9A.2 FORECAST CHALLENGES AT THE NWS STORM PREDICTION CENTER RELATING TO THE FREQUENCY OF FAVORABLE SEVERE STORM ENVIRONMENTS

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1. INTRODUCTION

In this study, we examine the frequency of important severe weather environments and the relationship of these environments to the performance of convective watches issued by the NOAA Storm Prediction Center (SPC). Important diagnostic parameters, such as convective available potential energy (CAPE) and deep layer bulk wind shear, are linked to SPC convective watches and verification metrics, such as the probability of detection (POD) and false-alarm ratio (FAR), are assessed as a function of these parameters. While the results are generally not surprising or unanticipated, the analyses presented here represent a useful quantification of the relationship between watch verification and convective environment, and also provide some further avenues for investigation into improving forecast performance.

2. SPC CONVECTIVE WATCHES

A convective watch is issued by the SPC when it is determined that there is an enhanced, imminent risk of severe convection over an area of at least 8,000 mi^2 (~ 20,700 km^2) and a duration of at least 2 hours (National Weather Service 2005). Severe convection is defined to be associated with at least one of the following:

- Hail ¾ inch (1.9 cm) or greater in diameter
- Convective wind gusts of 50 knots (25.7 m s^{-1}) or greater, or wind damage consistent with such wind gusts
- Tornadoes

In practice, the average size of a watch is around 25,000 mi^2 (~65,000 km^2) and the average duration is around 6 hours. Tornado Watches are issued when multiple tornadoes, or at least one EF2 or greater (on the Enhanced Fujita Scale) tornado is expected. Severe Thunderstorm Watches are issued when the main risk is determined to be severe wind and/or hail.

2.1. Watch Verification

SPC verifies watches using severe storm reports which are collected by National Weather Service (NWS) field offices and published in *Storm Data*. Important watch verification measures include POD of severe reports in watches, average lead time between watch and severe event, and FAR. While report-based measures like POD are straightforward to calculate (simply the fraction of severe reports that occur in watches), there are many ways that the false-alarm aspect of watch verification can be computed. Historically, watches and reports have been placed onto a 40 km grid, with each report in a watch activating a 5x5 grid box area (Weiss et al. 1980). Any unactivated grid boxes in the watch are considered to be false alarm area and it is then possible to define FAR as the percentage of false alarm grid boxes in the watch. In the verification aspect of this study, we focus mainly on POD and FAR as defined above.

3. SPC ENVIRONMENT DATABASE

The SPC has developed a comprehensive database of 3-dimensional environmental parameters associated with severe convection (Dean et al. 2006). This database is derived from archived hourly SPC mesoscale analysis (SfcOA) grids (40km x 40km grid box size) that are available from 2003-present (Bothwell 2002). The database also includes severe weather reports, gridded lightning data, and SPC forecast products, all of which can be linked to the environmental values corresponding to their location and time. While a wide variety of environmental parameters can potentially be explored, the focus here is on the frequency of severe convection and the performance of SPC convective watches as a function of most-unstable parcel CAPE (MU CAPE) and 0-6 km bulk shear (SHR6). These two fields provide information about fundamental characteristics of convective environments (e.g. Johns and Doswell 1992). This study will examine their relationship to forecasts and occurrence of severe storms.

3.1 A Note About Terminology and Plotting Conventions

In the figures presented below, results are accumulated in discrete bins in a 2-dimensional “CAPE-Shear” space, with MU CAPE on the x-axis and SHR6 on the y-axis. The bin sizes were arbitrarily defined as 250 J kg^{-1} for MU CAPE and 5 kt (2.5 m s^{-1}) for SHR6. SfcOA grid points where MU CAPE = 0 are not considered in this study, since these would otherwise dominate some of the distributions.

Some commonly used terms in the analysis below are

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defined as follows:

- *Environment hour* – An hourly grid point from SfcOA that is mapped into CAPE-Shear space. Only grid points located over the continental U.S. are considered.
- *Lightning hour* – An environment hour that contained at least one cloud-to-ground lightning flash, as detected by the National Lightning Detection Network (NLDN).
- *Report (tornado) hour* – An environment hour that contained at least one severe weather (tornado) report. Reports are mapped back to the most recent analysis prior to their occurrence (i.e. a report that occurred at 2245 UTC is mapped back to the 22 UTC SfcOA analysis).
- *Conditional probability of severe (tornado)* – The probability of a severe weather (tornado) report occurring in a SfcOA grid box, based upon the presence of at least one lightning flash in the grid box. In CAPE-Shear space, this is defined as the number of report hours divided by the number of lightning hours in a given bin.
- *Watch hour* – An environment hour that was within a valid watch. Since watches cover an area of multiple grid points and hours, there is no single environment that can be assigned to a given watch; rather, the hourly grid points contained in a watch are distributed across the environment space as determined by the SfcOA.
- *False alarm hour* – A watch hour that was never "affected" by any severe reports, as defined in section 2.1 above.

4. DISTRIBUTION OF SEVERE CONVECTION IN CAPE-SHEAR SPACE

An examination of the environment, lightning, and severe report distributions in CAPE-Shear space for the period 2003-2007 confirms the following intuitive results:

- Convective environments characterized by relatively low values of MU CAPE and SHR6 are far more common than environments characterized by high values of one or both of these parameters (see Figs. 1 and 2).
- The conditional probability of severe thunderstorms and tornadoes increases with increasing MU CAPE and SHR6 values (see Figs. 3 and 4).
- Most severe reports occur in environments falling somewhere in between the two conditional extremes described above, with tornadoes generally associated with higher values of SHR6 (see Figs. 5 and 6).

