Analysis of Severe Storm Initiation Along Drylines in the Southern Plains

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ABSTRACT

Severe weather often occurs along drylines, and one of the forecasting rules of thumb is that for severe storms you want to be north of the bulge in the dryline. To test the validity of this forecasting rule surface data and storm reports were collected starting from 2009 and going back to 2005. This data focused on the Southern Plains including the states of Oklahoma, Texas and Southern Kansas. The storm reports were then compared to the surface data to gauge initiation time and location. Also looked at were the overall storm reports and the locations of the majority of the reports and where each type of report was likely to be found. The results show that the favored area of initiation is an area stretching 50km to 250km north of the bulge in the dryline.

1. Introduction

In the United States the most common definition of a dryline is a narrow boundary separating maritime tropical air masses originating over the Gulf of Mexico and continental tropical air masses originating from the desert southwest of the United States. They most commonly occur over parts of Texas and Okalahoma stretching further north into parts of Kansas and even Nebraska. They can also occur in other regions and have at times made it into parts of Iowa and parts of North and South Dakota. When looking at a dryline often there will be an area where the dry air has moved further east than along the rest of the line. This area is called "bulge". They can occur up to 40 percent of days during the late spring and early summer months (Atkins 1998). The General rule of thumb is that storms generally fire to the north of the bulge for example see (http://www.stormtrack.org/forum/archive/index.php/t-3509.html) The strongest dewpoint differences tend to be at elevations of at least 2000 feet and tend to occur in the late afternoon (Rhea, 1966). A dryline's gradient of dewpoint change may be as sharp as several degrees Celsius per kilometer. The May average for dewpoint change is 0.04 degrees Celsius per kilometer. (Hane et al., 1997).

There are three main factors in the development and maintenance of a dryline. The first factor is low level vertical wind shear, or changes in the winds as you move up through the atmosphere. The second factor is sloping terrain. This occurs naturally as you move eastward out of the Rockies. The last factor is a gradient in soil moisture. With all of these factors in place an initial atmospheric moisture gradient is not required. However it remains unknown how these factors create the moisture gradient. One theory is the differences in virtual potential temperature on each side of the dryline results in solenoidal forcing. Often, however there is at already some form of atmospheric moisture gradient present. (Shaw et al., 1997).

Dryline movement is heavily dependent upon diurnal variations in mixing and topography. During the morning hours surface heating allows for dry adiabatic conditions to occur and for dry air to mix downward. Resulting the drylines movement to be rapidly eastward in the late morning. At times the dryline may even appear to “jump” eastward in the late morning hours. In the afternoon into early evening slow progression, if any, occurs. This is due in part to the amount of heat necessary to invert the deepening moist layer as you move away from the Rockies and start to move over the down sloping regions of the High Plains in western Texas and Oklahoma. Overnight drylines tend to retreat westward and the pattern may start again the following day. (McCarthy and Koch 1981) According to Hane et al (2002) the most difficult part of forecasting thunderstorms along drylines is determining the best location along the line for deep convection and accurately forecasting the location of the dryline itself. In a study done by Hane et al (2001) they found that multiple moisture gradients can occur along a single dryline in different places along the line.

According to a study done by Crawford and Bluestein in 1997 found no correlation between the occurrence of deep cumulus convection occurring and the rate of dew point drop as a dry line moves eastward across a region. This study showed that each dryline behaves differently and most drylines do not fit into the “classic” dryline model.

Not all drylines are able to create deep convection. In the 1990’s it was found that at times even if conditions were favorable for deep convection to form, it simply did not occur even with small values of Convection Inhibition (CIN). Strong updrafts along drylines are often not a direct result of thermal turbulence, that is to say it isn’t about obtaining the necessary Convective Available Potential Energy (CAPE) to overcome CIN for a parcel to rise to the Lifted Condensation Level (LCL) or the Level of Free Convection (LFC). Instead they are forced externally by mesoscale circulations. While removing CIN is important for any deep convection events to occur it is not the only thing necessary along a dryline. Relaxing some of the assumptions of parcel theory, and by tweaking proximity soundings to account for the mesoscale lift and the effects of wind shear from the west we can improve the prediction of convective initiation at the dryline itself (Ziegler and Rasmussen 1998).

