P5.6 EVIDENCE OF SMALLER TORNADO ALLEYS ACROSS THE UNITED STATES BASED ON A LONG TRACK F3 TO F5 TORNADO CLIMATOLOGY STUDY FROM 1880 TO 2003

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1. INTRODUCTION

The focus of this research is to show a historical representation of several smaller apparent tornado alleys across the United States as determined by a long track F3 to F5 tornado climatology study. A map of the United States from 1880 to 2003 was constructed showing normalized frequencies of F3 to F5 tornadoes with path lengths of at least 25 miles. Many smaller tornado alleys were identified across the Mississippi Valley, Tennessee Valley, Great Plains, Ohio Valley and Carolinas. Though there may undoubtedly be specific meteorological reasons why these apparent alleys exist, one hypothesis is the smaller alleys are related to topographic features that may modulate environmental conditions in ways that favor development of these types of tornadoes. This paper does not seek to substantiate this relationship, however, it appears that higher resolution variability does exist in the term "tornado alley".

2. METHODOLOGY

Owing to the rapid increase of weak tornadoes reported in the last 20 years, it is apparent that the most consistent records in both the current and historic tornado climatological databases are at the higher end of both the F-scale rating and damage path length spectrums. For this reason, we constructed a map from 1880 to 2003 using a database of United States F3 to F5 tornadoes with path lengths of at least 25 miles. The map is shown on the next page in Figure 1 as a full page map.

Recently, other researchers have created tornado frequency maps of the United States. Concannon et al. (2000) used no path length discriminations but used a smoothing function, showing all significant tornadoes and all violent tornadoes from 1921 to 1995. In contrast, the map in Figure 1 does not use a smoothing function but uses normalized data to determine the contouring. Because of this, local high frequency areas of long path F3 to F5 tornadoes are retained. This allows tornado alley and other areas to be seen in a fine scale resolution.

We chose the category of F3 to F5 tornadoes because this would include all violent tornadoes. But this category also accounts for F3 tornadoes that may have been stronger and where originally underrated in the storm damage survey. We defined long track as 25 miles or greater because it gave us a larger sample size than 50 miles or greater. In fact, from 1950 to 2003, just over one percent (1.24%) of all tornadoes reported, fall in the F3 to F5 25 mile or greater category. Yet long path F3 to F5 tornadoes had 46.4 % of the total destruction potential using DPI (Destruction Potential Index) for all tornadoes in that period.

From 1880 to 2003, we identified 979 tornadoes as F3 to F5 tornadoes with at least 25 mile path lengths. The number per year is shown in Table 1 at the upper right.

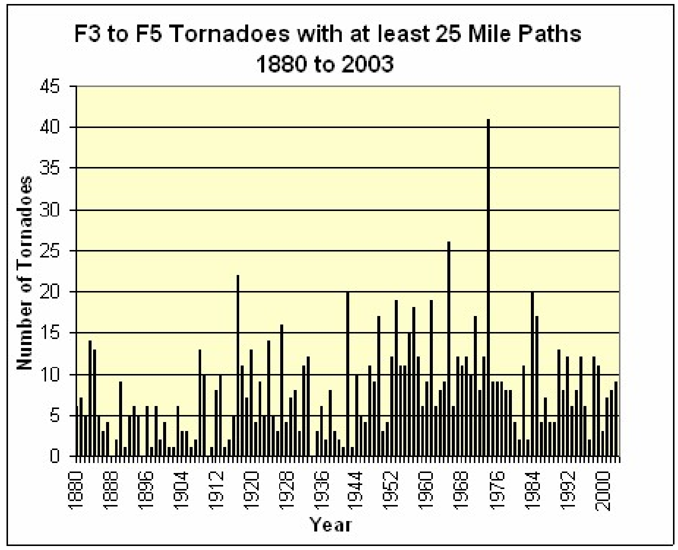

Table 1. The number of F3 to F5 tornadoes with at least 25 mile path lengths per year from 1880 to 2003.

On average, eight long track F3 to F5 tornadoes were reported in the United States each year from 1880 to 2003. The year with the greatest number was 1974 with 41. Remarkably, 25 of those long path F3 to F5 tornadoes occurred in a 13 hour period on April 3 and 4th, 1974.

We used the program Severe Plot created by John Hart of the Storm Prediction Center (SPC), to obtain tornado data from 1950 to 2003. For tornado records between 1880 and 1949, we used the reference book Significant Tornadoes 1680-1991 by Thomas Grazulis.

The tornado record from Grazulis did present uncertainty because some of the tornadoes were listed as families or as skipping tornadoes. We did not want to exclude all of these tornadoes because many of them likely had individual segments of 25 miles or greater. So for the data before 1950, we applied a rule that if the tornado skipped or had a family length of 50 miles or greater, it was likely that one of the segments lasted for at least 25 miles. As a result, the database includes 79 tornadoes that skipped or had a family for 50 miles or greater. All of these tornadoes were before 1950 and they account for 8.1 percent of the tornadoes in the database.

To plot the reports from 1950 to 2003 for each county, we used a program called County Climo Plotter. The program uses the database from Severe Plot and was designed by John Hart of the SPC for this study. County Climo Plotter adds up the number of reports per county and plots the raw number for each county on a map.

