P4.64 A CLIMATOLOGY OF GREAT PLAINS SUPERCELLS FROM 2005-2007

Cody D. Oppermann and Adam L. Houston

Department of Earth and Atmospheric Sciences
University of Nebraska, Lincoln, Nebraska

1. INTRODUCTION

Every year, supercell thunderstorms impact the central United States, causing damage to life and property. While rare, supercells (SCs) have been observed to produce the most severe weather of any type of thunderstorm (Doswell and Burgess 1993; Moller et al. 1994); therefore, it is necessary to understand the spatiotemporal variability of SCs as well as what percentage of thunderstorms are SCs. Previous SC (Hocker and Basara 2008) and mesocyclone (McGrath et al. 2002) climatologies have been developed, but not on a scale the size of the entire central U.S, nor have they analyzed the percentage of SCs. Doswell (2001) claims that a ratio of SCs to non-SCs is likely on the order of about 10 percent for the entire U.S, but studies are lacking to determine this. Determining the spatial distribution of the percentage of SCs is a critical first step towards solidifying an understanding of the environmental and geographic conditions that are most conducive for SCs. Understanding where SCs are most common can also allow more in-depth analysis of the conditions that support SC development and answer why SCs are most common in these locations. One metric commonly used in SC prediction is the vertical wind shear. As a starting point in looking at the environmental conditions in SC-prone areas, the vertical bulk wind differential (BWD) of their environments is analyzed.

In this work, a SC thunderstorm climatology for the Great Plains (Fig. 1) is developed based on the radar data obtained for this region, including cyclonically- and anticyclonically-rotating SCs. The spatiotemporal distribution of all thunderstorms is known using the Thunderstorm Observation by Radar algorithm (ThOR; Lahowetz et al. 2010) as well as a total number for the Great Plains; therefore, the percentage of SCs can be determined spatially and quantitatively. Also, as mentioned above, the average BWD for each track that intersects a high and low percentage area is analyzed.

2. METHODOLOGY

The thunderstorm identification and tracking technique developed for this work is based on the technique developed by Barjenbruch (2009). This work consists of combining reflectivity, velocity, and spectrum width (for quality control) radar data from more than 40 radars across the central U.S., National Lightning Detection Network lightning strike data, and NARR storm motion data for the years 2005-2007. Thunderstorm events are identified based on lightning strike occurrences. The corresponding radar data surrounding these lightning strikes in space and time are collected and merged together using the Warning Decision Support System – Integrated Information's (WDSS-II; Lakshmanan et al. 2007) "w2merger" algorithm. Next, thunderstorm clusters are identified from this merged radar data using WDSS-II's "w2segmotioll" algorithm. Before doing this however, to track only convective elements of thunderstorms and thus improve w2segmotionll's identification performance, stratiform precipitation is identified and filtered out by lowering the reflectivity values in these areas using simple horizontal and vertical reflectivity gradient thresholds to keep w2segmotionll from identifying these areas (Fig. 2). Lastly, the ThOR algorithm tracks these thunderstorm clusters' centroids by using NARR storm motion estimates to identify a "best guess" position of the centroid at a subsequent time and locate other centroids near this best guess position, if any, to make storm tracks. Finally, the lightning data is then attributed to the tracks to identify thunderstorm tracks.

Next, the Mesocyclone Detection Algorithm (MDA; Stumpf et al. 1998) is used on reflectivity and velocity data to identify the location of mesocyclones for each volume scan. These mesocyclones are then attributed to the ThOR-identified thunderstorm tracks and its cluster centroids if it is nearby in space and time, using a search radius around the centroids. If there are no MDA detections within the search radius, the

* *Corresponding author address:* Cody D. Oppermann, Department of Earth and Atmospheric Sciences, University of Nebraska, 120 Bessey Hall, Lincoln, NE 68588
E-mail: c.oppermann@huskers.unl.edu

cluster receives no mesocyclone association. If there are multiple candidate detections within the search radius, the closest detection is selected. If a segment of a thunderstorm track has 30 consecutive minutes of a mesocyclone associated with it (one cluster can be skipped to determine continuity as long as a mesocyclone is associated with a cluster at the time previous and the time after; Thompson et al. 2003; Barjenbruch 2009), then it is deemed a SC segment for spatial analysis and the whole tracked is deemed a SC for quantitative analysis (Fig. 3). Cyclonic mesocyclones are first attributed to the ThOR tracks and cyclonic SCs are identified. After the cyclonic mesocyclones have been attributed to ThOR tracks, the anticyclonic detections are attributed to the remaining ThOR tracks.

Before attribution, however, all MDA detections with a “strength rank” of zero, detections between 147 and 147.12 km (erroneous detections due to range folding), low, deep detections at the beginning of SC segments (that may have been associated with mesovortices), and all low, shallow detections, are filtered out. With the SCs identified, the SC tracks and ThOR tracks are analyzed in ArcGIS (using the Line Density tool with a grid size of 10 km x 10 km and the tool’s default search radius for all thunderstorm tracks across the area of 54 km) to identify the spatial distribution of SC thunderstorms as well as the spatial distribution of the percentage of SCs.

Finally, after the spatial distribution of the percentage of SCs has been analyzed, a high percentage and low percentage area with similar thunderstorm track densities are identified. Using RUC-20 analysis data, zero-to-one- and six- km BWD values are identified for each cluster centroid (for the nearest grid point with the largest MUCAPE) along each track that intersects these areas. The average BWD for each track is computed and the areas are compared.

3. RESULTS

Following Barjenbruch (2009), different search radii around thunderstorm clusters looking for MDA detections were tested to find the most effective search radius. Barjenbruch, who used the Storm Cell Identification and Tracking algorithm (SCIT, Johnson et al. 1998; the SCIT centroids are biased towards max reflectivity whereas the w2segmotioll algorithm centroids are not), found a search radius of 12 km to be effective. In this work, the aggregate ratio of SCs to non-SCs for 2005-2007, total SC segment duration, and mean SC segment duration were tested. Between the test values of 10 and 15 km, the ratio and total duration increase relatively linearly with increasing search radius, but the mean duration appears to level off at about 13 km (Fig. 4). Based on this result, the region of search radii Barjenbruch recommended (11-13 km), and possibly since w2segmotionll clusters are farther away from the MDA detections than would be SCIT centroids, a search radius of 13 km is chosen.

