

U.S. VIOLENT TORNADOES RELATIVE TO THE POSITION OF THE 850 MB JET

Chris Broyles¹, Corey K. Potvin², Casey Crosbie³, Robert M. Rabin⁴, Patrick Skinner⁵

¹ NOAA/NWS/NCEP/Storm Prediction Center, Norman, Oklahoma

² Cooperative Institute for Mesoscale Meteorological Studies, and School of Meteorology, University of Oklahoma, and NOAA/OAR National Severe Storms Laboratory, Norman, Oklahoma

³ NOAA/NWS/CWSU, Indianapolis, Indiana

⁴ National Severe Storms Laboratory, Norman, Oklahoma

⁵ Cooperative Institute for Mesoscale Meteorological Studies, and NOAA/OAR National Severe Storms Laboratory, Norman, Oklahoma

Abstract

The Violent Tornado Webpage from the Storm Prediction Center has been used to obtain data for 182 events (404 violent tornadoes) in which an F4-F5 or EF4-EF5 tornado occurred in the United States from 1950 to 2014. The position of each violent tornado was recorded on a gridded plot compared to the 850 mb jet center within 90 minutes of the violent tornado. The position of each 850 mb jet was determined using the North American Regional Reanalysis (NARR) from 1979 to 2014 and NCEP/NCAR Reanalysis from 1950 to 1978. Plots are shown of the position of each violent tornado relative to the center of the 850 mb low-level jet. The United States was divided into four parts and the plots are available for the southern Plains, northern Plains, northeastern U.S. and southeastern U.S. with a division between east and west at the Mississippi River. Great Plains violent tornadoes clustered around a center about 130 statute miles to the left and slightly ahead of the low-level jet center while eastern U.S. cases were oriented near the axis of the low-level jet to between 140 statute miles to the left and 120 statute miles to the right of the jet axis. Comparisons are made between the four regions and a plot is shown with 396 individual violent tornadoes plotted relative to the 850 mb jet.

1. INTRODUCTION

The importance of the low-level jet to tornado formation has been a focus of several studies throughout the years. Beebe and Bates (1955) showed that the most favorable location for tornado formation was downstream from a northern hemisphere upper-level trough to the left of the low-level jet. This conceptual model was modified by Maddox and Doswell (1981). A colorized version of this conceptual model is shown below in Figure 1.

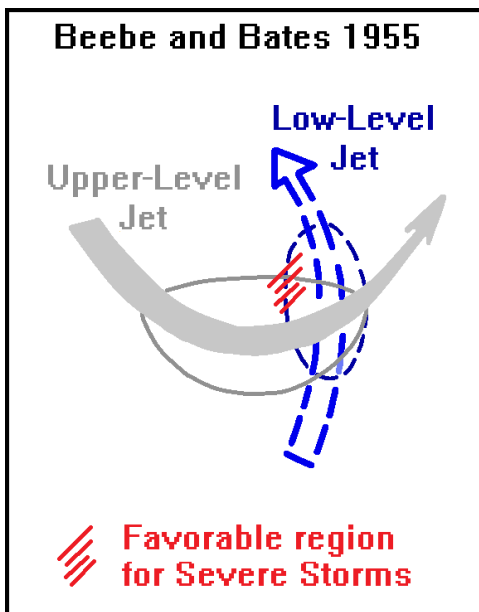


Figure 1. Conceptual model is taken from Beebe and Bates (1955) which was modified by Maddox and Doswell (1981). The model shows the most favorable location for tornado formation in red relative to the northern hemisphere upper-level trough in gray and low-level jet in blue. The graphic has been colorized.

Broyles et al. (2000) completed the first phase of this study and found the same principle holds true for violent tornadoes rated F4 to F5. That study looked at 38 U.S. violent tornadoes in seven years from 1993 to 1999. Figure 2 below is from the original study showing the location of the violent tornadoes relative to the 850 mb jet. This paper expands the original 2000 study to include 404 violent tornadoes from 1950 to 2014 and separates the plots into separate regions across the U.S.

