8B.6 A DETAILED ANALYSIS OF SPC "HIGH RISK" OUTLOOKS, 2003-2009

Jason M. Davis*[1], Andrew R. Dean[2], and Jared L. Guyer[2]
1 – Valparaiso University, Valparaiso, IN
2 – NOAA/NWS Storm Prediction Center, Norman, OK

1. INTRODUCTION

"High Risk" (HR) convective outlooks issued by the NOAA/NWS/Storm Prediction Center (SPC) are reserved for events that only occur a few days per year when all the ingredients for a high impact severe weather outbreak are expected to be present. On these days, forecasters have high confidence that there will be multiple tornadoes, some significant (EF2 or greater) over a concentrated area, creating a life-threatening situation in which serious property damage can also be expected. It is important that HR outlooks are not false alarms so that the affected public, emergency managers, and forecasters at local forecast offices do not become complacent and stray from the heightened level of alert required on HR days.

A HR outlook is issued when SPC forecasters determine that there is a 30 percent or greater probability of a tornado occurring within 25 miles of a point inside the outlook area (or a 25 percent probability for outlooks prior to 2006). It is almost always accompanied by a 10 percent probability of a significant (EF2 or greater) tornado occurring within 25 miles of a point. While HR outlooks may also be issued when there is a threat of widespread damaging wind gusts, this study focuses on only HRs that were issued due to the threat of widespread tornadoes.

This study looks at HRs issued during the period 2003-2009, when outlook, tornado report, and convective environment data are all available for study. A "climatology" of HRs for this period is presented, based on frequency, geographic distribution, and the progression of outlook upgrades leading up to the issuance of a HR. The verification of all HR outlooks is presented, along with differences in verification and environment based on geographical region, outlook issuance time, and season. The environment data will be used to attempt to determine why some outlooks did not verify as expected. The convective environments for tornado reports in HRs will be compared to the environments for tornado reports in other types of categorical risk areas in order to determine if any meaningful differences exist between these environments. Finally, a report clustering technique will be used to determine how many tornadoes that occurred in a sufficiently large area with at least 25% coverage were captured in a HR.

2. METHODOLOGY

Data was taken from the SPC's severe weather forecast verification database (Dean et al. 2006). This includes the date, issuance time, state location of the HR centroid, tornado probability forecast, and outlook size based on the number of affected grid points (40 km resolution) for each tornado-based HR outlook issued by SPC. The number of grid points covered at some point during the duration of the HR by a severe weather watch were also included, as well as the number of grid points that had a severe weather report (from *Storm Data*) within 40 km (25 mi). Finally, the area covered by severe weather warnings was computed, as well as the number of grid points that had lightning within 25 miles of the point using lightning data from the National Lightning Detection Network (NLDN).

Severe weather report coverage was calculated as the fraction of all grid points in the HR outlook that had a severe weather report within 40 km. Severe weather warning coverage was calculated based on the percentage of the area of the HR outlook that was covered by a severe weather warning at some point during the HR.

The convective environment data was taken from hourly SPC mesoscale analysis data (SfcOA) (Bothwell et al. 2002). Three different values for each parameter were calculated. The first was a mean value for the duration that a grid point was near a lightning strike, averaged over all the grid points. The second was the same except for the duration that a grid point was near a severe thunderstorm warning, and the third for tornado warnings. Environments at the grid point closest to a tornado report for all types of categorical risks were also used in the analysis.

In order to determine which tornado reports were concentrated enough to have potentially been in a high risk, a report clustering method was used, as described in Dean (2010).

3. CLIMATOLOGY

During the period 2003 to 2009, there were 100 HR outlooks issued on a total of 29 HR days. There was a median of five HR days per year, ranging from 2 in 2009 to 7 in 2003 (Fig. 1), showing that these are relatively rare events. HR outlooks occurred mainly in the spring. May was the peak month for HR days (Fig. 2), which is during the peak of severe weather season when strong instability and shear are most likely to coincide. Using the same regional subdivisions as used in Thompson et al. (2008), the Southern Plains were the most likely to have a HR, followed by the Southeast, the Midwest, and the Northern Plains (Fig. 3).

* *Corresponding author address:* Jason Davis, 2224 East 45th Street, Davenport, IA 52807; e-mail: Jason.Davis@valpo.edu.

The forecast evolution of outlooks leading up to the issuance of a high risk was also studied. The analysis focused on the highest risk level in place at each forecast lead time, but did not consider grid-point level changes in the area covered by the outlook. The Day 3 convective outlook always included at least a slight risk, so the potential for severe weather was always known at this point. Three HR days had enough confidence for a moderate risk on Day 3 (Fig. 4). HR days were most likely to be upgraded to a moderate risk on the Day 2 0600 UTC outlook, though some were still a slight risk until they were upgraded to a moderate risk on the 0600 UTC Day 1 outlook.

One HR day was upgraded to a high risk on the 1730 UTC Day 2 outlook, the only time this has ever been done, but HR days were most likely to be upgraded at either 0600 UTC or 1300 UTC on Day 1 (Fig. 5). However, in some cases the upgrade did not come until later due to forecast uncertainty.

Sometimes it is determined that a HR outlook no longer is needed once it has been issued, either due to a change in convective mode and loss of daytime heating which diminishes the tornado threat, or when a concentrated area of tornadoes fails to occur. HR downgrades tend to occur most often in the 0100 UTC Day 1 outlook (Fig. 6).

4. VERIFICATION

Outlooks were evaluated based on the high risk criteria in effect when they were issued, which was 25% coverage for 2003-2005 and 30% coverage for 2006-2009. On 62 percent of HR days, at least one HR outlook verified as a high risk for tornadoes, and 64 percent of all HR outlooks issued (including multiple outlooks in one day) verified as a high risk (Fig. 7). 81 percent of all HR outlooks verified as either a high or moderate risk (15 percent or greater tornado coverage). However, 11 percent of HR outlooks issued verified less than a slight risk (less than five percent tornado coverage), and seven percent did not even verify as a tornado risk area (less than two percent tornado coverage). Two HR days did not have any HR outlooks verify as a tornado risk area.

HR outlooks that verified less than a slight risk (less than five percent tornado coverage) were examined in greater detail. 64 percent of these were 0100 UTC outlooks. Often in these cases the convective mode had partially or totally transitioned from discrete supercellular structures into linear or MCS structures, diminishing the tornado threat and increasing the damaging wind threat. However, strong shear was usually still present such that some significant tornado threat remained, causing forecasters to maintain the high risk. Environment data for these cases shows increased convective inhibition and decreased instability that may have suppressed the development of tornadoes, but also strong shear that could allow tornadoes to develop in the window of opportunity before the diminishing thermodynamics and changing convective mode decreased the threat.

