16A.4 A COMPREHENSIVE 5-YEAR SEVERE STORM ENVIRONMENT CLIMATOLOGY FOR THE CONTINENTAL UNITED STATES

Russell S. Schneider[1] and Andrew R. Dean[1,2]
[1]DOC/NOAA/NWS/NCEP Storm Prediction Center
[2] OU-NOAA Cooperative Institute for Mesoscale Meteorological Studies

1. INTRODUCTION

Analysis of the mesoscale environments associated with observed severe convective storms can provide key insights into the character and predictability of severe storms and the challenges to achieving successful forecasts. The NOAA Storm Prediction Center (SPC) has constructed a database of severe storm environments associated with each severe weather report toward the goal of improving national severe weather forecasts. This portion of the effort focuses on analysis of estimated environments for all severe convective storms reported during the period between 2003 and 2007. This manuscript expands on the initial effort described in Schneider et. al. (2006) and Dean et. al. (2006). The compliment to this paper is a study which focuses on the use of this database to support context-based verification of SPC products and services (Dean and Schneider 2008)

2. DATA SET PREPARATION AND ANALYSIS

The estimated environment for each severe report is based on hourly 40 km horizontal resolution RUC analysis data above the surface combined with objectively analyzed surface observations using RUC surface conditions as a first guess (Bothwell et. al. 2002). These grid point data are analyzed for a variety of kinematic and thermodynamic diagnostic fields relating to severe convection using the NSHARP sounding analysis program (Hart and Korotky 1991). Environmental conditions are assigned from the nearest analysis grid point at the closest hourly time prior to the observed severe weather. The database 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. For the five year period, this database contains environmental estimates for 139,258 severe reports including 6643 tornadoes (7396 tornado county segments) (Fig. 1).

The data for the period from 2003 to 2007 were stratified and analyzed based on report intensity, location, and environmental characteristics. Plots of the frequency of severe weather reports and lightning within a variety of parameter space projections were used to investigate the characteristics of severe weather environments. While a wide variety of environmental parameters can potentially be explored, the focus in this study is on the frequency of severe convection as a function of 100 mb mixed layer parcel CAPE (ML CAPE) and 0-6 km bulk shear (SHR6). Conditional probabilities of severe weather, dependent on the presence of cloud to ground lightning, are also constructed for this CAPE-Shear parameter space. Computation methodologies and the terminology used to describe the results are detailed in Dean and Schneider (2008). Spatial and seasonal distributions of these results were examined and will be discussed at the conference.

3. RESULTS

Results illuminate the diverse nature of the severe storm environmental parameter space and corroborate and refine results from previous investigations of severe storm environments (Rasmussen and Blanchard 1998, Rasmussen 2003, Craven et. al. 2002, Thompson et. al. 2003, Markowski et. al. 2003). Although sample sizes in some areas of the country are small, the distribution of all reports during the five year period (Fig. 1) demonstrates that most standard attributes of the severe weather climatology of the United States are captured. The vast majority of reports occur in the eastern two thirds of the United States, with widespread tornado activity over the Great Plains, Upper Midwest and along an axis extending through the Southeast and northward to the Mid Atlantic. Smaller clusters of tornado reports are also found in Southern California, in the central valley of California, northern Arizona, and the Snake River Valley in Idaho. Severe weather reports west of the Rocky Mountains are sparse.

The spatial distribution of fractional hours with cloud-to-ground lightning over the 5 year sample (Fig. 2) reflects the general climatology of thunderstorms over the Continental United States (CONUS). Maximum frequencies of over 6 percent are found in south Florida with 3 percent or greater frequency generally confined to the Southeast United States and over select mountainous areas of New Mexico, Arizona, and Colorado. There is a general decline in thunderstorm frequency toward the north and west of the lightning frequency maximum.