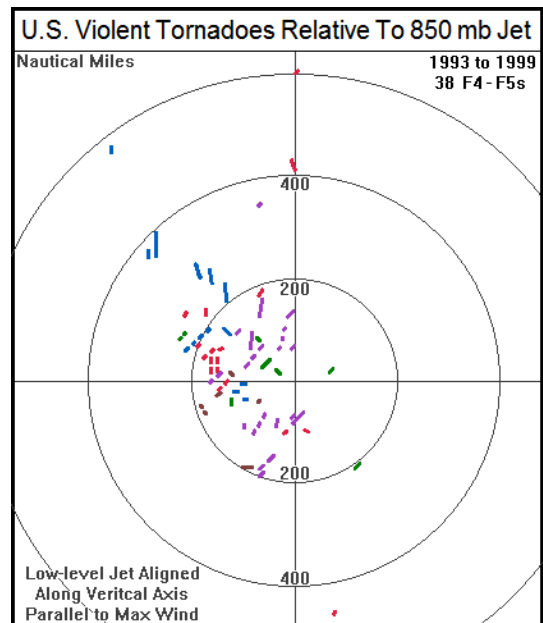


Figure 2. The circle plot is taken from Broyles et al. (2000), showing 38 U.S. violent tornadoes (F4-F5) relative to the position of the 850 mb jet. The low-level jet is oriented along the vertical axis parallel to the wind direction within the jet. The jet's center is located at the origin. The range rings are every 200 nautical miles. The regions are Southern Plains (red), Northern Plains (blue), Upper Midwest (green), Southeast (purple) and East (brown).

2. METHODOLOGY

The Violent Tornado Webpage at the address www.spc.noaa.gov/exper/outbreaks, was used to collect the data for this study. From that webpage, violent tornado events are available from 1875 to 2014. Violent tornadoes from 1950 to 2014 were included in this study. Events before 1950 were excluded due to the 20th Century Reanalysis being less reliable. From 1979 to 2014, the North American Regional Reanalysis was used and all violent tornadoes were analyzed. From 1950 to 1978, the NCEP/NCAR Reanalysis was used but only for cases in which four violent tornadoes occurred within a 72 hour period. The webpage does not include events with one to three violent tornadoes within a 72 hour period prior to 1979. On the webpage, the two data sets encompass 65 years of analysis (1950-2014) including 182 events and 404 violent tornadoes rated F4 to F5 (EF4 to EF5 after February 1, 2007). 850 mb jets (also referred to as the low-level jet in this paper) were identified for 396 violent tornadoes where the jet was radially within 625 statute miles of the tornado. For the remaining eight violent tornadoes, the 850 mb jet was outside of that radius and they are not included on the plots.

To begin the data collection, transparencies were obtained. A thin black vertical line was drawn down the center of each transparency while a thin black horizontal line was also drawn through the center from left to right. The two lines intersected near the center of the transparency. This intersection was used as the position of the 850 mb jet for each violent tornado. After a case was loaded onto the Violent Tornado Webpage, the image resolution was set at 100 percent. Four transparencies were made for each region. A fine point blue marker was used for Southern Plains cases. Red was used for Northern Plains cases. Green was used for the Southeast and purple was used for the Northeast. Regional divisions are shown below in Graphic 3.

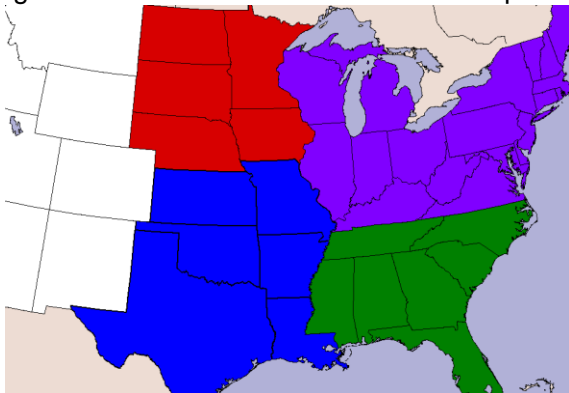


Figure 3. For the regions in this study, the east-west division is at the Mississippi River. The north-central U.S. (Northern Plains) are red, south-central U.S. (Southern Plains) blue, Great Lakes to New England (Northeast) purple and Southeast green.

For each violent tornado, the transparency for that region was used to record the position of the violent tornado relative to the low-level jet center. The transparency was placed on a wide monitor at the

Storm Prediction Center (SPC) with the line intersection overlaid at the center of the 850 mb jet for each violent tornado. The vertical line was aligned with the direction of the maximum wind within the 850 mb jet. Then, the centroid between the start and end point of each violent tornado track was recorded as a dot on the transparency.

For cases from 1979 to 2014, the position of the 850 mb jet was identified every three hours (21Z, 00Z, 03Z, etc.) and the violent tornadoes were within 90 minutes before or after the plot time. For cases from 1950 to 1978, the position of the 850 mb jet was identified every six hours (18Z, 00Z, 06Z, etc.) and the violent tornadoes were within 180 minutes of the plot time. Two summer cases (Wyoming and North Dakota) had an 850 mb jet of 15 knots which is the lowest isotach displayed by the Violent Tornado Webpage. The remaining 180 events had an 850 mb jet of at least 20 knots. Most of the time, the low-level jet was identified using a closed contour. However, 19 of the cases (10.44%) had areas of enhanced wind speeds within an unclosed contour. In most of those cases, the low-level jet was either in a developing or decaying state, showing up distinctly on the previous or following 3 or 6 hour map. When this happened, time continuity was used to estimate where the low-level jet was. In most of those instances, the low-level jet maximum contour was evident on three sides. Beebe and Bates (1955) described this type of jet as a plateau of high wind speeds often extending southeastward away from the major jet axis, calling them “secondary jets”.