Analysis of the spatial distribution of the SCs shows that there is a peak in cyclonic SCs along the Oklahoma/Arkansas border (Fig. 5) and a peak in anticyclonic SCs in southeastern Kansas (Fig. 6). Quantitatively, after tracks that were completely outside of 230 km from any of the radars used in this work were removed (since MDA detections can only be identified within 230 km of a radar), a percentage of 6.7 percent was found for cyclonic SCs and 1.3 percent for anticyclonic SCs. The aggregate percentage of all SCs was found to be 7.9 percent. Since cyclonic SCs outweigh anticyclonic SCs by more than six to one, the peak in all SCs is also located over the Oklahoma/Arkansas border (Fig. 7).

After dividing the spatial distribution of SCs by the spatial distribution of all ThOR-identified thunderstorm tracks (Fig. 8), analysis of the spatial distribution of the percentage of SCs shows that northeastern Colorado observes the highest percentage (Fig. 9). The Oklahoma/Kansas border may experience SCs frequently, but experience non-SC thunderstorms much more frequently. Northeastern Colorado experiences relatively fewer thunderstorms altogether, but much more of them are SCs. Past observations agree with this observation since it tends to be observed that SCs initiate in the western Great Plains then grow upscale into multiple storms as they travel eastward. This matches the spatial distribution results that are observed in this work.

In 2005, 175,465 ThOR tracks were identified and 5.4 percent of them were SCs. There were 197,083 thunderstorm tracks in 2006; 7.15 percent of them were SCs. 2007 saw the least thunderstorms with 174,446 tracks, but 11.3 percent of them were SCs. All of these statistics are shown in Table 1.

For the analysis of the BWD in high and low percentage areas, two areas with relatively similar thunderstorm track densities were selected. These areas are the Texas panhandle, which experiences a relatively higher percentage of SCs, and the North Dakota/Minnesota/Iowa/Nebraska area (Fig. 9). The analysis of these tracks shows that the mean BWD in the low percentage region is higher (11.03 m s^{-1} for the 0-1 km BWD and 17.84 m s^{-1} for the 0-6 km BWD) than those tracks in the high percentage region (8.12 m s^{-1} and 14.10 m s^{-1}, respectively). These differences are statistically significant at the 95 percent confidence level, all of which is unexpected. It is important to note that in this analysis, ALL tracks that intersected in this area are included. BWD values from a track that started in New Mexico and ended just inside this area, for example, would be included. Regardless, future analysis will be completed, such as probability of exceedance analysis for different BWD thresholds. It is hypothesized that for higher BWD values, the higher percentage area will see a higher probability of exceedance.

4. CONCLUDING REMARKS & FUTURE WORK

In this work, a cyclonic and anticyclonic SC thunderstorm climatology was developed using the ThOR algorithm and the MDA algorithm and associating the locations of mesocyclones with thunderstorm tracks. A maxima in cyclonic (anticyclonic) SCs over the time period was observed over the Arkansas/Oklahoma border (southeastern Kansas). The highest percentage of SCs was observed over northeastern Colorado. This percentage was found to be 7.9 percent over the Great Plains over 2005-2007. Also, the low percentage region was found to have generally higher BWD values than the high percentage region, but future analysis will be performed regarding this.

In this work it is important to note that the w2segmotionll tool performed sub-optimally with non-isolated thunderstorms (see how some clusters are not identified by w2segmotioll in Fig. 2c), but did well with isolated thunderstorms. Also noteworthy is that there appears to be a dependence on mesocyclone detection with radar range as larger peaks in supercells are found near the center of radars. Several studies have implemented ways to mitigate radar range bias in rainfall estimates and tornado shear signatures (Seo et al. 2000; Chumchean et al. 2004; Newman et al. 2011), but a similar mitigation approach was not implemented in this work. However, analysis (not shown in this work) of stronger supercells as determined by the MDA detections' "strength rank" shows less of a dependence on radar range.

Future work involves analyzing the seasonal and diurnal cycle of SCs, as well as their initiation and termination times. Also, the reasoning behind the lower BWD in the higher SC percentage area will be further evaluated by doing a probability of exceedance analysis for different BWD values. Other work could include analyzing the synoptic patterns associated with these years as well as comparing these results to the distribution of storm reports in order to analyze the hypothesis that SCs are the most severe type of thunderstorm.

5. ACKNOWLEDGEMENTS

Funding was provided by the Department of Earth and Atmospheric Sciences (EAS), University of Nebraska – Lincoln. Thanks are extended to current and past members of the EAS's Severe Storms Research Group for their insight as well as Valliappa Lakshmanan for assistance with WDSS-II products.

6. REFERENCES

Barjenbruch, B. L., 2009: A technique for developing an objective climatology of supercell and non-supercell thunderstorms. M.S. thesis, Dept. of Earth and Atmospheric Sciences, University of Nebraska - Lincoln, 70 pp.

Chumchean, S., A. Seed, and A. Sharma, 2004: Application of scaling in radar reflectivity for correcting range-dependent bias in climatological radar rainfall estimates. *J. Atmos. Oceanic Technol.*, **21**, 1545-1556.

Doswell, C. A. III, and D. W. Burgess, 1993: Tornadoes and tornadic storms: A review of conceptual models. *The Tornado: Its Structure, Dynamics, Prediction, and Hazards*, Geophys. Monogr. No. 76, Amer. Geophys. Union, 161-172.

Doswell, C. A., 2001: Severe convective storms - an overview. *Severe Convective Storms, Meteor. Monogr.*, No. 28, Amer. Meteor. Soc., 1-26.

Hocker, J. E., and J. B. Basara, 2008: A geographic information systems–based analysis of supercells across Oklahoma from 1994 to 2003. *J. Appl. Meteor. Climatol.*, **47**, 1518-1538.

Johnson, J. T., P. L. MacKeen, A. Witt, E. D. Mitchell, G. J. Stumpf, M. D. Eilts, and K. W. Thomas, 1998: The Storm Cell Identification and Tracking algorithm: An enhanced WSR-88D algorithm. *Wea. Forecasting*, **13**, 263-276.

Lahowetz, J., A. Houston, G. Limpert, A. Gibbs, and B. L. Barjenbruch, 2010: A technique for developing a US climatology of thunderstorms: The ThOR algorithm. *Proc. 25th Conf. on Severe Local Storms*, Denver, CO, Amer. Meteor. Soc., 82-83.

Lakshmanan, V., T. Smith, G. Stumpf, and K. Hondl, 2007: The Warning Decision Support System-Integrated Information. *Wea. Forecasting*, **22**, 596-612.

McGrath, K. M., T. A. Jones, and J. T. Snow, 2002: Increasing the usefulness of a mesocyclone climatology. Preprints, *21st Conf. on Severe Local Storms*, San Antonio, TX, Amer. Meteor. Soc., 5.4.

