17A.5 DEVELOPMENT OF A RADAR BASED THUNDERSTORM CLIMATOLOGY FOR NORTH DAKOTA

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1. INTRODUCTION

Traditionally thunderstorm climatologies have been derived using either surface station reports of thunderstorms, e.g. Changnon (1988a,1988b), or severe wind and damage reports from the National Climatic Data Centre's (NCDC) storm events database, e.g. Kelly *et al*. (1985). Both approaches have their limitations, and in particular the fact that the use of either of these two data sources tends to lead to results that are biased towards either the surface station locations or areas where there are concentrations of population, such as large urbanized centres. A further limitation associated with the use of these two data sources is that while it is possible to broadly define the area affected by thunderstorms on any given day, the ability to track thunderstorm movements in both time and space is extremely limited because of the coarse spatial and temporal resolution of the underlying data.

As an alternative to using surface station thunderstorm reports or the NCDC's storm events database a number of authors have examined the possibility of using radar data to develop thunderstorm climatologies. Bellon and Zawadzki (2003) developed a climatology of convectively driven severe weather events for southern Quebec for the period 1993-2001 using Doppler weather radar data from the J.S. Marshall Radar Observatory at McGill University. Similarly Klimowski *et al*. (2003) used a combination of radar data and severe wind reports to identify the convective systems responsible for severe winds over the northern High Plains in the period 1996-1999.

In this paper, as part of a larger project examining the effects of high intensity winds (HIW) on transmission lines, we consider the use of WSR-88D radar data to develop a thunderstorm climatology for the state of North Dakota that allows both temporal and spatial variations in thunderstorm activity in the region to be explored. Ultimately the intention is to use the resulting climatology to derive statistical distributions for parameters such as the translation speed, heading and intensity of thunderstorms for use in a stochastic thunderstorm risk model for the area that could be used to assess the risk to transmission line networks due to high winds associated with thunderstorms.

2. DATA

Level III storm structure (NSS) files for the three WSR-88D radar stations (Bismarck (KBIS), Grand Forks (KMVX) and Minot AFB (KMBX)) located in North Dakota were obtained from the NCDC. Data for the first two stations was available back to the mid-1990's, while data for the latter station was only available from 2001 onwards. In an effort to reduce the amount of data that needed to be processed only data from the period March to September of each year was considered on the basis of surface station thunderstorm reports which showed that this was the peak time for thunderstorm activity in the region.

An initial examination of the data showed that the number of storm cells identified from 2002 onwards at all three radar stations was significantly higher than the number of storm cells observed prior to this date. The reasons for the significant increase in storm cell numbers from 2002 onwards are unclear, although it was also noted that prior to 2002 files were available on a roughly 15 minute cycle, while after this date the time difference between successive files dropped to around 5-6 minutes. As a result a decision was made to concentrate on data for the period 2002-2006, and to exclude data earlier than this from our analysis. In spite of these restrictions there are still a number of months of missing data in this time period for both KBIS (March-April 2006) and KMBX (April-July 2004), while KMVX is missing data for the entire year of 2002.

The storm structure files themselves are derived from the base Level II data using the storm cell identification and tracking (SCIT) algorithm described by Johnson *et al*.(1998). This algorithm identifies 3-D reflectivity-based storm cells by first indentifying 2-D segments of reflectivity exceeding a particular reflectivity threshold for each elevation scan before assembling the 2-D segments into 3-D storm cells. Output from the algorithm includes the range and azimuth of each identified storm cell relative to the radar site, the latitude and longitude of the storm cell's centroid, the height of the maximum reflectivity associated with the storm cell, the top and base heights of the storm cell and the vertically integrated liquid (VIL). The SCIT algorithm has a number of limitations, one of the more pertinent ones for the work described in this paper being the lack of storm cells identified at longer ranges from the radar because of the height of the lowest elevation scan above ground at these distances.