After the data were gathered for the 396 violent tornadoes associated with 850 mb jets, the plots were transferred from the transparencies to a digital format and imported into Microsoft Paint. Microsoft Paint was used to create a clean digital image showing the dots where the violent tornadoes were relative to the 850 mb jet. While in Microsoft Paint, a grid was overlaid onto each plot. Due to the U.S. map projection on the Violent Tornado Webpage, the grid spacing represents approximately 78 statute miles. The large dataset of 396 violent tornadoes in this part of the study enabled a higher resolution than the climatology portion of the study in which meteorological features were analyzed. The sample size of meteorological features was smaller necessitating a lower resolution.

3. RESULTS

The plots showing each violent tornado relative to the 850 mb jet further confirmed that the area to the left of the low-level jet is favored in the Great Plains. Figure 4 shows the distribution of violent tornadoes relative to the 850 mb jet for the Southern Plains, Northern Plains, Northeast and Southeast. For the Southern Plains, most of the violent tornadoes occurred to the left of the low-level jet axis, similar to those in the Northern Plains. In contrast, violent tornadoes in the Southeast and Northeast were distributed along and to either side

U.S. Violent Tornadoes Relative to the 850 mb Jet 182 Events (396 Violent Tornadoes)

850 mb Jet Aligned Along Thick Vertical Line Parallel To The Max Wind Speed With Jet Center Located At The Crossover
NCEP/NCAR Reanalysis 1950-1978 North American Regional Reanalysis 1979-2014

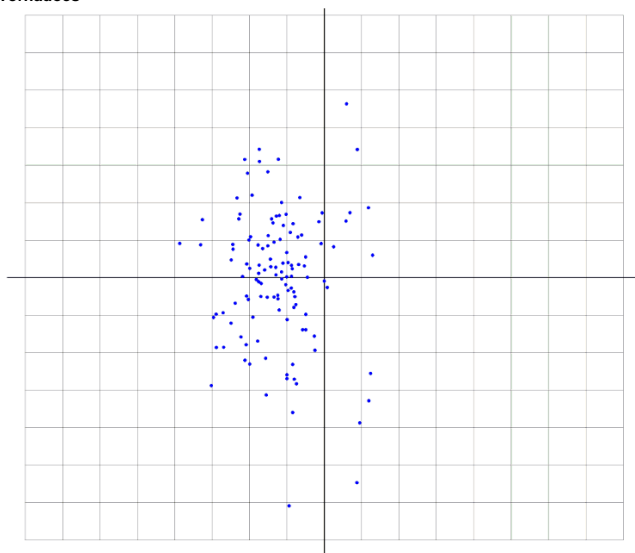
(Including MO, AR, LA)

Southern Plains

122 Violent
Tornadoes

78 Statute Mile Grid Boxes

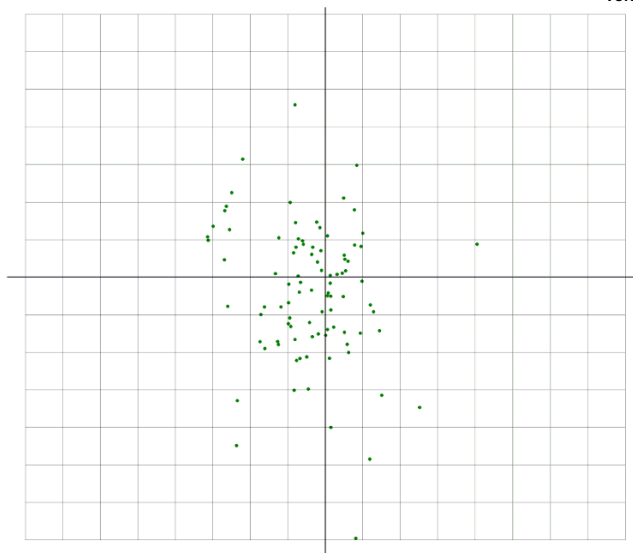
1950 to 2014



Southeast

78 Statute Mile Grid Boxes

93 Violent
Tornadoes



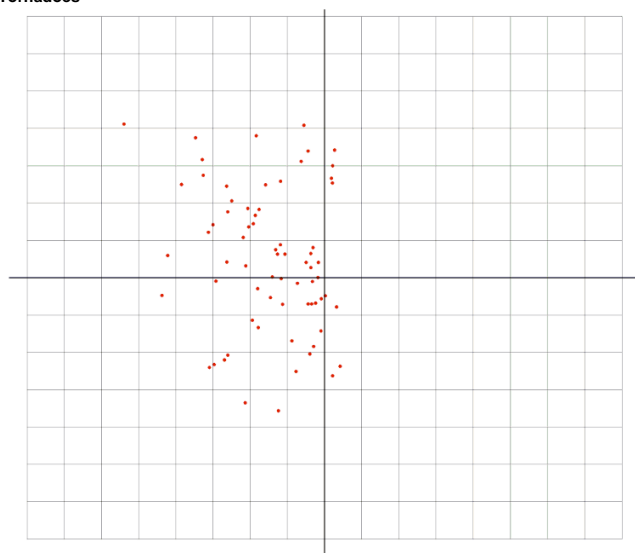
(Including MN, IA)

