P5.5 A Climatology of Severe Weather Reports as a Function of Convective System Morphology

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1. Introduction

Many attempts have been made to classify the morphologies of midlatitude convective systems. Parker and Johnson (2000) devised three main morphologies for linear convective systems: those with trailing stratiform, those with leading stratiform, and those with parallel stratiform rain. In addition, Bluestein and Jain (1985) proposed four different organizational modes for the formation of squall lines: broken line, broken areal, embedded areal, and backbuilding. Classification of storm morphology is important because different modes may behave differently and be dominated by different dynamics.

In addition, it has long been recognized that storms of different morphologies produce different types of severe weather events. As early as 1978, Fujita provided insights in to the development of bow echoes, and recognized that this type of storm was associated with the production of severe wind events. Supercell storms have long been recognized in the meteorological community as the most common producers of tornadoes. Using Parker and Johnson's classification scheme, Pettet and Johnson (2003) found that storms with leading stratiform and parallel stratiform morphologies played a role in flash flooding. A better understanding of the correlation between storm morphology and severe weather reports will allow for better forecasting of severe events during convective storms, and could lead to a better understanding of the behavior of convective storms.

2. Data and Methods

Using radar data from the UCAR warm season archive (http://locust.mmm.ucar.edu/episodes/), all convective storms that occurred over ten Midwestern states during the period between May 15, 2002 and August 31, 2002 were classified according to their predominant morphology. In order to be counted as a part of the dataset, a storm had to persist for at least one hour, had to attain a peak radar echo intensity of at least 30 dBZ, and had to be greater than approximately 6km by 6km in areal coverage. These criteria were selected due to the limitations on the spatial and temporal resolution of the radar data. Radar images were available at most once every 30 minutes, and were limited to approximately 2km by 2km horizontal resolution.

Storms were classified as cellular, non-linear, or linear. Cellular systems were those in which the strongest radar echoes were organized into discrete, individual cells. Cellular storms were subdivided into three morphologies: individual cells (with no weaker radar echoes connecting the cells), clusters of cells (connected by weaker radar echoes), and broken squall lines (where individual cells were arranged in a linear fashion). Linear systems were those in which the strongest radar echoes were organized in a connected, linear fashion at least 75 kilometers in length, at least three times as long as wide, with these criteria maintained for at least two hours. There were five morphologies that fell into the linear category, including three morphologies proposed by Parker and Johnson (2000): squall lines with trailing, leading, or line-parallel stratiform, as well as two other morphologies, squall lines without stratiform and bow echoes. Non-linear convective systems were those in which the strongest radar echoes were organized in a connected but non-linear fashion. Storms were classified according to the dominant morphology (over time) exhibited.

In addition, using data from the NCDC Storm Events Database, all the severe weather reports that occurred over the same time period were recorded, catalogued, and correlated with the storm systems that produced them. Categories of severe reports included Hail <1", Hail 1-2", Hail 2" or greater, Severe Wind <

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65 knots, Severe Wind ≥ 65 knots, Floods/Flash Floods, and Tornadoes. The purpose of this study is to determine whether there is a significant difference in the types and amounts of severe reports that are produced by convective storm systems having different morphologies.

There are several potential sources of error that should be noted that could affect the results of this study. First of all, only ten states were examined for just one summer. A larger sample size might provide more reliable results. Secondly, not all severe weather is reported, especially in sparsely populated regions, and not all reports that are filed are accurate. For example, the size of hail might be incorrectly reported, causing that report to be included in the wrong category. Finally, classification of morphology is somewhat subjective, and difficult at times. Even with strict objective guidelines defining each morphology, there are still storms that are so close to the border between morphologies that they might be classified in multiple ways.

3. Results

There were 748 separate storm systems that were identified over the time and area covered by this study. Cellular systems were most common, comprising 45% of all storms. Non-linear systems comprised 32% of storm systems, and linear systems comprised the remaining 23%. Non-linear convective systems were the most common of the 9 morphology categories given, while squall lines with leading stratiform rain were the rarest, occurring only five times during the period of observation. There were a total of 6683 severe reports produced by the 748 systems recorded. Cellular systems produced the most severe reports, accounting for 41% of severe weather reports. Linear systems, though they comprised only 23% of observed storm systems, produced 36% of severe weather reports. The remaining 23% of severe reports were caused by non-linear convective systems.

When the results are broken down according to type of severe report, additional observations can be made. First, however, we must define a basis for comparison that accounts for the fact that the number of occurrences of different morphologies varied widely. There were over 200 occurrences of individual cells, but just five occurrences of squall lines with leading stratiform rain. Because of this variation, it is sensible to normalize the number of severe reports observed for each morphology by the number of occurrences of that morphology to arrive at a number of severe reports per case.