Tornado warning coverage in HRs was also studied. While tornado warnings do not verify HRs, we wanted to determine whether or not high risks that did not verify for tornado reports had storms with low-level rotation that posed a threat of tornadoes. 73 percent of HR outlooks issued met the equivalent high risk threshold for tornado warnings, which is nine percent more than the number of HRs that verified for tornado reports (Fig. 8). 90 percent of HR outlooks issued met the equivalent high or moderate risk threshold for tornado warnings, suggesting that almost all HR forecasts were correct in identifying the environments conducive for a concentrated outbreak of tornadoes. Five percent of HR outlooks still had less than five percent coverage of tornado warnings, however.

5. COMPARISON OF HR ENVIRONMENTS

Convective environments were compared between HR outlooks that verified as high risks (25%/30% coverage), moderate risks (15-25% coverage), or less than moderate risks (< 15% coverage). In this case, the environment parameters were averaged for all convection in the outlook area rather than just the tornado warning environments.

There appears to be a correlation between instability and how well an outlook verified, as outlooks that verified as high risks tended to have higher MLCAPE values (median MLCAPE of 1520 J/kg) than those that verified less than a moderate risk (median MLCAPE of 673 J/kg), though there were low CAPE, high shear environments that did verify as high risks (Fig. 9). While large MLCAPE is not necessary for the development of tornadoes, it appears that it may be beneficial for widespread coverage of tornadoes.

There is no apparent correlation between the amount of shear present and how well a HR outlook verified (Fig. 10). Shear was always high in HR outlooks; inadequate shear was not a reason that a HR outlook did not verify. Shear can be easier to forecast than instability, due to cloud cover affecting surface heating, so it would be expected that HR outlooks would tend to not verify due to a lack of instability rather than a lack of shear.

Overall, thermodynamics appear to play an important role in determining whether or not a HR outlook will verify, though other factors such as convective mode and storm interactions that cannot be captured using the environment data also play an important role.

6. COMPARISON OF VERIFICATION AND ENVIRONMENTS BETWEEN DIFFERENT HR OUTLOOK TIMES

The progression of outlooks leading up to the issuance of a HR was also studied to compare high risks that verified with those that did not. No correlation could be found between how well a HR verified and whether or not an HR day was a moderate risk on the Day 2 or Day 3 outlook. However, HR days when an outlook was upgraded to a high risk earlier during Day 1 tended to verify better than lower confidence days when an upgrade did not come until later in the day. 83 percent of HR days that upgraded to a high risk by the 1300 UTC Day 1 outlook had at least one outlook verify as a high risk, with no HR days verifying less than a slight risk (Fig. 11). For HR days that upgraded to a high risk at 1630 UTC, 2000 UTC, or 0100 UTC, however, only 27 percent of these days had at least one outlook verify as a HR, and two of these days did not have any HR outlook verify even as a slight risk for tornado coverage (Fig. 12). When all outlooks are considered, 0600 UTC and 1300 UTC HRs were most likely to verify (Fig. 13).

There was a particularly noticeable decline in verification for the 0100 UTC outlooks, with only 35 percent of these outlooks verifying as a high risk, suggesting that the loss of daytime heating and/or change in convective mode from supercellular to linear and MCS convective modes during the evening diminished the tornado threat (Fig. 14). 65 percent of 0100 UTC outlooks verified as a high or moderate risk, and 25 percent of 0100 UTC outlooks did not verify as a tornado risk area, with less than 2% coverage. When looking at tornado warning coverage, however, 65 percent of 0100 UTC outlooks had the equivalent of high risk coverage, 85 percent had the equivalent of at least moderate risk coverage, and only 10 percent had less than two percent coverage (Fig. 15). This suggests that rotation was still occurring in storms, but that they were not producing tornadoes.

When comparing the 0100 UTC outlook environments with other outlook environments, median MLCAPE was similar for all outlooks for hours and grid points with convection occurring. The 0100 UTC outlook did tend to have more MLCIN than other outlooks than the previous outlook at 2000 UTC, as the loss of daytime heating creates more convective inhibition (Fig. 16). 0-1 km shear and 0-3 and 0-1 km SRH tended to be strongest for the 0100 UTC outlook compared to other outlook times, however, possibly due to the influence of the low-level jet (Fig. 17). This shows the challenge in the forecast of the 0100 UTC outlook, as there is usually strong low-level shear present and it may be difficult to determine how soon convective inhibition or a change in storm mode will diminish the tornado threat.

7. COMPARISON OF VERIFICATION AND ENVIRONMENTS BETWEEN REGIONS

When comparing the verification of HR outlooks between regions, the Midwest is most likely to have an outlook verify as a HR, with 82 percent of HR outlooks verifying, and 100 percent of HR days in the Midwest having at least one HR outlook verify (Fig. 18). The Northern Plains are least likely to verify, at 40 percent of HR outlooks, and only one of four HR days had at least one outlook verify as a high risk. They also have the smallest number of HR outlooks, so the small sample size likely affects this result. When comparing tornado warning coverage between regions, the Southeast has a sharp increase in the number of HR outlooks with tornado warning coverage greater than the HR threshold compared to tornado report coverage, from 52 percent to 96 percent (Fig. 19). The Southeast tends to have high coverage of storms occurring at all hours of the day, providing more opportunities for tornado warnings. The tornado warning coverage in other areas does not change much from the tornado report coverage, with the decrease in the Southern Plains likely having to do with the way tornado warning coverage is calculated using warning area, compared to the neighborhood approach for the reports.

The high percentage of Midwest HRs verifying may be correlated with the much higher MLCAPE values that tend to be present compared to other regions (Fig. 20). The Southeast has relatively low MLCAPE and high 0-6 km shear values, which is expected because HRs in the Southeast tend to be cool season events (Fig. 21).

8. COMPARISON OF VERIFICATION AND ENVIRONMENTS BETWEEN DIFFERENT TIMES OF THE YEAR

HR outlooks were divided into three groups: late winter, spring, and early summer. One November HR case was omitted from this section since it was not during or close to the spring season like the rest of the HRs. The three seasonal groups were defined as 5 February-11 April, 13 April-15 May, and 22 May-7 June. HR outlooks that occurred later in the spring were somewhat more likely to verify than HR outlooks that occurred earlier in the spring (Fig. 22). MLCAPE tends to increase for HR outlooks that occur later in the spring as there is more heating and moisture available, and MLCIN also increases (Fig. 23). Again instability appears to correlate with how well a HR verifies. Shear parameters are all greater earlier in the spring as would be expected due to stronger winds aloft, and again shear does not correlate with how well a HR verifies because there is high shear in all cases (Fig. 24). Outlooks between May 22 and June 7, which were most likely to verify, were also apparently higher confidence forecasts, since they were more likely to be upgraded to a HR earlier in the day, with 44 percent being high risks at 0600 UTC and 78 percent at 1300 UTC.