Convergence along the dryline is often much greater than would be expected from the interaction and confluence between two air masses. This convergence suggests that frontogenetical processes are occurring. This increases the potential for initiation of deep convection. Some suggested frontogentical mechanisms for this increased convergence include: symmetric instability, inland sea breeze effect, vertical transport of momentum, and waves. (Atkins 1998)

In this paper I hypothesize that if a dry line is present and storms are able to fire, the preferred area for initiation of severe storms is the area 50-250 kilometers north of the bulge.

2. Data and Methods

Surface plots for this study were obtained from the National Center for Atmospheric Research (NCAR) Warm Season Precipitation Episodes archive, Iowa State Meteorology data archives, and Unisys surface data archive. Storm Prediction Center (SPC) storm report archives were also used in this study. Surface data was looked at for late spring and summer months (April, May, June, and July). The area examined was the Southern Plains including the states of Texas, Oklahoma, Kansas, Easter New Mexico, and parts of Colorado, Nebraska, Arkansas, and Missouri where drylines are common during the time period studied. Data was looked at starting in 2009 and going back to 2005. This makes for a small sample size but the archives used were more complete for this time range yielding a more accurate representation of the surface data and therefore accurate representation of dryline locations. A total of 215 cases were gathered and examined.

Figure 1. Map of the area of interest in this study

The first step in the data collection was to look for signs of a dryline on the surface map and determine if there was one present and analyze where it is and how it progressed. To determine if a dryline was present surface dewpoint gradients and wind shifts were looked for on a map. If a gradient and wind shift were found analyzed surface maps were looked at to determine if there was another boundary present or if it was a dryline. Once the location of the dryline was established Storm Reports where looked for to figure out if the dryline had been able to produce significant storms. If there were no significant storms to report that particular dryline was skipped over. Storm report timestamps and locations were then examined to determine the time and the location of the first severe storm event associated with the dryline.

To determine what area along a dryline favors severe storm development the dry line was divided into regions. The first region is “At the Bulge” this is an area 50km North or South of the dryline. The next areas are “Just North of the Bulge” and “Just South of the Bulge” These areas go from 50km away from the bulge to 250 kilometers away from the bulge going northward and southward respectively. Past the 250 kilometer distance are the categories “Well North of the Bulge” and “Well South of the Bulge” respectively. The cut off points off 300 kilometers was used because this is a reasonable distance that a storm chaser might be able to move around in, and about the distance of a typical forecast area of a National Weather Service Office. After the categories were established, the location of the first storm report for each event was logged into one of the categories. A statistical analysis of this breakdown was completed.

3. Observations

For this study the locations of initial reports of severe storms were looked at and then placed into corresponding categories. There were 212 separate events looked at. The categorical breakdown of these events is shown in figure 2. Category 1 is the area at the bulge, Category 2 is Just North of the Bulge, Category 3 is Well North of the Bulge, Category 4 is Just South of the Bulge, and Category 5 is Well South of the bulge. Figure 1 shows that most instances of severe storm initiation occurred in the area just north of the bulge, followed by the area at the bulge and then the area just south of the bulge. No sever storm initiations occurred well south of the bulge.

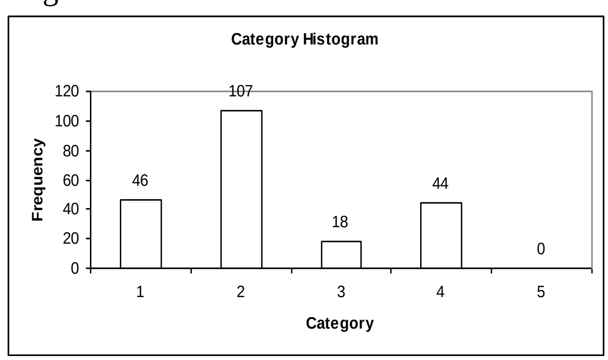

Figure 2. Category Histogram

Breaking the data into categories allows for a more in depth look at the data as well as a better understanding of the whole data set. For the purpose of these analyses zero was set to be the point where the most bulge was

Average Distances for Category 1	
Location	**Average (km)**
North	33.9
South	-33.4
Overall	9

Table 1. Shows the Average Distances for all events occurring under Category 1 (At the Bulge)

occurring, with distances to the north being positive and to the south being negative.

