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A GIS-BASED ANALYSIS OF SUPERCELL AND SQUALL LINE OCCURRENCE ACROSS OKLAHOMA

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1. INTRODUCTION

Meteorological phenomena are inherently geographic by nature. This does not mean that geography controls the occurrence of such events, but rather is the setting for an array of various meteorological conditions which oftentimes exhibit preferred regions of development and occurrence. In terms of storms, Oklahoma is an excellent example of a region that experiences a high frequency of severe storms. Research and observation have shown that severe storms occur primarily during the spring time months of April, May, and June with a secondary fall season in September and October (Kelly et al. 1985, Brooks et al. 2000). While the seasonal geographic changes of storm occurrence are well documented for many regions, limited work has been done to investigate the contribution of specific storm modes to regional storm climatologies.

Geographic information systems (GIS) have traditionally been a tool used for work involving topics such as urban development, site selection applications, or social studies. More recently, GIS have experienced an increased use in meteorological applications including river forecast center datasets, historical hurricane viewer online, and the National Climatic Data Center's Nexrad Radar Java Viewer. The use of GIS within the research sector of meteorology has been quite limited thus far, but several studies identify potential applications. Yuan et al. 2003 and Yuan et al. 2004 proposed a database framework for representing weather features in both a spatial and temporal context. It appears that GIS is a suitable method for establishing historical datasets due its ability to link the spatial aspects of weather features to attribute information in a database format.

This study examines the contribution of two of the most highly prolific storm report producing modes across Oklahoma: supercell and squall line storms. Further, GIS is utilized as a display, analysis, and database development tool to evaluate its use within the research field of meteorology. Results from 1994-2001 are presented herein with an emphasis placed on overall frequency and average storm motions.

2. EVENTS

Storm report data from the Storm Prediction Center's (SPC) storm report database were analyzed across Oklahoma for the period 1994-2001 to build a list of candidate events. Significant severe weather events were defined as any single convective day (1200 UTC – 1159 UTC) when (a) the total combined severe storm reports (hail and wind) was greater than or equal to 20 or (b) any tornado was reported in Oklahoma. The criteria were selected to yield mainly organized severe weather events.

Using this approach more than 250 severe weather events were identified across Oklahoma from 1994 to 2001. The distribution of events by month show the typical peak in severe weather activity in the springtime months of April, May, and June with a significant drop off in activity beginning in July (Figure 1). On an annual timescale, there is notable variability in severe storm occurrence from year to year with 1999 being the most active of the study period (Figure 2).

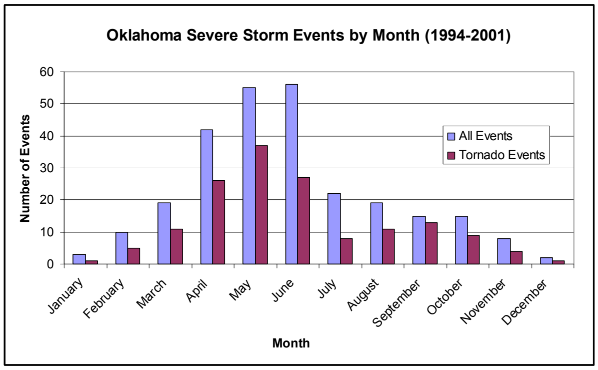

Figure 1. Monthly frequency of severe storm events across Oklahoma from 1994-2001 for all events (blue) and events associated with a tornado report (purple).

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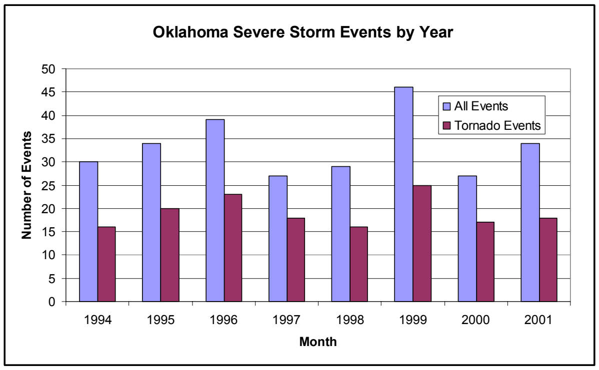

Figure 2. Annual frequency of severe storm events in Oklahoma from 1994 to 2001 for all events (blue) and tornado events (purple).