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

Newman, J. F., V. Lakshmanan, P. L. Heinselman, T. M. Smith, 2011: Range correction for radar-derived azimuthal shear: applications to a tornado detection algorithm. Preprints, *27th Conference on Interactive Information Processing Systems (IIPS)*, Seattle, WA, Amer. Meteor. Soc., 8B.4.

Seo, D.-J., J. Breidenbach, R. Fulton, D. Miller, and T. O'Bannon, 2000: Real-time adjustment of range-dependent biases in WSR-88D rainfall estimates due to nonuniform vertical profile of Reflectivity. *J. Hydrometeor.*, **1**, 222-240.

Stumpf, G. J., A. Witt, E. D. Mitchell, P. L. Spencer, J. T. Johnson, M. D. Eilts, K. W. Thomas, D. W. Burgess, 1998: The National Severe Storms Laboratory mesocyclone detection algorithm for the WSR-88D. *Wea. Forecasting*, **13**, 304-326.

Thompson, R. L., R. Edwards, J. A. Hart, K. L. Elmore, and P. Markowski, 2003: Close proximity soundings within supercell environments obtained from the Rapid Update Cycle. *Wea. Forecasting*, **18**, 1243-1261.

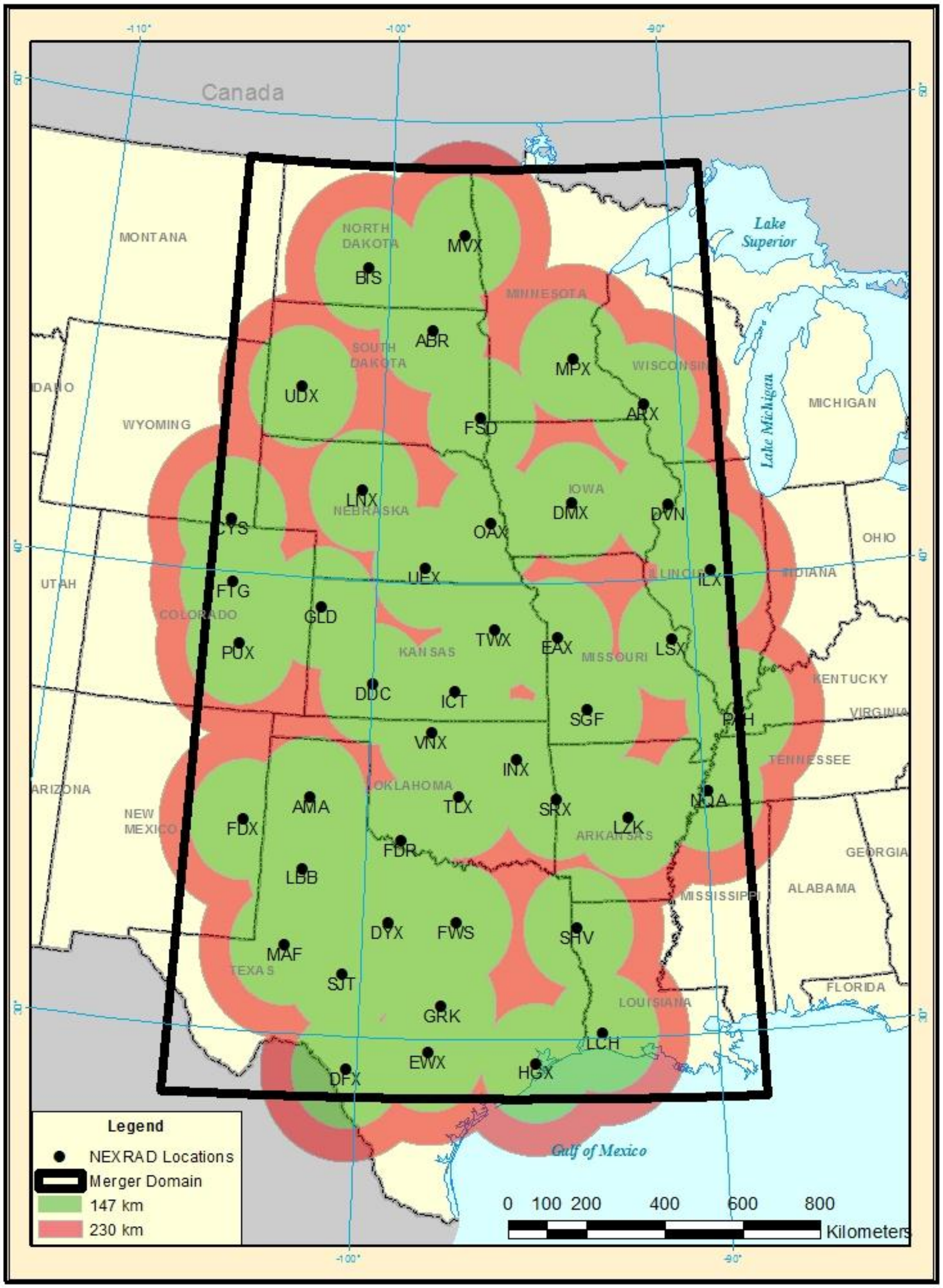

Figure 1: Spatial definition of the Great Plains based on the coverage of the radars used in this project. Note the 147-km and 230-km ranges. The MDA only examines radar data up to 230 kilometers from the radar. The 147-km range has been observed to be a location of spurious MDA detections usually associated with range folding and thus detections at this range have been removed. ThOR tracks can only be detected within the merger domain, thus defining the domain used in this project.