Along with looking at the location of the initial storm reports this study also looks at the location of the majority of the reports for each event and breaks them down in to the same categories. Also examined was where the majority of each type of storm report was found across all 215 cases.

a. Categorical Analysis

Category 1 had a total of 46 cases (from Figure 1). This makes up 21% of the total number of cases. This category is unique in that it consists of both distances north and south of the bulge. Figure 3 shows the breakdown of how many severe storm initiations occurred north of the bulge and how many south. From the Figure we can see that there are more instances of severe initiation north of the bulge (blue) than there are south of the bulge (red). If we look at average distances for North and South of the bulge respectively we get the data listed in Table 1. The average distances for instances north and south of the bulge are very close, but the overall average is to the north of the bulge due to the increased number of initiations found there.

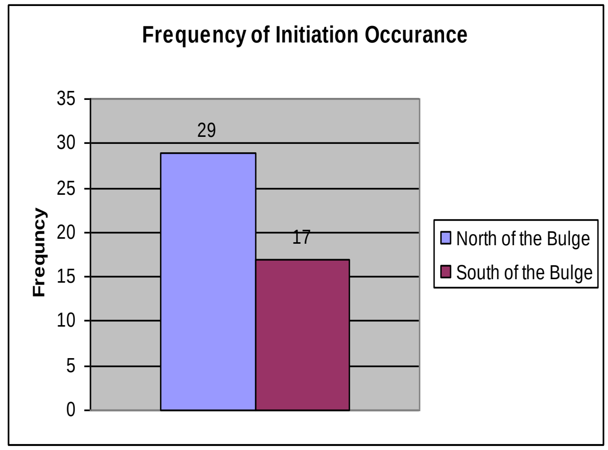

Figure 3. Initiation Frequency for Category 1

Category 2 is the area starting at 50 kilometers north of the bulge and extended to 250 kilometers north of the bulge. Figure 2 shows that this is the category that had the most instances of severe storm initiation with 107 cases. This accounts for 50% percent of the total number of cases studied and more than double the number of cases in any other category. The average distance away from the bulge for this area is 140 kilometers, which is almost the middle of this particular region. The median value for this category is 99.5 kilometers. Since the median is smaller than the mean (average) it can be stated that the distances further than 99.5 kilometers north are further away from the median than are the smaller distances Table 2 shows the average distances for the rest of the categories.

Average Distances for Categories 2-5	
Category	**Average (km)**
2	140.65
3	267.66
4	99
5	N/A

Table 2. Average Distance away from the bulge for Categories 2-5.

Figures 4 and 5 show the surface analysis and storm reports for May 6, 2007. The surface analysis is valid for 12z. Monitoring the development of the system and looking at the time stamps from the storm reports puts this particular case into Category 2.

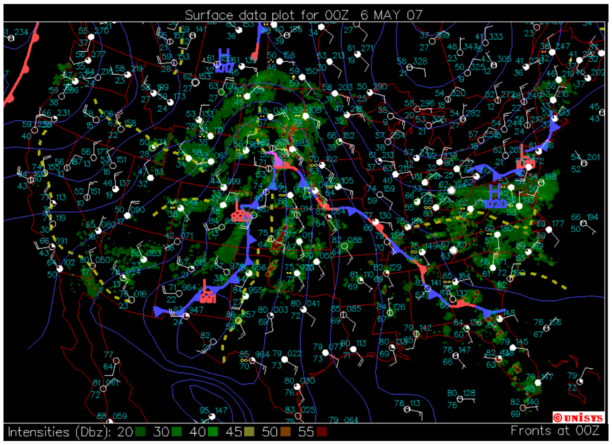

Figure 4. 12z Surface and Satellite Analysis for May 6th 2007

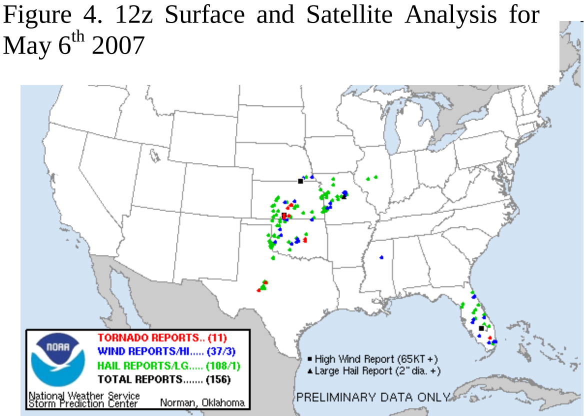

Figure 5. Storm Reports for May 6th 2007

Category 3 consists of anything over 250 kilometers north of the bulge. Figure 2 shows that just 18 cases occurred in this category. This accounts for only 8% of the total cases studied. The average distance away from the bulge for this area is 267.67 kilometers. The maximum distance away was 289 kilometers away.