3. METHODOLOGY

3.1 *Radar Data Analysis and Storm Criteria*

Two main software packages were used to analyze radar data for the 8 year climatology. For Level-II data a program entitled GRLevel2 (available at http://www.grlevelx.com/) was used to view and track both supercells and squalls lines. Level-III data was viewed and analyzed via NCDC's online Java NEXRAD viewer (available at http://www.ncdc.noaa.gov/oa/radar/jnx/jnv.jnlp).

Several criteria were developed to identify supercell storms and squall lines for the climatology. Supercells were required to contain a mesocyclone and persist for 30 minutes or more. A velocity couplet of at least 15 knots in the lowest several radar tilts (0.5, 1.5, and 2.5 degrees) was used to identify mesocyclones. This threshold was selected to capture the full spectrum of supercell sizes including high precipitation, classic, low precipitation, anticyclonic left split, and mini-supercells. Radar features discussed in Moller et al. (1994) such as deviant motion, hook echoes, or bounded weak echo regions (BWER) were used to assist in supercell identification and tracking. In addition, initiation was based on the first occurrence of a 40 dBz echo and termination was based on loss of a mesocyclone and supercell characteristics. Supercells were tracked following the region within the forward flank just north of the storm inflow. This region typically had among the highest reflectivity values due to the abundance of large hydrometeors which occur just north of the main storm updraft. Figure 3 illustrates an example of supercell tracking for the May 3, 1999 tornado outbreak.

The criteria for squall lines was taken similarly to Bluestein et al. (1985) and Klimowski et al. (2003). For this study squall lines were required to have a linear organization, have a length to width ratio of at least 5:1, have a region of 40 dBz or greater reflectivity 50 km in length, and persist for 30 minutes or longer. Initiation was taken to be the first time at which all the criteria were met and termination was the time at which the line became smaller than 50 km or the length to width ratio became smaller than 5:1. Squall lines were tracked using a central feature which indicated the motion of the line as well as two end points which determined the extent of the squall line swath. Figure 4 shows an example of squall line tracking as displayed in ArcMap.

3.2 *Compiling the GIS Storm Database*

With the use of the storm criteria, supercell and squall line locations were geocoded for the more than 250 events illustrated in Figures 1 and 2. For each supercell storm identified, a series of attribute data were recorded for each point providing information about the latitude, longitude, storm ID (cell or supercell), date, time, reflectivity, radar used, azimuth, range, height, and miscellaneous information at roughly 15 minute intervals. These data were then imported into ArcGIS as a series of point features. Next, using a 'points to line vector' data tool, the series of points for each storm were then converted into a storm track vector which took into account the chronological order of the points. The final result was a total of 742 supercell tracks in a GIS format that included both spatial and attribute (text table) information about where and when every storm occurred.

A similar process was carried out in creating the squall line storm portion of the storm database. In addition to all the information recorded for supercells, squall line data also included the latitude and longitude coordinates at each of the end points of the line. Data for squall lines were collected at roughly 30 minute intervals (or shorter if the line changed dramatically) and these series of points were imported into ArcGIS. Points were transferred into a set of three lines for each squall line, one representing the central part of the line including its direction and two representing the end points of the line. Next, two more lines were edited into ArcGIS to help close the perimeter of the squall line swath. To finalize the squall line features, a 'line features to polygon' tool was implemented to create a single polygon element. This process developed a total of 358 separate squall line polygon swaths across Oklahoma.