The native format Level III storm structure files were first converted into ArcGIS shape files using the Java NEXRAD Data Exporter described by Ansari and Del Greco (2005). At the time that the storm cells are first identified they are allocated a storm cell ID, composed of a letter-number combination, to identify them. This gives a possible 260 letter-number combinations before storm cell IDs must be recycled. Since we want to be able to uniquely identify storm cells within the database, the first time a particular storm cell ID was used a unique storm cell ID, made up from a combination of the date/time stamp at which the storm cell ID was first used and the storm cell ID itself, was allocated to the storm cell. This

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unique storm cell ID was then allocated to all storm cells bearing the same original storm cell ID at successive time-steps, until the original storm cell ID was no longer found. At this point it was assumed that the storm cell had dissipated, and that the next time the storm cell ID was used it was a completely new storm cell at which point a new unique storm cell ID was created and the cycle repeated. Following the allocation of unique storm cell IDs at each time-step the individual shape files were then combined to form a single storm cell database for the period 2002-2006 for each of the three radar stations considered.

Although some uncertainty must be attached to the decision to use the operationally produced storm structure files, we justify the decision to use this data on the grounds that the purpose of this study is to explore the use of radar data to develop a thunderstorm climatology as an alternative to traditional means of doing so. In an ideal world we would apply the SCIT algorithm in a consistent fashion to the base Level II data from all three radar stations considered ourselves. This would, however, require computational resources that are beyond the scope of this project, not to mention the time and effort required to process the data itself. For this reason we chose to use the operationally produced storm structure files. In spite of this decision the processing of the downloaded Level III storm structure files and creation of the databases still took some considerable time.

In order to provide a comparison for the radar-derived climatology surface data was obtained from the NCDC's Integrated Surface Database for eight ASOS stations located in North Dakota. Thunderstorm reports were extracted from the surface data records, as were any peak wind reports (gust wind speeds exceeding 25 kts (12.9 m/s) that occurred with an hour of the reported thunderstorm beginning and end times using the ASOS-WX software described by Lombardo and Main (2006).

3. RESULTS

As an initial check on the resulting storm cell databases the average number of days with storm cells per year was calculated for the period 2002-2006, and then compared to the average number of thunderstorm days per year derived from surface station thunderstorm reports. For the three radar stations considered the average number of storm cell days per year were found to be 30 (KBIS), 21 (KMVX) and 19 (KMBX) respectively. The corresponding average number of thunderstorm days per year from surface station thunderstorm reports varied from 35 to 19 for the eight ASOS stations considered in North Dakota, with an overall average across all eight stations of 29 thunderstorm days per year. There was good correspondence between the number of storm cell days derived from the radar data and thunderstorm days based on surface station thunderstorm reports at KBIS (30 and 29 respectively) where the radar and ASOS stations are more or less co-located. The average number of storm cell days per year at the other two radar stations considered were between 60 and 80% of the value of the average number of thunderstorm days reported at the closest surface station, which would suggest that the data contained in the storm structure files for these two radar stations is not completely representative of thunderstorm activity in the region.

An examination of the monthly distribution of storm cell numbers for the period March to September of each year suggests that thunderstorm activity peaks over a three month period from June to August of each year, with peak activity occurring in July in the southern part of North Dakota, and June in the northern part of the state. Figure 1 shows the distribution of storm cells by month for KBIS, very similar plots being obtained for the other two radar stations considered. Similar trends were noted in the surface data with thunderstorm activity peaking over the same three month period, with peak activity at individual surface stations occurring in either June or July. In considering the monthly distribution of convectively generated severe wind reports over the northern High Plains Klimowski *et al*. (2003) found a similar peak in activity in July, somewhat later than the peak in thunderstorm activity seen further south in the Central Plains-Mid-Mississippi Valley region.

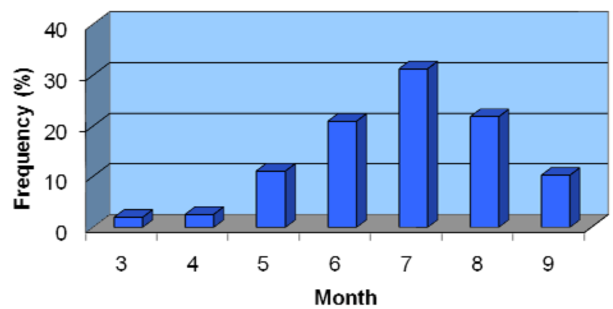

Figure 1: Distribution of storm cells by month for KBIS

The annual diurnal distribution of storm cell numbers at KBIS, as shown in Fig. 2, shows a clear minimum at around 10:00-11:00 am CDT, with peak storm cell numbers occurring in the late afternoon/early evening. This pattern is consistent with the diurnal pattern exhibited by both the overall number of surface-based thunderstorm reports and those surface thunderstorm reports associated with a peak wind report, both of which show a clear minimum in activity at the same time. When considered on a month by month basis clear seasonal variations can be seen in the diurnal pattern, with storm cell activity peaking mid-morning in March, before a late-afternoon peak in activity emerges in May and continues through to August before starting to disappear again in September. Similar patterns are visible in the surface station data with a clear trend for activity to peak in the late afternoon/early evening.

