Estimating the Probability of Severe Convective Storms: A Local Perspective for the Central and Northern Plains

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ESTIMATING THE PROBABILITY OF SEVERE CONVECTIVE STORMS: A LOCAL PERSPECTIVE FOR THE CENTRAL AND NORTHERN PLAINS

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Abstract

Probabilities provide a means of quantifying both the likelihood of a particular meteorological event and the degree of certainty in its forecast. In the future, probabilities will likely be issued routinely for the occurrence of severe convective storms. As a prelude to such efforts, this study developed a procedure for estimating probabilities of severe convective storms as applied to a local area. The primary intent is to acquaint local forecasters and potential users with representative probabilities for time and space scales for which forecasts are made. Probabilities of severe convective storm occurrence within local areas near selected cities were computed. The period of record was 1992-1994. For this study, a "local area" was defined as within 30 nautical miles (nm) of the center of a selected city. Cities selected were Kansas City and Saint Louis, Missouri; Indianapolis, Indiana; Minneapolis, Minnesota; and Omaha, Nebraska. The relative frequency of at least one severe convective event while an Outlook and/or Watch were in effect provided an estimate of the local probability associated with that product. A composite model was developed from the combined data from the five local areas. This model reflected local probability associated with Outlooks and Watches and trends relative to the period from issuance to end of valid time. An operational scenario is described in which local probabilities are estimated and grids of probability are constructed.

1. Introduction

Expression of forecasts in terms of probabilities allows quantification of the forecaster's certainty. Also, probabilities allow "end users" to make objective decisions based on such forecasts. For over 30 years, the National Weather Service (NWS) has issued probability-of-precipitation (PoP) forecasts. Use of hurricane "strike" probabilities has received wide acceptance (Sheets 1985). Currently, development of procedures for probabilistic quantitative precipitation (Krzysztofowicz et al. 1993) and stream flow (Fread et al. 1995) forecasts is underway. Additionally, plans of the NWS (NWS 1999) include expansion of the use of probabilities in operational products. One of these areas is the forecasting of severe convective storms. As a prelude to such efforts, this study describes a procedure to estimate probabilities of the occurrence of severe convective storms within local areas. Results provide forecasters, as well as others (e.g., local emergency management officials) with representative probabilities within a familiar framework. Also, an operationally-oriented application of these results is described.

2. Background

A Bayesian (Winkler 1985) approach has been taken in the development of a procedure to estimate probabilities of severe convective storms for local areas. That is, probabilities developed in this study are considered to be "prior" probabilities (hereafter referred to as simply "probabilities"). They are valid, but are capable of being modified as new information becomes available to the forecaster, from any of a variety of sources. The Law of Large Numbers (Wilks 1995)

$$\Pr\{\,|a/n - \Pr\{E\}| \le \varepsilon\} \rightarrow 0 \text{ as } n \rightarrow \infty \qquad (1)$$

provides the basis for the procedure. This law states that the relative frequency (a/n) of an event {E} converges to its true probability Pr{E} as the number of opportunities of occurrence becomes large, where a is the number of occurrences and n the number of opportunities; ε being an arbitrarily small number. As derived in this study, probability estimates are "data-based", rather than being obtained from a theoretical probability distribution.

Local probabilities are estimated for the occurrence of any severe convective event: (1) tornado, (2) wind gust of at least 50 kts (> 25 ms^{-1}), (3) hailstones having a diameter of at least three quarters of an inch (1.9 cm), or (4) wind damage produced by a convective storm. For this study, a local area[1] is defined as being within 30 nm of the center of a selected city. This definition reduces the sampling error often noted in the collection of severe convective event reports (Kelly et al. 1982) and parallels a procedure used by Brown (1996). Convective Outlooks and Watches issued by the NOAA/NWS/National Severe Storms Forecast Center (NSSFC), now the Storm Prediction Center (SPC), provided the foundation for the estimation of local probabilities of severe convective storm occurrence. Such attachment of probabilities to

[1]Values of relative frequency, and thus estimated probabilities, are dependent on the size of the local area. The local area size used for this study was considered representative of the metropolitan areas surrounding the five selected cities.

operational products produced a framework familiar to both forecasters and "end-users." The period of record for this study is 1992-94. Selected cities include Saint Louis and Kansas City, Missouri; Indianapolis, Indiana; Minneapolis, Minnesota; and Omaha, Nebraska.