9. COMPARISON OF HR ENVIRONMENTS WITH ENVIRONMENTS OF OTHER CATEGORICAL RISK TYPES

Convective environments associated with tornadoes in all types of categorical risks were studied, in order to determine how extreme the environments in high risks were. Environment data was taken from the grid point nearest to the tornado report at the nearest hour prior to the report. Median MLCAPE values steadily increased for higher risk thresholds (Fig. 25). Weak instability was likely a reason that missed tornadoes were not in a categorical risk area, and stronger instability was an important factor in determining moderate and high risk areas. However, instability was not a discriminating factor between moderate and high risk areas.

Shear values did clearly discriminate between risk areas, with missed tornadoes having very marginal values of vertical shear that would not typically warrant an outlook, and high risks having more extreme values of shear compared to other categories (Fig. 26). The very high shear in high risks, coupled with the substantial instability, is very favorable for widespread coverage of tornadoes, while the lower shear for tornadoes not in a risk area would not typically warrant a categorical risk area. The severe weather composite parameters also discriminated well between categorical risk areas, as they were designed to do, with extreme values of the parameters in high risk outlooks (Fig. 27).

10. VERIFICATION OF REPORTS IN TORNADO CLUSTERS

Report clustering was used to determine how many tornadoes were in a concentrated area that was comparable in size to a typical HR forecast. While only 25 percent of clustered tornadoes were in a HR, 70 percent of these tornadoes were in either a high or moderate risk (Fig. 28). Therefore most tornadoes that were in a concentrated area with high risk coverage were at least captured in a risk area where enhanced severe weather was forecast. The tornadoes not in a categorical risk area were often just outside a slight risk area, and all but one of them were associated with tropical cyclones.

11. CONCLUSIONS

HR outlooks are relatively rare events that tend to occur in the spring in the Plains, Southeast, and Midwest when confidence is high that widespread tornadoes will occur in a concentrated area. 64 percent of high risk outlooks verify as high risks based on tornado reports, with tornado warning coverage being somewhat greater than tornado report coverage. HRs later in the spring and located in the Midwest are most likely to verify.

Successful verification of a high risk appears to be correlated with the magnitude of instability present, with high risk outlooks that verify often being associated with higher MLCAPE values than high risk outlooks that did not verify as well. Stronger instability appears to be more favorable for widespread coverage of tornadoes. However, HRs can verify with lower MLCAPE values, such as in low CAPE, high shear environments. Better forecasts of instability would likely help to improve HR verification. HR verification did not correlate with shear, however, because shear tended to be well forecast in all HR outlooks and be sufficient for a significant outbreak of tornadoes. Convective mode and storm interactions, which were not researched in this study, likely correlate with HR verification. They should be further studied, and forecasts of these should be improved in order to improve HR verification.

Higher confidence HR days, with an HR upgrade by the 1300 UTC outlook, were much more likely to verify than lower confidence HR days that did not upgrade to a HR until 1630 UTC or later. Only 35 percent of 0100 UTC HR outlooks verified as high risks. Strong shear is still present, but the loss of daytime heating begins to decrease instability and increase convective inhibition. Convective mode also tends to become less favorable, as linear and MCS structures begin to replace supercellular structures.

The instability and shear associated with tornado reports in HRs tend to be much more extreme than the environments associated with tornadoes in other categorical risk areas. Severe weather composite parameters for environments associated with tornadoes tend to discriminate well between the different categorical risk areas where the tornadoes were located.

Further research is required in determining how well high risks cover the exact area where high risk coverage of tornadoes occurs, such as if the HR outlook is too big, too small, or displaced from the area of HR coverage. How well the outlooks leading up the HR do in highlighting the area of high risk coverage also should be studied. As more HRs occur and are added to the database, more definitive conclusions about HR environments can be drawn.

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13. FIGURES

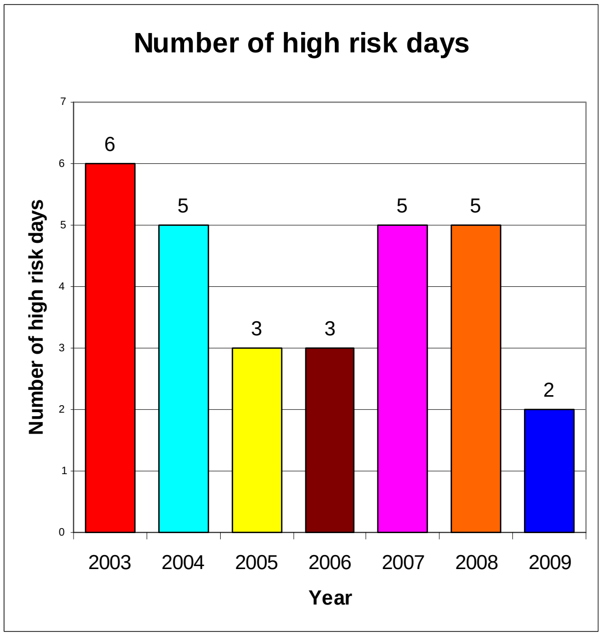


Fig. 1. Number of days with at least one HR outlook during each year.

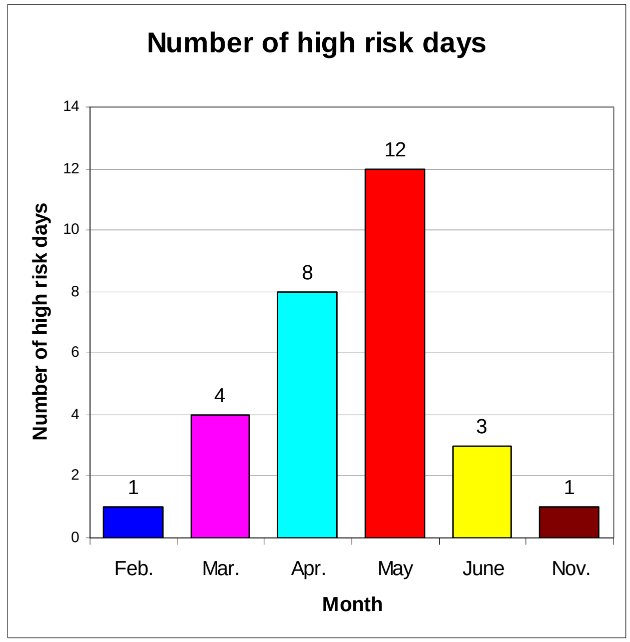


Fig. 2. Number of days with at least one HR outlook during each month.