For a more detailed environmental analysis of severe convection for the 2003-2007 period, refer to Schneider and Dean (2008).

5. SPC WATCH DISTRIBUTION IN CAPE-SHEAR SPACE

Figures 7 and 8 show the distribution of watch environment hours and watch lightning hours, respectively, in CAPE-Shear space. Figures 9 and 10 show the same for tornado watches only. As expected, the greatest concentration of watch hours is displaced towards an area of greater severe risk compared to the overall distribution of environment hours, with the greatest concentration of tornado watch hours displaced even further toward higher severe risk. The distribution of lightning hours is similar to that of environment hours for both all watches and tornado watches.

The greatest concentration of lightning hours overall in CAPE-Shear space (MU CAPE, SHR6) is located near the point (1000 J kg^{-1}, 20 kt), as shown in Figure 2. In comparison, the greatest concentration of watch lightning hours (Figure 8) is around (1000 J kg^{-1}, 40 kt) and the greatest concentration of tornado watch lightning hours (Figure 10) is around (1000 J kg^{-1}, 50 kt). Thus, an increase in diagnosed severe threat from no watch to watch to tornado watch appears to correspond more with an increase in deep-layer shear in observed convection compared to an increase in MU CAPE. This is consistent with operational severe weather forecasting techniques that focus on potential for tornadic supercells to develop. Idealized cloud model simulations (e.g. Weisman and Klemp 1982,1984) and observational studies (e.g. Thompson et al. 2003) have found that deep-layer shear on the order of 30-40 kt (15-20 m s^{-1}) is sufficient to support supercell thunderstorms. It is also worth noting the sharp decrease in tornado watch hours below SHR6 values of 30 kt.

Figures 11 and 12 show the probability that a lightning hour will be in any watch and in a tornado watch, respectively. As expected, the probability of observed convection being in a watch increases with increasing MU CAPE and SHR6. However, the greatest concentration of lightning hours in watches (see Figs. 8 and 10) in environment space corresponds to only about a 20% overall chance of a lightning hour being in a watch, indicating again the disconnect between areas of high conditional probability of severe in environment space and areas where most convection is actually observed. Again, this is a result of sample size in each bin of the parameter space, where the frequency of occurrence in the upper right quadrant is very low (Fig. 1).

6. WATCH VERIFICATION IN CAPE-SHEAR SPACE

Watch verification as a function of environment will be discussed mainly in terms of POD and FAR, as described in section 2a. We define a quantity "good area percentage" (GAP) to use in the FAR analysis, defined as GAP = 1 – FAR, so that both aspects of verification can be described in terms of positively oriented (higher is better) variables.

POD for both any report in any watch and any tornado report in a tornado watch increases with increasing MU CAPE and SHR6, as shown in Figures 13 and 14. These data exhibit a general inverse relationship between CAPE and shear, such that as CAPE increases, the shear decreases for constant values of POD. This is consistent with environment-report relationships seen in Figures 4 and 5. Operational experience of severe weather forecasters has noted this relationship through the years (e.g. Johns et al. 1990), and its application is evident in Figures 13 and 14. GAP for any severe reports in any watch (Figure 15) shows the same pattern, which is also expected, given the increasing probability that convection will produce severe weather as MU CAPE and SHR6 increases (Figures 3 and 4). However, GAP for tornadoes in tornado watches (Figure 16) generally does not demonstrate a coherent pattern, other than a slight tendency for GAP to decrease as MU CAPE drops below 1000 J kg^{-1}. This suggests larger uncertainty exists for tornado development in low CAPE environments, which are more common in the cool season (e.g. Guyer et al. 2006, Smith et al. 2008).

It is also instructive to examine the distribution of missed severe reports (relating to POD) and false alarm grid boxes (relating to FAR). Figures 17 and 18 show the distribution of missed reports and missed tornado reports (tornado reports not in tornado watches). Areas of parameter space with the highest concentration of missed reports have the largest negative contribution to overall POD. In the case of all severe reports, the greatest concentration of missed reports is in an area of moderate MU CAPE but relatively weak deep-layer shear, around (1750 J kg^{-1}, 25 kt). This corresponds to an area of relatively low conditional probability of severe (Figure 3), indicating that this environment occurs frequently without severe storm development. The distribution of missed tornado reports is somewhat noisier, but also tends toward the area of CAPE-Shear space where the conditional risk of tornadoes is relatively low. Note that the greatest number of missed tornado reports is located in regimes of moderate CAPE (1000-2000 J kg^{-1}) and marginal shear (25-35 kt), or low CAPE (< 1000 J kg^{-1}) and sufficient shear for supercells.

Figures 19 and 20 show the distribution of false alarm grid points in all watches and tornado watches, respectively. In both cases, the greatest distribution of false alarm points tends to be shifted toward areas of lower MU CAPE and higher SHR6, compared to the distribution of missed reports. Thus, while both missed reports and false alarm area tend to concentrate in areas where the conditional risk of severe weather is similarly low, the environmental character of each tends to differ. Overall, these results suggest that false alarm is a bigger problem in low CAPE-high shear regimes, while the greatest problem with missed events occurs in moderate CAPE, low shear regimes. This is not unexpected, as the low CAPE-high shear environment occurs relatively frequently during the cool season (Schneider et al. 2004), and these environments can be associated with an enhanced risk of severe storms, including strong (EF2 or greater) tornadoes (e.g. Guyer et al. 2006, Thompson et al. 2008). Since the societal impact "penalty function" is larger for missed events, additional research is needed to better understand severe storms in low CAPE environments.