In the following charts, different morphologies are denoted by the following abbreviations: NL = Non-linear systems, IC = Individual cells, CC = Clusters of cells, BL = Broken squall lines, NS = Squall lines with no stratiform, TS = Squall lines with trailing stratiform, LS = Leading stratiform, PS = Line-parallel stratiform, and BE = Bow echoes.

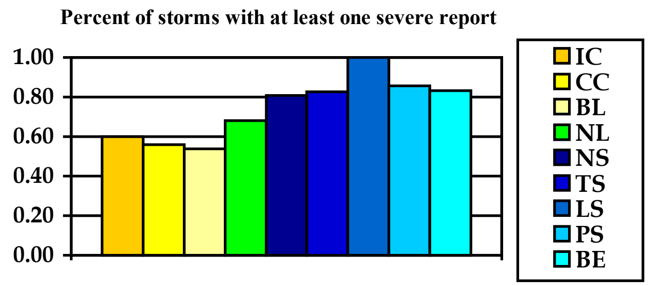

Figure 1: Percentage of storms with at least one severe report, organized by morphology.

From the data in Figure 1, we can see that more linear storms, 83%, had at least one severe report, than non-linear (68%) and cellular (58%) storms. The tendency for cellular storms to appear less severe is likely a result of the fact that non-linear and linear storms are far larger in areal coverage than cellular storms, and thus have a much greater area in which to accumulate at least one severe report. Also notable is the fact that all observed cases of squall lines with leading stratiform (LS) had at least one severe report.

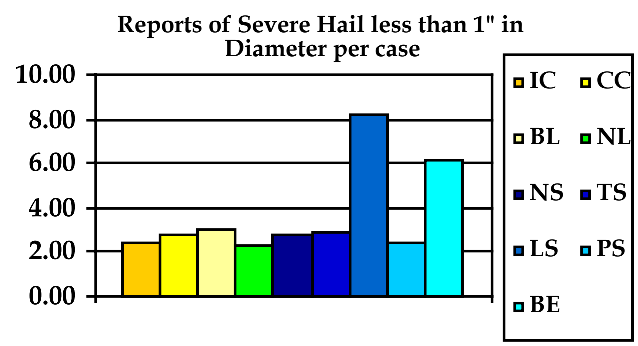

Figure 2: Reports of severe hail less than 1” in diameter per case, sorted by morphology.

Figure 2 shows that the most reports per case of hail less than 1” in diameter were observed in squall lines with leading stratiform (LS) rain and in bow echoes (BE). Squall lines with leading stratiform rain had 8.20 reports per case, and bow echoes had 6.17; no other morphology had more than 3 reports per case. An important consideration to keep in mind when interpreting this result is the fact that only five squall lines with leading stratiform rain were observed. This small sample size casts doubt on the generality of the results for LS storms.

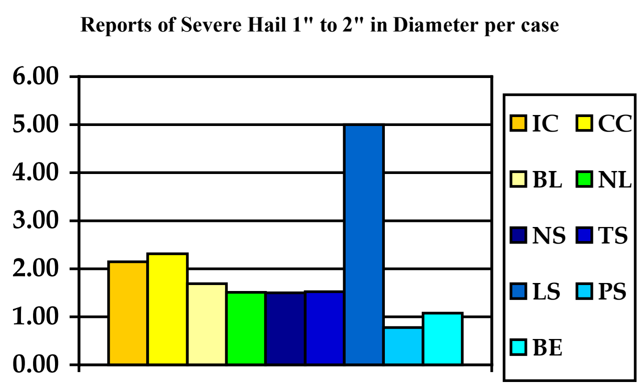

Figure 3: Reports of severe hail1" to 2" in diameter per case, sorted by morphology.

For severe hail 1" to 2" in diameter (Fig. 3), squall lines with leading stratiform (LS) rain once again had the most reports per case. LS storms had 5.00 reports per case, while no other morphology had more than 2.5. It should again be noted that only five LS storms were observed, so that the result should be interpreted cautiously.

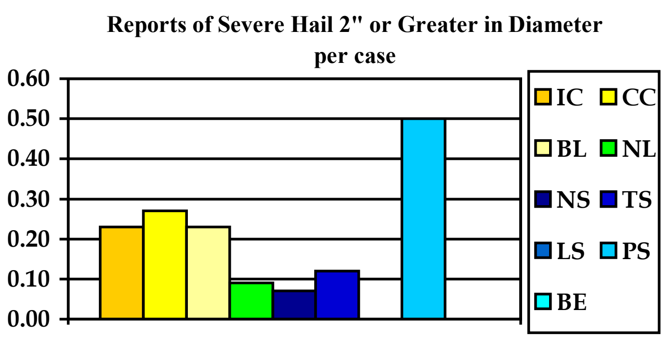

Figure 4: Reports of severe hail 2" or greater in diameter per case, sorted by morphology.