The primary results from this study are reflected in plots of environment hours or report frequency in ML CAPE versus SHR6 parameter space. The distribution of environment-hours with ML CAPE greater than zero (Fig. 3a) documents that the vast majority of environment hours are characterized by ML CAPE less than 250 J kg^{-1}. Environments characterized by ML CAPE less than 2000 J kg^{-1} and deep-layer shear less than 20 m s^{-1} (40 kt) are far more frequent than more extreme severe weather environments. The lightning environment-hour distribution in CAPE-Shear space (Fig. 3b) has similar characteristics to the overall

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* *Corresponding author address: Russell S. Schneider, NOAA/NWS/NCEP Storm Prediction Center, 120 David L. Boren Blvd. Suite 2300, Norman, OK 73072; e-mail: russell.schneider@noaa.gov.*

environment-hour distribution, but with greater emphasis on instability, particularly for ML CAPE less than 1000 J kg^{-1} and SHR6 less than 15 m s^{-1} (30 kt).

The frequency distribution of tornado reports in CAPE-Shear space highlights the importance of deep layer shear in supercell formation and tornadic supercell occurrence (Fig. 4a). Approximately 84 percent of all tornadoes within the sample occurred with SHR6 greater than 15 m s^{-1} (30 kt), and 65 percent occurred with shear greater than 20 m s^{-1} (40 kt). The dependence on CAPE is much less pronounced, with almost half of all tornadoes (49 percent) occurring with ML CAPE less than 1000 J kg^{-1}. The high frequency of occurrence of environments (Fig. 3a) and common occurrence of thunderstorms (Fig. 3b) in environments characterized by SHR6 greater than 15 m s^{-1} (30 kt) and ML CAPE less than 1000 J kg^{-1} (Figs 3a, 3b, 4a) makes these potential tornado producing environments more common than higher CAPE environments.

Significant tornado (F2-F5) occurrence (Fig. 4b) is characterized by a stronger dependence on deep layer shear than the entire tornado sample (Fig. 4a). Almost all significant tornadoes (98.8 percent) occurred with SHR6 greater than 15 m s^{-1} (30 kt), and 86.7 percent occurred with shear greater than 20 m s^{-1} (40 kt). In addition, 99.2 percent of all tornadoes characterized by SHR6 less than 15 m s^{-1} (30 kt) were rated F0 or F1. Unlike the general tornado population, the significant tornado occurrence maximum is displaced toward slightly higher CAPE with a maximum between 500 and 1250 J kg^{-1}. Nevertheless, it would be unwise to use a minimum value of CAPE to determine if significant tornadoes are possible, since 16.2 percent of significant tornadoes occurred in environments with ML CAPE less than 500 J kg^{-1}.

Analyses were also performed for severe hail (≥ 0.75 inch) and significant hail (≥ 2.00 inch) reports (Figs. 5a, b) and for severe wind (≥ 50 kt) and significant severe wind (≥ 65 kt) reports (Figs. 6a, b). Additional analyses were performed using MUCAPE, but they are omitted from this manuscript for brevity. Thus, hail reports associated with elevated instability are displayed in the column for 0-250 J kg^{-1} MLCAPE (Fig. 5). In addition, for elevated storms, the SHR6 layer is not necessarily representative of the cloud bearing layer.

There is a greater dependence on stronger deep layer shear for severe hail reports than for severe wind reports (compare Figs. 5, 6). This is likely due to the importance of supercell thunderstorms in the climatology for severe hail, with supercell thunderstorms largely dependent on SHR6 greater than 15 m s^{-1} (30 kt) (Rasmussen and Blanchard 1998, Thompson et. al. 2003). Significant hail shows the greatest dependence on deep layer shear (Fig. 5b) with 89.4 percent of reports characterized by environments with SHR6 greater than 15 m s^{-1} (30 kt). Similarly, only 1.5 percent of all severe hail reports with SHR6 less than 15 m s^{-1} (30 kt) were of diameter greater than 2 inches, whereas for SHR6 ≥15 ms^{-1}, 4.9 percent of reports were ≥ 2 inches. Similar to severe hail, significant severe wind reports show a greater dependence on SHR6 than the general population of severe wind reports (Figs. 5a, b; 6a, b); however, the shear dependence apparent in all hail reports (Fig. 5a) is not noticeable for the severe wind sample (Fig. 6a).