Northern Plains

69 Violent
Tornadoes

78 Statute Mile Grid Boxes

1950 to 2014



(Including IL, WI, OH Valley, Great Lakes)

Northeast

78 Statute Mile Grid Boxes

112 Violent
Tornadoes

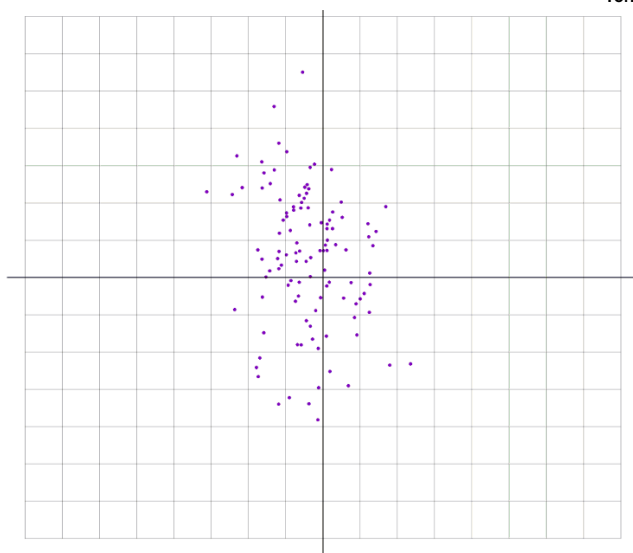


Figure 4. Plots of the distribution of violent tornadoes relative the 850 mb jet are shown for each region. For each plot, the 850 mb jet is located at the intersection of the thick vertical and horizontal lines. The vertical axis is aligned with the direction of the maximum wind speed within the 850 mb jet. The violent tornadoes in the Southern Plains and Northern Plains are distributed mostly to the left of the 850 mb jet axis while the distribution in the Southeast and Northeast are mostly located near the 850 mb jet axis.

of the low-level jet axis. The Southern Plains and Northeast distributions were the most concentrated while the Northern Plains was the most dispersed.

The Southern Plains, Northern Plains and Northeast had the greatest concentration of violent tornadoes to the left and just ahead of the jet center. In contrast, the center of the distribution in

the Southeast was along and just behind the low-level jet center, being to the south of the jet in many cases. Of the four plots, the Northern Plains had the fewest violent tornadoes to the east of the 850 mb jet axis. In contrast, the Southeast and Northeast plots both had a substantial number of violent tornadoes to the east of the 850 mb jet axis.

U.S. Violent Tornadoes Relative to the 850 mb Jet 182 Events (396 Violent Tornadoes)

850 mb Jet Aligned Along Thick Vertical Line Parallel To The Max Wind Speed With Jet Center Located At The Crossover
NCEP/NCAR Reanalysis 1950-1978 North American Regional Reanalysis 1979-2014