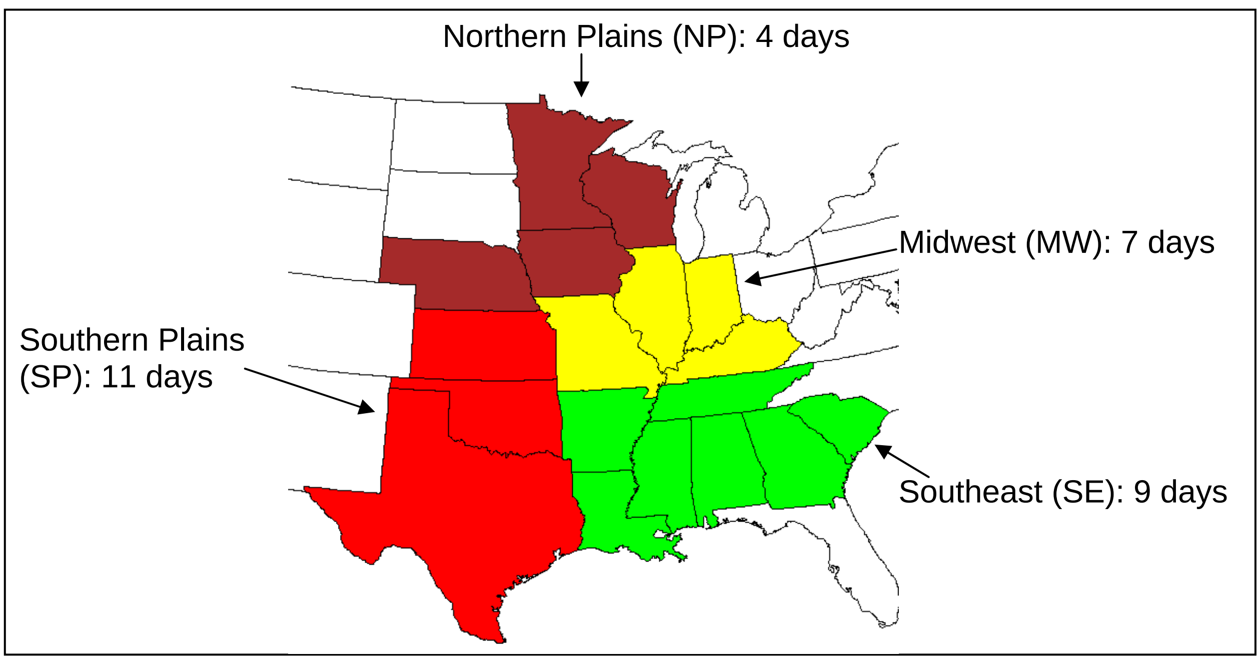
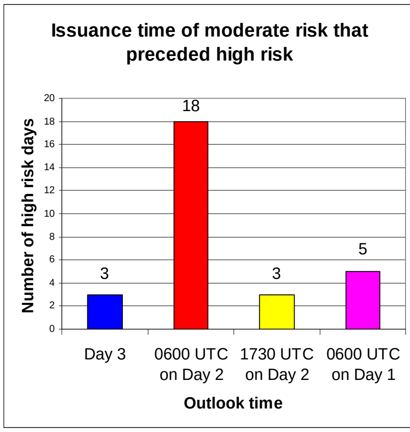
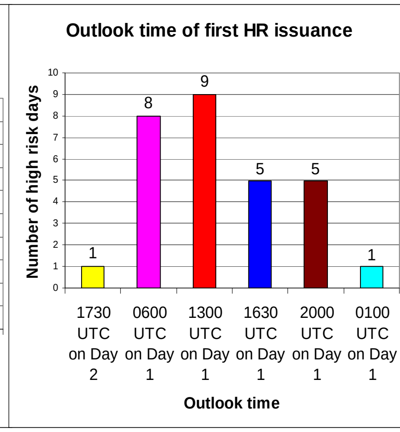


Fig. 3. Number of days with at least one HR outlook whose centroid was in each region (regional divisions taken from Thompson et al. (2008)).





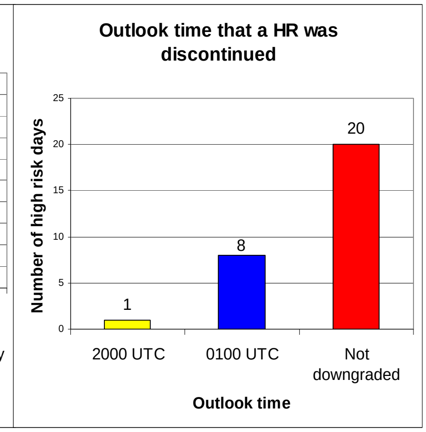


Fig. 4. Outlook time when first moderate risk was issued for days that would eventually have high risk outlooks.

Fig. 5. Outlook time when the first HR outlook was issued for HR days.

Fig. 6. Outlook time when an HR day was first downgraded from a HR.

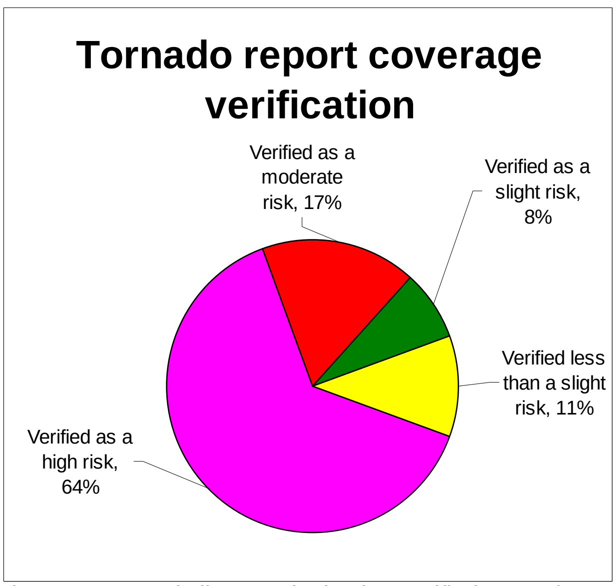


Fig. 7. Percent of all HR outlooks that verified as each categorical risk type based on tornado report coverage.