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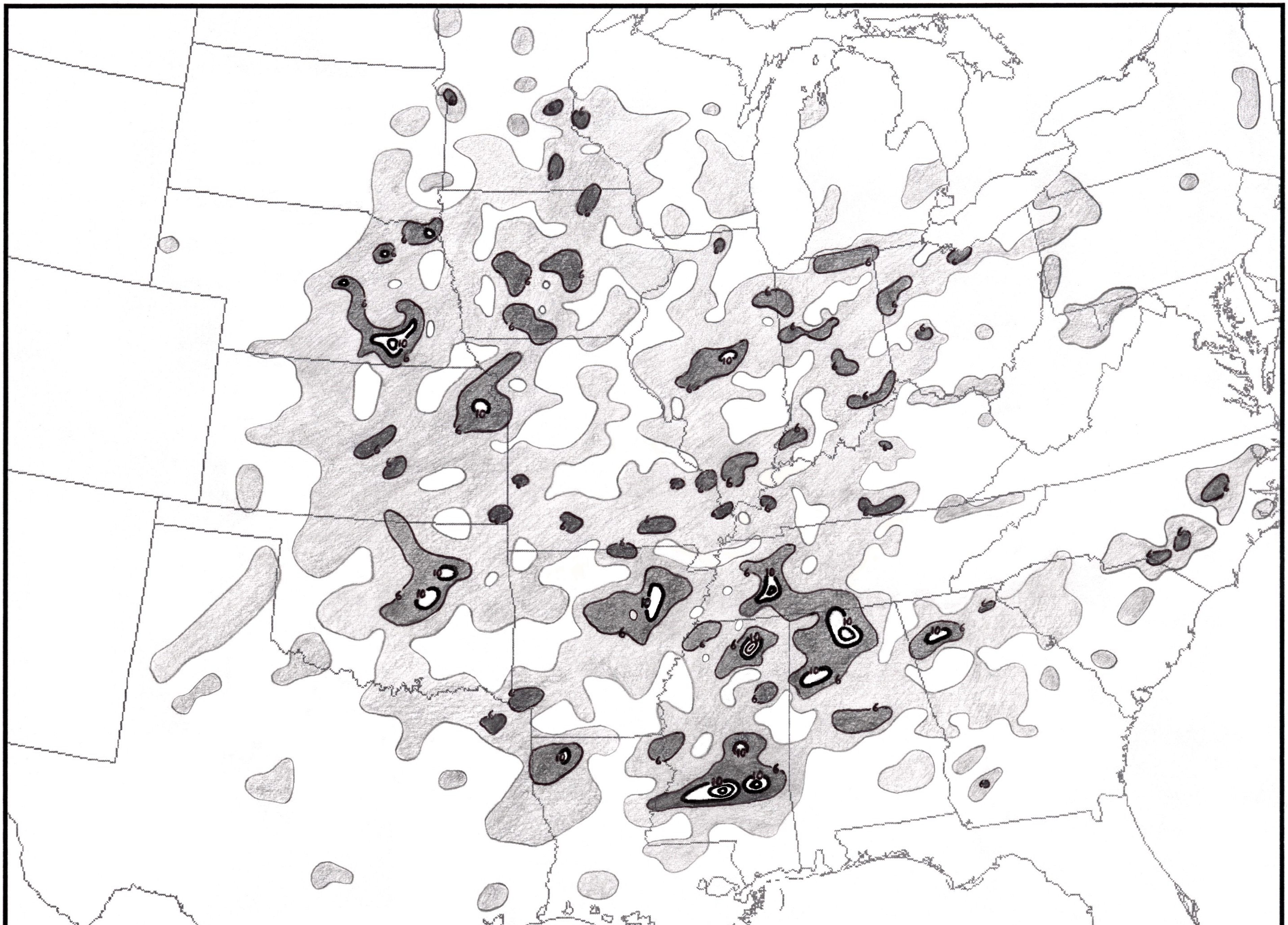

Figure 1. A map showing the frequency of F3 to F5 tornadoes with at least 25 mile tracks from 1880 to 2003 normalized to 1,000 square miles. Contours are 2, 6, 10, 14 and 18. The lower Mississippi Valley is the most active region followed by the Great Plains. South-central Mississippi and northern Mississippi have the highest frequencies of long path F3 to F5 tornadoes. Other active areas are northern Alabama, central to northeast Oklahoma, southeast Nebraska, northeast Arkansas, northeast Kansas, northwest Georgia and eastern North Carolina. A large minimum extends north northeastward from southeast Oklahoma through Missouri, eastern Iowa into Wisconsin.

To create the frequency map, we counted the number of 25 mile or greater F3 to F5 tornadoes from 1880 to 1949 by going through the Grazulis data by hand. Then we added this number to the number of long track F3 to F5 tornadoes from 1950 to 2003 generated by County Climo Plotter, to obtain the total number of long path F3 to F5 tornadoes per county. This was normalized by dividing the tornado total by the square mileage of the county, then multiplying by 1,000 to get the number of tornadoes per 1,000 square miles (about the area of a circle with a diameter of 35 miles). Counties less than 250 square miles in size were combined and tallied with the smallest neighboring county to avoid overly inflated values due to extremely small county size. The frequency map was generated by contouring the normalized numbers for each county.