7. SUMMARY AND CONCLUSIONS

Forecasting severe convection is a major challenge in part because it is a relatively rare event that can have large societal impacts. However, it is the ambiguity inherent in more frequently observed environments that has the greatest adverse affect on watch performance, with the best forecast performance in the rarest environments. This is neatly summarized in Figures 21 and 22, where the fraction of lightning hours and reports (Fig. 21) and POD and GAP (Fig. 22) are plotted as a function of the conditional probability of severe thunderstorms based on MU CAPE and SHR6 values (as shown in Fig. 3). The distribution of lightning hours decreases rapidly as the conditional probability of severe increases (Fig. 21). Meanwhile, watch forecast performance, as measured by POD and GAP, increases with increasing conditional probability of severe (Fig. 22).

These results indicate that it is the rarity of severe convective occurrence relative to a given observed environment that strongly relates to forecast performance, rather than simply the overall rarity of observed severe convective events. Thus, the frequency of observed favorable severe weather environments must be taken into account in order to accurately assess trends in forecast performance over a given time period. Quantifying the environmental effect on forecast performance is a substantial area of potential future analysis.

The work presented here only scratches the surface of what can be done with SPC's environmental verification database. This study was limited to using MU CAPE and SHR6 in order to simplify the analysis and allow for easy visualization of the results, but numerous other parameters are also available in the database. In particular, parameters such as low level shear, storm-relative helicity, and LCL height all add additional valuable information to the generalized CAPE-Shear space, particularly in the case of tornado events (Thompson et al. 2003, 2007). Further work will continue to expand on what was presented here in order to provide a richer context for forecast verification and a sharper focus on areas of potential forecast improvement.

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8. REFERENCES

Bothwell, P. D., J. A. Hart, and R. L. Thompson, 2002: An integrated three-dimensional objective analysis scheme in use at the Storm Prediction Center. *Preprints, 21st Conf. on Severe Local Storms*, San Antonio, TX, Amer. Meteor. Soc., J117–J120.

Dean, A. R., R. S. Schneider, and J. T. Schaefer, 2006: Development of a comprehensive severe weather forecast Verification system at the Storm Prediction Center. *Preprints, 23nd Conf. Severe Local Storms*, St. Louis, MO, Amer. Meteor. Soc., CD-ROM.

Guyer, J. L., D. A. Imy, A. Kis, and K. Venable, 2006: Cool season significant (F2-F5) tornadoes in the Gulf Coast states. *Preprints, 23rd Conf. on Severe Local Storms*, St. Louis, MO, Amer. Meteor. Soc., CD-ROM.

Johns, R. H., J. M. Davies, and P. W. Leftwich, 1990: An examination of the relationship of 0-2 km AGL "positive" wind shear to potential buoyant energy in strong and violent tornado situations. *Preprints, 16th Conf. on Severe Local Storms*, Kananaskis Park, Alberta, Canada, Amer. Meteor. Soc., 593-598.

Johns, R. H., and C. A. Doswell III, 1992: Severe local storms forecasting. *Wea. Forecasting*, **7**, 588-612. National Weather Service, 2005: National Weather Service Instruction 10-512. [Available online at http://weather.gov/directives/sym/pd01005012curr.pdf.]

Schneider, R. S., J. T. Schaefer, and H. E. Brooks, 2004: Tornado outbreak days: an updated and expanded climatology (1875-2003). *Preprints, 22nd Conf. on Severe Local Storms*, Hyannis, MA, Amer. Meteor. Soc., CD-ROM.

Schneider, R. S. and A.R. Dean, 2008: A comprehensive 5-year severe storm environment climatology for the continental United States. *Preprints, 24th Conf. on Severe Local Storms*, Savannah, GA, Amer. Meteor. Soc., CD-ROM.

Smith, B. T., J. L. Guyer, and A. R. Dean, 2008: The climatology, convective mode, and mesoscale environment of cool season severe thunderstorms in the Ohio and Tennessee Valleys, 1995-2006. *Preprints, 24th Conf. on Severe Local Storms*, Savannah, GA, Amer. Meteor. Soc., CD-ROM.

Thompson, R. L., R. Edwards, J.A. Hart, K.L. Elmore and P.M. Markowski, 2003: Close proximity soundings within supercell environments obtained from the Rapid Update Cycle. *Wea. Forecasting,* **18**, 1243-1261.

Thompson, R. L., C. M. Mead, and R. Edwards, 2007: Effective storm-relative helicity and bulk shear in supercell thunderstorm environments. Wea. Forecasting, **22,** 102-115.

Weisman, M. L. and J. B. Klemp, 1982: The dependence of numerically simulated convective storms on vertical wind shear and buoyancy. *Mon. Wea. Rev.*, **110**, 504-520.

Weisman, M. L. and J. B. Klemp, 1984: The structure and classification of numerically simulated convective storms in directionally varying wind shears. *Mon. Wea. Rev.*, **112**, 2479-2498.