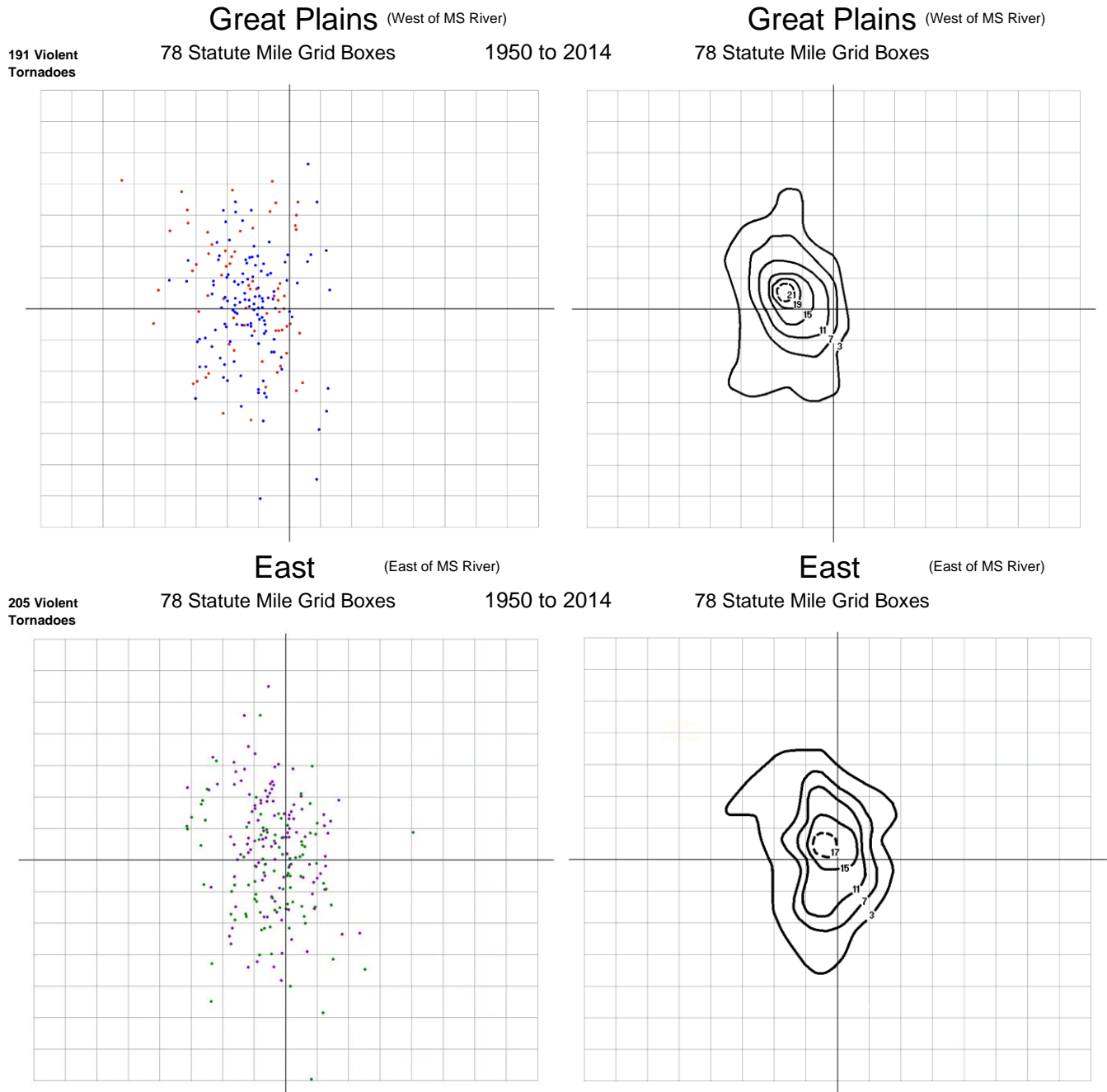


Figure 5. Plots showing the distribution of violent tornadoes relative to the 850 mb jet are shown for the Great Plains including all areas west of the Mississippi River and for the eastern U.S. including all areas east of the Mississippi River. For each plot, the 850 mb jet is located at the intersection of the thick vertical and horizontal lines. The vertical axis is aligned with the direction of the maximum wind speed within the 850 mb jet. The Great Plains violent tornadoes are distributed mostly to the left of the 850 mb jet axis while the eastern United States violent tornadoes are mostly from 140 statute miles to the left to 120 statute miles to the right of the low-level jet axis.

The upper part of Figure 5 shows the violent tornado distribution combined for the Southern Plains and Northern Plains. The bottom part of the graphic shows the violent tornado distribution combined for the Southeast and Northeast. The contoured plots were made by counting the number of violent tornadoes in each grid box. The counts were placed in the center of each grid box and contoured. The Great Plains including all areas

to the west of the Mississippi River had most of the violent tornadoes to the left of the low-level jet axis out to about 230 statute miles away from the jet axis. The eastern states including all areas to the east of the Mississippi River had most of the violent tornadoes near the low-level jet axis between 140 statute miles to the left and 120 statute miles to the right of the low-level jet axis. The differences between the two plots are an important distinction.

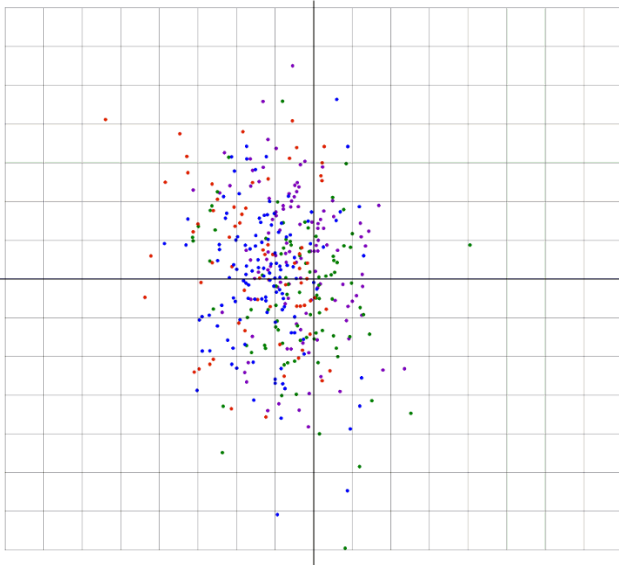
U.S. Violent Tornadoes Relative to the 850 mb Jet 182 Events (396 Violent Tornadoes)

