P2.8 Severe Weather Reports as a Function of Convective System Morphology

William A. Gallus, Jr., Nathan Snook, and Elise V. Johnson

Iowa State University

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 April 1, 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. Examples of the 9 classifications used are shown in Fig. 1.

Because the number of linear systems having either line-parallel or leading stratiform rainfall was small over the ten Midwestern states during the 2002

Corresponding author address: William A. Gallus, Jr., ISU, 3010 Agronomy Hall, Ames, IA. Email: wgallus@iastate.edu.

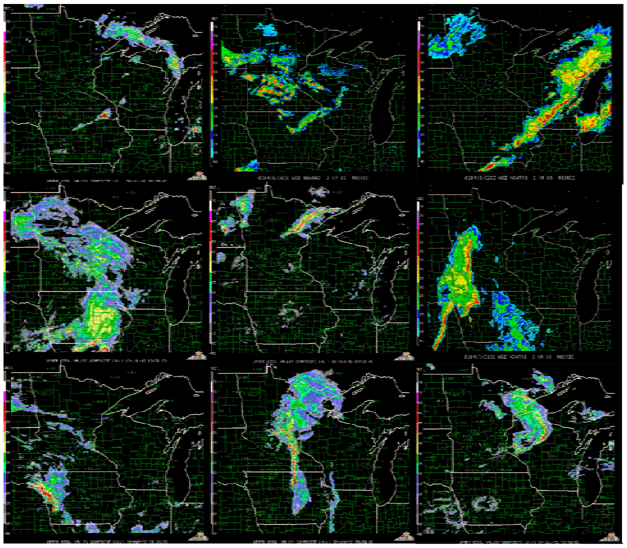

Figure 1: Radar images from cases demonstrating the 9 different convective morphologies used in the study. Top row shows individual cells (left), clusters of cells (center) and broken squall line (right). Middle row shows nonlinear system (left), squall line without stratiform rain (center), and squall line with trailing stratiform rain (right). Bottom row shows squall line with leading stratiform rain (left), line-parallel rain (center) and bow echo (right).

period, this data set was supplemented by including a total of 24 linear systems having line-parallel and leading stratiform rainfall during 1996 and 1997, identified by Parker and Johnson (2000) in the same 10 state region.

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 < 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.

A few limitations of the present study should be noted. First, only ten Midwestern states were examined, and primarily for just one summer. Despite these spatial and temporal limitations, over 900 different systems were identified. Nonetheless, a larger sample size might be needed to generalize the results, particularly to other geographic regions. Second, 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 may exhibit two or more morphologies so making classification difficult.

3. Results

There were 925 separate storm systems that were identified over the time and area covered by this study. Cellular systems were most common, comprising 50% of all storms. Non-linear systems comprised 29% of storm systems, and linear systems comprised the remaining 21%. Non-linear convective systems were the most common of the 9 morphology categories given, while squall lines with leading stratiform rain and bow echoes were the rarest, occurring only 16 times in the dataset. There were a total of 9678 severe reports (meeting Storm Prediction Center criteria for hail size, wind speed, or tornado) produced by the 925 systems recorded, with 1122 flooding reports. Cellular systems produced the most severe reports, accounting for 46% of severe weather reports. Linear systems, though they comprised only 24% of observed storm systems, produced 35% of severe weather reports. The remaining 19% of severe reports were caused by non-linear convective systems. Of the 9 specific morphologies examined, clusters of cells produced the largest total of severe weather events, followed closely by nonlinear systems and isolated cells. Flooding events were dominated by nonlinear systems, with trailing stratiform linear systems next in importance.

When the results are broken down according to type of severe report, additional observations can be made. First, however, a basis for comparison must be defined that accounts for the fact that the number of occurrences of different morphologies varied widely. There were nearly 250 occurrences of individual cells, but just 16 occurrences each of squall lines with leading stratiform rain and bow echoes. Because of this variation the number of severe reports observed for each morphology was normalized by the number of occurrences of that morphology to arrive at a number of severe reports per case. Although this normalization helps in some ways to better convey the risk of severe weather from a particular morphology, it must be noted that the great variations in areal coverage among the storm types also must be considered. Normalization by area would provide additional information to help convey the risk, but such normalization would require a huge amount of additional time and was beyond the scope of this study. One should keep in mind while interpreting the results that follow that cellular systems are much smaller in scale than (areal coverage often less than 10% of) linear and nonlinear systems.