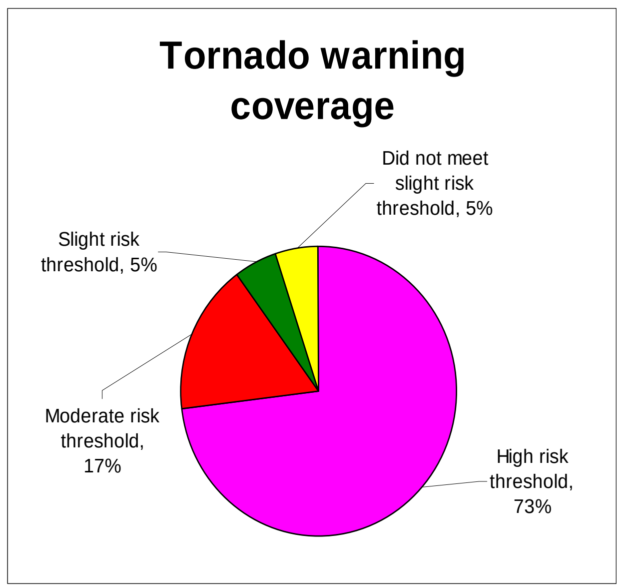
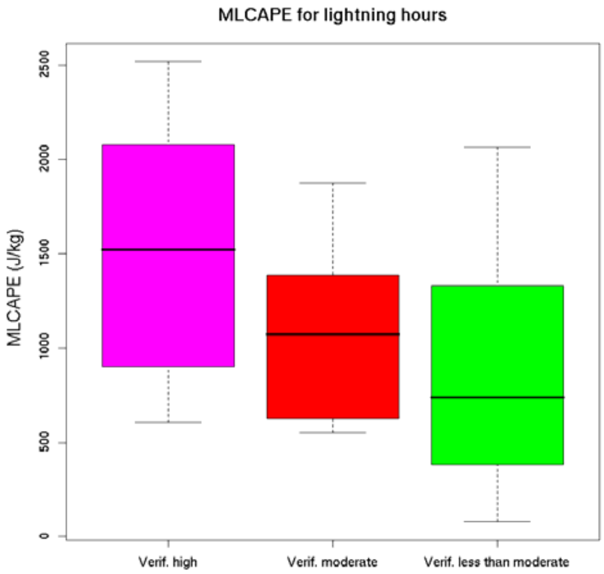


Fig. 8. Percent of all HR outlooks that met each equivalent categorical risk threshold based on tornado warning coverage.



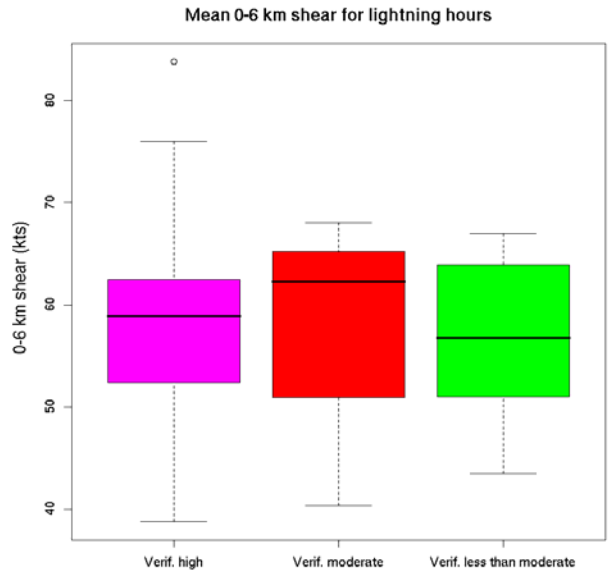


Fig. 9. Box and whiskers plot of MLCAPE averaged for each HR outlook for grid points that had lightning averaged over the duration of the lightning based on how each HR verified based on tornado report coverage.

Fig. 10. Same as Fig. 9, except with 0-6 km shear.

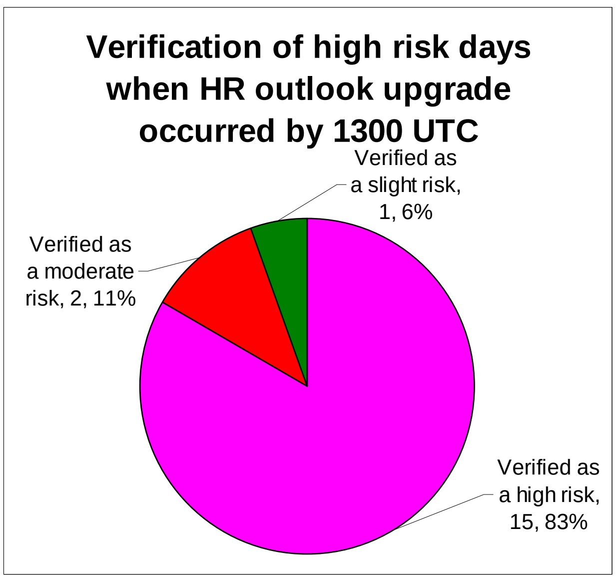


Fig. 11. Percent of HR days that were upgraded to HRs by 1300 UTC whose best-performing outlook verified as each categorical risk type based on tornado report coverage.

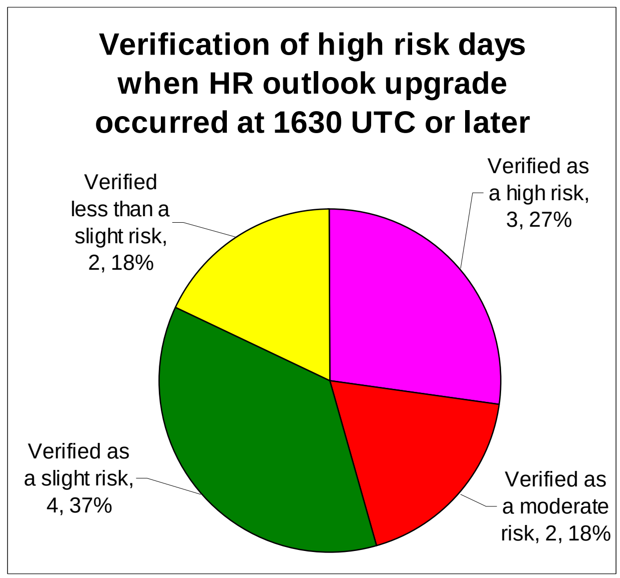


Fig. 12. Percent of HR days that were upgraded to HRs after 1300 UTC whose best-performing outlook verified as each categorical risk type based on tornado report coverage.