850 mb Jet Aligned Along Thick Vertical Line Parallel To The
Max Wind Speed With Jet Center Located At The Crossover
NCEP/NCAR Reanalysis 1950-1978 North American Regional Reanalysis 1979-2014
1950 to 2014

United States

78 Statute Mile Grid Boxes

396 Violent
Tornadoes



United States

78 Statute Mile Grid Boxes

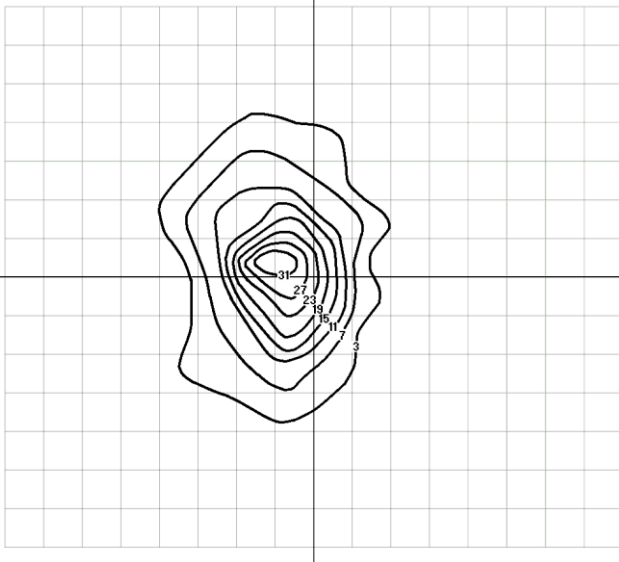


Figure 6. Plots show the violent tornado distribution relative to the 850 mb jet for the United States from 1950 to 2014. Violent tornadoes are color coded by region with Southern Plains in blue, Northern Plains in red, Southeast in green and Northeast in purple. The distribution's center is located about 75 statute miles to the left and about 30 statute miles ahead of the low-level jet center. The low-level jet is oriented along the vertical axis with the maximum wind speed of the jet located where the thick lines intersect.

In the Great Plains, violent tornadoes are often displaced to the left of the 850 mb jet because of the dryline. The dryline develops on the western edge of a moist airmass where cloud cover is often

minimal. This allows the air along and behind the dryline to heat up while areas to the east along the moist corridor remain relatively cooler. Due to this, the instability axis sets up between the thermal and moist axes. Storms typically initiate just to the east of the dryline and move across the instability corridor, producing violent tornadoes to the west of the low-level jet and moist axis.

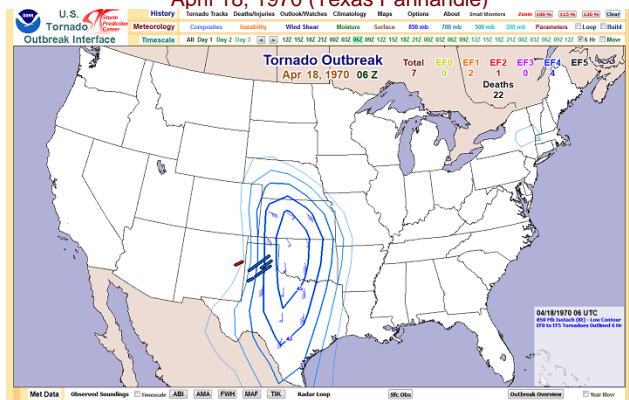
By the second day, systems often deepen and move into the eastern U.S. The moist and thermal axes typically become in better alignment. Violent tornadoes are then most likely near the moist axis and low-level jet where instability is maximized. This is a key difference between the Great Plains violent tornado cases and eastern U.S. cases.

4. EXAMPLES

Some Great Plains low-level jet examples are shown below using maps from the Violent Tornado Webpage. The case at the top in Figure 7

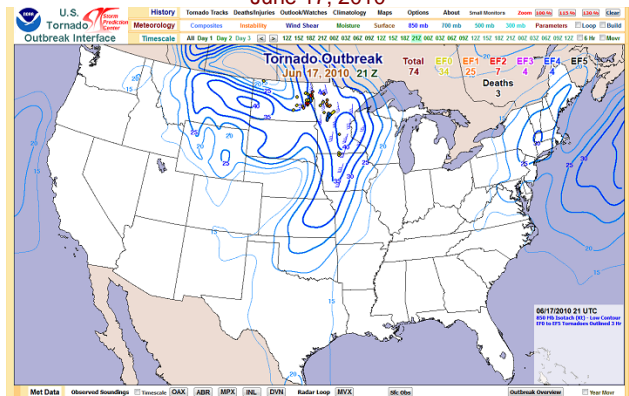
Southern Plains 850 mb Jet Example

April 18, 1970 (Texas Panhandle)