The conditional probability of cloud-to-ground lightning (Fig. 7) is a strong function of increasing SHR6. The rapid increase in the conditional probability of thunderstorms for SHR6 greater than 20 m s^{-1} (40 kt) is indicative of the strong large-scale forcing typically present in the vicinity of warm sectors characterized by strong, deep layer shear. Spatial plots of these conditional probabilities (shown in oral presentation) support this assertion. Although most thunderstorms occur at relatively low instability and shear (Fig. 3b), when SHR6 is strong, the probability is maximized (Fig. 7).

The conditional probability of tornadoes given the occurrence of lightning (Fig. 8), which maximizes in areas of CAPE-Shear space that are rarely observed (Fig. 3), highlights the portion of CAPE-Shear space most commonly associated with tornadoes. The observation that the greatest conditional probability of tornadoes is associated with ML CAPE greater than 500 J kg^{-1} and SHR6 generally greater than 25 m s^{-1} (50 kt) for low CAPE, decreasing stepwise to 15 m s^{-1} (30 kt) for large CAPE (Fig. 8) is consistent with current severe weather forecaster perception of tornado risk. In fact, the probability of detection for tornadoes in SPC watches is closely correlated to the conditional tornado probability (see Dean and Schneider 2008).

Comparison of the frequency of thunderstorms (Figs. 2, 3b), the frequency of tornadoes (Fig. 4a), the probability of thunderstorms (Fig. 7), and the conditional probability of tornadoes (Fig. 8) highlights the fact that large numbers of thunderstorm hours in strong SHR6, low CAPE environments produce a large percentage of tornadoes observed in the United States, despite a lower conditional probability than more optimal environments. This contributes to high false alarm ratios in strong SHR6, low CAPE environments, as demonstrated in Dean and Schneider (2008).

4. SUMMARY AND FUTURE WORK

Analysis of severe weather report environments for 2003-2007 allowed isolation of key severe weather environment characteristics for the continental United States. Calculations of the conditional probability of severe weather as a function of environmental space illuminate the higher probability of thunderstorms and conditional probability (given lightning) of tornadoes for large mixed-layer CAPE (MLCAPE > 1000 J kg^{-1}) and strong shear (0-6 km Shear > 40 kt). However, because of the more common occurrence of environments characterized by MLCAPE less than 1000 J kg^{-1}, over 48 percent of all tornadoes within the five year sample, including 39 percent of F2-F5 tornadoes, occur in these low CAPE environments. The large percentage of environmental hours characterized by strong 0-6 km shear and low CAPE contributes to a large percentage of tornadoes observed in the United States, despite a lower conditional probability for these conditions than more optimal environments. This contributes to high false alarm ratios in strong SHR6, low CAPE environments as demonstrated in Dean and Schneider (2008). Additional dimensions of this study (not shown) include analyses of regional and seasonal differences in severe weather environments and maps of the frequency of occurrence for key severe weather environment subclasses. The ultimate goal of this project, in addition to analysis of the environments of storms, is to create an interactive severe weather forecast support tool for SPC forecasters, and to use these data to perform context-based analyses of SPC products and services to support SPC forecast improvements (Dean and Schneider 2008).