Weiss, S .J., D. L. Kelly, and J. T. Schaefer, 1980: New objective verification techniques at the National Severe Storms Forecast Center. *Preprints, 8th Conf. on Weather Analysis and Forecasting*, Denver, CO, Amer. Meteor. Soc., 412-419.

9. FIGURES

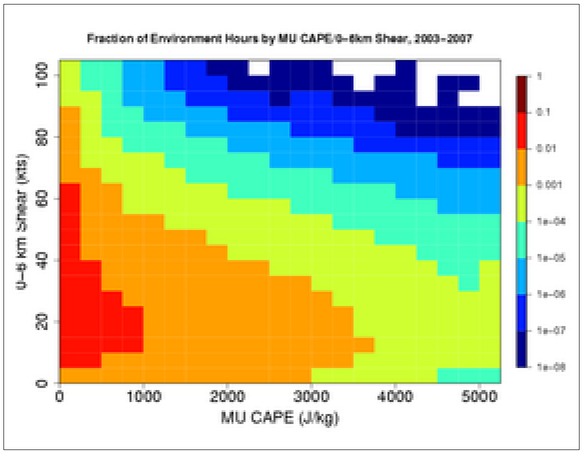

Fig. 1. Distribution of total environment hours for 2003-2007 that occurred in each MU CAPE/0-6km Shear bin, normalized by the total number of environment hours in the sample. Please note the logarithmic scale. Environment hours where MU CAPE = 0 are not included.

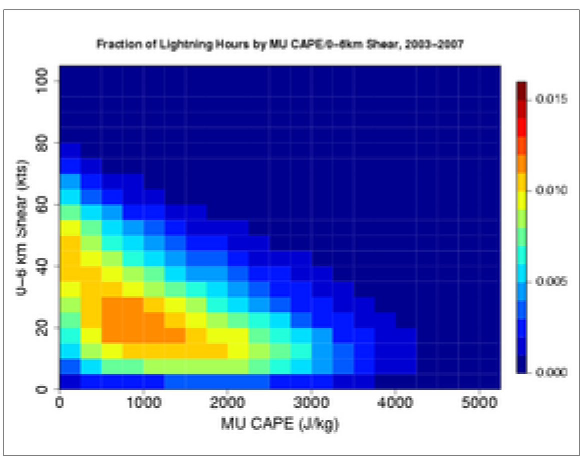

Fig. 2. Distribution of lightning hours for 2003-2007 that occurred in each MU CAPE/0-6km Shear bin, normalized by the total number of lightning hours in the sample.

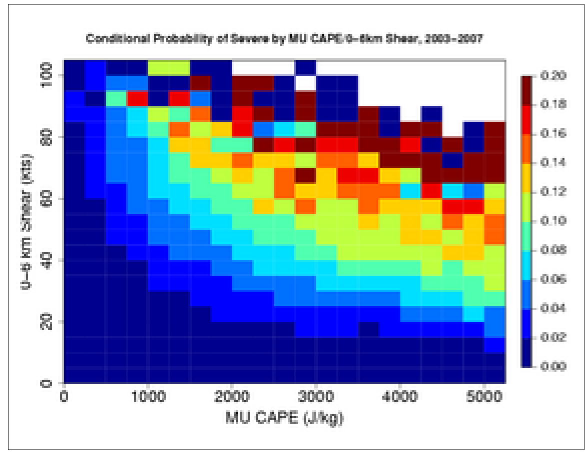

Fig. 3. Conditional probability of severe thunderstorms (including tornadoes) for 2003-2007 by MU CAPE/0-6km Shear bin, conditional on the presence of lightning.

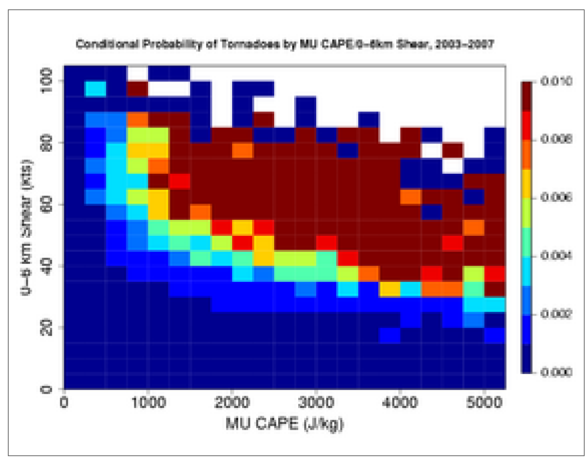

Fig. 4. Conditional probability of tornadoes for 2003-2007 by MU CAPE/0-6km Shear bin, conditional on the presence of lightning.

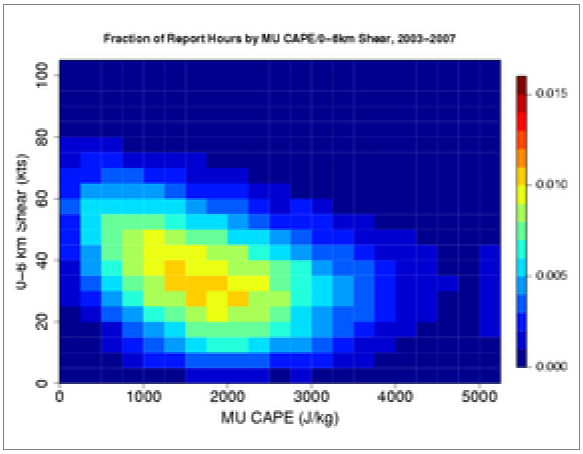

Fig. 5. Distribution of severe report hours for 2003-2007 by MU CAPE/0-6km Shear bin, normalized by the total number of severe report hours in the sample.