3. Procedure

According to (1), the probability of severe convective storm occurrence is estimated by a relative frequency during a specified period. Such relative frequencies were computed for local areas around each city during the years 1992-94. A probability, P {E}, is estimated by

$$P\{E\} = \sum_{i=1}^{n} x_i \Big/ \sum_{i=1}^{n} y_i \qquad (2)$$

where E represents any severe convective event, n is the number of years in the period of record, y_i is the number of forecast periods during which the center of a selected city was included within a forecast area in year i, and x_i is the number of forecast periods from y_i during which one or more severe convective events occurred within a selected local area.

By use of data from the same three-year period, an adaptation of this procedure estimated a background (climatological) probability for each local area. A severe convective season was defined as the number of days from first to last severe convective events, inclusive, in a local area during each year i of the period of record. Each day of a season represented a forecast period. Thus, a background probability, P_c is given by (2) when n is the number of years in the period of record, x_i is the number of days in year i during which at least one severe convective event occurred within the local area, and y_i is the number of days in the severe convective season of year i. The resulting probability is applied as a "daily probability" throughout the severe convective season, without regard to forecasts.

All Convective Outlooks and Watches that included the geographical location (latitude/longitude) of the center of each city during 1992-94 were compiled. Times of issuance and the length-of-time (Δt) from issuance to the end of its valid period for the various products are listed in Table 1. Then, all severe convective events that occurred in each local area during 1992-94 were compiled. As computed via (2), the relative frequency of occurrence of one or more severe convective events within a local area while an Outlook or Watch was in effect during the period of record provided an estimate of the local probability.

Table 1. Issue times and length of time (Δt) between issuance and the end of valid periods for Outlooks and Watches considered in this study.

Product	Issue Time (UTC)	Δt (hours)
0800 UTC Day-2 Outlook	0800	52
1800 UTC Day-2 Outlook	1800	42
0600 UTC Day-1 Outlook	0600	30
1500 UTC Day-1 Outlook	1500	21
1900 UTC Day-1 Outlook	1900	17
Convective Watches	as needed	6

This study focuses on the defined local areas, not the entire area included within an Outlook or Watch. Therefore, results are not comparable to standard verification of the products. Objective guidance in terms of probabilities provided by Model Output Statistics [MOS] (Reap and Foster 1979; Charba 1979) was available to forecasters during preparation of Outlooks and Watches. Because such guidance is part of the process leading to the selection of areas to be placed within Outlooks and Watches and assigned either a risk category or watch type, probabilities computed in this study have not been compared directly to these guidance probabilities. However, such probabilities do remain a source of information by which forecasters can modify probability estimates.

Table 2 is a combined tabulation of all events, Outlooks and Watches from the five local areas. Again, probabilities associated with Outlooks and Watches were based on the occurrence of at least one event in each local area while these products were in effect during the period 1992-94. Note that Moderate and High Risk Outlooks have been combined due to the small number of issuances. Also, Tornado and Severe Thunderstorm Watches have been combined because the probabilities are for the occurrence of any severe convective event. Figure 1 depicts the highest and lowest probabilities computed from any of the five local areas, as well as probabilities computed from the combined data, relative to Outlooks and Watches. It has been assumed for this study that (1) there is no systematic bias in the forecasting of severe convective storms and (2) sampling of severe convective events is sufficient within the selected local areas. These assumptions support consideration of the combined data as exchangeable (Gelman et al. 1998). That is, all data are considered as being sampled from the same population. Results derived from this combined sample are considered representative of local areas throughout the central and northern Plains region.

Table 2. Combined summary of severe events, outlooks, and watches for the five local areas addressed in this study; 1992-94.

Severe Events: Total: 720 Hail: 215 Wind: 452 Tornado: 53

Convective Outlooks:	Total	Slight Risk	Mdt/High Risk
0800 UTC Day-2	503		
1800 UTC Day-2	537		
0600 UTC Day-1	554	514	40
1500 UTC Day-1	556	514	42
1900 UTC Day-1	530	480	50

Convective Watches: Total: 263 Severe Thunderstorm: 194 Tornado: 69

4. Trends in Local Probabilities

Figure 2 depicts local probabilities derived via the combined data summarized in Table 2. Values associated with each product are plotted in the order of product issuance. This order is also relative to the length of time