Table 2 below shows the total number of long path F3 to F5 tornadoes that occurred for each month from 1880 to 2003 in which most of them occurred in the Spring. During this period, May with 257 had the most long track F3 to F5 tornadoes per month. This was closely followed by April with 244. March was third with 142 followed by June with 123. A small peak was also seen in the fall with November having 47. The least active month was August with only 18 long track F3 to F5 tornadoes during the 124 year period.

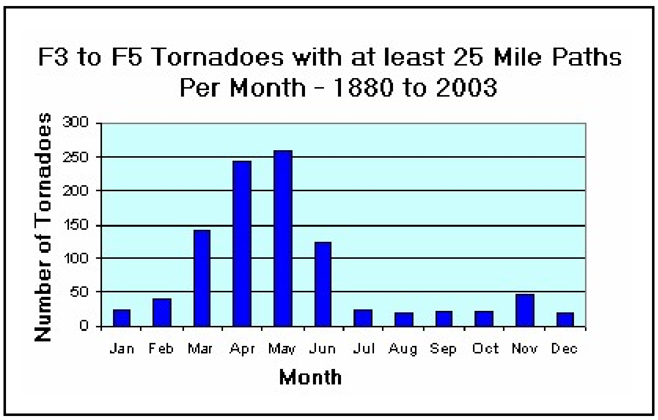

Table 2. The total number of F3 to F5 tornadoes with at least 25 mile path lengths per month from 1880 to 2003.

3. RESULTS

The contoured map in Figure 1 on page 2, displays the county values across the United States from 1880 to 2003 of long track F3 to F5 tornadoes normalized to 1,000 square miles. Two main areas of frequent long path F3 to F5 tornadoes were identified. These areas encompass a large irregular circle extending from the Great Plains eastward to the Ohio and Tennessee Valleys. The first high frequency area is in the lower Mississippi Valley extending eastward to the southern Appalachian Mountains and north northeastward to the Ohio Valley. The second high frequency area is in the Great Plains extending north northeastward into the Upper Midwest. A large minimum exists from southeast Oklahoma extending north northeastward through Missouri into eastern Iowa and Wisconsin. This minimum separates the two high frequency areas.

Table 3 at the upper right shows the total areal coverage of the eight contour for states with counties having eight or greater long path F3 to F5 tornadoes per 1,000 square miles. The eight and greater contours covered counties with a total of 40,485 square miles across the United States which is about the size of Ohio. The average county size was about 600 square miles which means for an average county to have eight as a frequency, the county would have been affected by five long path F3 to F5 tornadoes during the 1880 to 2003 period. That would mean one long path F3 to F5 tornado about every 25 years. In Table 3, Mississippi was the state with the most areal coverage with almost 20 percent of the total for the United States. This was followed by Oklahoma at number two and Alabama at number three. The spatial distribution of normalized frequencies of long path F3 to F5 tornadoes will now be discussed for each region.

States with Counties having Eight or Greater Long Path F3 to F5 Tornadoes per 1,000 Square Miles from 1880 to 2003

Rank	State	Square Mileage	Rank	State	Square Mileage
1.	Mississippi	7789	9.	Tennessee	2019
2.	Oklahoma	4540	10.	Kansas	1627
3.	Alabama	4376	11.	Georgia	1471
4.	Arkansas	3629	12.	Missouri	983
5.	Nebraska	3343	13.	Illinois	979
6.	Indiana	2891	14.	N. Carolina	690
7.	Louisiana	2737	15.	Minnesota	430
8.	Iowa	2571	16.	Ohio	410

Table 3. The rank and areal coverage for states with counties having eight or greater long path F3 to F5 tornadoes per 1,000 square miles from 1880 to 2003.

a. Lower Mississippi Valley and Tennessee Valley

The lower Mississippi and Tennessee Valleys show the highest frequency of long track F3 to F5 tornadoes of any region in the United States from 1880 to 2003 (Figure 2 on the following page). The best defined area shows up just south of Jackson, Mississippi and runs west to east across the entire breadth of south-central Mississippi. This vicinity includes the largest continuous area in the United States with eight or greater long track F3 to F5 tornadoes per 1,000 square miles. In fact, Simpson County had the highest frequency of any county in southern Mississippi and was second in the United States with 18.68 long path F3 to F5 tornadoes per 1,000 square miles (See Appendix). This corresponds to eleven F3 to F5 long track tornadoes affecting the county from 1880 to 2003. In contrast, most of the far southern Mississippi counties (the three southern rows) had no long track F3 to F5 tornado reports during that period.

Another area with very high frequency of long path F3 to F5 tornadoes includes northern Mississippi, northern Alabama and western Tennessee. This vicinity includes the largest continuous area with six or greater long track F3 to F5 tornadoes per 1,000 square miles in the United States which is across northern Alabama extending to the northwest into western Tennessee. Union County in northeast Mississippi had the highest frequency in the United States with 19.28 long track F3 to F5 tornadoes per 1,000 square miles. The relatively small county had eight long track F3 to F5 tornadoes during the 124 year period.

Another high frequency area is located in the Tennessee Valley with northwest Georgia having a bullseye just north and northwest of the Atlanta metropolitan area.