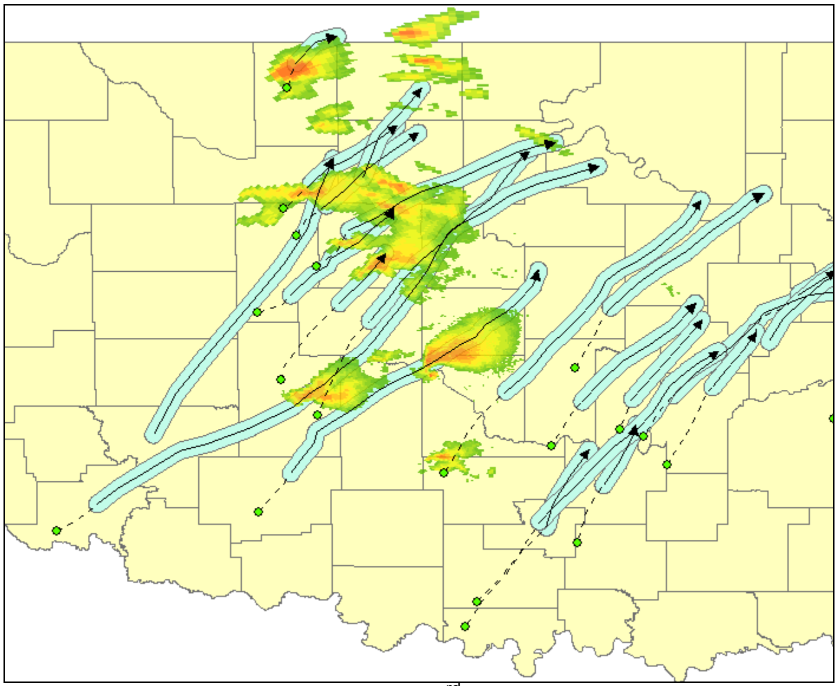

Figure 3. Example supercell tracking from the May 3rd, 1999 event. Image includes KTLX radar base reflectivity from 00:07:25 UTC on 5/4/1999 with supercell initiation points (green circles), cell tracks (dashed lines), supercell tracks (black vectors), and storm swaths 10 km wide (blue polygons) overlaid for the entire May 3rd event.

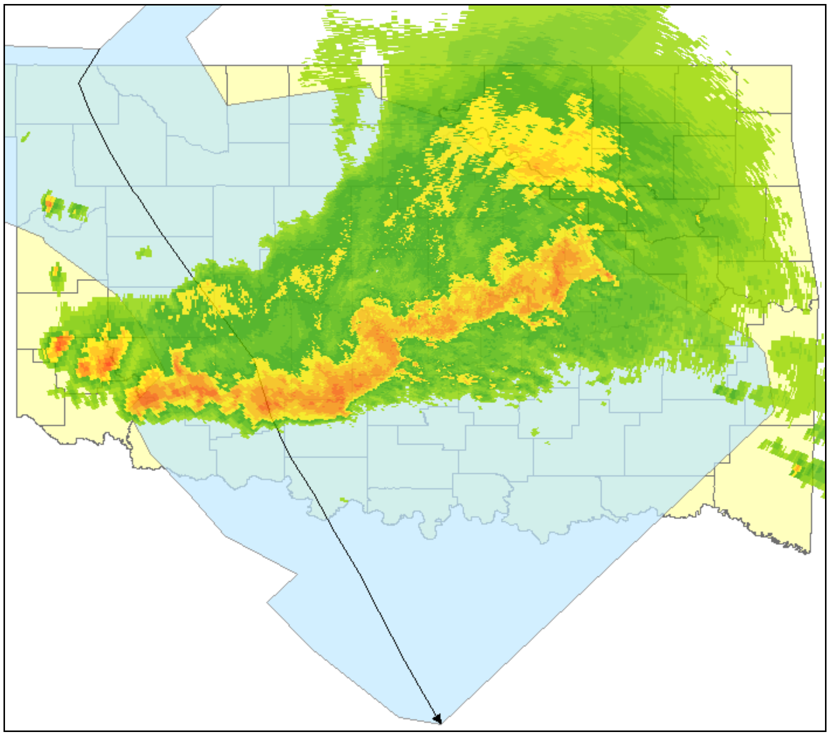

Figure 4. Example squall line tracking from the May 27, 2001 event. Image includes KTLX radar base reflectivity from 03:53:34 UTC on 5/28/2001 with the squall line swath polygon and storm track vector shown. The swath polygon denotes the area swept out by the squall line and is generated from the endpoints identified in the analysis.

4. RESULTS AND GIS ANALYSIS

During the period of 1994-2001, 742 supercells and 358 squall lines were identified across Oklahoma from radar sites both within and near the state. This equates to a yearly average of nearly 93 supercells and approximately 45 squall lines annually. While the storms identified do not represent all supercells and squall lines to occur during the 8 year period, they do represent storms observed in relatively organized events in which 20 or more storm reports or any tornado report were observed. Figure 5 illustrates the cumulative monthly frequencies of each storm type for all months and shows that both storm types are most common in April through June with a secondary period of activity in October.

