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CLIMATOLOGY AND STRUCTURE OF HIGH WIND-PRODUCING MESOSCALE CONVECTIVE SYSTEMS OVER THE NORTHERN HIGH PLAINS

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1. INTRODUCTION

According to Kelly *et al*. (1985), damaging winds account for approximately 61% of the total number of severe thunderstorm reports across the United States. Relatively little is known, however, about the frequency and types of convective systems which produce these severe and damaging winds. In light of this, a research project was initiated early in 1996 to investigate high wind-producing convective events and linear convective systems over the Northern High Plains. This research is a cooperative effort between the South Dakota School of Mines and Technology (SDSM&T) and the Rapid City National Weather Service Forecast Office (NWSFO), supported by a grant from the Cooperative Program for Operational Meteorology, Education and Training (COMET).

This cooperative research effort consists of three primary components: 1) to clarify the kinematics, dynamics and antecedent conditions of convective systems that produce severe winds over the Northern High Plains; 2) to gain a greater understanding of the evolution of storm structure of linear convective systems; and 3) to compare the observed structure and evolution of these Northern High Plains storms with those in the Mid-Mississippi Valley, which are being studied by the St. Louis NWSFO. Additionally, in order to develop a reference frame from which to better observe our results, a detailed climatology of high wind-producing convective systems is being created. This paper focuses on the results of the climatological study, and the structures of the high wind events observed over the Northern High Plains since the advent of this research project.

2. NATURE OF THE DATA SET

The area of interest for this study is the Northern High Plains (Figure 1). Two primary data sets were analyzed for this research: a climatological database of severe convective weather reports from 1955 to 1995; and radar observations of severe wind events over the past three convective seasons. The climatological data were used to assess the spatial and temporal frequency of damaging wind (and hail) events over this area, while the radar and other observations were used to assess the convective structure of the recently observed high wind events.

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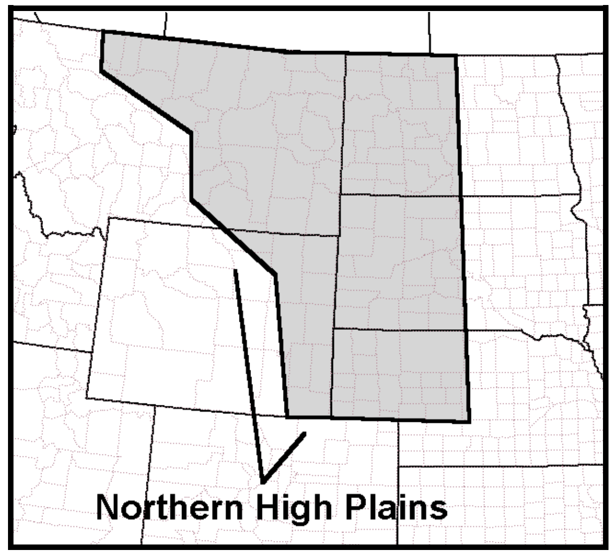

Figure 1. Areal extent of the Northern High Plains region (shaded).

2.1 Climatological analyses

For the climatological portion of this research, all severe wind and hail reports over the Northern High Plains from 1955 through 1995 were extracted from the historical severe weather archives produced at the Storm Prediction Center (SPC). Only storms which occurred between 1 May and September 30 were considered in order to represent the primary convective season over this northern region. It should be noted that the following climatological analyses have also been performed with all of the available severe weather data throughout the year, and the results were very similar. The SVRPLOT software (Hart, 1993) was used to analyze these data.

2.2 Observed high wind event database

All convective systems which produced multiple high wind reports over the Northern High Plains during the convective seasons of 1996, 1997, and 1998 were evaluated and analyzed for this project. A convective system is included in the database as a *high wind event* if the storm system had at least two severe wind (>25 m/s) or wind damage reports at least 15 miles apart and separated in time by more than 15 minutes. A convective system associated with an isolated high wind report may also be included in the database if the structure of the event was organized in such a way that additional (but unreported) high winds were likely. If the structure of a convective system changed significantly while producing wind damage, the storm may be counted as more than one high wind event. For instance, a supercell which evolved into a bow echo would be counted twice if severe winds were recorded with each phase of the storm. However, if the system maintained the same convective structure throughout its life, it is counted only as a single event no matter how long the damage path may be. Additionally, all linear convective systems (squall lines and bow echoes) which occurred over the Northern High Plains were also included. For all identified events, radar data were acquired for analysis; and surface, upper-air, satellite, and model data were all utilized to characterize the state of the convective environment in which the convection formed.

Radar reflectivity and velocity fields were utilized to catagorize the convective structures of the recorded high wind events. For simplicity, the observed wind events were partitioned into four different categories: 1) squall lines; 2) bow echoes; 3) supercells; and 4) other non-linear systems (multicells). Definitions and descriptions as given in the *Glossary of Meteorology* (1959), Fujita (1978), Weisman and Klemp (1986), and Moller *et al.* (1994) were used as guidance in categorizing the storms.