Figure 4 shows the number of severe reports per case of severe hail 2" or greater in diameter for each morphology. Squall lines with line-parallel stratiform (PS) had the greatest number of reports per case, 0.50. Also, storms having all three cellular morphologies had considerable numbers of reports per case. Note that squall lines with leading stratiform rain (LS) and bow echoes (BE) had no reports of hail 2" or greater in diameter within the domain of this study.

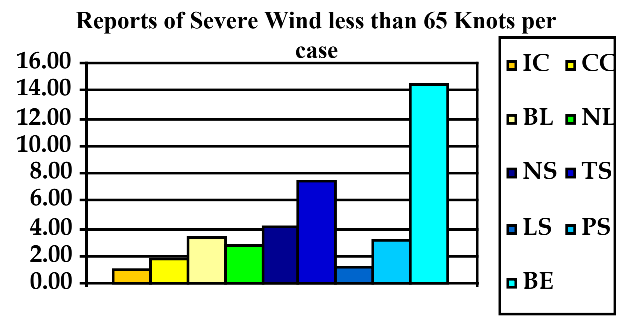

Figure 5: Reports of severe wind less than 65 knots per case, sorted by morphology.

The results for reports of severe wind less than 65 knots are shown in Figure 5. Bow echoes (BE) clearly dominate in this category, with 14.50 reports per case, nearly twice as many reports per case as any other morphology. This result corresponds well with the longstanding traditional perception of bow echoes as prolific wind producers (Fujita, 1978). Squall lines with trailing stratiform (TS) rain also had a large number of wind reports (7.35). A possible explanation for the large number of reports for this morphology is that trailing stratiform systems often have well-developed rear-inflow jets which can transfer momentum toward the surface. The results for reports of severe wind 65 knots or greater in magnitude (Fig. 6) were very similar to those for severe wind less than 65 knots.

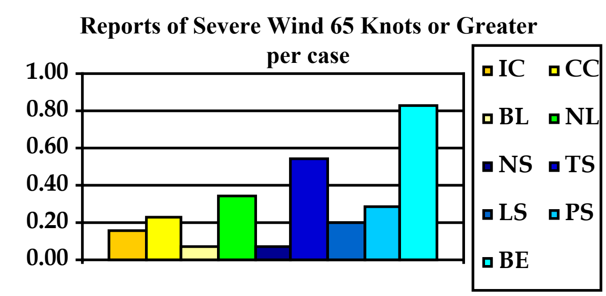

Figure 6: Reports of severe wind 65 knots or greater per case, sorted by morphology.

As shown in Figure 7, two different linear morphologies had the greatest number of reports of flooding per case. These morphologies were squall lines with line-parallel stratiform (PS) rain, with an average of 5.00 reports per case, and squall lines with trailing stratiform (TS) rain, with an average of 3.22 reports per case. Interestingly, another linear morphology, squall lines with line-forward stratiform (LS) rain had no reports of flooding at all. Broken squall lines (BL) also had no reports of flooding.

The fact that there was such a marked difference between different linear morphologies suggests that the location of the stratiform rain in relation to the squall line is very important in predicting flooding potential. In cases of squall lines with line-parallel stratiform rain, winds aloft are generally rather strong and parallel to the line; this wind profile is necessary to cause stratiform rain to be blown in a direction parallel to the line. This also suggests that training cells, likely steered by these strong line-parallel upper-level winds, may be a cause of flooding in these cases. In cases of squall lines with trailing stratiform rain, the often very large area of stratiform rain behind the squall line can cause heavy rainfall totals and induce flooding. Leading stratiform rain cases likely occur with strong rear-to-front flow aloft that would likely increase the speed of movement of these systems, minimizing any flood threat.

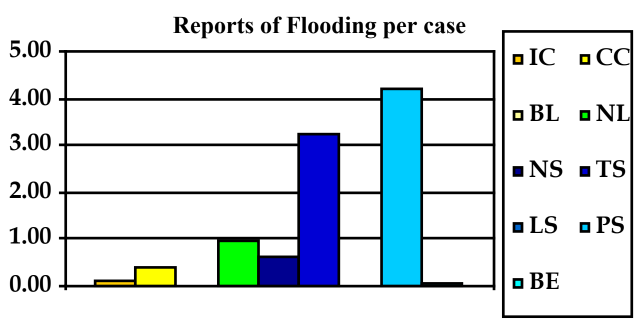

Figure 7: Reports of flooding (of any kind) per case, sorted by morphology.