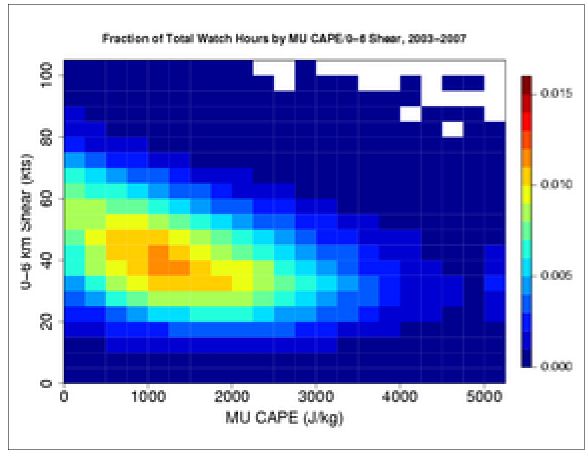

Fig. 7. Distribution of watch hours for 2003-2007 by MU CAPE/0-6km Shear bin, normalized by the total number of watch hours in the sample.

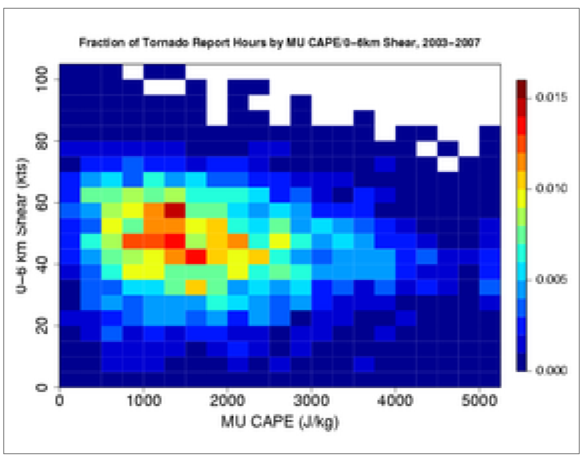

Fig. 6. Distribution of tornado report hours for 2003-2007 by MU CAPE/0-6km Shear bin, normalized by the total number of tornado report hours in the sample.

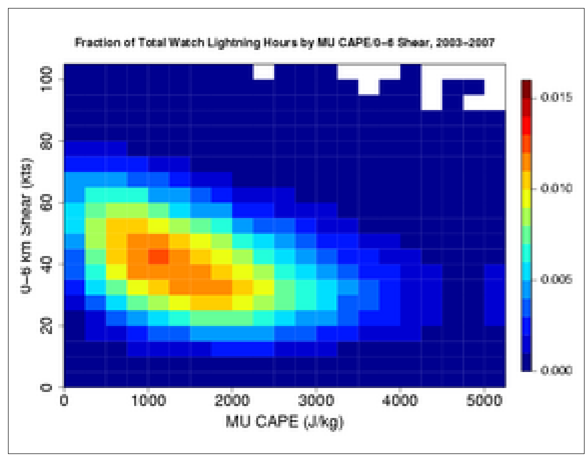

Fig. 8. Distribution of watch lightning hours for 2003-2007 by MU CAPE/0-6km Shear bin, normalized by the total number of watch lightning hours in the sample.

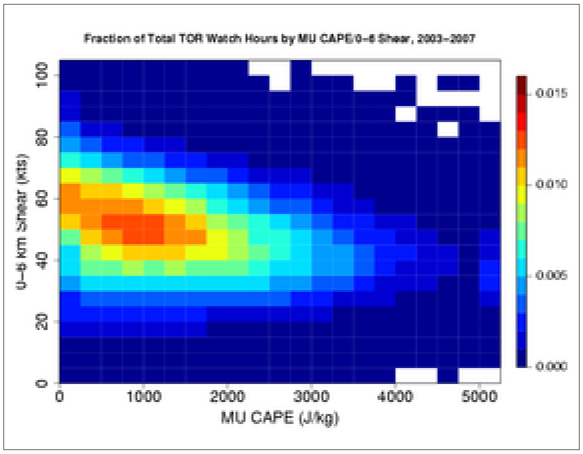

Fig. 9. Distribution of tornado watch hours for 2003-2007 by MU CAPE/0-6km Shear bin, normalized by the total number of tornado watch hours in the sample.

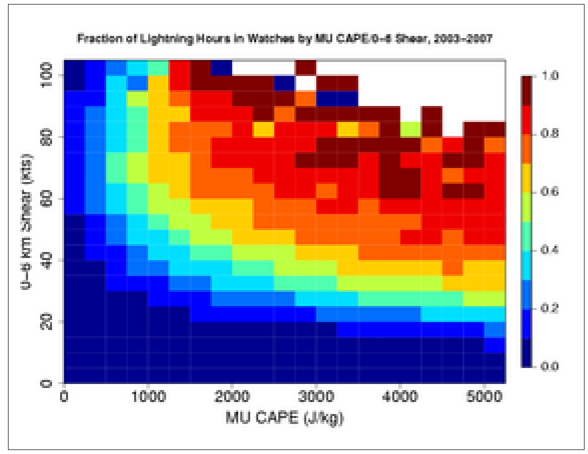

Fig. 11. Probability of lightning hours being in any watch for 2003-2007 by MU CAPE/0-6km Shear bin.