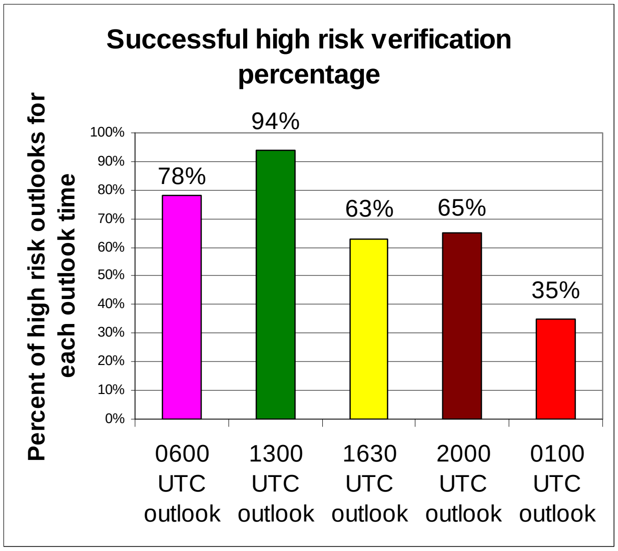


Fig. 13. Percent of HR outlooks issued at each outlook time that verified as a HR based on tornado report coverage.

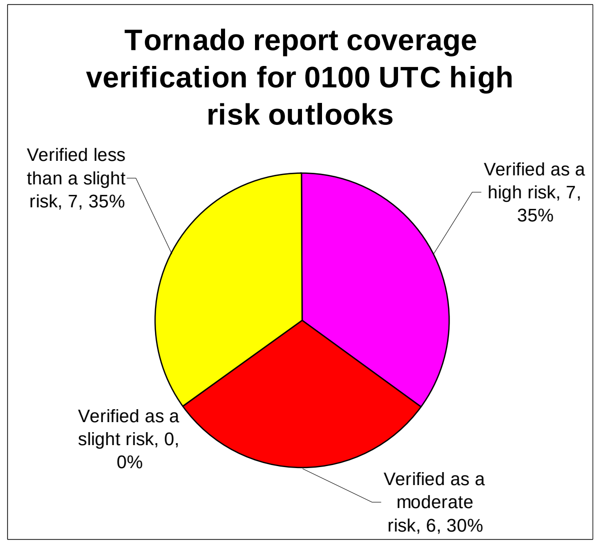


Fig. 14. Percent of HR outlooks issued at 0100 UTC that verified as each categorical risk type.

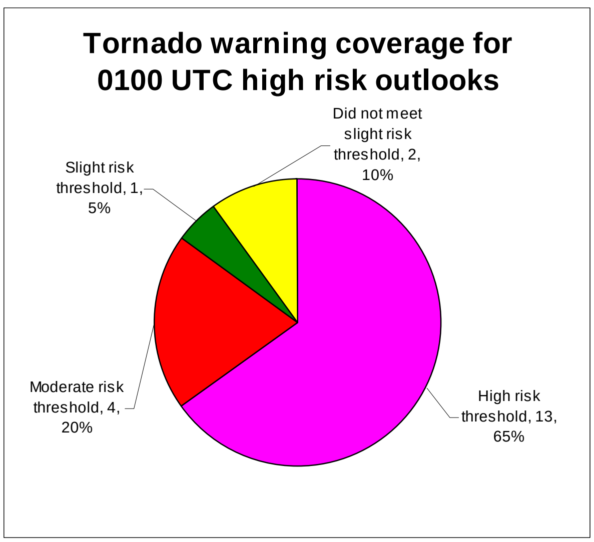


Fig. 15. Percent of HR outlooks issued at 0100 UTC That met each equivalent categorical risk threshold based on tornado warnings.

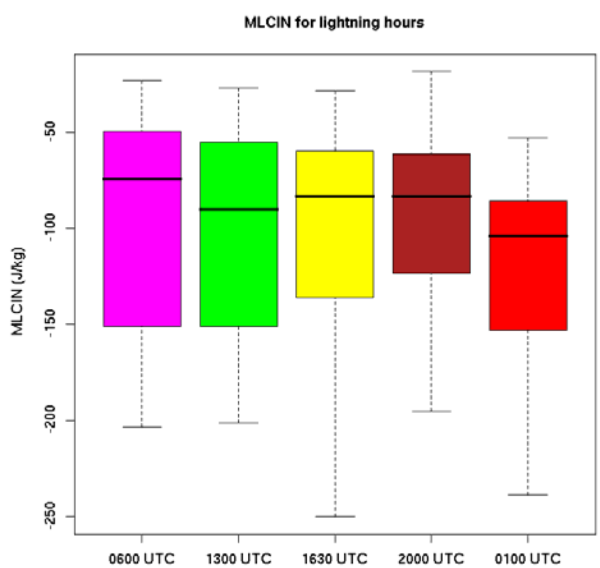


Fig. 16. Same as Fig. 9., except with MLCIN based on HR outlook time.

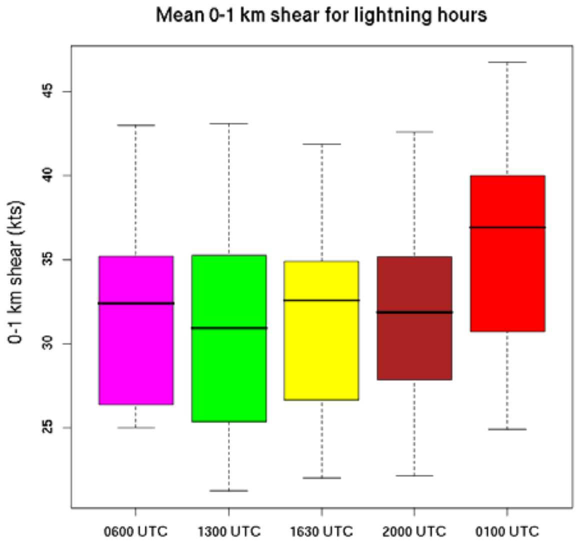


Fig. 17. Same as Fig. 16, except with 0-1 km shear.