Category 4 moves south of the bulge to the area 50-250 kilometers away from the bulge. This category had 44 cases accounting for 20% of cases. This category along with Category 1 The average distance and median distance in this category was 99 kilometers. This shows that the distances in this category were fairly evenly distributed across the range. The average for this region is closer to the bulge than the middle of the region, meaning most of the cases falling in this region were closer to the bulge rather than on the outskirts of this category. There were no cases falling into Category 5- Well South of the Bulge.

b. Overall Analysis

Figure 6 shows a density plot of the distances from all the cases examined. From this plot an eyeball would guess that the majority of initiations occurred within 275 kilometers on either side of the bulge. This figure also shows a much steeper decline to the south of the bulge. To the north of the bulge there is a much more gentile decline as you move away from the bulge. Figure 6 shows a histogram of all distances north and south of the bulge. This figure also shows the steep decline as you move south of the bulge with a more gradual taper to the north.

The average distance across all 215 cases studied was 76.48 kilometers with a median distance of 70 kilometers. The standard deviation is 124 kilometers. Which means that 68% of cases occurred in the range of 48 kilometers south of the bulge to 200 kilometers north of the bulge. Going out one more standard deviation shows that 95 percent of cases occurred within a range of 172 kilometers south of the bulge to 324 kilometers north of the bulge. Comparing these numbers to the density and distance histograms (Figure 6 and Figure 7) it is clear that they are in agreement. The mathematics also aligns fairly well with the earlier estimate of most cases occurring within 275 kilometers of the bulge.

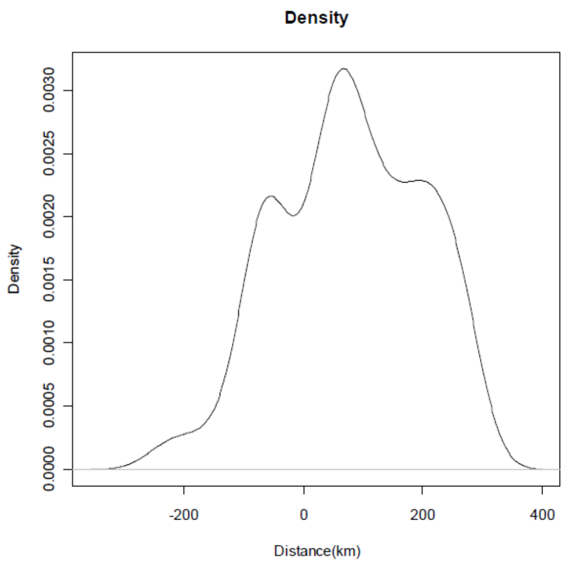

Figure 6. Density of Distances. Distances north of the bulge are positive while negative distances are south of the bulge.

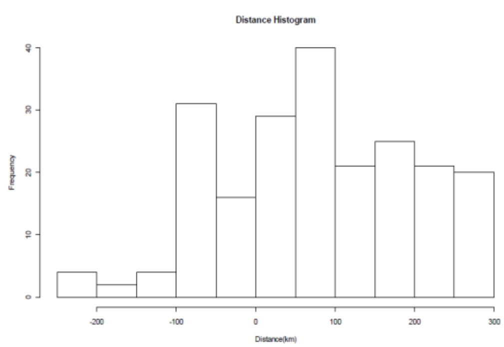

Figure 7. Distance Histogram Positive distances are those north of the bugle while negative distances are south of the bulge

c. Analysis of Total Storm Reports

In addition to looking at the initial storm report distance away this study also looked at the overall storm report distribution for each case, as well as a breakdown of each type of storm report and the distribution across the categories of each of these. In cases where the initial storm report was reported in the area just north of the bulge the majority of storm reports also fell into this category with a total of

This forecasting rule is especially useful for storm chasers so an area of particular interest was where the majority of tornado reports fell along the dry line. There were tornado reports all along the dryline including some reported well south of the bulge. Only 178 cases reported tornadoes, and of those 78% or 138 cases had most of the tornado reports occurred in the area classified as just north of the bulge. The other cases fell into the categories At the Bulge and Well North of the Bulge. Figure 8 shows the histogram of this breakdown.