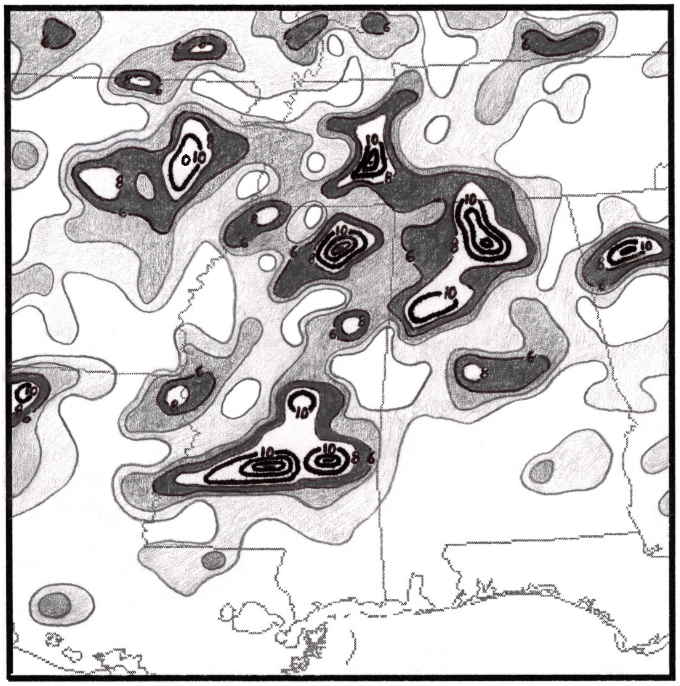

Figure 2. Map of the lower Mississippi Valley and Tennessee Valley of the United States showing county values of all F3 to F5 tornadoes with path lengths of 25 miles or greater from 1880 to 2003 normalized to 1,000 square miles. The contours are 2, 4, 6, 8, 10, 12, 14 and 16.

Farther west in the Mississippi Valley, northwest Louisiana and northeast Arkansas also have high frequency areas of long path F3 to F5 tornadoes. Jackson County in northeast Arkansas had the highest frequency in Arkansas with 12.62 long path F3 to F5 tornadoes per 1,000 square miles. The center of high frequency in northeast Arkansas is located east of the Ozark Mountains (See Figure 3 below). Figure 3 shows a topographic map of Arkansas and far eastern Oklahoma overlaid with the higher frequency contours of long path F3 to F5 tornadoes from 1880 to 2003. On this map, the maximum in northeast Arkansas extends westward into the northern part of the Arkansas River Valley with higher frequencies reaching northern sections of Fort Smith and eastern Oklahoma. Comparing Figure 3 and Figure 4, minimums occur in the Ozarks Mountains northeast of Fort Smith. Also, a large minimum is located south of Fort Smith extending westward into southeastern Oklahoma.

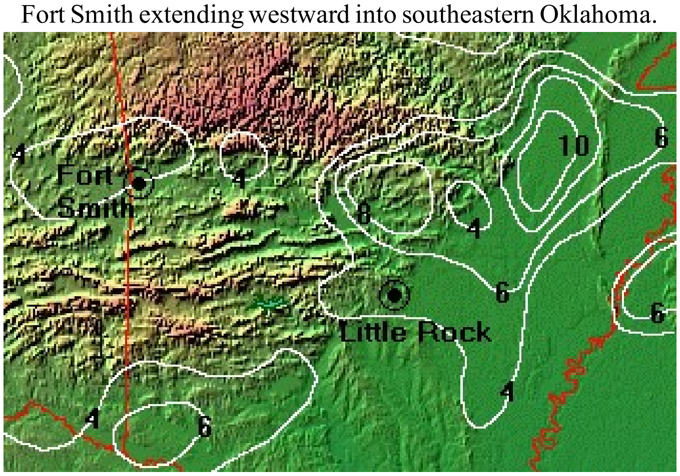

Figure 3. Normalized frequencies of four or greater long path F3 to F5 tornadoes from 1880 to 2003 overlaid onto a topographic map of Arkansas and eastern Oklahoma.

Finally in Figure 2, a notable minimum is present across a narrow corridor of west-central to north-central Mississippi. Other minimums are located across far eastern Mississippi, north-central Louisiana and southern Arkansas.

b. Great Plains and Upper Midwest

The second most active region across the United States for long track F3 to F5 tornadoes is the Great Plains and Upper Midwest where three alleys stand out across the region including central to northeast Oklahoma, southeast Nebraska and far northeast Kansas (see Figure 4 below). The largest maximum exists across east-central to northeast Oklahoma. This area is north of the Canadian River along the I-44 corridor from Oklahoma City to Tulsa. Okfuskee County in a rural area to the east of Oklahoma City, had the highest frequency in the Southern Plains and fourth highest in the Great Plains with 11.13 long path F3 to F5 tornadoes per 1,000 miles. It was affected by seven long path F3 to F5 tornadoes during the 124 year period.