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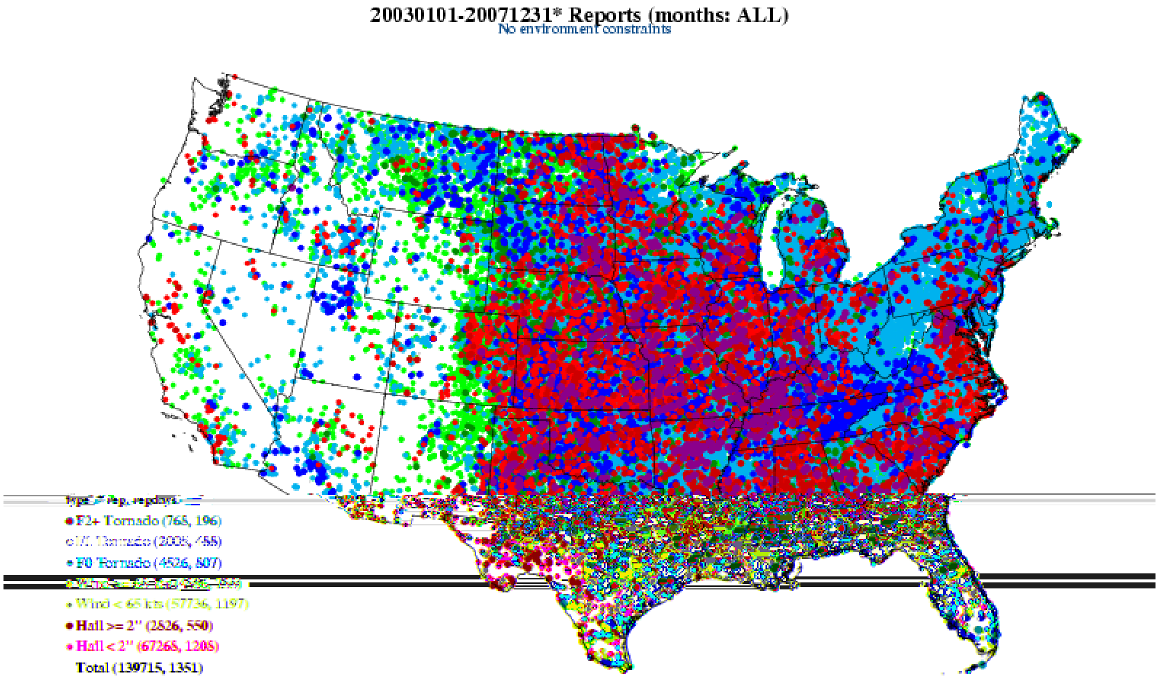

*Report data from 20070101 to 20071231 is preliminary

Figure 1. Plot of all severe weather reports from 2003-2007. The legend at the lower left indicates the report type and magnitude, along with the number of reports and report days.