3. CLIMATOLOGY OF CONVECTIVE HIGH WIND EVENTS

Several analyses were performed with the SPC historical severe weather archives to determine the spatial and temporal characteristics of severe wind observations over the Northern High Plains. These included temporal analyses, which focused on the frequency of severe wind reports as a function of time of day; comparative analyses, which determined the relationships between severe wind and severe hail reports over the Northern High Plains, and time-space analyses, which illustrate the spatial preference for severe wind events for certain times of day.

3.1 Spatial Analyses

The spatial distribution of all the severe convective wind reports over and around the area of interest from 1955 through 1995 is shown in Figure 2. There are three primary maxima in the severe wind frequency; one located in western North Dakota; one extending from the Black Hills south along the Front Range of Wyoming and Colorado; and a larger maxima extending to the south from eastern South Dakota. While there is no doubt that this distribution is heavily influenced by population density (Kelly *et al.,* 1985), one can also reasonably explain the observed pattern through meteorological reasoning. The strong diurnal convective cycle and relatively dry atmosphere over the elevated terrain of the western Plains can account for the maxima located in western South Dakota, along the Front Range of Wyoming, Colorado and Montana. The areal distribution of reports for various times of day (not shown) illustrate that a high wind frequency maximum axis moves eastward across the Plains, corresponding to the tendency for convection to organize into larger-scale convective systems (under favorable conditions) and move across the Plains overnight. This nighttime convective activity, combined with the usual diurnal convective cycling over the Plains,

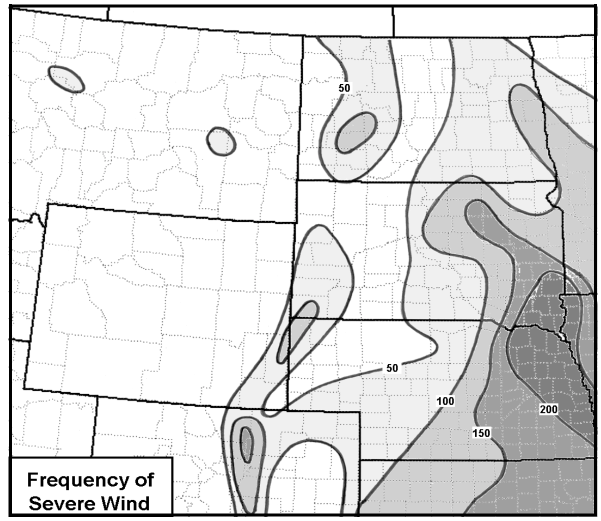

Figure 2. Subjectively analyzed frequency of severe thunderstorm wind occurrence per 10,000 km^2 during the convective season from 1955 through 1995. Contours and shading every 50 reports per 10,000 km^2.

could account for the maximum frequency which extends 500-700 km east of the Rocky Mountains through western North Dakota, eastern South Dakota and Nebraska. The climatological analyses in this study are largely sampling the western areal frequency maxima.

3.2 Temporal Distributions

While the spatial frequency of reports will be influenced by the distribution of population, the temporal frequency calculated over a specific area should accurately represent the diurnal variation of these events.

One characteristic which distinguishes the Northern High Plains from the Plains further to the east is the great diurnal dependance of the frequency of high wind reports in this area (Figure 3). During the three hour period of greatest high wind frequency (18 to 21 CDT), 1379 high wind reports were recorded over the Northern High Plains from 1955 to 1995. This is 92 times the amount which occurred during the three hour period from 8 to 11 CDT, during which only a total of only 15 severe wind reports

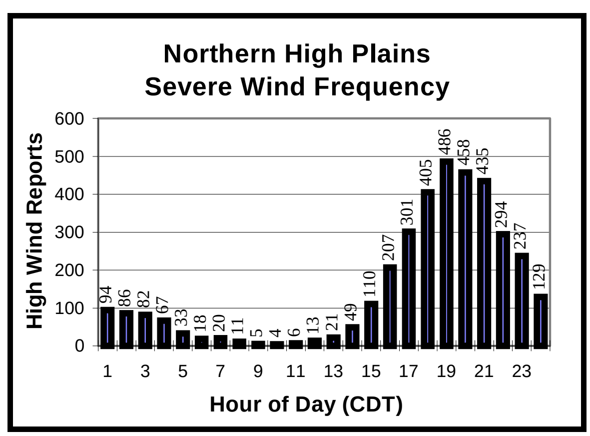

Figure 3. Hourly distribution (CDT) of severe thunderstorm wind occurrence over the Northern High Plains.

have been recorded. For comparison, analyses performed over the entire United States exhibited only an ~8 times difference between the most and least active three-hour periods (Kelly *et al.*, 1985). Similarly, temporal analyses performed over the Central Plains exhibited a ~6 times difference between maximum and minimum frequency.