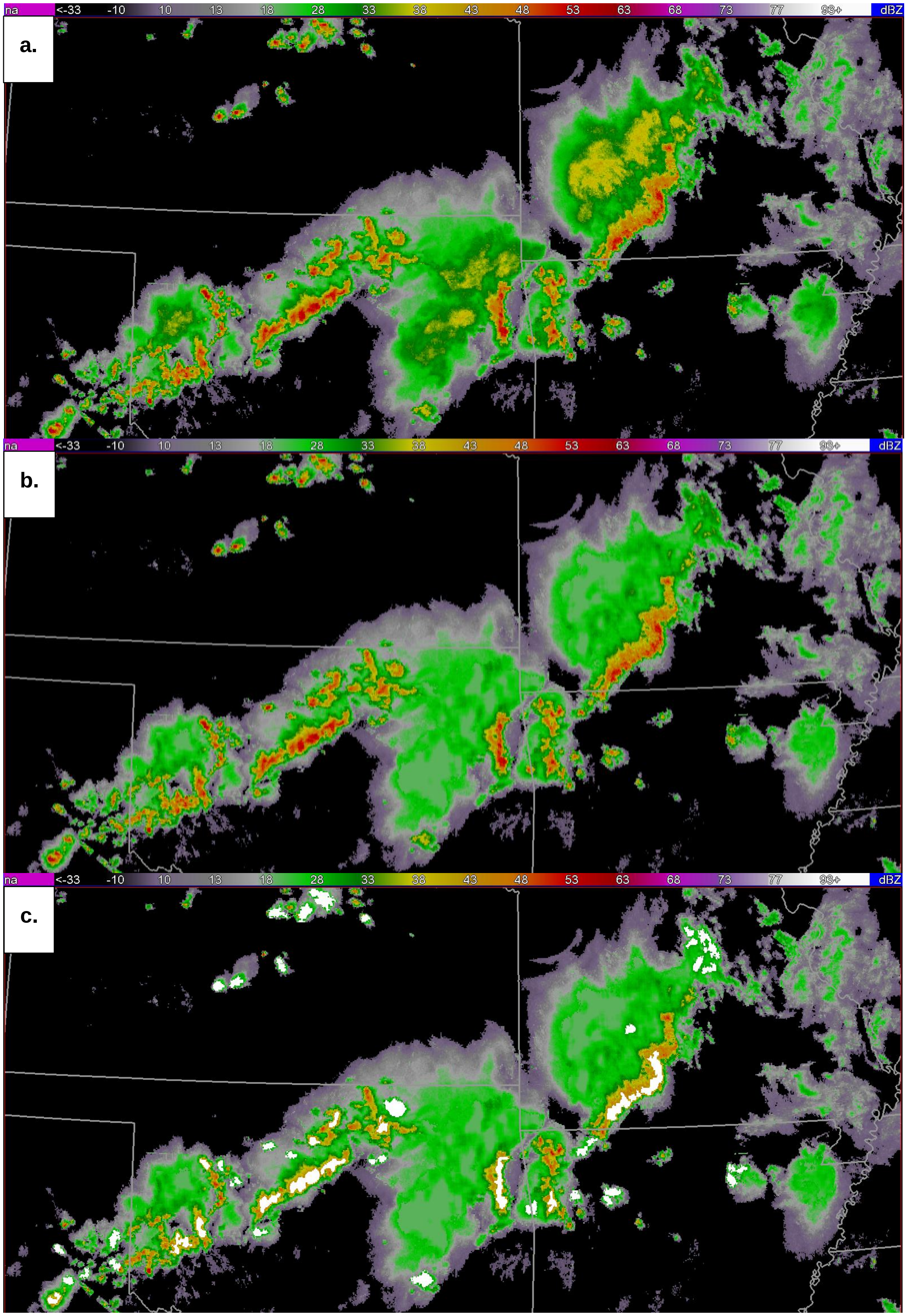

Figure 2: (a) An example merged composite reflectivity mosaic (MCR) on 11 July 2006 produced by w2merger. The time stamp for the image is 00:01:12 UTC. (b) The stratiform-filtered MCR corresponding to (a). (c) The w2segmotionll-identified clusters corresponding to (b).

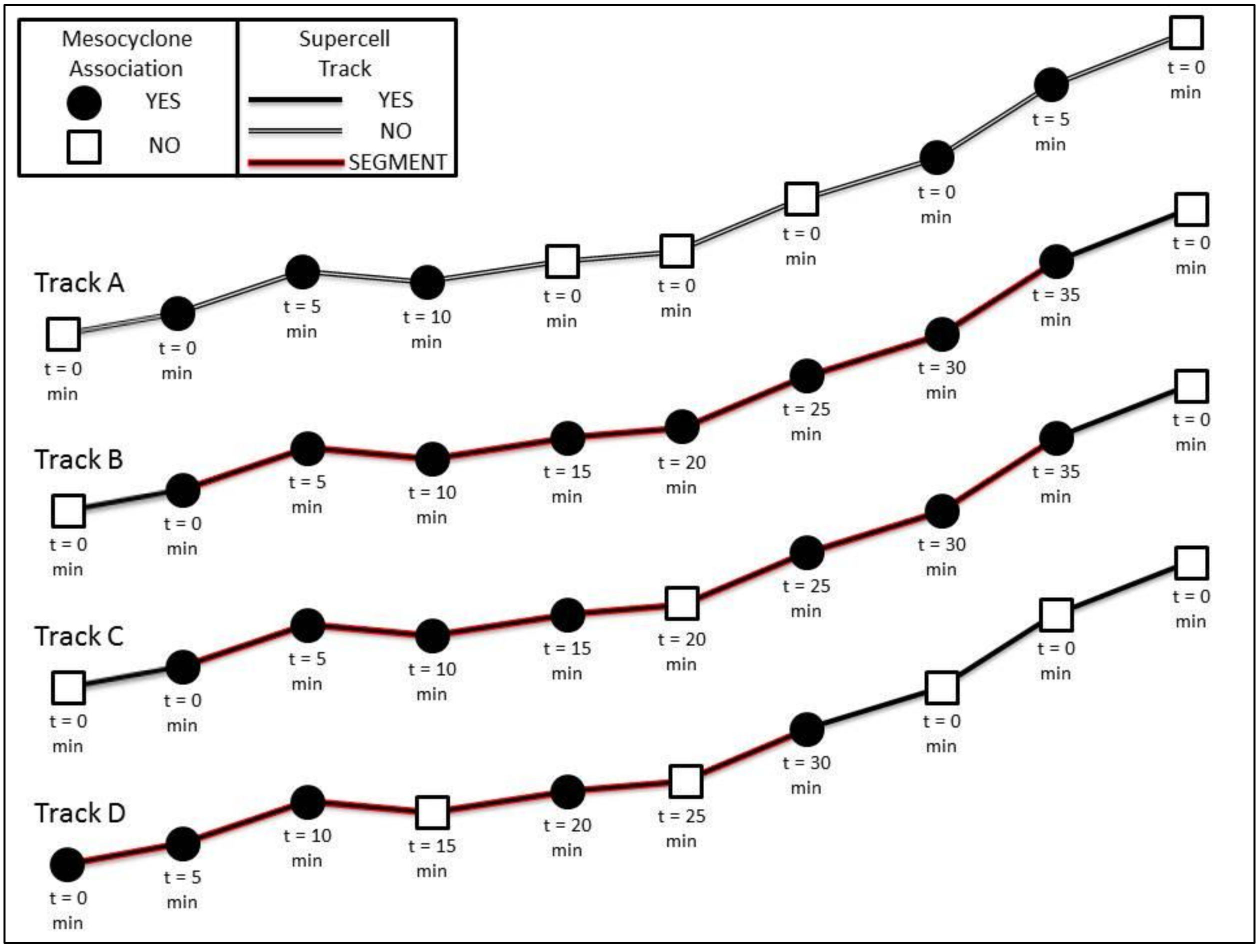

Figure 3: This figure illustrates the mesocyclone association to the ThOR tracks and which tracks are considered a supercell as well as indicating the supercell segments which are only used in spatial analysis. Time values at each point indicate the running length of time during which supercell criteria is satisfied. Tracks B, C, and D are designated supercells because of the continuous observations of clusters associated with MDA detections (including skipped times). While Track A is associated with a mesocyclone for a significant portion of its track, it fails to have a persistent, continuous segment of MDA detections (adapted from Barjenbruch 2009).