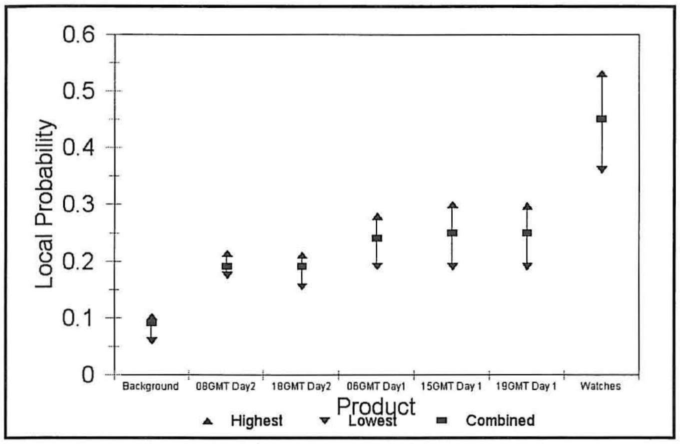

Fig. 1. Highest and lowest local probabilities computed from any of the five local areas; compared to local probabilities computed via combined data from all five local areas. Values are associated with products as listed in Table 1.

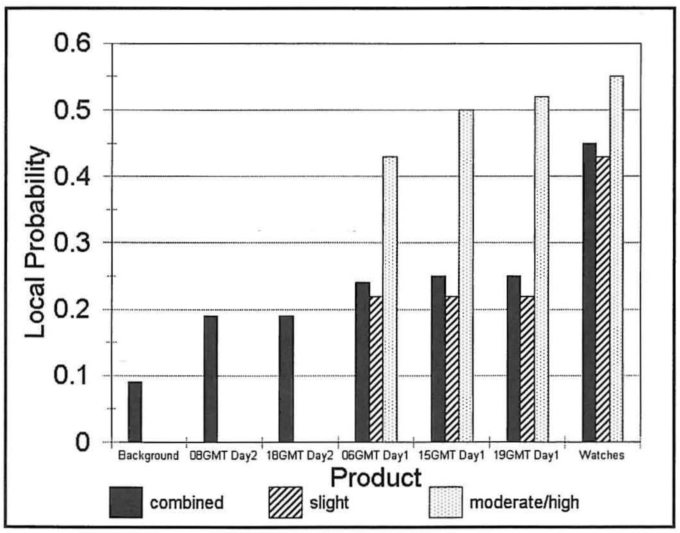

Fig. 2. General model of the local probability of at least one severe convective event within a local area of the central and northern Plains. Values are associated with products as listed in Table 1.

(Δt) between the time of issuance and the end of the valid period for each product. The probability assigned prior to issuance of the initial Day-2 Outlook is a seasonal background (climatological) value. Outlooks and Watches are associated with increased probabilities relative to the background probability. With the combined data, a mesoscale time frame (six hours) is reached before a large increase in local probability is evident.

Additionally, separate probabilities were computed for Outlooks according to assigned categories of risk. During the period used for this study (1992-94), a risk category was not assigned for Day-2 Outlooks. Therefore, stratification by risk only applied to Day-1 Outlooks. As seen in Fig. 2, probabilities associated with Moderate/ High Risk Outlooks are greater than those of both Slight Risk and Combined values. Many more Outlooks are issued with a Slight Risk than with a Moderate/High Risk (Table 2). Thus, probabilities are heavily weighted toward the values associated with Slight Risk Outlooks. There is a much larger increase in probability when Watches are issued during a valid Slight Risk Outlook than during a Moderate/High Risk Outlook. These results suggest that when synoptic-scale forcing of severe convective events will predominate, these episodes can be identified "early" and are predicted rather well, even at times when numerical model output is the primary guidance. On the other hand, no clear synoptic forcing leads to lower probabilities at Outlook times.

5. Operational Application

The SPC issues Outlooks routinely and Watches as needed. From a verification perspective, each risk category has an associated expected areal coverage (NWS 1979). Over time, expected areal coverage is related to probability. The current study addresses the occurrence of at least one event anywhere in the local area. This is an area probability (Winkler and Murphy 1976). As discussed by Schaefer and Livingston (1990), such an area probability is greater than or equal to the expected areal coverage. Thus, probabilities derived in this study differ from those inferred from expected areal coverage used for verification of Outlooks and Watches (Weiss et al. 1979).

In addition, if the general model for local probabilities in the central and northern Plains is applied in conjunction with the issuance of Outlooks and Watches, results suggest a means for production of grids of probabilities. Because local probabilities derived in this study are estimates and in order to avoid suggestion of unjustified preciseness, values are rounded to the nearest 0.10 for operational application.