Another interesting aspect of the Northern High Plains is the relative frequency of severe wind to severe hail reports. Over the study area, severe winds accounted for only 41% of the non-tornadic severe storm reports; while nationally, approximately 61% of the non-tornadic severe weather were wind related. Plotting the ratio of high wind/severe hail occurrences as a function of time illustrates that there is a diurnal variation which increases to over 1.0 around midnight, and decreases to less than one during the rest of the day (Figure 4). Plots such as these can lend insight into the temporal variation in these convective structures, as the ratio between high wind and hail likely varies as a function of convective types.

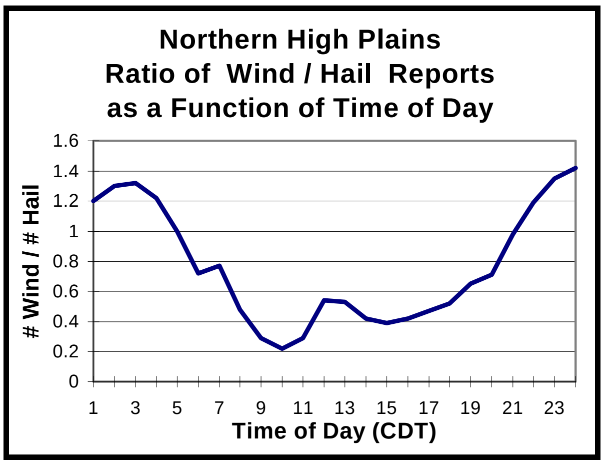

Figure 4. Ratio of severe wind to severe hail reports as a function of time of day (CDT).

4. OBSERVED STRUCTURE OF HIGH WIND EVENTS

At the time of this writing, sixty-nine high wind convective events have been identified over the Northern High Plains since the inception of the research (April 1996). For each of these events, the radar data has been analyzed and the structure of the storm has been identified (where possible). The observed high wind producing storms were partitioned into the four categories described earlier: 1) squall lines; 2) bow echoes; 3) supercells; and 4) and other non-linear (multicell) storms. Another category ("unknown") has been included herein to cover those convective storm structures which have not yet been determined. Table 1 lists the number of severe high wind events which fall under each of the above categories and the mean ratio between hail and wind reports for these cases. All occurrences of squall lines and bow echoes over the Northern High Plains, independent of severity, were also logged. For these systems, the number with no severe wind reports were noted in the table.

Table 1. Parameters associated with the high wind and linear convective events described in the text.

High Wind Convective Structure	# High wind events (% of total)	Hail / Wind Report Mean Ratio	# Non-Severe
Squall lines	21 (30%)	0.36	35
Bow Echoes	21 (30%)	0.28	11
Supercells	6 (9%)	2.1	
Non-linear	12 (17%)	1.8	
Unknown	9 (13%)		

These data indicate that the majority (60%) of organized high wind events identified over the Northern High Plains were derived from linear-type convective events comprised of squall lines or bow echoes. While the large, 'classic'-type convective lines (Smull and Houze, 1987; Houze, 1990) do not occur frequently in this area, there is a predominance of smaller linear systems which cause a significant proportion of the damaging wind events. The number of squall lines and bow echos which produced severe winds were equal (21). It is interesting to note, however, that the number of squall lines without severe winds was approximately three times as great as that of bow echos. This supports the large body of research which has found that the bow echo convective structure is inherently prone to strong or severe winds.

As wind driven hail can be an extreme health and property hazard, the frequency of hail associated with these high wind events was also calculated. (It should be noted that the hail reports given here did not necessarily occur at the same time as the high wind report). The frequency of hail within squall lines and bow echoes over the Northern High Plains in these systems is quite low (severe hail reports were approximately one-third as frequent as severe wind reports). However, for supercell and multicell storms with severe winds, the ratio is almost completely reversed. For these two storm types, hail was twice as frequent as the severe winds.

5. SUMMARY AND CONCLUSIONS

The analyses presented herein indicate that convectively generated severe winds over the Northern High Plains have diurnal variations and relative frequencies which are significantly different than other areas of the Plains east of the Rocky Mountains, and from the United States as a whole. While some of this difference can be attributed to the proximity of this area to the elevated terrain bordering on its western side, further analyses will be necessary to discriminate the pertinent factors responsible this behavior.

Analyses of the severe wind events as a function of storm structure indicated that the majority came from organized linear convective systems (squall lines or bow echos), with a smaller percentage from multicellular convection. Several of the most severe wind events were associated with supercell thunderstorms, where the strong winds were combined with large hail, producing devastating results (e.g., Klimowski *et al.* 1998).

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