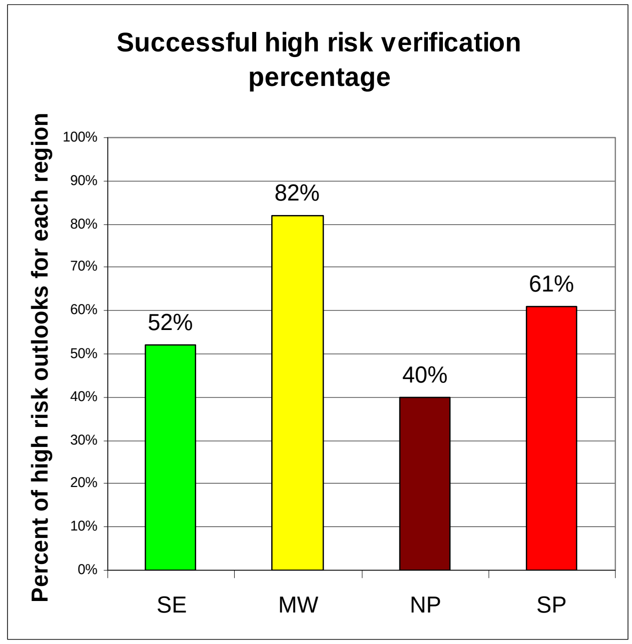


Fig. 18. Percent of HR outlooks in each region that that verified as a HR based on tornado report coverage.

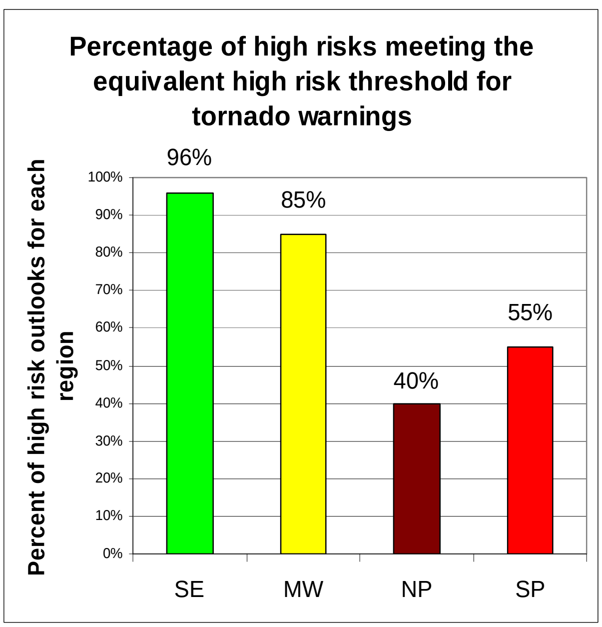


Fig. 19. Percent of HR outlooks in each region that met the equivalent HR threshold for tornado warnings.

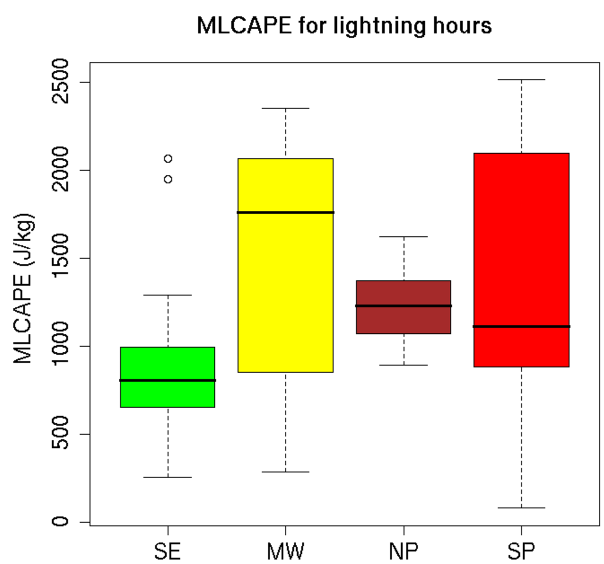


Fig. 20. Same as Fig. 17, except with MLCAPE based on region.

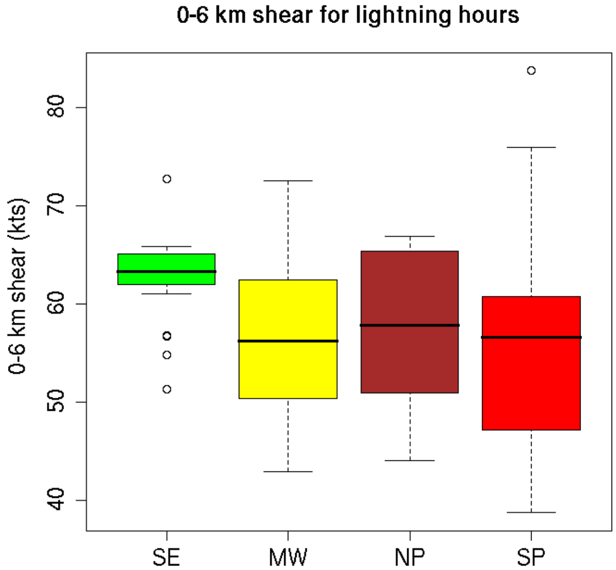


Fig. 21. Same as Fig. 20, except with 0-6 km shear.

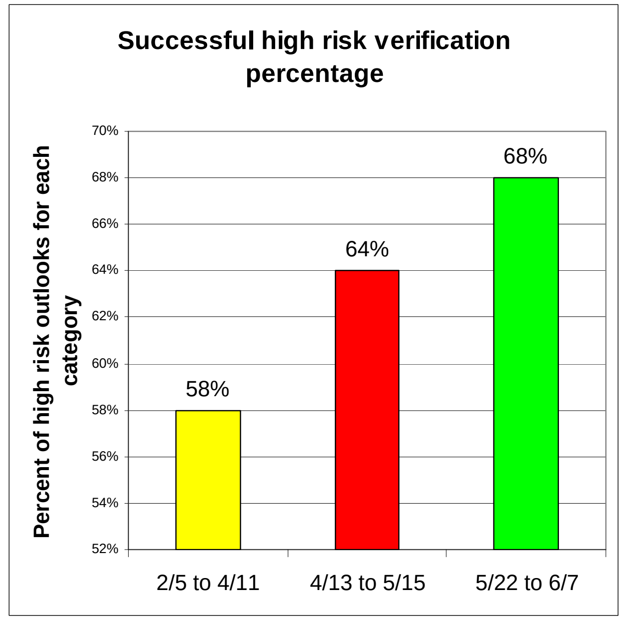


Fig. 22. Percent of HR outlooks for each time of year that verified as a HR based on tornado report coverage.