As an example of operational application, consider the 1500 UTC Convective Outlook for 1 July 1997 shown in Fig. 3. This outlook includes all five of the sites considered in this study. An area primarily in Iowa and southern Minnesota was assigned a High Risk. From the general model (Fig. 2), Moderate/High Risk at 1500 UTC is associated with a probability of 0.50. A Slight Risk at 1500 UTC is associated with a probability of 0.22. Also, the overall background probability is near 0.10. These results suggest that the risk outlines can be labeled with probabilities as follows: (1) 0.10 for the general thunderstorm outline, (2) 0.20 for the Slight Risk outline, and (3) 0.50 for the High Risk outline. Strictly speaking, a value of 0.10 applies to all areas outside an Outlook or Watch. However, when thunderstorms, a prerequisite of severe convective events, are not expected, the forecaster makes a statement suggesting a lower probability in such areas. Thus, the value of 0.10 is retained within the general thunderstorm area only. Figure 4 shows the corresponding risk of severe convective storms in terms of probability for 1500 UTC 1 July 1997. For any local area, values estimate the probability of at least one severe convective event occurring during the next 21 hours. Further, when Tornado Watches were issued in the High Risk area at 1800 and 2000 UTC 1 July, a probability of 0.60 would have been assigned to local areas within these Watches (Fig. 5) for the valid periods of each Watch.

From the probabilities depicted in Fig. 4, a grid of probabilities can be constructed. All points within a given risk area are (1) considered as the center of a local area and (2) assigned the associated probability. Importantly,

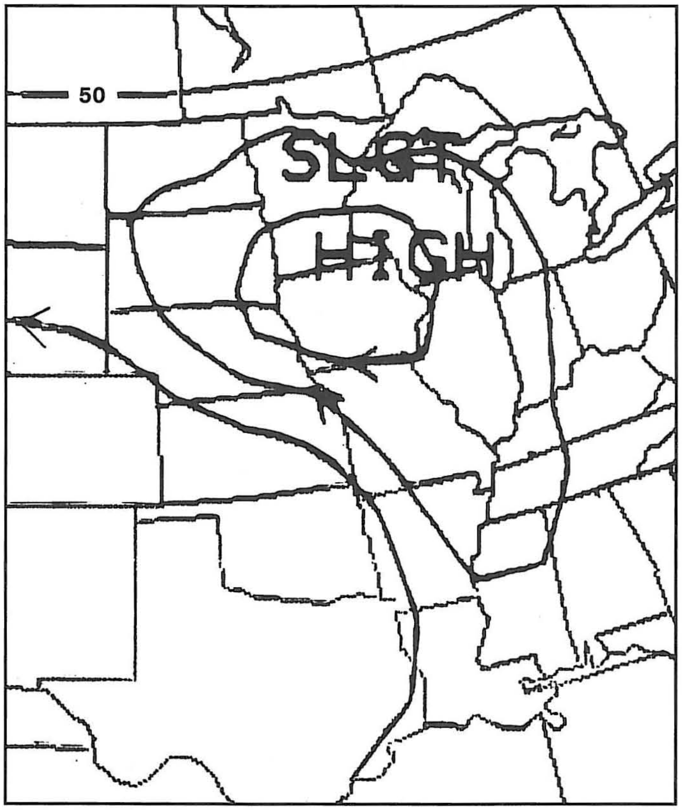

Fig. 3. Graphical depiction of the Day-1 Convective Outlook issued by the Storm Prediction Center at 1500 UTC 1 July 1997, indicating areas of risk of severe convective storms.