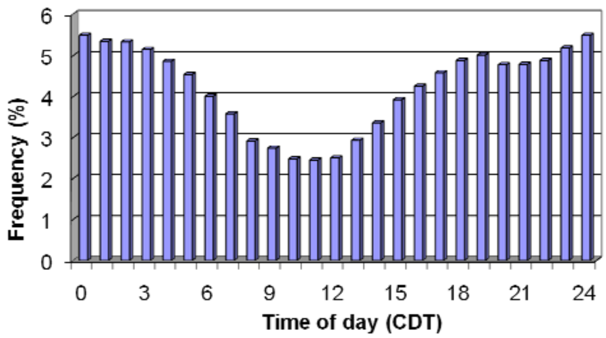

Figure 2: Diurnal distribution of storm cells for KBIS

In considering the life cycle of individual storm cells the average lifetime of a storm cell was found to be 23.6 minutes. This number is heavily influenced by the large number of short-lived storm cells with durations significantly less than this value, although one storm cell was tracked for over eight hours at one of the radar stations considered. It was found that 24% of all storm cells considered lasted longer than 30 minutes, while 8% lasted longer than 60 minutes. The average lifetime of a storm cell shows very little variation from month to month, although an examination of the diurnal variation of storm cell duration from month to month does show a clear trend for longer lasting storm cells in the afternoon for the months of June, July and August.

Not surprisingly longer lasting storm cells tended to have higher maximum reflectivity and VIL values over the lifetime of the storm cell. The results showed that 86% of all storm cells with a maximum reflectivity over the lifetime of the storm cell lying between 30 and 50 dBz had a duration of less than 30 minutes, while only 44% of those storm cells with a maximum reflectivity exceeding 55 dBz lasted less than 30 minutes. These numbers are very similar to those reported by MacKeen *et al*. (1999) in their study of reflectivity derived thunderstorm parameters applied to the forecasting of storm longevity.

The average distance travelled by a storm cell over its lifetime was found to be 21.8 km, with a tendency towards slightly longer storm cell track lengths in March and September, and commensurately higher forward speeds in these two months. In the intervening months average forward speeds were of the order of 55-60 km/hr, with relatively tight clustering around these values. In contrast, the average forward speed in March was found to be of the order of 75 km/hr, with individual values distributed much more broadly around this value.

The average direction of travel for storm cells was found to show a clear seasonal variation, as shown in Fig. 3. Somewhat surprisingly the predominant direction of travel for storm cells observed in March was found to be in a westerly direction for two of the radar stations and northerly for the other. From April through to June storm tracks become increasingly organized with an apparent initial tendency to travel in a north-easterly direction. By July the storm tracks are very well organized and there is a clear tendency for storm cells to travel in an easterly direction. The storm cell tracks continue to remain very well organized in August and September with the preferred direction of travel swinging back to the north. Overall, the general trend for storm cells to travel in a north-easterly or easterly direction in this region agree well with the results of Klimowski *et al*. (2003), who found similar results when examining the tracks of high-wind producing severe convective events over the northern High Plains.