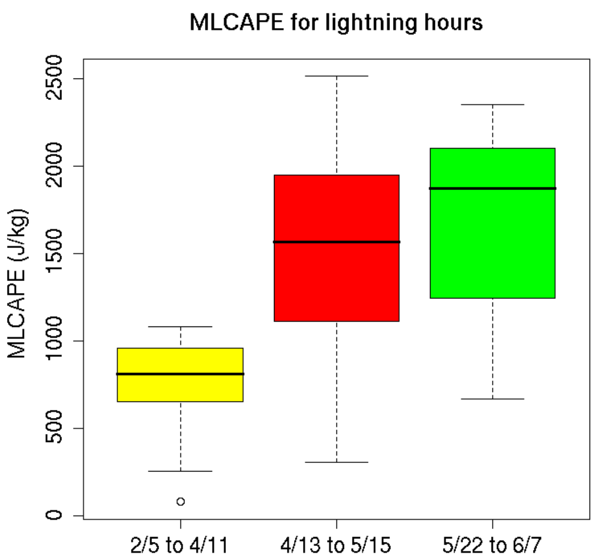


Fig. 23. Same as Fig. 21, except with MLCAPE based on the time of year that the HR occurred.

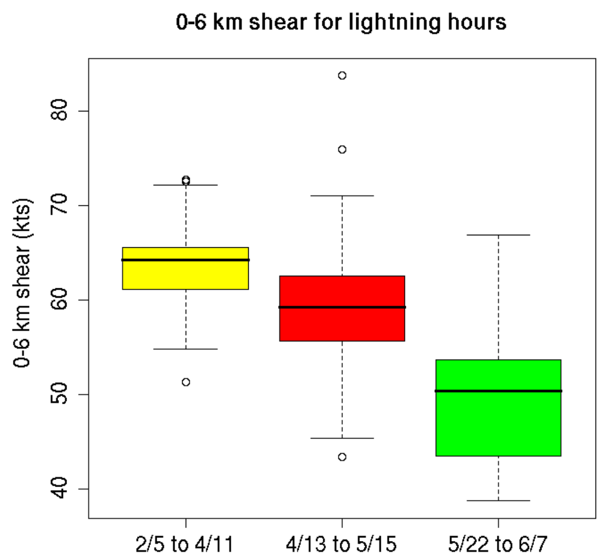
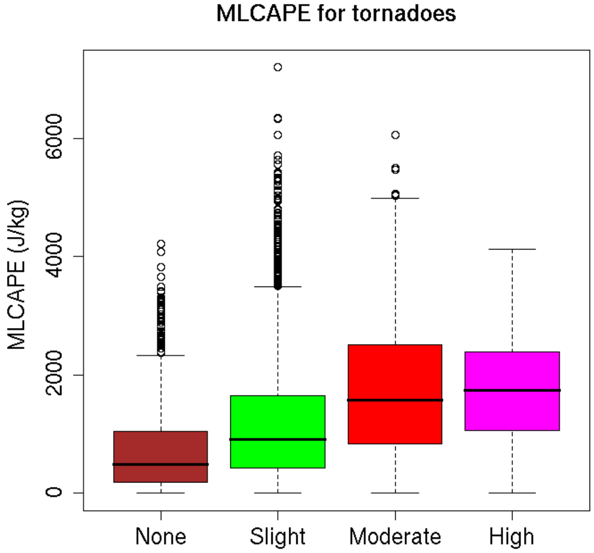


Fig. 24. Same as Fig. 23, except with 0-6 km shear.



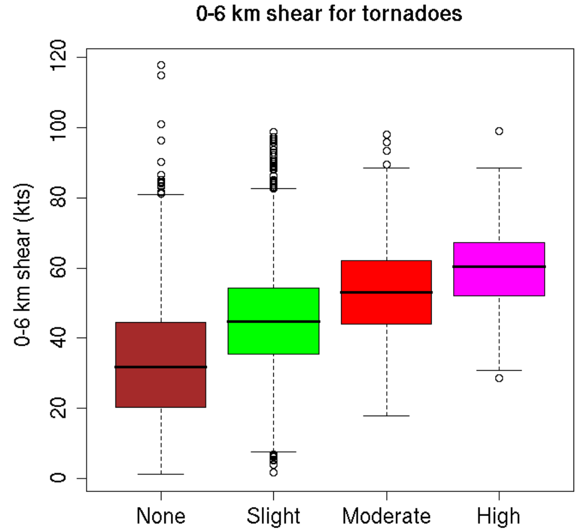
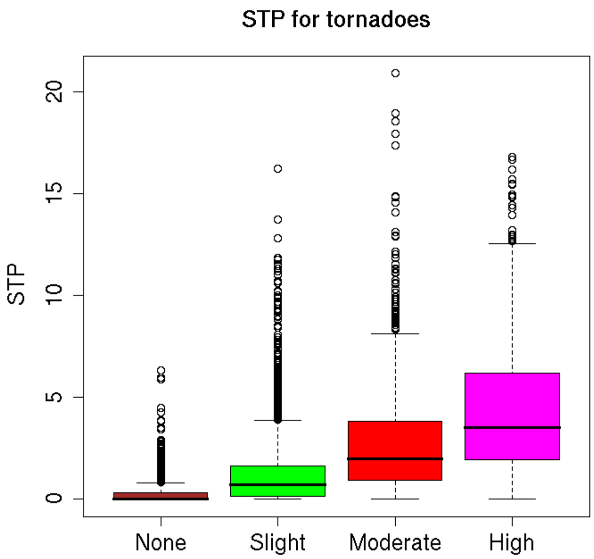


Fig. 25. Box and whisker plot of MLCAPE at the grid point closest to each tornado based on the categorical risk that the tornado was in.

Fig. 26. Same as Fig. 25 except with 0-6 km shear.



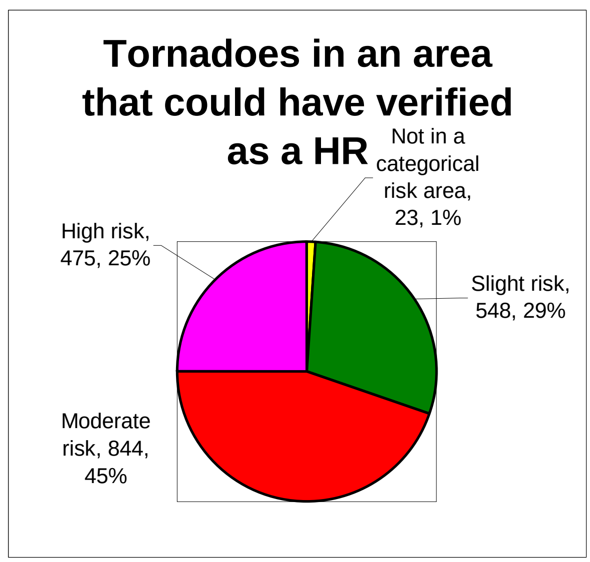


Fig. 27. Same as Fig. 26 except with the significant Tornado parameter.

Fig. 28. Percent of tornadoes in an area that could have verified as a HR that were in each type of categorical risk area.