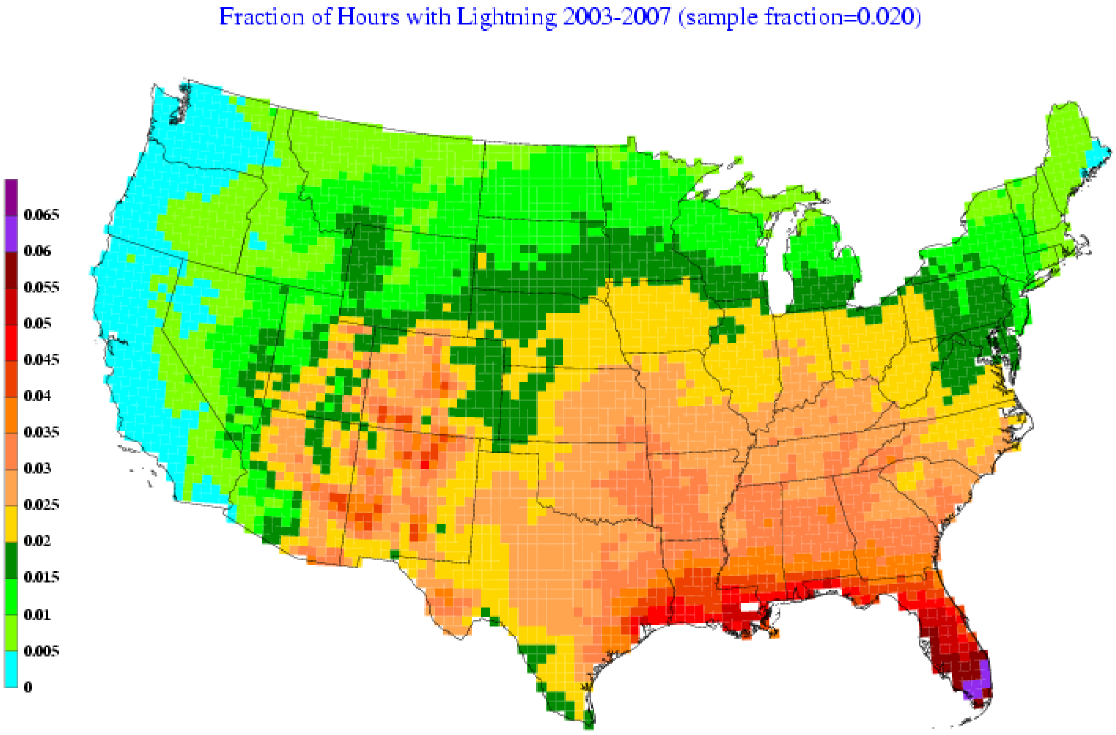

Figure 2. Fraction of total hourly grid boxes that contained at least one lightning flash for the period 2003-2007. Values are computed from gridded hourly lightning data.

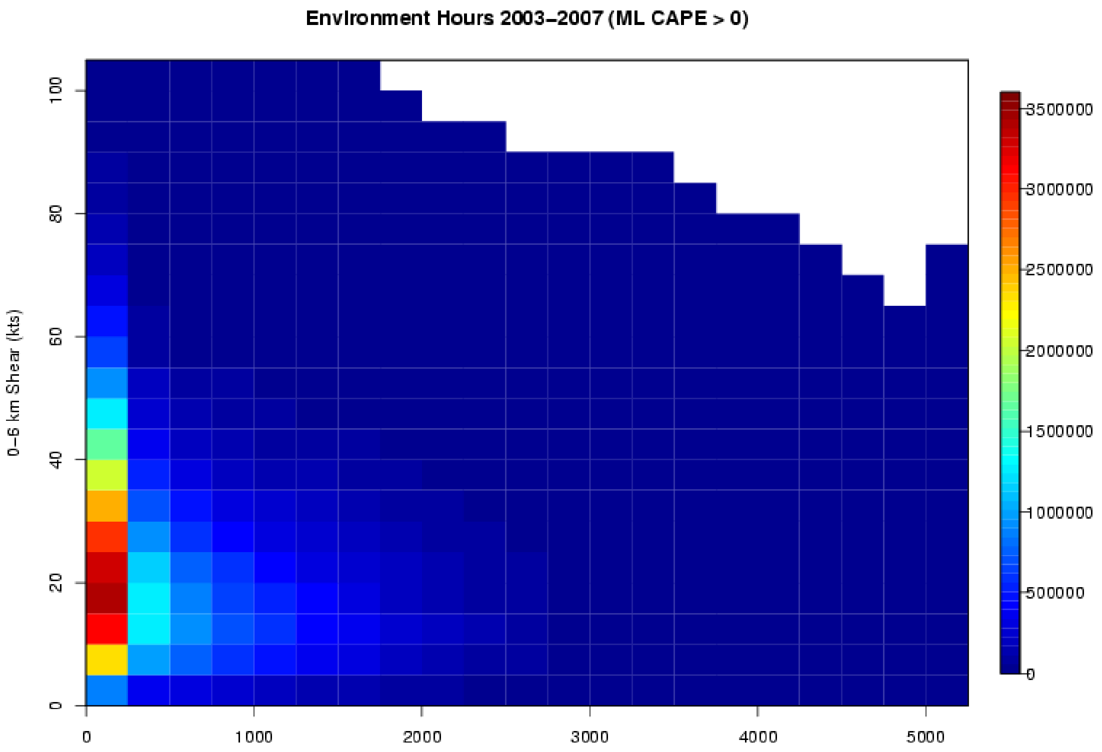

Figure 3a. Distribution of grid point environment hours over the continental United States. for 2003-2007, binned by values of ML CAPE and 0-6 km bulk shear. Values are computed from hourly surface analysis grids.