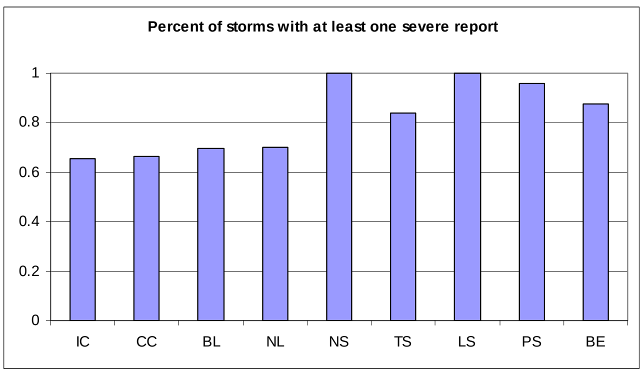

Figure 2: Percentage of storms with at least one severe report, organized by morphology with IC = Individual cells, CC = Clusters of cells, BL = Broken squall lines, NL = nonlinear systems, NS = squall lines with no stratiform, TS = squall lines with trailing stratiform, LS = leading stratiform, PS = line-parallel stratiform, and BE = bow echoes.

From the data in Figure 2, we can see that more linear storms, 91%, had at least one severe report, than non-linear (70%) and cellular (66%) storms. The tendency for cellular storms to appear less severe is likely a result of their much smaller areal coverage. Also notable is the fact that all observed cases of squall lines with leading stratiform (LS) and no stratiform rain (NS) had at least one severe report.

Figure 3 shows that the most reports per case of hail less than 1” in diameter were observed in bow echoes (BE) and broken lines. Bow echoes averaged 9.88 reports per case, and broken lines 8.34. Of the linear types of systems, the largest hail frequency was in line-parallel stratiform cases, followed by leading stratiform, trailing stratiform, and finally no stratiform rain. These results differ slightly from Snook and Gallus (2004) who had found the largest frequency of small hail to be in linear systems with leading stratiform rain. However, that study correctly surmised that the small number of these events may have led to that conclusion. The addition of more of these types of events reduced the frequency, although it still remains above the average for all events.

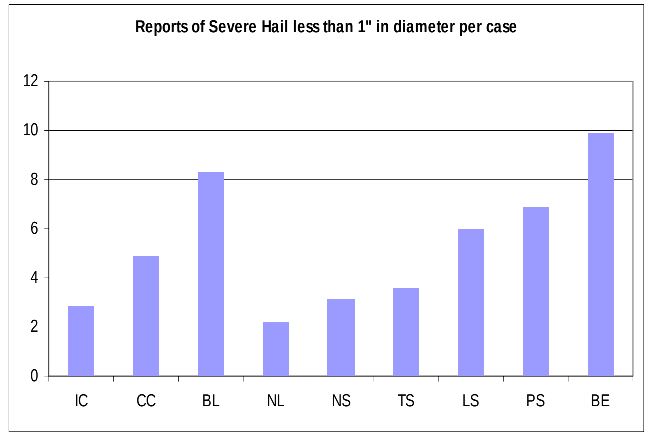

Figure 3: Reports of severe hail less than 1” in diameter per case, sorted by morphology.

For severe hail 1” to 2” in diameter (Fig. 4), broken lines clearly dominated with the most events per case (8.3). LS and PS storms had between 5 and 6 reports per case, while no other morphology had more than 4.

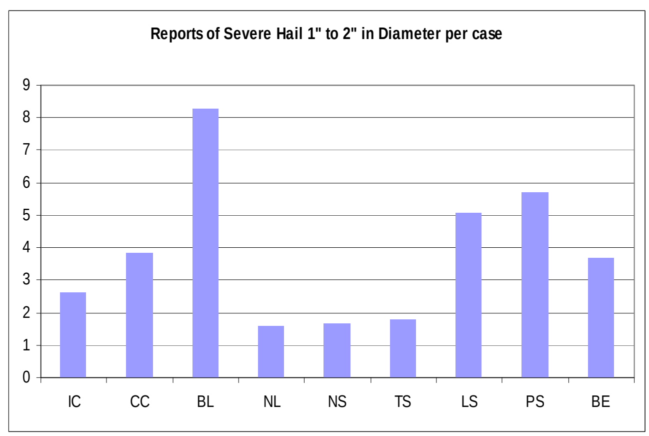

Figure 4: Reports of severe hail1” to 2” in diameter per case, sorted by morphology.