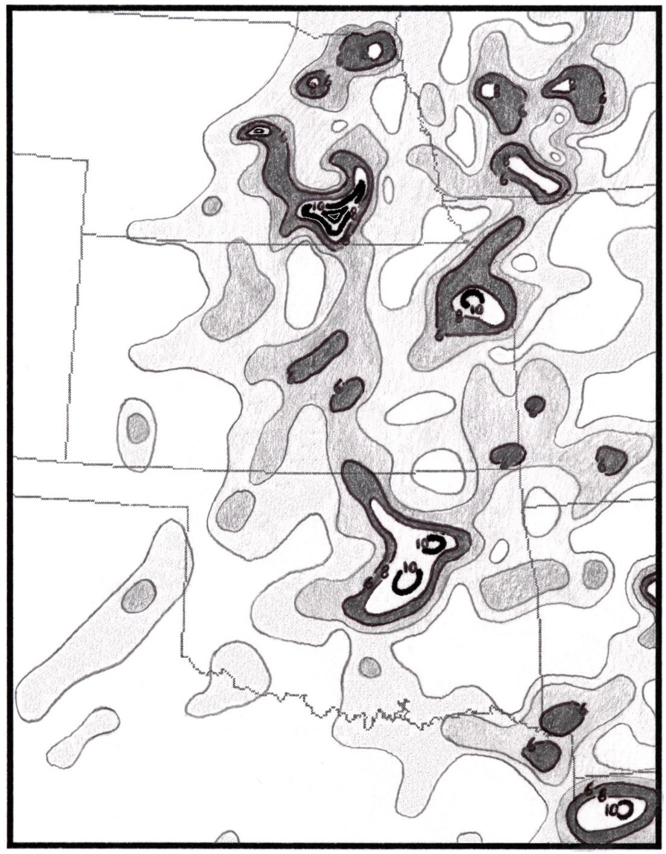

Figure 4. As in Fig. 2, except for the Great Plains and western Ozarks. The contours are 2, 4, 6, 8, 10 , 12 and 14.

When looking at Figure 1, it is apparent that the highest frequencies are not located in population centers in most cases. However, some cities like Tulsa, Oklahoma do fall near maximums. In fact, Tulsa, Oklahoma had the highest incidence in the United States of long track F3 to F5 tornadoes from 1880 to 2003 for cities with greater than 100,000 people. Table 4 on the following page, lists the top 20 cities (with populations of 100,000) in the United States for long track F3 to F5 tornadoes from 1880 to 2003. The list was created by determining the counties for each city and averaging the frequencies for those counties.

Top 20 Cities for Long Track F3 to F5 Tornadoes in the United States from 1880 to 2003

Rank	Value	City, State	Rank	Value	City, State
1.	10.2	Tulsa, OK	11.	5.8	Kansas City, KS
2.	9.3	Shreveport, LA	12.	5.7	Oklahoma City, OK
3.	8.8	South Bend, IN	13.	5.2	Omaha, NE
4.	7.6	Indianapolis, IN	14.	5.2	Little Rock, AR
5.	7.5	Huntsville, AL	15.	5.0	Wichita, KS
6.	7.3	Topeka, KS	16.	4.7	St. Louis, MO
7.	6.9	Springfield, IL	17.	4.5	Minneapolis/St. Paul, MN
8.	6.2	Jackson, MS	18.	4.4	Cleveland, OH
9.	6.0	Nashville, TN	19.	4.2	Cedar Rapids, IA
10.	5.9	Springfield, MO	20.	4.0	Memphis, TN

Table 4. The top 20 cities for long track F3 to F5 tornadoes in the United States from 1880 to 2003. The frequency of long track F3 to F5 tornadoes per 1,000 square miles is given for each city next to its rank.

Another substantial area in Figure 4 includes southeast Nebraska. The maximum is southeast of Grand Island, Nebraska in the slightly higher terrain south of the Platte River Valley. In fact, two counties that border each other in southeast Nebraska which are Fillmore and Thayer Counties, had the highest frequencies in the Great Plains with 15.63 and 13.91 long path F3 to F5 tornadoes per 1,000 square miles, respectively. Nine long path F3 to F5 tornadoes affected Fillmore County and eight affected Thayer County during the 124 year period.

Another area of high incidence is located from central to northeast Nebraska. This broken corridor as well as the maximum in southeast Nebraska is in slightly higher terrain away from the Platte River Valley on the north and south sides of the valley as show in Figure 5 below. Similarly, the maximum across southwestern and central Iowa follows the slightly higher terrain forming a broken semicircle around Des Moines, Iowa. Comparing Figure 4 and Figure 5, the minimum is located just to the west of Des Moines in the lower elevations of the Des Moines River Valley. Another pronounced minimum exists in the Missouri River Valley just to the west of Omaha. This minimum extends southward several hundred miles reaching the Flint Hills of southeast Kansas.

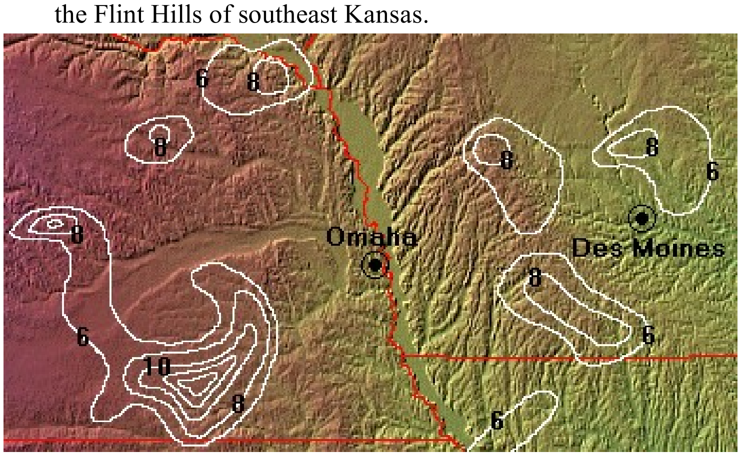

Figure 5. Normalized frequencies of six or greater long path F3 to F5 tornadoes from 1880 to 2003 overlaid onto a topographic map of eastern Nebraska, Iowa and far northwest Missouri.