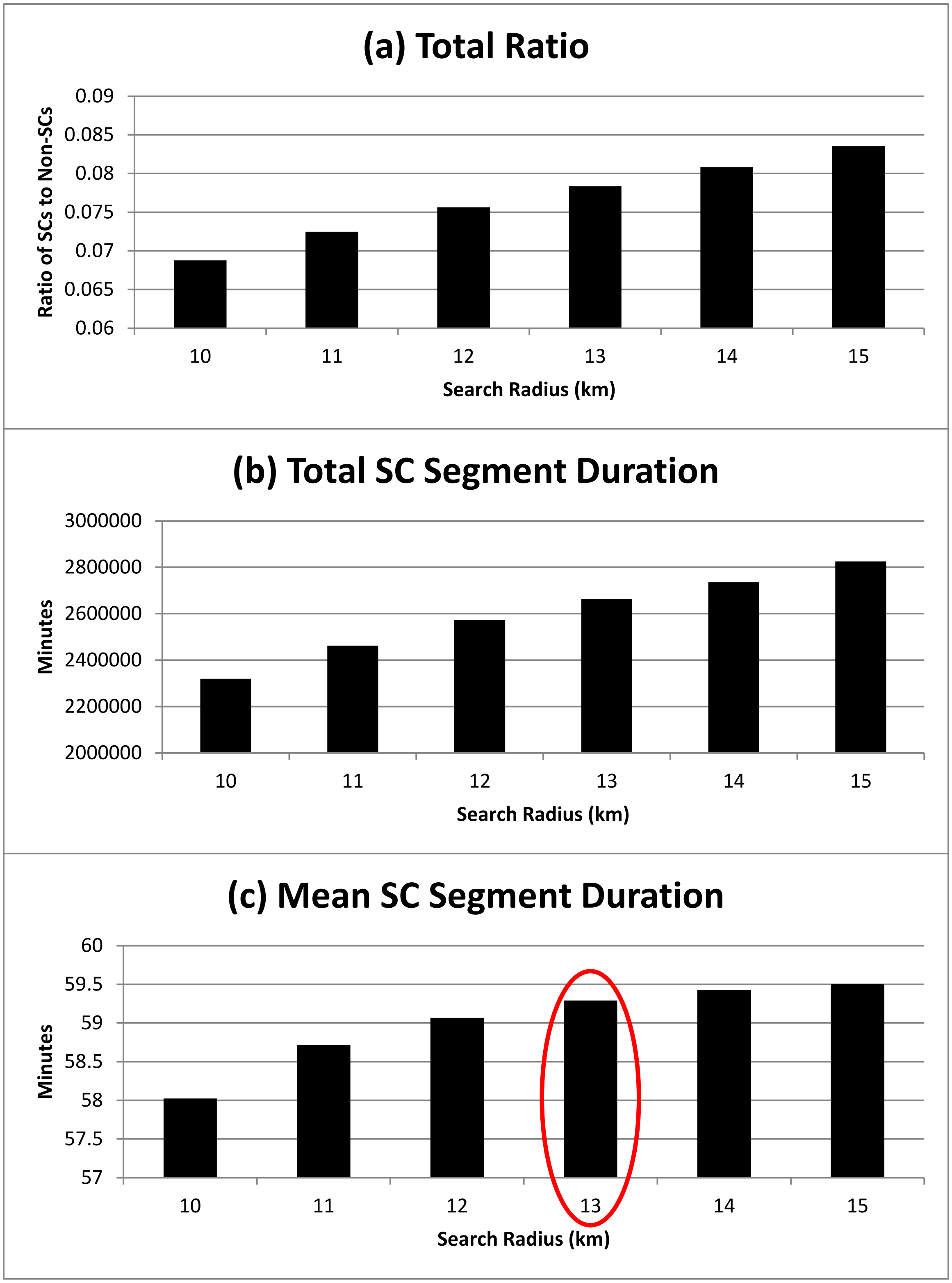

Figure 4: Different attributes were evaluated to determine a proper search radius. The ratio of SCs to non-SCs (a), and the total SC *segment* duration (b) appear to increase linearly, whereas the mean SC *segment* duration (c) levels off at about 13 km. Following Barjenbruch (2009) who found that where these values flatten out, it is a good indication that little value is added at higher search radii, therefore this leveling out point is chosen. In this work, based mainly off the mean SC *segment* duration, a search radius of 13 km is chosen.