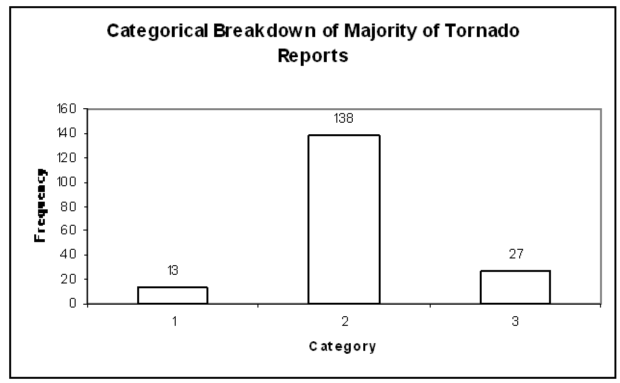

Figure 8. Categorical Breakdown of where the majority of tornado reports occurred for cases with tornado reports

Most of the distances put them very close to being classified into Just North of the Bulge. There were 13 cases where that fell into the At the Bulge category. The average distance for these was approximately 42 kilometers north of the bulge. The other 27 cases fell into the Well North of the Bulge category. The average distance for these cases was 275 kilometers north of the bulge. For a storm chaser traveling 300 kilometers on a day is not uncommon so being in the area just to the north of the bulge is still a good spot to be as you could travel those distances. Hail and wind events were reported all along the drylines from well north of the bulge to well south of the bulge. The hail and wind were much more evenly distributed. Figure 5 shows the reports for May 6th 2007. Hail was the most common report for this day and for 163 other cases as well. The other 51 cases had high winds as the most commonly reported event.

For hail and wind events the most common place for continued development was the category of initial severe development and the categories immediately to the north and south of that category. For instance if the initial storm report fell into the category At the Bulge the majority of the reports were in the area stretching from Just North of the Bulge to Just South of the Bulge, with more development being to the south. This is likely due to the preferential growth in this region. Thus wind and hail events are more common in the areas Just North of the Bulge, At the bulge and Just South of the Bulge than in the area well North of the Bulge. Figures 9 and 10 show the categorical histograms for hail and wind reports respectively. There are cases with a lot of hail and wind reports Well North of the Bulge, but these cases usually had the initial severe development there as well.

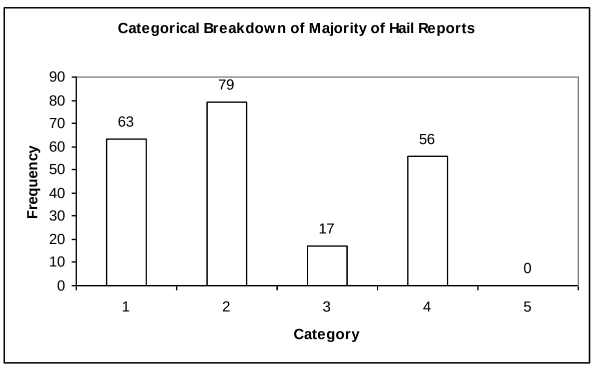

Figure 9. Categorical Breakdown of where the majority of hail reports fell for each of the 215 cases

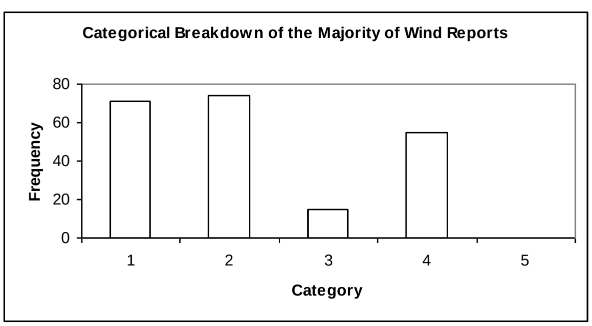

Figure 10 Categorical Breakdown of where the majority of wind reports fell for each of the 215 cases

4. Conclusion

In general the area within 200 kilometers on either side of the bulge is where most severe storms initiate, with the rate of declining cases being much steeper to the south than in the north. In general the area to the north is favored for severe storm initiation. Based on the data in this study it is clear that for the best area for severe storm initiation along a dryline is the area just to the north of the bulge. This area of 50-250 kilometers north of the bulge would be the ideal place for a storm chaser to be. The range of this area is a reasonable range for a storm chaser to travel around in, and about the size of a forecast region for the National Weather Service.

This region is not only favored for initial severe storm development but also prolonged development as well. The majority of tornado reports were found in this region. Hail and Wind events were also common in this region; however the overall favored region for hail was the area at the bulge. Based on the results of this study the hypothesis that severe storm initiation will occur in the region just north of the bulge is proven true.

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