In Figure 4, the higher frequencies associated with the semicircular maximum in south-central Iowa, extend south southwestward into northeastern Kansas. Jefferson County in a rural area west of the Kansas City metropolitan area had the highest normalized frequency in Kansas and was third in the Great Plains with 11.19 long path F3 to F5 tornadoes per 1,000 square miles. Another area of interest in the plains is a nearly continuous corridor in the eastern Texas Panhandle extending northeastward into central Kansas. This corridor begins on the Caprock of west Texas and extends northeastward along the edge of the higher terrain eventually reaching the plains of southern Kansas.

c. Ohio Valley and Mid Mississippi Valley

The third most active region across the United States for long track F3 to F5 tornadoes is the Ohio Valley where two broken corridors of higher incidence exist, oriented to the east northeast (see Figure 6 below). The most substantial broken corridor extends from central Illinois across northern Indiana into far southern lower Michigan and northwest Ohio. At the beginning of the corridor, De Witt County, a small county just to the east northeast of Springfield, Illinois, had the highest normalized frequency in the Ohio Valley with 10.05 long path F3 to F5 tornadoes per 1,000 square miles. Van Wert County in northwest Ohio, had the highest normalized frequency of any county in the upper Ohio Valley with 9.76 long path F3 to F5 tornadoes per 1,000 square miles. Both counties totaled four long path F3 to F5 tornadoes from 1880 to 2003.

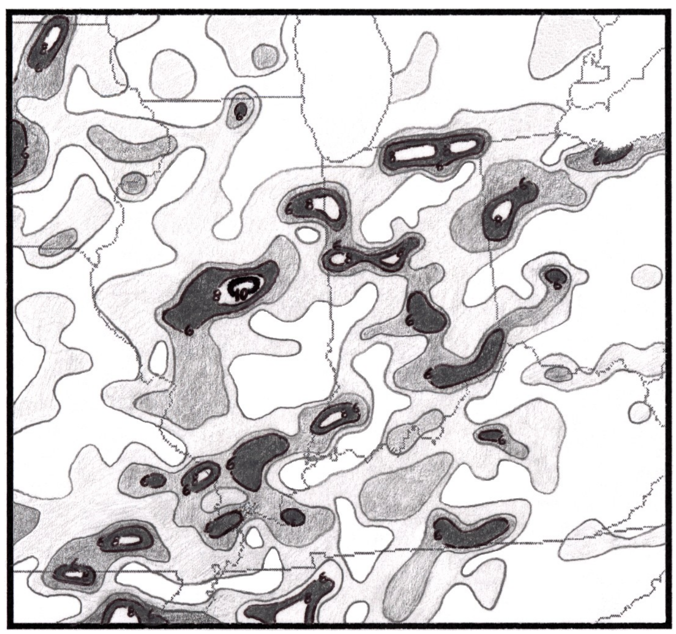

Figure 6. As in Fig. 2, except for the Ohio Valley, Mid Mississippi Valley and Southern Great Lakes. The contours are 2, 4, 6, 8 and 10.

As shown in Figure 7 on the following page, the first broken corridor begins southeast of the Illinois River Valley near Springfield and extends east northeastward across the flatter sections of the Till Plains into the Wabash River Valley to the north and northeast of Indianapolis, Indiana.

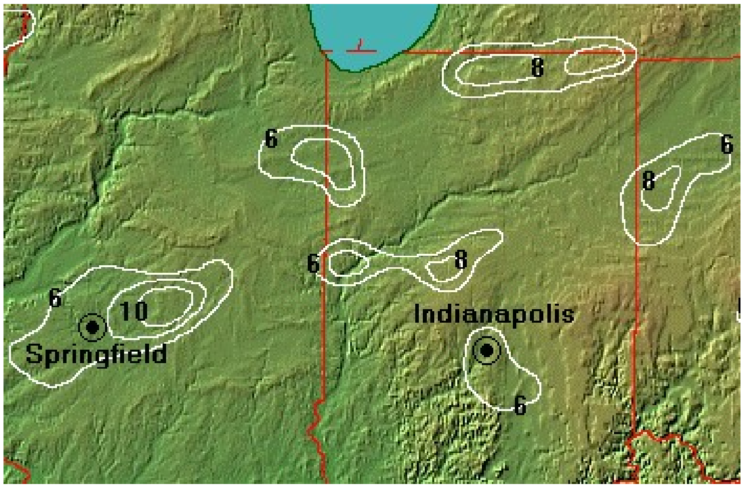

Figure 7. Normalized frequencies of six or greater long path F3 to F5 tornadoes from 1880 to 2003 overlaid onto a topographic map of Illinois, Indiana and far western Ohio.