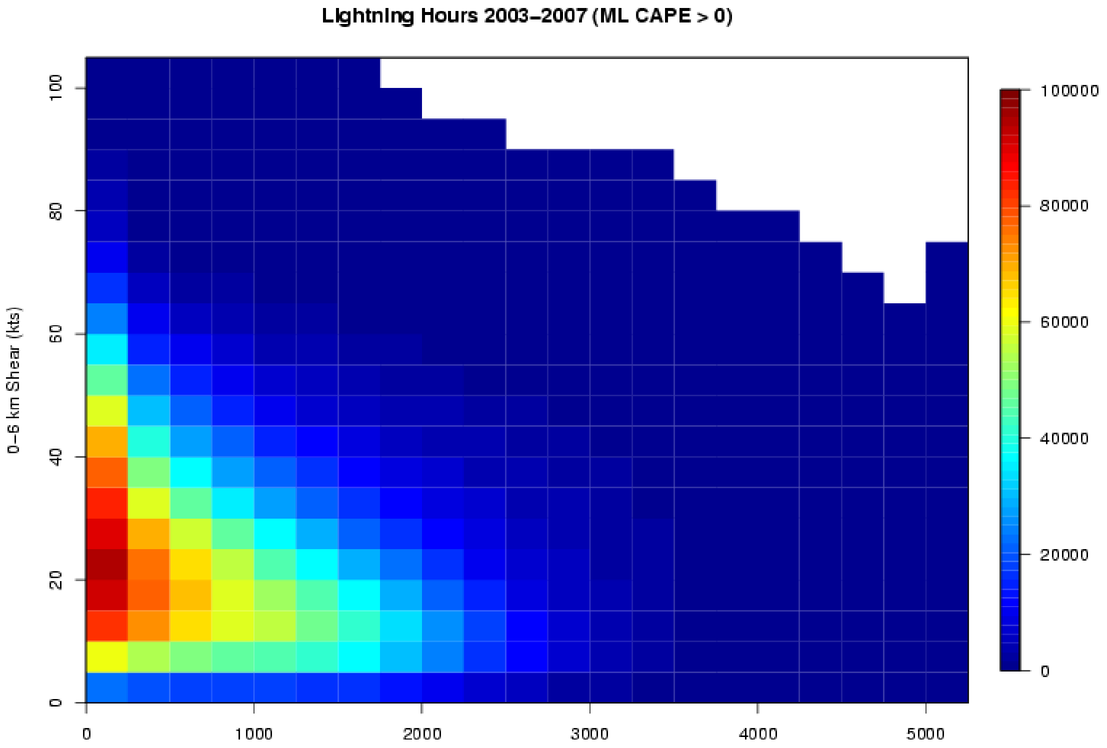

Figure 3b. Distribution of grid point environment hours with lightning over the continental U.S. for 2003-2007, binned by values of ML CAPE and 0-6 km bulk shear. Values are computed from hourly surface analysis and lightning grids