Figure 5 shows the number of severe reports per case of significantly severe hail (2” or greater in diameter) for each morphology. Surprisingly, squall lines with line-parallel stratiform (PS) had the greatest number of reports per case, 0.83. Apparently linear systems frequently generate smaller sized severe hail but have difficulty generating hail larger than 2 inches in diameter, whereas cellular convection has less difficulty generating the largest hail. This result is especially evident for bow echoes (BE) which had no reports of hail 2 inches or greater in diameter within the domain of this study, despite having the highest frequency of severe hail less than 1 inch in diameter. In general, a relative minimum in hail frequency was present for nonlinear systems, and linear systems with trailing stratiform rain, or no stratiform rain.

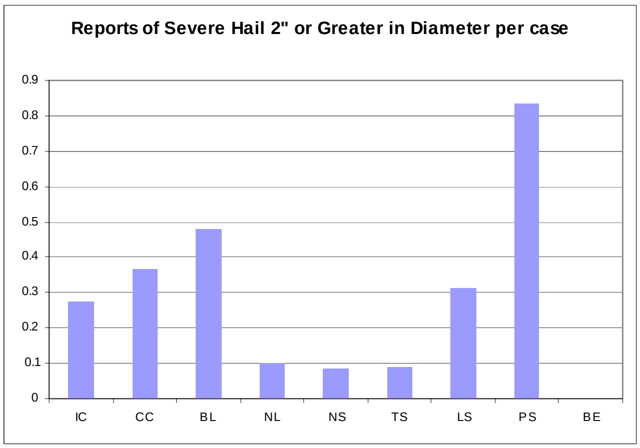

Figure 5: Reports of severe hail 2” or greater in diameter per case, sorted by morphology.

The results for reports of severe wind less than 65 knots are shown in Figure 6. Bow echoes (BE) clearly dominate in this category, with 18.56 reports per case, over twice as many reports per case as the next most active morphology, squall lines with trailing stratiform rain (7.92). This result corresponds well with the longstanding traditional perception of bow echoes as prolific wind producers (Fujita, 1978). A possible explanation for the large number of reports for the TS 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. 7) were very similar to those for severe wind less than 65 knots.

As shown in Figure 8, 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 3.75 reports per case, and squall lines with trailing stratiform (TS) rain, with an average of 3.04 reports per case. Flood frequency was much less for linear systems lacking stratiform rain. Broken lines (BL) in the present study were fairly substantial flood producers, unlike the Snook and Gallus study where no flooding had been found with this morphology. The present results suggest that in 2002, springtime broken line events were often associated with flooding but not summer events. As might be expected due to their small size, the other two cellular morphologies had the smallest frequency for flood reports.

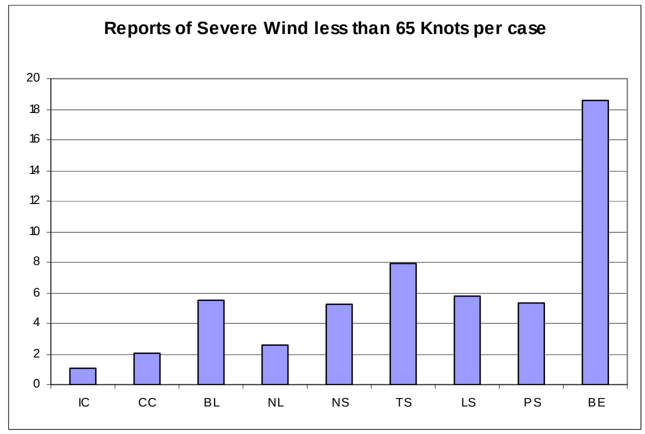

Figure 6: Reports of severe wind less than 65 knots per case, sorted by morphology.

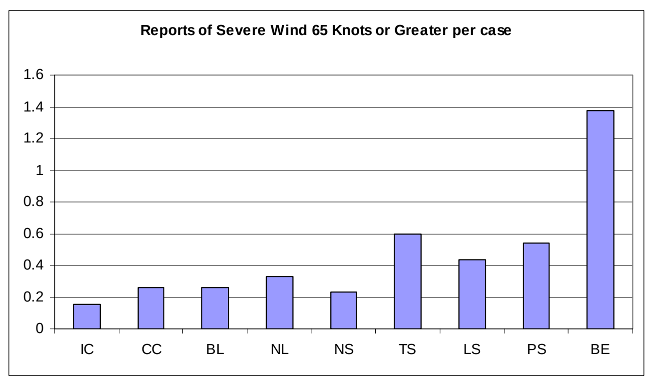

Figure 7: Reports of severe wind 65 knots or greater per case, sorted by morphology.