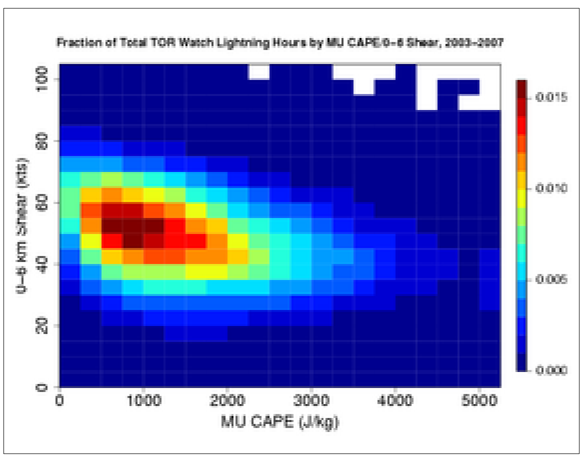

Fig. 10. Distribution of tornado watch lightning hours for 2003-2007 by MU CAPE/0-6km Shear bin, normalized by the total number of tornado watch lightning hours in the sample.

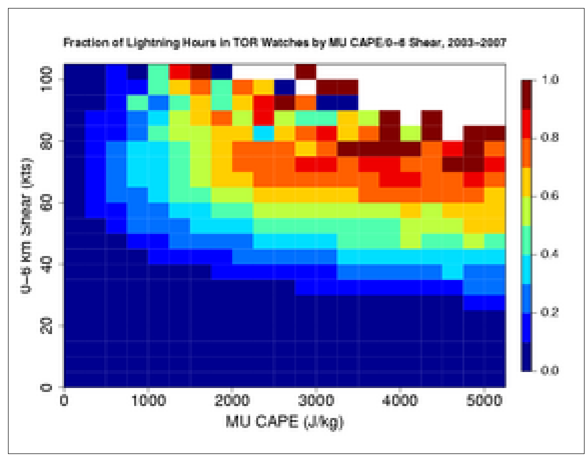

Fig. 12. Probability of lightning hours being in a tornado watch for 2003-2007 by MU CAPE/0-6km Shear bin.

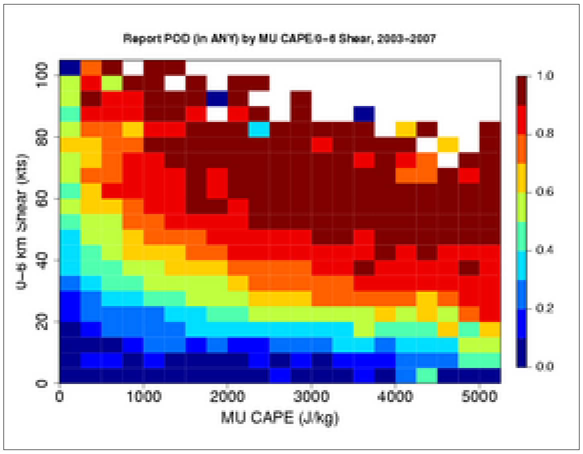

Fig. 13. Report POD (in any type of watch) for 2003-2007 by MU CAPE/0-6km Shear bin.

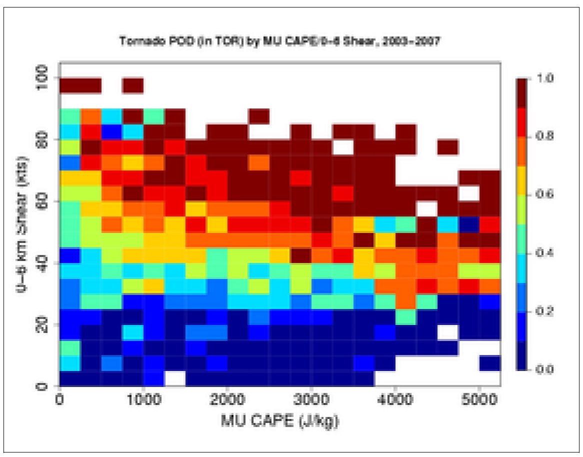

Fig. 14. Tornado report POD (in a tornado watch) for 2003-2007 by MU CAPE/0-6km Shear bin.

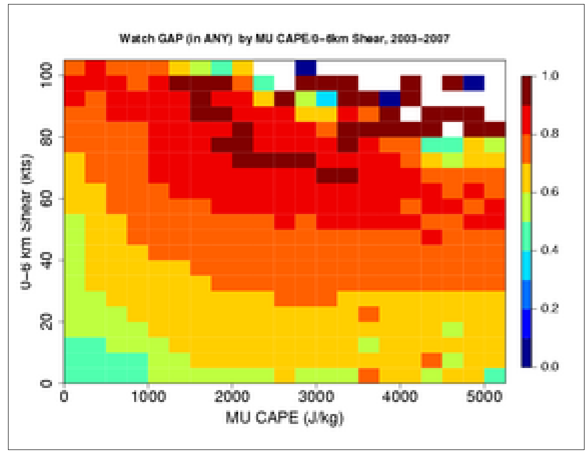

Fig. 15. Watch GAP (good area percentage) for 2003-2007 by MU CAPE/0-6km Shear bin. GAP = 1 – FAR.