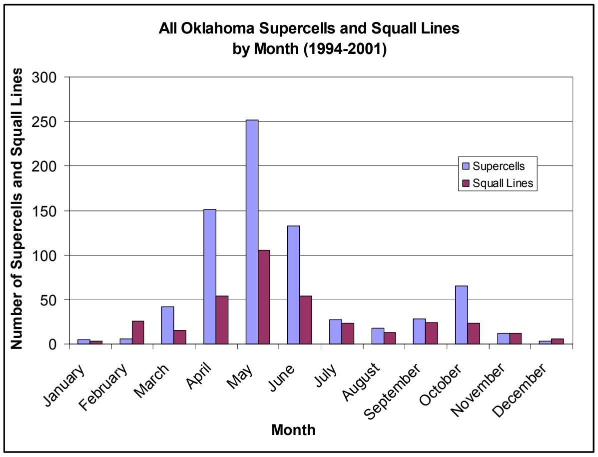

Figure 5. Cumulative monthly frequencies of supercells (blue) and squall lines (purple) across Oklahoma from 1994-2001.

4.1 *GIS Analysis Setup*

Using the developed storm database, a series of GIS analyses were carried out to determine the spatial characteristics of supercell and squall line storms across Oklahoma. To facilitate several of the overlay analyses that were conducted, a grid of equally sized 0.25 by 0.25 decimal degree cells (approximate 28 km by 23 km) was established across the state. Each grid cell represents the number of storm swaths that occurred within roughly 12.5 km of a point thus providing high resolution storm frequency information for all locations across Oklahoma. Figure 6 illustrates the grid of cells developed for the frequency analysis as created in ArcGIS.

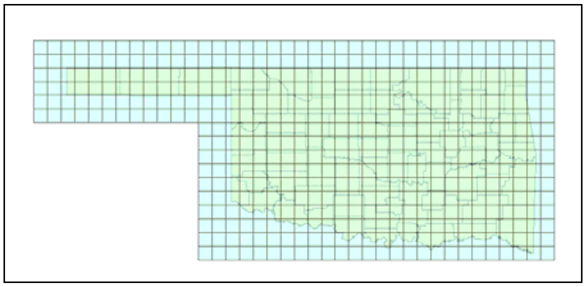

Figure 6. Array of 0.25 by 0.25 decimal degree cells overlaid on the state map of Oklahoma. A total of 488 grid cells covers the body of Oklahoma, the borders, and the neighboring regions.

4.2 *GIS Analysis: Supercell Tracks*

Using the supercell storm tracks dataset, storms were buffered at 5 km on either side of the tracks to develop supercell swaths. In future analyses, different buffer distances will be implemented for comparison, however 10 km wide swaths were chosen as a conservative approximation for this study. The swaths were overlaid on the statewide grid and a polygon in polygon tool summed up the number of storms that resided in each cell. The result of the 8 year cumulative summation is shown in Figure 7.

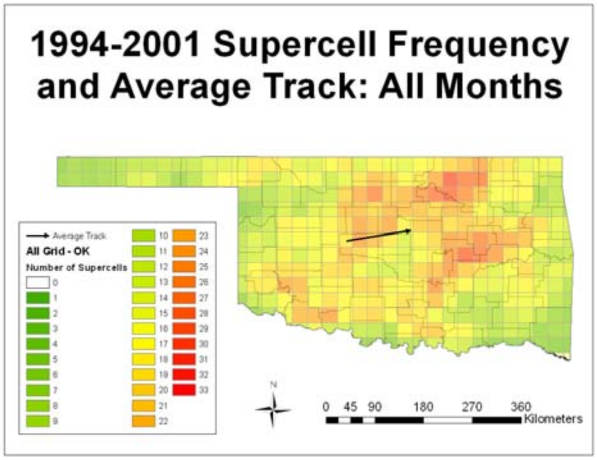

Figure 7. Frequency of supercells across Oklahoma from 1994-2001 (red denotes higher numbers, green denotes fewer). Overlaid is the average storm motion vector for the 8 years (black vector).

The results of Figure 7 are quite revealing. During the period from 1994 to 2001 supercells were most frequent in three main regions: north central, east central, and southwestern Oklahoma. Potential reasons for the distributions include climatological upper and lower level features, land surface impacts, or possibly just coincidence. Also shown in Figure 7 is the mean storm motion calculated for all storms during the time period. Overall, supercells moved from southwest to northeast thus indicating the higher likelihood of such storms within southwest flow regimes at mid to upper levels of the atmosphere.