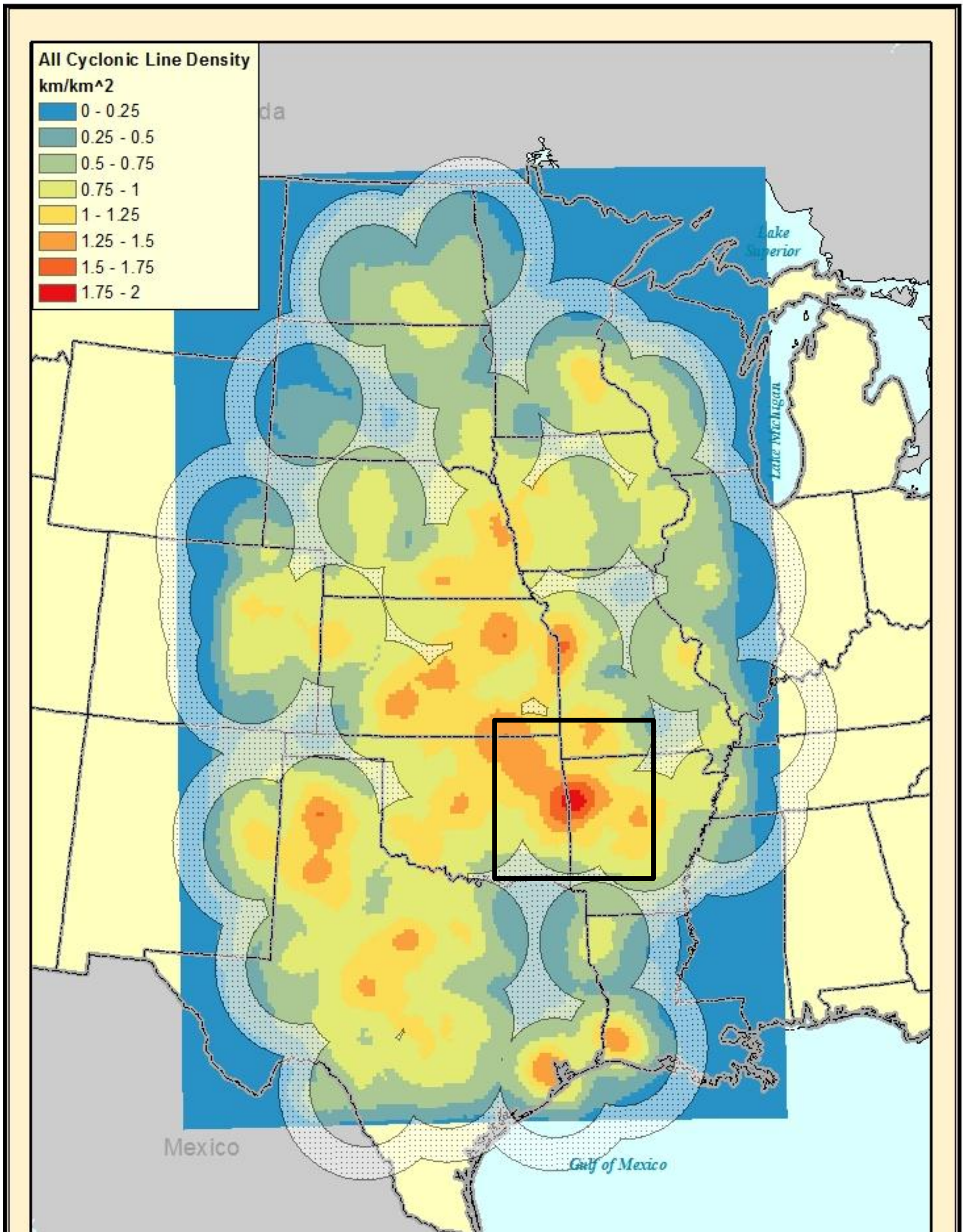

Figure 5: The cyclonic SC spatial climatology. The line density of cyclonic SC *segments* are shown. Note the difference in shading values between this figure and figures 6-8. The location of the maxima of cyclonic SCs is shown in the black box. (Grid size: 10 km x 10 km).

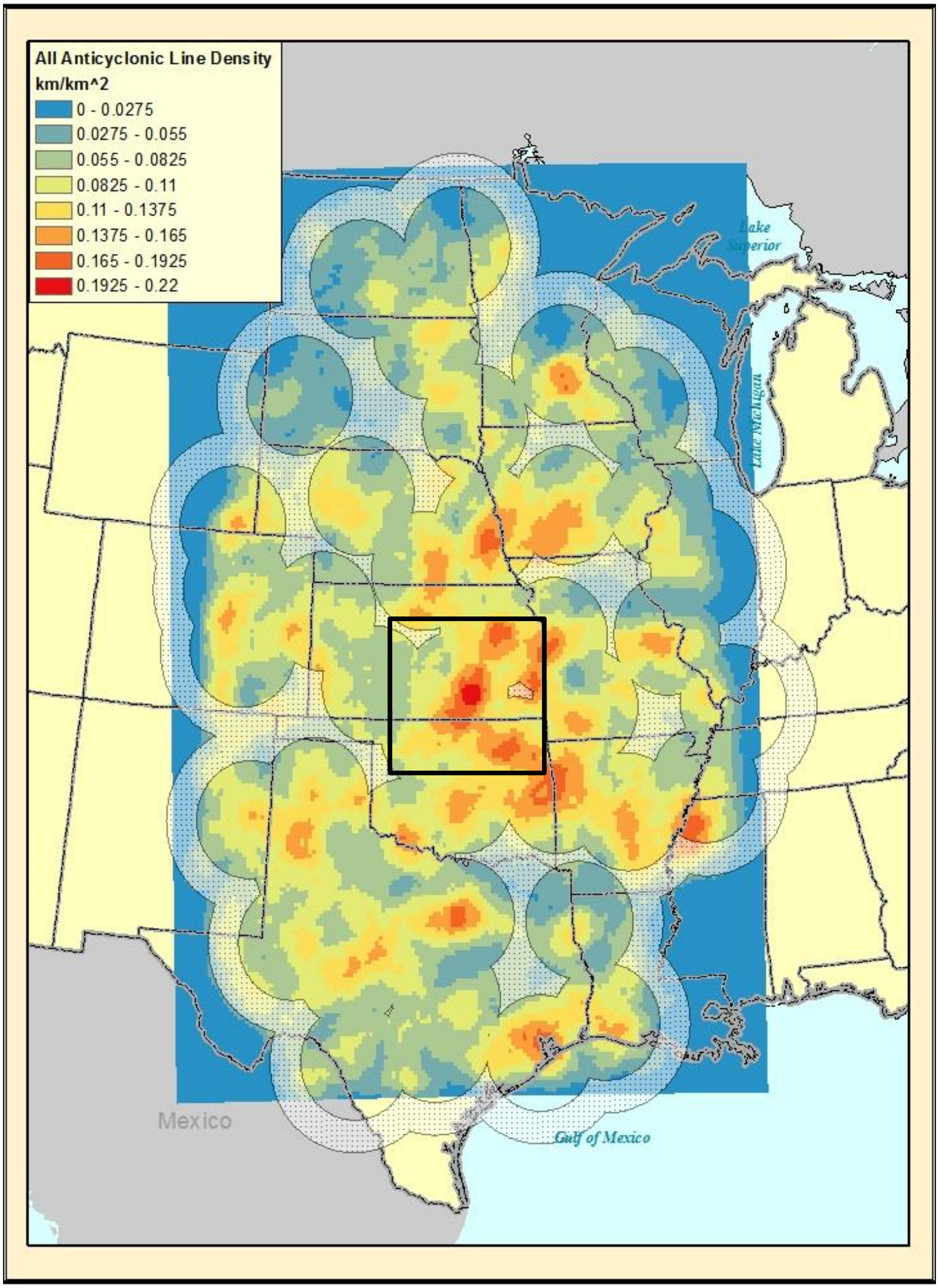

Figure 6: As in Fig. 5, but for anticyclonic SCs.