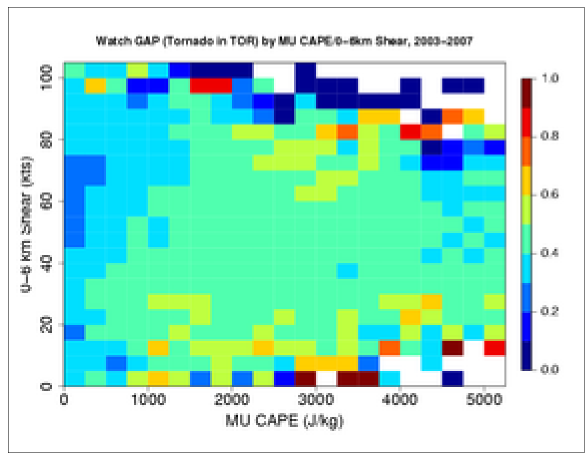

Fig. 16. Tornado watch GAP (good area percentage) for 2003-2007 by MU CAPE/0-6km Shear bin. GAP = 1 – FAR.

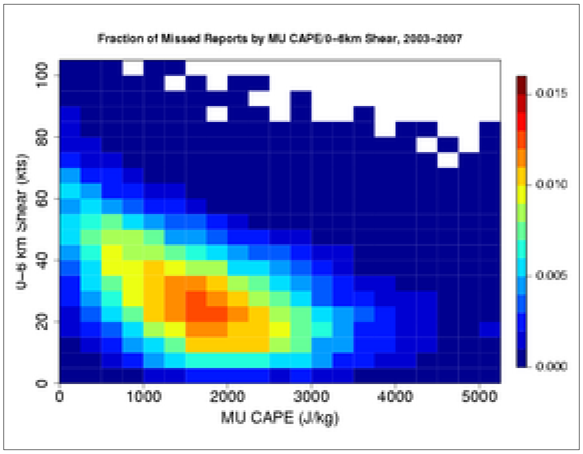

Fig. 17. Distribution of missed (not in watch) severe reports for 2003-2007 by MU CAPE/0-6km Shear bin, normalized by the total number of missed severe reports in the sample.

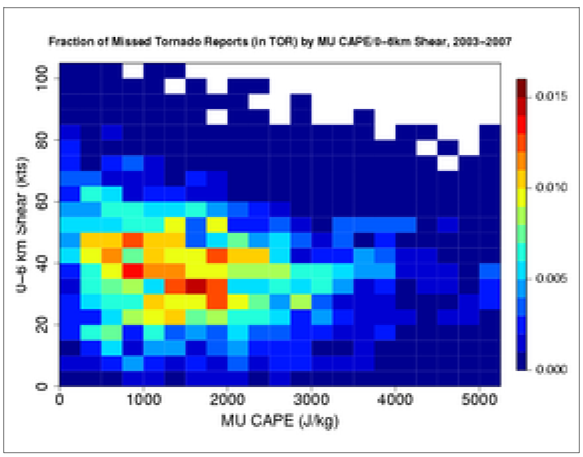

Fig. 18. Distribution of missed (not in tornado watch) tornado reports for 2003-2007 by MU CAPE/0-6km Shear bin, normalized by the total number of missed tornado reports in the sample.

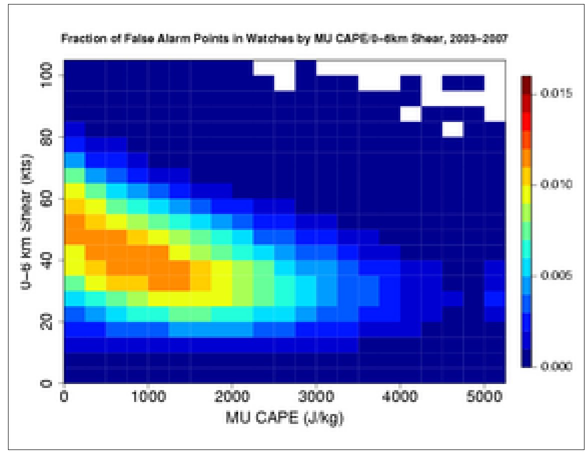

Fig. 19. Distribution of watch false alarm hours for 2003-2007 by MU CAPE/0-6km Shear bin, normalized by the total number of watch false alarm hours in the sample.

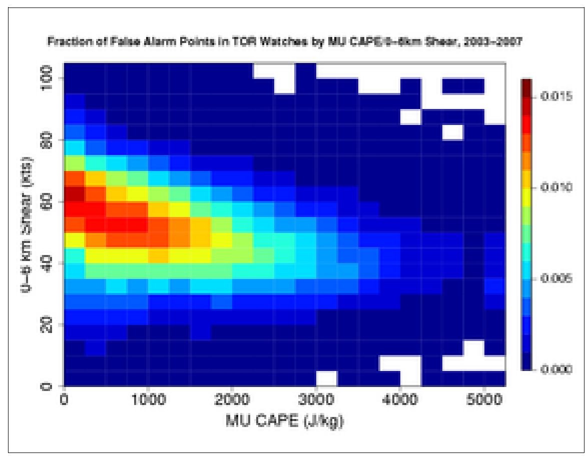

Fig. 20. Distribution of tornado watch false alarm hours for 2003-2007 by MU CAPE/0-6km Shear bin, normalized by the total number of tornado watch false alarm hours in the sample.

