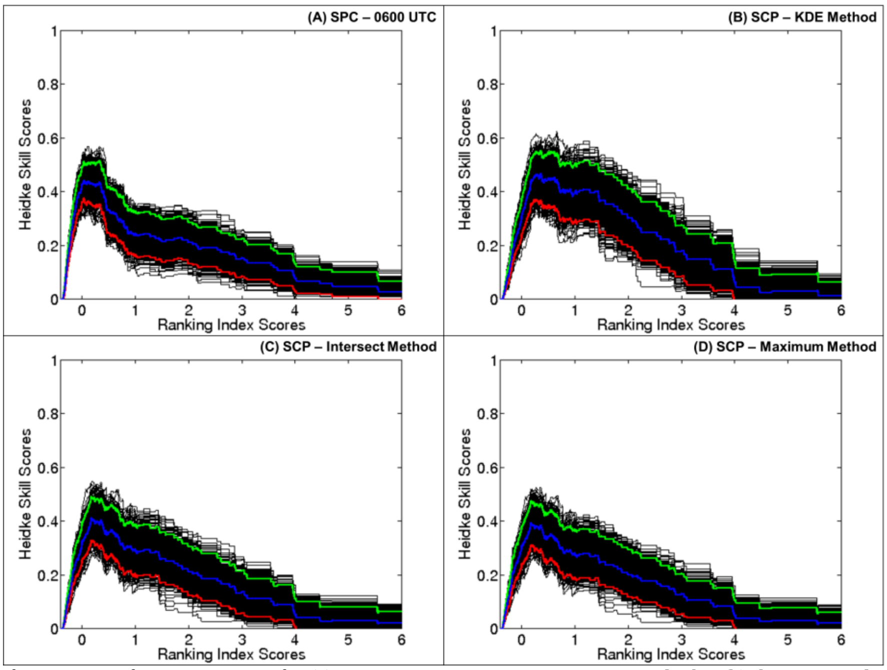

FIG. 3: As in Fig. 2d, for 727 cases from 2003-2008, for (a) SPC 0600 UTC Day-1 convective outlooks, (b) the SCP areal coverage sum using the KDE method, (c) the same as (b), using the intersect method, and (d) the same as (b), using the maximum method.

Fig. 3). In general, SPC convective outlooks exhibit comparable skill to the areal coverage techniques. Moreover, no areal coverage technique is statistically significantly better than the others. These findings suggest that the areal coverage technique can be incorporated easily into a forecast setting, with potentially useful guidance.

SPC forecasts of moderate or higher risks of severe convection are most skillful at index scores of approximately 0-0.5 (Fig. 3a). Subjective analysis of cases with these index scores suggest that events with scores above these values feature multiple significant tornadoes (i.e., F2 or greater) and/or an anomalously large number of significant nontornadic reports. If the high risk is used as the threshold to distinguish major and minor outbreaks, maximum skill is observed with N15 scores of ~2.75 (not shown). Most cases above the N15 index score of 2 are major tornado outbreaks. Note that the sample size of high-risk outlooks is very small (<30 of 727 cases), and the uncertainty associated with these statistics and observations is quite large.

Although there is skill with outbreak discrimination, the results indicate a false alarm problem and considerable variability in the areal coverage values as a function of case rank (Fig. 1). Although some of this uncertainty is associated with nonmeteorological artifacts with the severe weather report variables used to compute the ranking index scores (SD11), this variability indicates a lack of physical understanding regarding the mechanisms responsible for the occurrence of major tornado outbreaks. There are no known variables that account for this uncertainty at present.

IV. ACKNOWLEDGMENTS

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