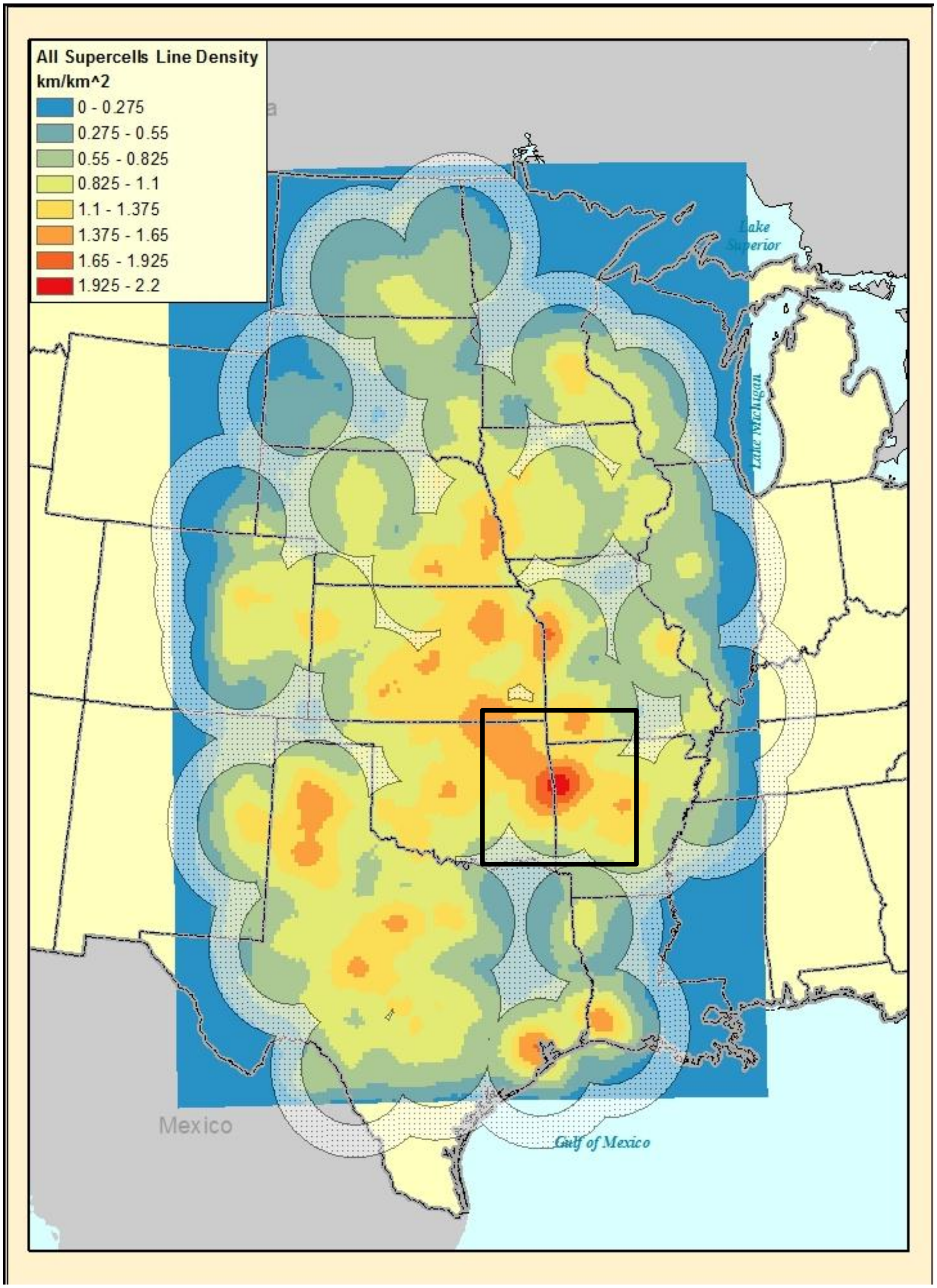

Figure 7: As in Fig. 5, but for all SCs.

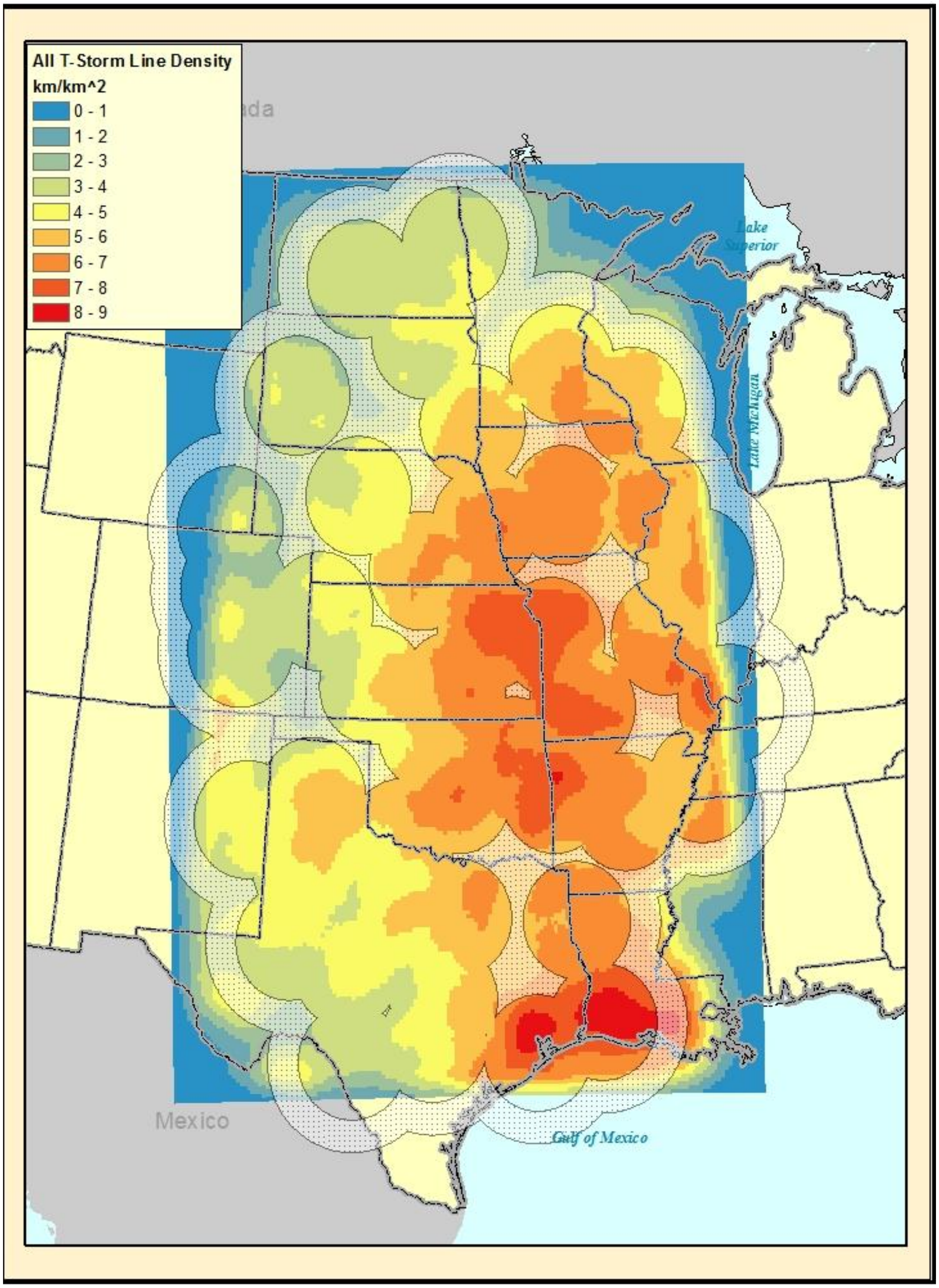

Figure 8: As in Fig. 5, but for all ThOR-identified thunderstorm tracks.