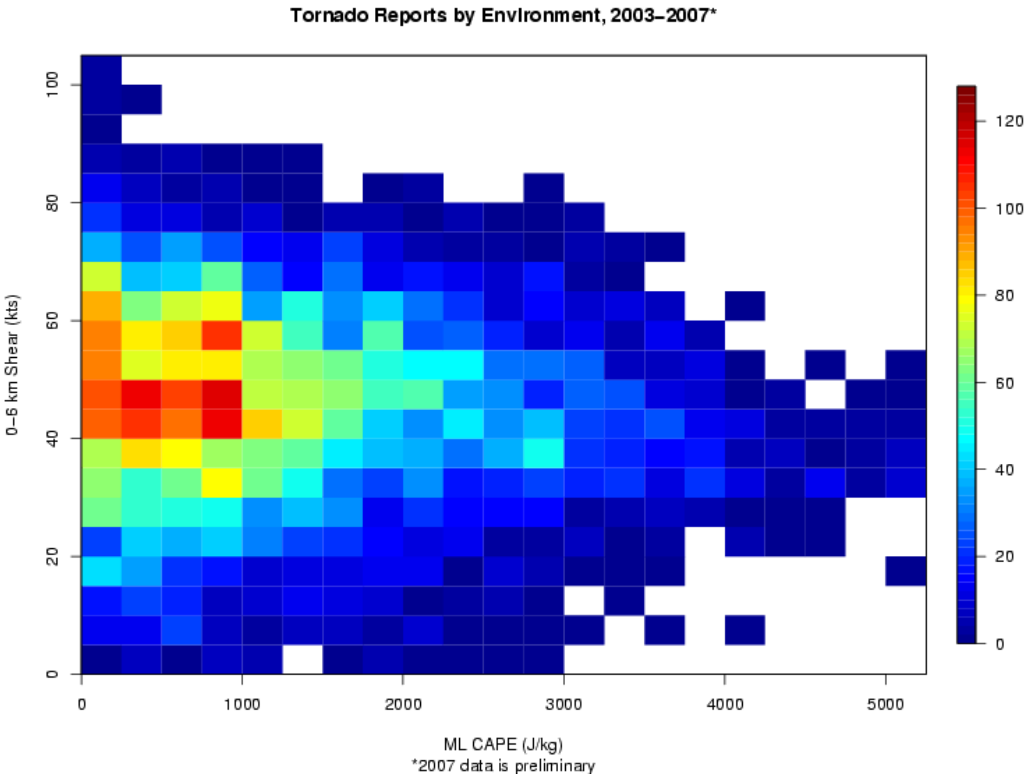

Figure 4a. Distribution of tornado reports for 2003-2007, binned by values of ML CAPE and 0-6 km bulk shear. Values are computed by associating each report with the appropriate hourly surface analysis grid values.