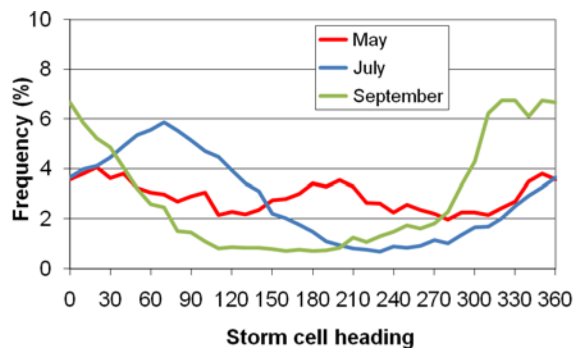

Figure 3: Distribution of storm cell headings by month for KBIS

Using the maximum reflectivity of the storm cell over its lifetime as a measure of intensity, the average storm cell intensity was found to increase slightly from March to the months of July and August, before decreasing again in September. The results suggest that although storm cell activity peaks in June or July, late season storms tend to be on average slightly more intense. The diurnal variation of intensity was found to show a slight increase in the late afternoon. Using the average peak wind speed associated with surface station thunderstorm reports as a surface-based measure of thunderstorm intensity, a very similar diurnal trend was observed in the surface data. When considering severe wind reports (gust wind speeds in excess of 50 kts (25.8 m/s)) however, a very clear diurnal trend emerged with the majority of severe wind reports only occurring in the evening or early morning. Since one of the goals of the work described in this paper is to develop a stochastic thunderstorm risk model for the prediction of high surface wind speeds and their effects on transmission lines, it is clear that additional information is required to supplement the maximum reflectivity as a predictor of high wind speeds at the surface.

Although the hope was that by using radar data more insight into the spatial variability of thunderstorms in North Dakota could be obtained, the results obtained were somewhat inconclusive. One of the major issues is that storm cells move in both space and time and as they do so they are often within range of two or more radars. Figure 4 shows a snapshot of the storm cells identified within a 1-minute window on 26 June, 2005 by all three radar stations considered. It is clear that several of the storm cells have been identified by multiple radars more or less simultaneously, while others have only been identified by a single radar. Closer inspection of the storm cell parameters for those storm cells identified by more than one radar shows that quite different values can be obtained for the same storm cell by different radars depending on the location of the storm cell relative to the radar. This leads to a number of problems when trying to create a storm cell database covering a region larger than the region covered by an individual radar station by combining data from two or more radars. The first is identifying storm cells common to the individual radar station databases being combined so storm cells are not double-counted, while the second is then deciding what the appropriate storm cell parameters to use are. A preferred approach to the creation of a regional storm cell database would be to mosaic the base Level II data from a number of different radar stations into a single image before then applying the SCIT algorithm.

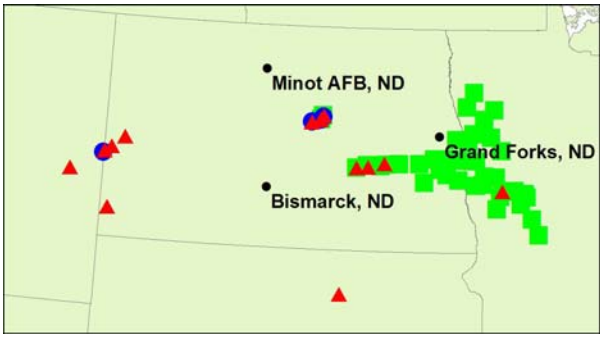

Figure 4: Storm cells detected by KBIS (red triangles), KMBX (blue circles) and KMVX (green squares) between 19:11:47 and 19:12:36 GMT on 26 June 2005.

The general impression obtained from consideration of the spatial characteristics of a number of parameters such as the number of storm cells observed per county and the average maximum reflectivity by county was that the resulting patterns tended to be influenced by the location of the county relative to the radar station being considered. This was especially apparent when considering the average maximum reflectivity by county, where it was obvious that the radar was only picking up the most intense storm cells at longer ranges.

4. CONCLUSIONS

An initial analysis of a set of storm cell databases created using Level III storm structure files for three WSR-88D radar stations in North Dakota for the period 2002-2006 showed very clear seasonal and diurnal variations in the observed storm cell characteristics, including the frequency, duration, intensity as measured by the maximum reflectivity, and heading. Comparison with surface data from eight ASOS stations in North Dakota over the same time period showed a good match with those seasonal and diurnal parameters that were directly comparable such as thunderstorm frequency. The results suggest that radar data can successfully be used as an alternative to more traditional data sources to create a thunderstorm climatology for a given region.

Attempts to explore the spatial characteristics of thunderstorms in North Dakota using the resulting storm cell databases were somewhat inconclusive and require further study to determine how much of the resulting variability is due to limitations in the radar data itself and how much is due to the underlying climatology of thunderstorms in this area.

5. REFERENCES

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