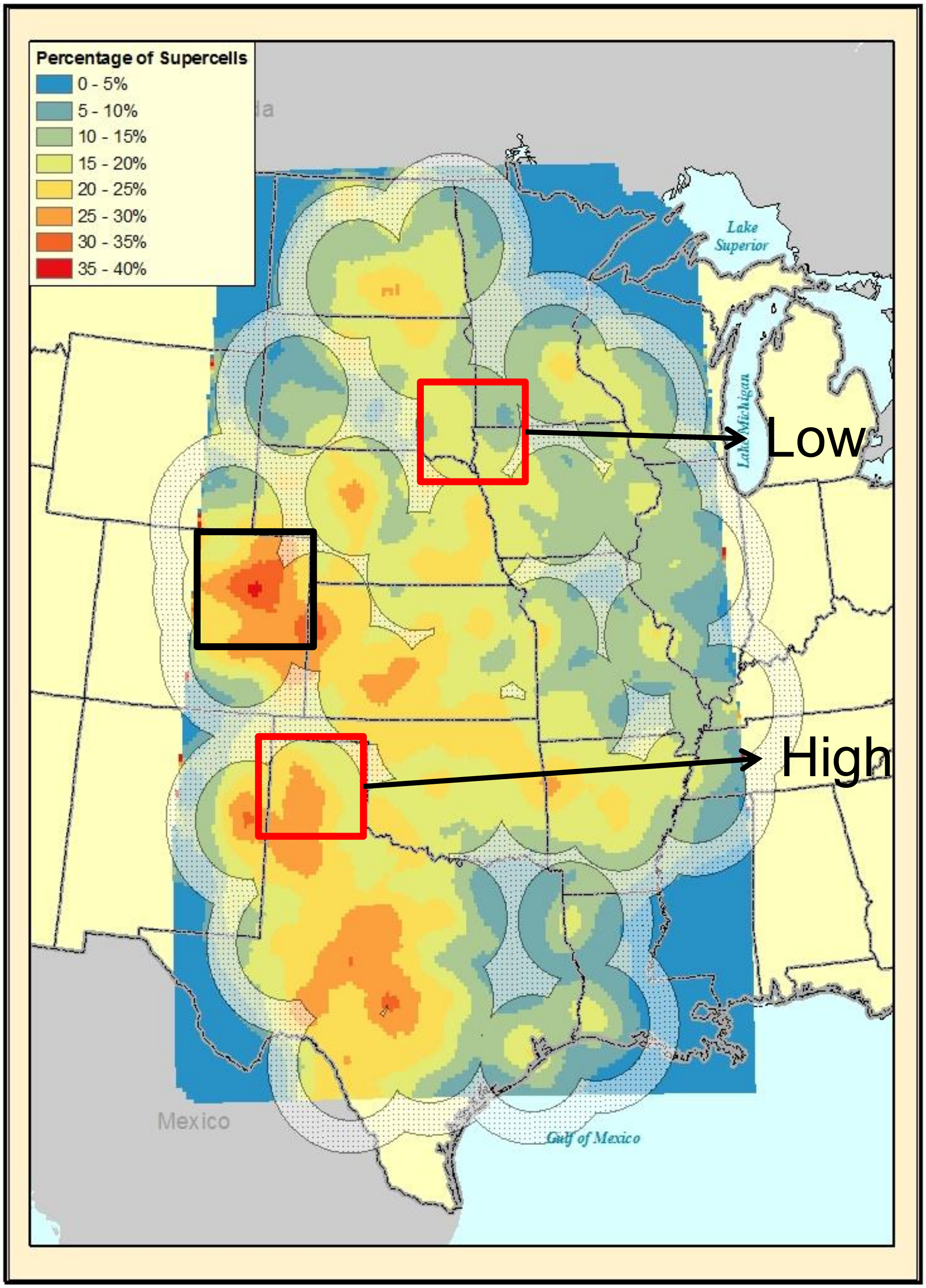

Figure 9: The spatial distribution of the percentage of SCs here is determined by dividing the values in Fig. 7 by the values in Fig. 8. While more SCs may affect the Oklahoma/Arkansas border, the largest percentage of SCs is observed in northeastern Colorado. Also shown is the high (Texas panhandle) and low (South Dakota/Minnesota/Iowa/Nebraska) percentage areas used in the BWD analysis. All tracks that intersect these areas are analyzed. (Grid size: 10 km x 10 km).

	2005 (175,465 t-storm tracks)			2006 (197,083 t-storm tracks)			2007 (174,446 t-storm tracks)			**Total (546,994 t-storm tracks)**		
Type	Cyclonic SCs	Anti-cyclonic SCs	All SCs	Cyclonic SCs	Anti-cyclonic SCs	All SCs	Cyclonic SCs	Anti-cyclonic SCs	All SCs	**Cyclonic SCs**	**Anti-cyclonic SCs**	**All SCs**
# of tracks	7,998	1,556	9,554	12,009	2,078	14,087	16,432	3,317	19,749	**36,439**	**6,951**	**43,390**
% of total t-storm tracks	4.56%	0.89%	5.44%	6.09%	1.05%	7.15%	9.42%	1.90%	11.32%	**6.66%**	**1.27%**	**7.93%**
Ratio of SCs to non-SCS	4.78%	0.89%	5.76%	6.49%	1.07%	7.70%	10.40%	1.94%	12.77%	**7.14%**	**1.29%**	**8.62%**

Table 1: Climatology statistics by year: The total number of thunderstorm, cyclonic SC, anticyclonic SC, and total SC thunderstorm tracks by the years included in this work and their corresponding percentages and ratios. This work found a combined percentage of SCs of 7.93% and a ratio of SCs to non-SCs of 8.62%.