The second substantial corridor in Figure 6, extends east northeastward from far southern Missouri across southern Illinois, southern Indiana into southwest Ohio. Along this corridor, the three counties with the highest incidence of long track F3 to F5 tornadoes were Gibson, Perry and Carter Counties. Gibson County is in southwest Indiana with Perry and Carter Counties in southeast Missouri. Gibson and Perry counties were hit directly by the Tri-state Tornado on March 18, 1925. Perry county near the Mississippi River and Gibson County near the Illinois River in far southwest Indiana had 8.42 and 8.18 long path F3 to F5 tornadoes per 1,000 square miles, respectively. Each county had a total of four long track F3 to F5 tornadoes during the 124 year period. One of these was the famous Tri-state tornado which tracked east northeastward from southeastern Missouri through southern Illinois into southern Indiana. This tornado had the longest track on record for the United States with a path length of 219 miles. This F5 tornado killed a record 695 people and tracked right down the middle of the center section of the second broken corridor shown in Figure 8 below.

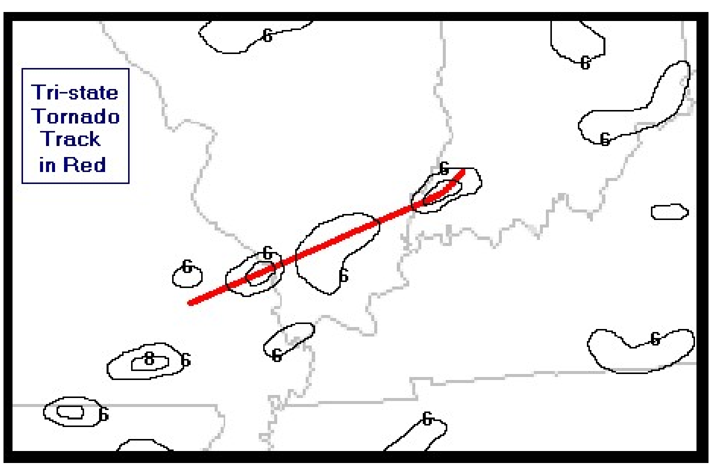

Figure 8. The approximate track of the Tri-state Tornado of March 18, 1925 overlaid with the normalized frequencies of long path F3 to F5 tornadoes from 1880 to 2003.

d. Carolinas Region

The fourth region of high incidence in the United States of long path F3 to F5 tornadoes is the Carolinas Region (see Figure 9 below). One main alley extends southwestward across eastern and southern North Carolina. This area is located in the flatter terrain east of the Appalachian Mountains as shown in Figure 10 below. Scotland County in southern North Carolina to the east southeast of Charlotte, North Carolina, had the highest frequency of long path F3 to F5 tornadoes east of the Appalachian Mountains with 9.40 per 1,000 square miles.

Another alley extends eastward across northern Georgia into northwestern South Carolina. The two alleys line up together with a break across northern South Carolina.

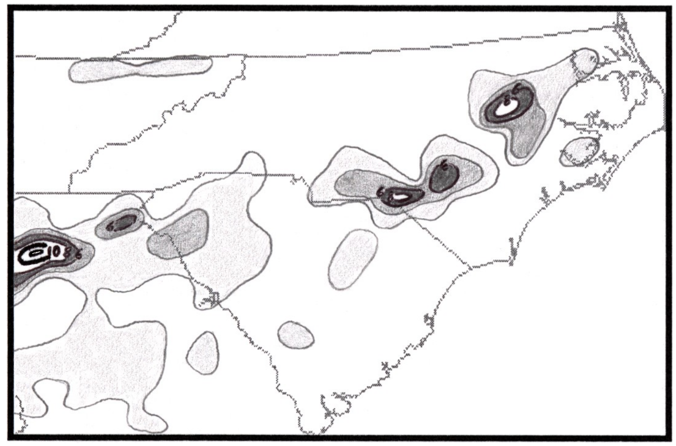

Figure 9. As in Fig. 2, except for the Carolinas Region. The contours are 2, 4, 6, 8, 10 and 12.

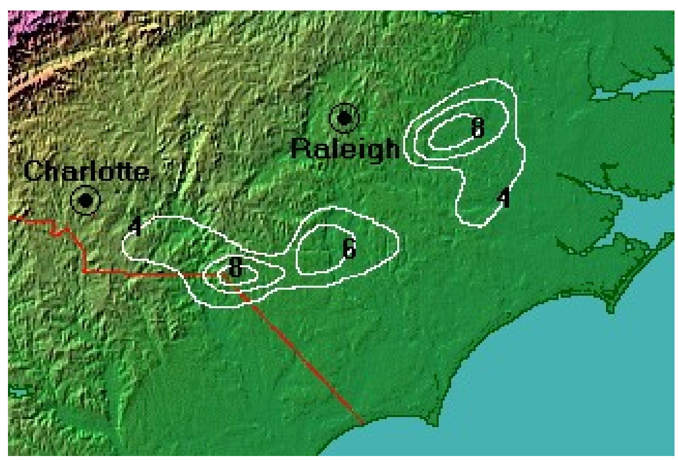

Figure 10. Normalized frequencies of six or greater long path F3 to F5 tornadoes from 1880 to 2003 overlaid onto a topographic map of parts of North Carolina and South Carolina.