Northern Plains/Upper Mississippi Valley 850 mb Jet Example

June 17, 2010



Figures 7. The case at the top is from April 17 and 18, 1970 in which four violent tornadoes occurred from the Texas Panhandle southward into west Texas. The second case at the bottom of the figure shows the June 17, 2010 case in which four violent tornadoes occurred in the Upper Mississippi Valley and Northern Plains. Both of these cases were close to the climatological centroid evident in Figure 5 for the Great Plains. The April 17 and 18, 1970 case shows the 850 mb jet at 06Z with all tornadoes between 03Z and 09Z. The June 17, 2010 case shows the 850 mb jet at 21Z with all tornadoes between 1930Z and 2230Z.

is from April 17 and 18, 1970. This major tornado outbreak occurred from the Texas Panhandle southward into west Texas. For that event, four violent tornadoes developed during the evening and overnight period. The tornadoes occurred about 140 statute miles to the west of the 850 mb jet which is close to the climatological centroid shown in Figure 5 for the Great Plains.

The second case at the bottom in Figure 7 is the major tornado outbreak that occurred on June 17, 2010 in the north-central U.S. In that case, four violent tornadoes occurred about 150 statute miles to the left and just ahead of the low-level jet center. Again, this was close to the climatology centroid shown in Figure 5 for the Great Plains.

Figure 8 shows three cases of major tornado outbreaks that occurred in the eastern United States. The first case at the top is the major tornado outbreak that occurred in the Great Lakes and Ohio Valley on Palm Sunday, April 11, 1965. On that day, the tornado outbreak covered a large area with 17 violent tornadoes. Those tornadoes occurred from near the center of the low-level jet extending to the left and ahead of the jet center about 250 statute miles. The distribution on this day encompassed approximately the upper half of the distribution shown on the eastern U.S. plot in Figure 5.

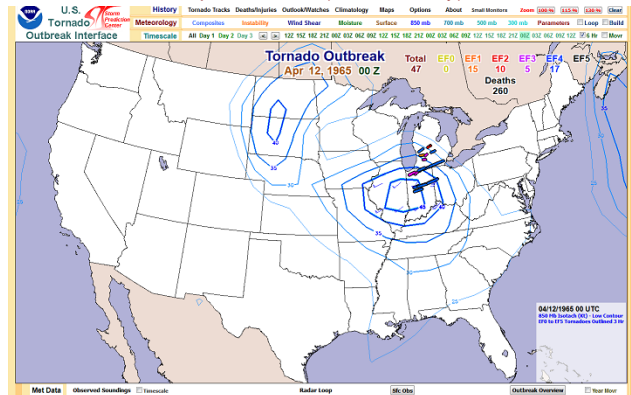
The middle map in Figure 8 shows the Super Outbreak that occurred in the Southeast on April 27, 2011. There were 15 violent tornadoes on that day including four EF5 tornadoes. The center of the tornado outbreak was near the center of the 850 mb jet being close to the climatological centroid for the eastern U.S. shown in Figure 5.

The bottom map in Figure 8 shows the Super Outbreak that occurred in the Ohio and Tennessee Valleys on April 3 and 4, 1974. There were 30 violent tornadoes on that day including seven F5 tornadoes mostly oriented along and near the 850 mb jet axis. The tornado outbreak was aligned close to the climatological axis of highest incidence shown for the eastern U.S. in Figure 5.

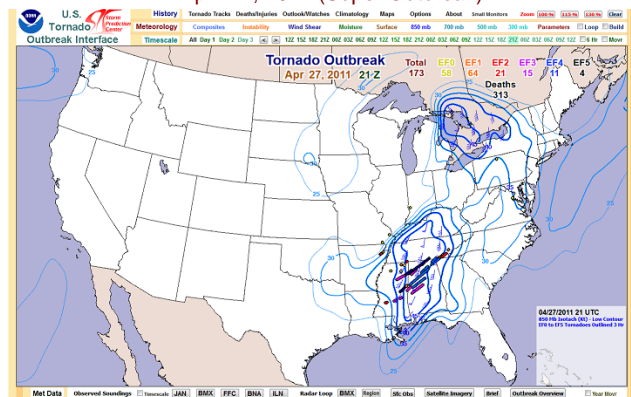
5. CONCLUSION

In this study, 404 violent tornadoes were analyzed. An 850 mb jet was associated with 396 of those violent tornadoes in the U.S. from 1950 to 2014. The 396 violent tornadoes were plotted relative to the 850 mb jet near the time of the tornado. The Southern Plains violent tornadoes were the most