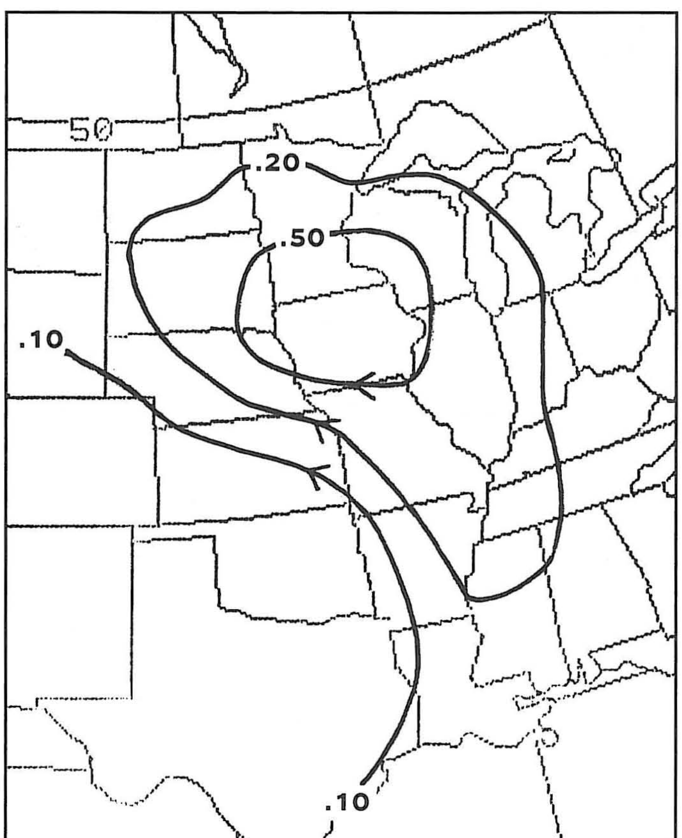

Fig. 4. Same as Fig. 3, except areas are expressed in terms of local probabilities based on the general model in Fig. 2.

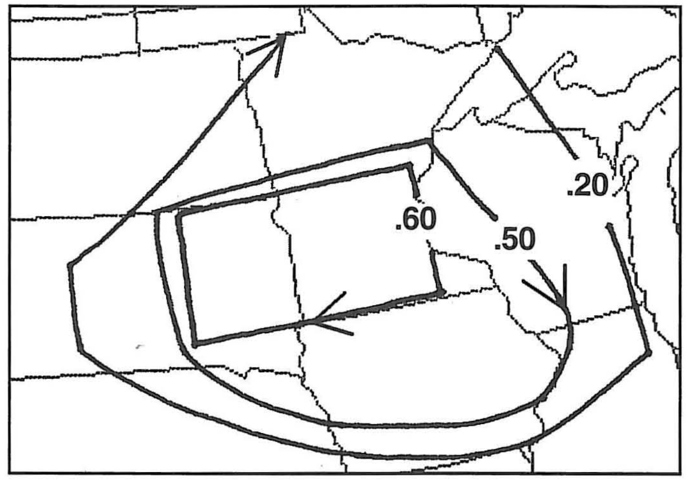

Fig. 5. Areas of two Watches and the Convective Outlook in effect at 2000 UTC 1 July 1997 depicted in terms of local probabilities of at least one severe convective event.

such gridded values are in terms of the threat to a local area, and thus meaningful to local forecasters and other local users. Being considered prior probabilities, they can be adjusted based on additional information that becomes available. For example, values within a local County Warning/Forecast Area (CWFA) can be adjusted based on issuance of other Outlooks and Watches, analysis of local data, statistical guidance, radar algorithm output or automated analysis procedures (Smith et al. 1998).

6. Discussion

The primary intent of this study is to demonstrate concepts of probabilities of severe convective events from the perspective of a local area. Such probabilities were obtained via relative frequencies of events while the geographical centers of designated cities were included within an Outlook or Watch. Values and trends of probabilities inherent in various Outlooks and Watches suggest potential operational utility.

Experimental efforts are underway at the SPC to develop a fully operational procedure for subjective estimation of probabilities of severe convective storms. These comprehensive efforts address local probabilities from a forecaster's perspective and result in probabilities compatible to those computed in this study, when the size of the area of application is taken into account. A discussion of the SPC effort, how results apply to local areas, and experimental forecasts can be viewed on the Internet via the SPC Web page[2].

7. Summary and Conclusions

A procedure to estimate probabilities of the occurrence of severe convective storms within local areas has been described. Probabilities were based on a simulated climatology and the relative frequency of severe convective events when a selected site was contained within

[2]http://www.spc.noaa.gov/products/exper/

an operational Outlook or Watch. Combined data from five local areas were used to develop a general model for local probabilities within the central and northern Plains region. Attachment of probabilities to specific products placed values within a framework familiar to both forecasters and "end-users." Application of results in an operational scenario demonstrated representative local probabilities and supported production of grids of probabilities.

Reasonable results have been obtained, and concepts of probabilities applicable to local areas have been developed. As such, results of this study support the comprehensive effort currently underway at the SPC to produce a fully operational procedure.

Acknowledgments

The author thanks Deborah J. White and Michael Manker for technical support with this paper. Reviews by two NWS Science and Operations Officers, Rich Naistat and Llyle Barker, significantly improved this work. Their assistance is greatly appreciated.

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