4.2 *GIS Analysis: Squall Line Swaths*

The same analysis was carried out for the squall line swath dataset to better understand the spatial distribution of organized linear convective systems across Oklahoma. The result of this frequency analysis is shown below in Figure 8.

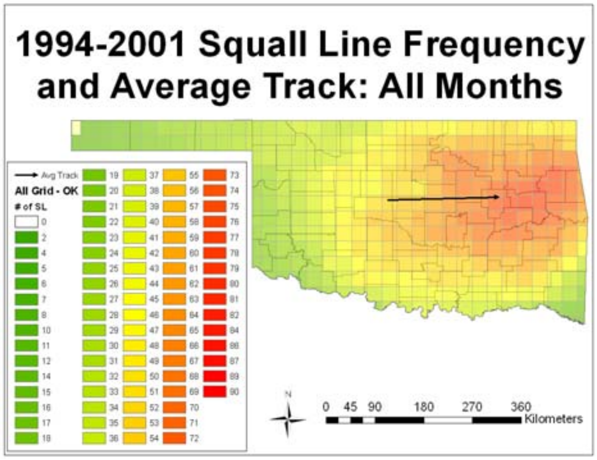

Figure 8. Frequency of squall lines across Oklahoma from 1994-2001 (red denotes higher numbers, green denotes fewer). Overlaid is the average storm vector for the 8 years (black vector).

The results indicate a stronger spatial signal than the supercells exhibited and were found to have a strong preferential placement across the eastern half of Oklahoma. Squall line activity decreased towards the west with the lowest occurrences found in the panhandle. The average squall line motion was from nearly due west to east.

5. CONCLUSIONS AND FUTURE RESEARCH

Analyzing storm tracks and swaths within a GIS environment appear to be an effective way to gather important spatial and attribute information. Through this methodology supercells were found to be most common across primarily the north central into the east central portion of Oklahoma during 1994 to 2001 with an average storm motion from southwest to northeast. Squall line results were quite significant with a very strong occurrence across eastern Oklahoma relative to the rest of the state. Motion was most commonly from west to east.

A multitude of work continues to be completed with this dataset. Current goals are to add supercell and squall line data for 2002 and 2003 to the dataset for further GIS analysis. A series of monthly analyses are also being completed which contain information pertaining to cell initiation locations, storm frequencies, average storm motion vectors, and termination points for cumulative month periods. Other future research includes developing a GIS dataset of hail, wind, and tornado reports in Oklahoma for comparison with the supercell and squall line frequency analyses. Other plans are to make the completed 10 year storm dataset available for public download for use in any other number of research studies which could include: upper air analyses of events, surface analyses using Oklahoma Mesonet data, or radar studies utilizing identified storms within prescribed ranges from radar sites.

6. REFERENCES

Bluestein, H. B and M. H. Jain, 1985: Formation of mesoscale lines of precipitation: severe squall lines in Oklahoma during the spring. *Journal of the Atmospheric Sciences*, **42**, 1711-1732.

Brooks, H.E., M. P. Kay, D. S. Zaras, N. Blais, and B. Flickinger, 2000: Daily probabilities of severe thunderstorms in the United States. *Preprints*, 12th Conference on Applied Climatology, Asheville, North Carolina, American Meteorological Society, 335-338.

Kelly, D. L. and J. T. Schaefer, 1985: Climatology of nontornadic severe thunderstorm events in the United States. *Monthly Weather Review*, **113**, 1997-2014.

Klimowski, B. A., M. J. Bunkers, M. R. Hjelmfelt, J. N. Covert, 2003: Severe convective windstorms over the Northern High Plains of the United States. *Weather and Forecasting*, **18**, 502-519.

Moller, A. R., C. A. Doswell III, M. P. Foster, and G. R. Woodall, 1994: The operational recognition of supercell thunderstorm environments and storm structure. *Weather and Forecasting*, **9**, 327-347.

Yuan, M. and J. McIntosh, 2003: Weather intelligence: A GIS approach to enrich weather databases. *Preprints*, 19th Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology, Long Beach, California, American

Meteorological Society, unpaginated CD-ROM.

Yuan, M. and J. McIntosh, 2004: Data retrieval based on spatiotemporal characteristics of weather events. *Preprints*, 20th Conference on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology, Seattle, Washington, American Meteorological Society, unpaginated CD-ROM.