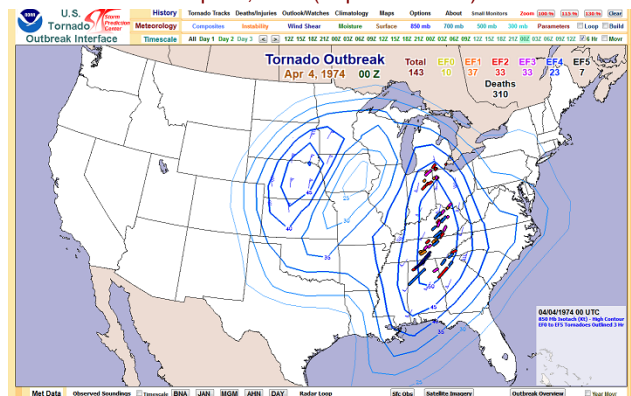
Southern Great Lakes 850 mb Jet Example
April 11, 1965 (Palm Sunday)



Southeast 850 mb Jet Example
April 27, 2011 (Super Outbreak)



Southeast 850 mb Jet Example
April 3, 1974 (Super Outbreak)



Figures 8. The case at the top is from April 11, 1965 in which 17 violent tornadoes occurred. The case shows the 850 mb jet at 00Z on April 12, 1965 with all tornadoes plotted from 21Z/11 to 03Z/12. The tornado outbreak occurred from near the 850 mb jet center outward about 250 statute miles to the left and ahead of the low-level jet. The middle case is the Super Outbreak from April 27, 2011 in which 15 violent tornadoes occurred. The case shows the 850 mb jet at 21Z on April 27, 2011 with all tornadoes plotted from 1930Z/27 to 2230Z/27. The third case is the Super Outbreak from April 3 and 4, 1974 with 30 violent tornadoes on that day. The case shows the 850 mb jet at 00Z on April 4, 1974 with all tornadoes plotted from 21Z/3 to 03Z/4. Both Super Outbreaks had the tornado outbreak aligned along the axis of the 850 mb jet similar to the eastern U.S. plot in Figure 5.

concentrated distribution with the centroid being about 130 statute miles to the left and just ahead of the 850 mb jet center. The Northern Plains violent tornadoes were more spread out but favored the left quadrants of the 850 mb jet encompassing the same general area as the Southern Plains violent tornadoes. The Northeast and Southeast violent tornadoes were generally located along the 850 mb jet axis between 140 statute miles to the left and 120 statute miles to the right of the jet axis.

The west-to-east difference is an important distinction of this study. Great Plains violent tornadoes are most likely to develop to the left of the 850 mb jet while eastern U.S. violent tornadoes are most likely to develop along the 850 mb jet axis. Tornadic storms in the Great Plains often initiate just to the east of the dryline and move eastward into the strongest instability. Great Plains violent tornadoes occur as the storms move across the instability corridor which is typically to the west of the 850 mb jet and moist axes. As systems move eastward away from the dryline, the instability axis becomes better aligned with the moist axis. As a result, violent tornadoes in the eastern U.S. are more likely to develop near the 850 mb jet axis where moisture and instability are maximized.

Another consideration is that northeastern U.S. violent tornadoes are mostly concentrated just ahead of the 850 mb jet center. In contrast, the southeastern U.S. violent tornadoes are mostly concentrated just behind the 850 mb jet center which would be to the south of the low-level jet in many cases.

To conclude, when thermodynamic, kinematic and lift conditions in the atmosphere are favorable, the 850 mb jet provides a good proxy as to where violent tornadoes are most likely to develop. Hopefully, this research can be used by forecasters to create more accurate predictions of tornado outbreaks in the future.

6. REFERENCES

Beebe, R. G., and F. C. Bates, 1955: A mechanism for assisting the release of convective instability. *Mon. Wea. Rev.*, 83, 1–10.

Broyles, J. C., N. Dipasquale, R. Wynne, 2000: Synoptic and mesoscale characteristics associated with violent tornadoes across separate geographic regions of the United States: Part 1 - low-level characteristics. Preprints, 21st Conf. Severe Local Storms, San Antonio, TX, J65-J68.

Broyles, J. C., N. Dipasquale, R. Wynne, 2000: Synoptic and mesoscale characteristics associated with violent tornadoes across separate geographic regions of the United States: Part 2 - upper-level characteristics. Preprints, 21st Conf. Severe Local Storms, San Antonio, TX, J69-J72.

Maddox, R. A., and C. A. Doswell III, 1981: An examination of jet stream configurations, 500 mb vorticity advection and low-level thermal advection patterns during extended periods of intense convection. *Mon. Wea. Rev.*, 110, 184-197.