When the distribution of tornado reports (Fig. 8) is examined, two morphologies have particularly high numbers of reports per case. Squall lines with leading stratiform (LS) had an average of 1.00 reports per case, and broken squall lines (BL) had 0.92 reports per case. The LS value should be interpreted cauitiously, however, because only five LS storms were observed, and of the five tornadoes reported in these storms, four were in a single case. If this case were removed from the study, LS storms would have only 0.25 reports per case, a value that compares well to the other linear morphologies.

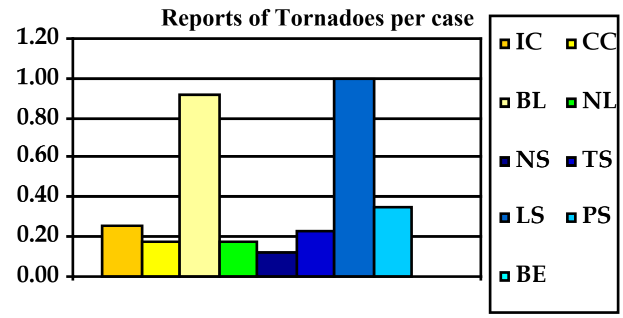

Figure 8: Reports of tornadoes per case, sorted by morphology

Another interesting result is the stark difference between clusters of cells (CC) and broken squall lines (BL). Both of these morphologies generally consisted of multiple cells, and had comparable areal coverage. When compared to clusters of cells, though, broken squall lines had nearly five times as many reports per case of tornadoes. This may suggest that the zones of light stratiform rain connecting the cells in CC storms may in some way inhibit tornado formation.

One might expect that individual cells (IC) would have the most reports of tornadoes per case, but this morphology has relatively few, only 0.25. There are several possible causes for this. First of all, individual cells are often much smaller in areal coverage than all the other morphologies, sometimes involving only a single, short-lived cell. Also, many airmass thunderstorms, which are quite unlikely to produce tornadoes, fell into this morphology, likely decreasing the observed number of reports per case. Finally, it should be noted that individual cells did have the most total reports of tornadoes, but were so numerous that relatively few reports per case resulted.

4. Conclusions

From the data presented in this study, it can be concluded that significant differences exist between the types and numbers of severe reports in storms of different morphologies. These differences are especially pronounced for severe wind and flooding, but are also noticeable for severe hail and tornadoes.

Also, no morphology of convective storm is without a severe threat – all morphologies were observed to have at least some reports of severe weather.

In non-linear storms the greatest threats appear to be small hail, flooding, and marginally severe wind. Of the three types of storms (linear, non-linear, and cellular), non-linear produced the fewest reports of hail overall, and tended to have fewer severe reports than any other category of storms. The single biggest threat with this type of storm appears to be flooding.

For linear storms, the biggest threats are small to moderate hail, flooding, and severe wind. Of these threats, the single greatest threat appears to be severe wind. In linear storms, severe wind was observed to be most likely in bow echoes and squall lines with trailing stratiform rain. Bow echoes produced especially high numbers of severe wind reports per case. Flooding in linear storms was observed to be most likely to occur in squall lines with line-parallel or trailing stratiform rain. The location of the stratiform rain appears to be important in predicting flooding potential, as squall lines with line-forward stratiform produced no reports of flooding at all during the period of this study. The results also indicate that tornadoes may be a threat in squall lines with line-forward stratiform rain, but additional study would be needed to confirm this, since only five storms of this morphology were observed. It would be interesting to see if isolated cells that may have formed in front of the squall line and later ended up embedded within the stratiform rain produced the tornadoes.

Cellular storms appear to present two major threats: hail, ranging in size from small to huge, and tornadoes. The most reports of tornadoes per case occurred when cells were organized in a broken squall line, and relatively few tornado reports were observed when cells were organized in clusters. Also, when organized as a broken squall line, marginally severe winds were also observed to be a threat. Of the three cellular morphologies, broken squall lines tended to produce the most severe reports per case.

When interpreting the results, areal coverage of the storm system should also be taken into account. Cellular storms with relatively few severe reports per case should not be viewed as less dangerous than linear or non-linear storms with more reports per case, because cellular storms cover such a small area compared to linear and non-linear storms. Because the reports are concentrated in such a small area, any given point affected by a cellular storm may actually be more likely to receive severe weather than any given point affected by a linear or non-linear system.

Several areas of additional research could be done to enhance the results of this study. First of all, additional years could be analyzed to expand the database of observations and obtain a larger sample size. Secondly, model output could be studied to determine how accurately various numerical weather prediction models predict storms of various morphologies, similar to the work done by Grams et al (2004). In addition, a study could be conducted to determine whether or not storm morphology can be linked to geographical location; that is, to determine whether or not certain morphologies of storms are more likely in some geographical regions than others.

5. Acknowledgments

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6. References

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