4. SUMMARY AND FUTURE WORK

The four most prominent tornado alleys that were identified in the United States include south-central Mississippi, east-central to northeast Oklahoma, southeast Nebraska and the area from western Tennessee to northeast Mississippi and northern Alabama. Other prominent alleys include northeast Kansas to central Iowa, northeast Arkansas, northwest Georgia, central Illinois to northwest Ohio, northwest Louisiana, northeast Nebraska, southeast Missouri to southwest Ohio and east to southeast North Carolina.

In the future, we plan to explore the reasons why the alleys identified in this paper appear to be favored more than other areas nearby. In addition, we would like to present maps using smaller time periods showing the frequencies of long path F3 to F5 tornadoes. These maps would reveal the variability of the smaller alleys in time and space. And finally, we would like to present a map of all tornadoes across the United States with population biases and other biases removed.

5. REFERENCES

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6. APPENDIX

Counties in the United States by Region with Frequencies of Eight or More Long Path F3 to F5 Tornadoes from 1880 to 2003 normalized to 1,000 square miles
(To find the number of long path F3 to F5 tornadoes affecting a county from 1880 to 2003, multiply the frequency by the square miles and divide by 1,000)

a. Lower Mississippi Valley and Tennessee Valley

Mississippi(14), Alabama(7), Arkansas(6), Tennessee(4), Louisiana(4), Georgia(3)

Rank	Frequency	County	Square Miles
1.	19.28	Union, MS	415
2.	18.68	Simpson, MS	589
3.	17.30	Chester, TN	289
4.	15.46	Morgan, AL	582
5.	14.79	Jasper, MS	676
6.	13.07	Bartow, GA	459
7.	12.62	Jackson, AR	634
8.	12.32	Limestone, AL	568
9.	11.58	Copiah, MS	777
10.	11.54	Henderson, TN	520
11.	11.15	Fayette, AL	628
12.	10.29	Leake, MS	583
13.	10.22	Woodruff, AR	587
14.	10.08	Webster, LA	595
15.	10.08	Walker, AL	794
16.	9.78	Clay, MS	409
17.	9.64	Prentiss, MS	415
18.	9.63	Jefferson, MS	519
19.	9.54	Bossier, LA	839
20.	9.50	East Carroll, LA	421
21.	9.43	Smith, MS	589
22.	9.43	Cherokee, GA	424
23.	9.27	Faulkner, AR	647
24.	9.07	Caddo, LA	882
25.	9.03	Rankin, MS	775
26.	8.99	Conway, AR	556
27.	8.82	Marshall, AL	567
28.	8.73	Tippah, MS	458
29.	8.52	Lawrence, AR	587
30.	8.50	Gordon/Pickens, GA*	588
31.	8.37	Desoto, MS	478
32.	8.35	Carroll, TN	599
33.	8.21	Scott, MS	609
34.	8.18	Giles, TN	611
35.	8.14	Winston, AL	614
36.	8.09	Fulton, AR	618
37.	8.05	Bibb, AL	623
38.	8.03	Pontotoc, MS	497

b. Great Plains and Upper Midwest

Nebraska(6), Oklahoma(6), Iowa(5), Kansas(3), Minnesota(1), Michigan (0), North Dakota(0), South Dakota(0), Texas(0), Wisconsin (0)

Rank	Frequency	County	Square Miles
1.	15.63	Fillmore, NE	576
2.	13.91	Thayer, NE	575
3.	11.19	Jefferson, KS	536
4.	11.13	Okfuskee, OK	629
5.	10.56	Valley, NE	568
6.	10.47	Clay, NE	573
7.	10.43	Seward, NE	575
8.	10.22	Tulsa, OK	587
9.	9.43	Union, IA	424
10.	9.40	Decatur, IA	532
11 .	9.32	Lincoln, OK	966
12.	9.30	Steele, MN	430
13.	9.28	Creek, OK	970
14.	8.83	Pottawatomie, OK	793
15.	8.78	Carroll, IA	569
16.	8.73	Story, IA	573
17.	8.46	Howard, IA	473
18.	8.40	Pawnee, OK	595
19.	8.40	Dixon, NE	476
20.	8.39	Johnson, KS	477
21.	8.14	Leavenworth/Wyandotte, KS*	614

c. Ohio Valley and Mid Mississippi Valley

Indiana(7), Illinois(2), Missouri(2), Ohio(1), Kentucky(0),

Rank	Frequency	County	Square Miles
1.	10.05	De Witt, IL	398
2.	9.95	Newton, IN	402
3.	9.88	Clinton, IN	405
4.	9.84	Carter, MO	508
5.	9.76	Van Wert, OH	410
6.	9.71	Steuben, IN	309
7.	8.75	Saint Joseph, IN	457
8.	8.62	Elkhart, IN	464
9.	8.61	Macon, IL	581
10.	8.42	Perry, MO	475
11.	8.22	Warren, IN	365
12.	8.18	Gibson, IN	489

d. Carolinas

North Carolina(2), South Carolina(0)

Rank	Frequency	County	Square Miles
1.	9.40	Scotland, NC	319
2.	8.09	Wilson, NC	371

* Counties with less areal coverage than 250 square miles were combined and tallied with the smallest nearby county to prevent overly inflated values for extremely small counties