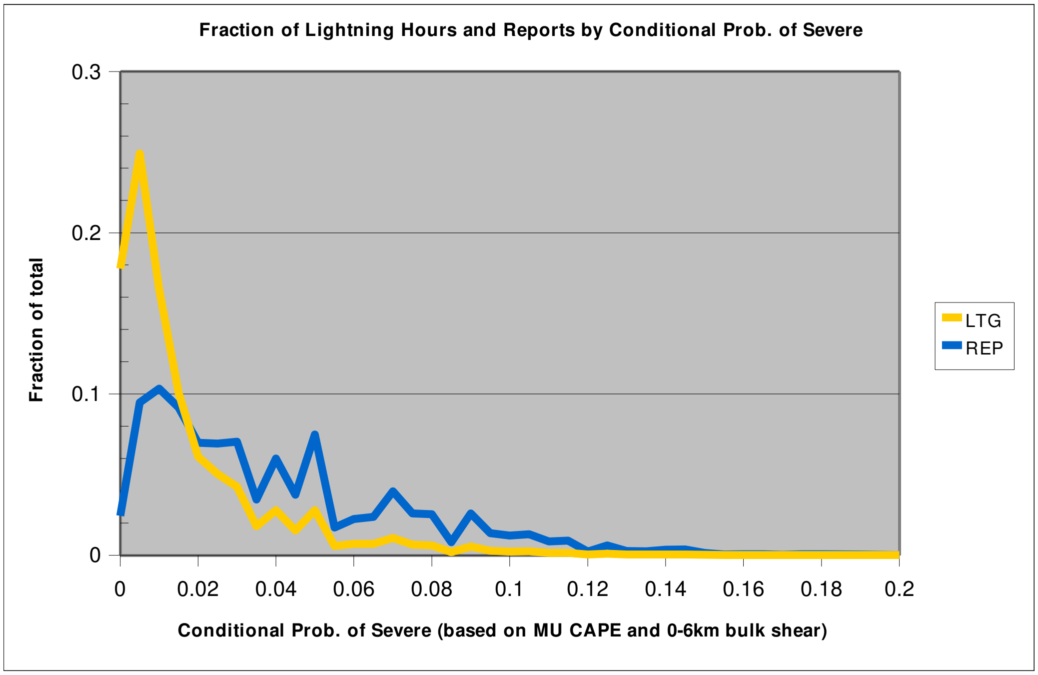

Fig. 21. Fraction of lightning hours (LTG) and reports (REP) as a function of the conditional probability of severe thunderstorms (based on MU CAPE and SHR6), as shown in Fig. 3). Conditional probabilities are binned by values of 0.005 in order to accumulate the values of LTG and REP.

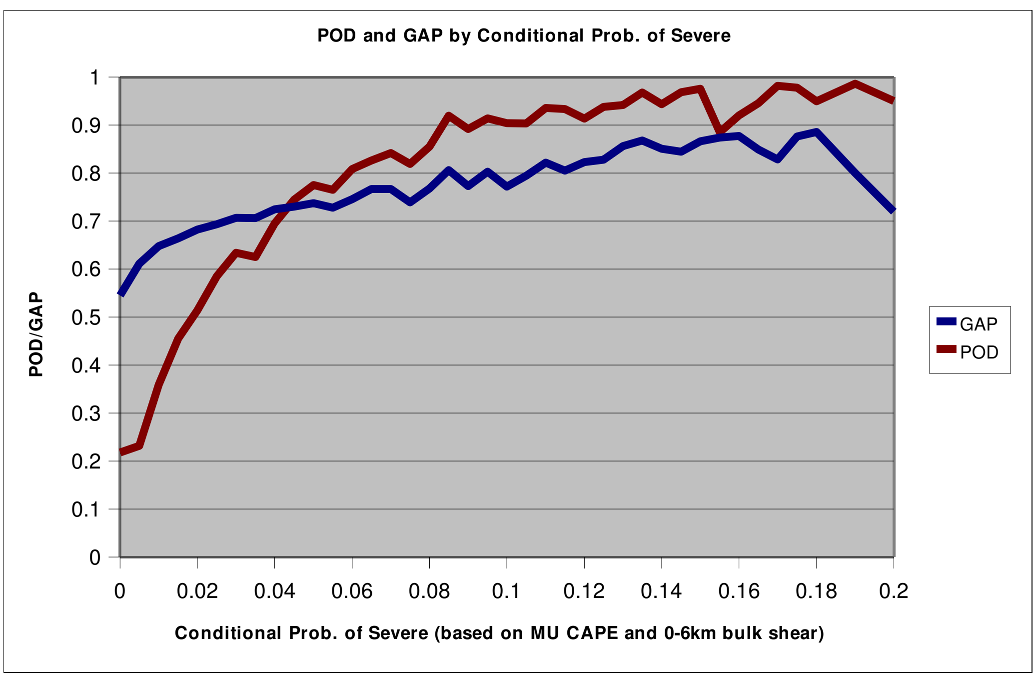

Fig. 22. Report POD (probability of detection of any report in any watch) and watch GAP plotted as a function of the conditional probability of severe thunderstorms (based on MU CAPE and SHR6), as shown in Fig. 3. Conditional probabilities on the x-axis are binned by values of 0.005.