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, reducing the flood threat. It is unknown why linear systems lacking stratiform rain have the least likelihood of producing flooding, although the total rain volume produced by the systems may be less due to the absence of the stratiform rain.

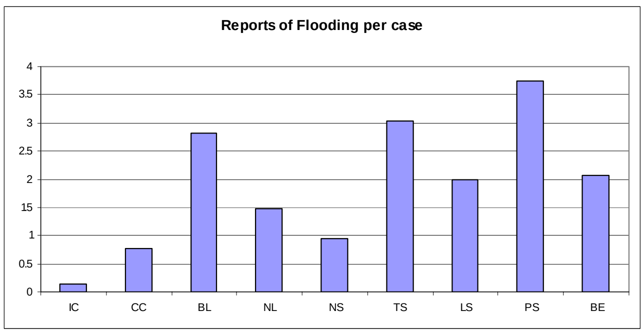

Figure 8: Reports of flooding (of any kind) per case, sorted by morphology.

When the distribution of tornado reports (Fig. 9) is examined, two morphologies have particularly high numbers of reports per case. Squall lines with line-parallel stratiform (PS) had an average of 1.79 reports per case, and broken squall lines (BL) had 1.61 reports per case. 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 0.43. 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. As with the larger hail sizes, the NL, NS and TS systems had the smallest frequency of tornadoes.

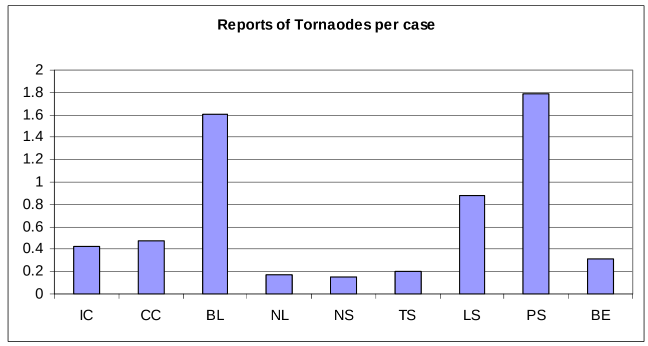

Figure 9: Reports of tornadoes per case, sorted by morphology

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. 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 broader types of storms (linear, non-linear, and cellular), non-linear tended to have fewer severe reports than any other category of storms.

For linear storms, all types of severe weather were a threat, but the frequencies depended greatly on the specific type of linear system. Overall, the single greatest threat appears to be severe wind which was most likely in bow echoes and squall lines with trailing stratiform rain. Bow echoes produced especially high numbers of severe wind reports per case. Hail reports were common, especially in bow echoes, and lines with line-parallel or leading stratiform rain. Flooding in linear storms was observed to be most likely to occur in squall lines with line-parallel or trailing stratiform rain. The presence and location of the stratiform rain appears to be important in predicting flooding potential, as squall lines with no stratiform rain or leading stratiform rain had noticeably less reports of flooding during the period of this study. Tornadoes are a greater threat in linear systems with line-parallel and leading stratiform rain than in other types of linear systems. The environments leading to this type of structure may contain greater wind shear, such that embedded supercells are more likely to occur.

Cellular storms appear to present two major threats: hail of all sizes, and tornadoes. The most reports of tornadoes per case occurred when cells were organized in a broken squall line. The flood threat was surprisingly high for this type of cellular convection as well. Of the three cellular morphologies, broken squall lines tended to produce the most severe reports per case. This result is partly related to the larger areal coverage of this type of system compared to an individual cell. However, the clusters of cells generally had similar areal coverages and yet produced fewer severe reports for most categories.

When interpreting the results, areal coverage of the storm system must 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 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 should be done to enhance the results of this study. First, additional years should be analyzed over a wider geographical area to expand the sample size and determine the generality of the results. Second, 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 (2006) which focused on rainfall alone. In addition, further work could be conducted to determine whether or not certain morphologies of storms are more likely in some geographical regions than in others.

5. Acknowledgments

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6. References

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