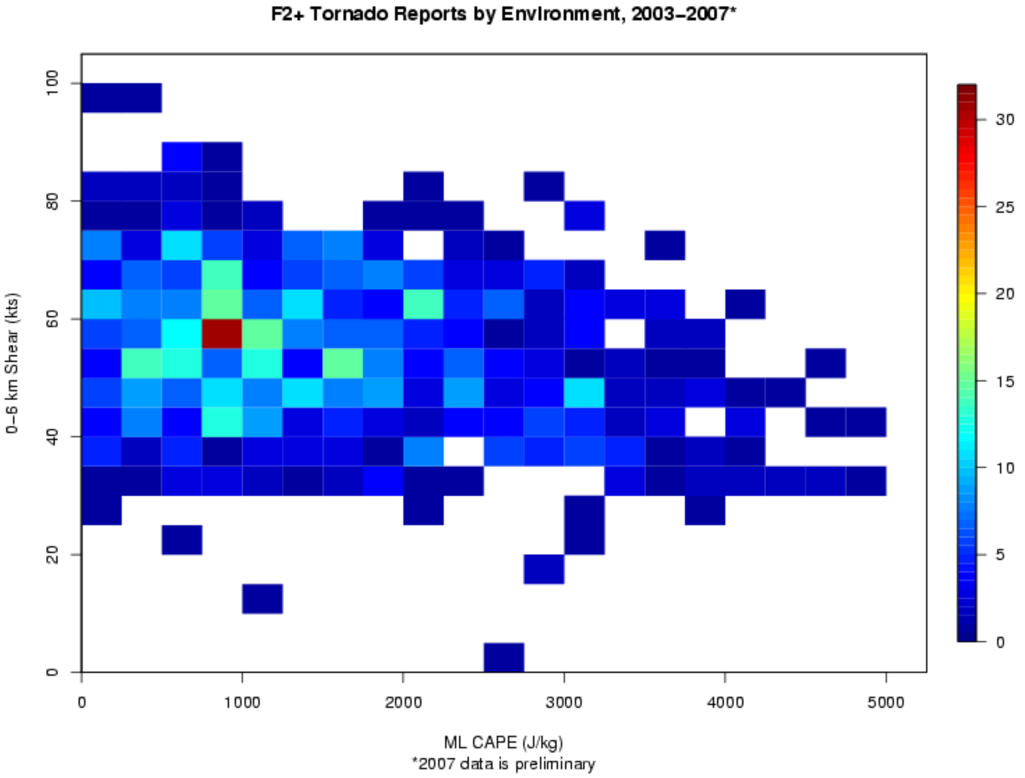

Figure 4b. Distribution of F2+ tornado reports for 2003-2007, binned by values of ML CAPE and 0-6 km bulk shear. Values are computed by associating each report with the appropriate hourly surface analysis grid values.

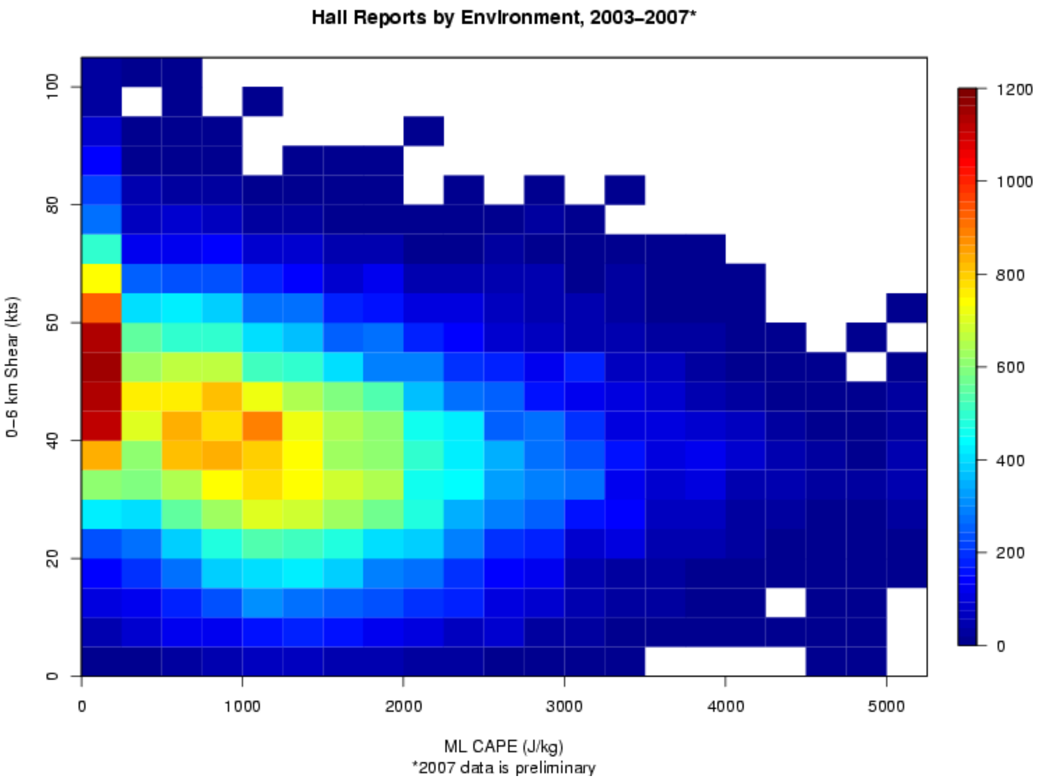

Figure 5a. Distribution of severe hail reports for 2003-2007, binned by values of ML CAPE and 0-6 km bulk shear. Values are computed by associating each report with the appropriate hourly surface analysis grid values.

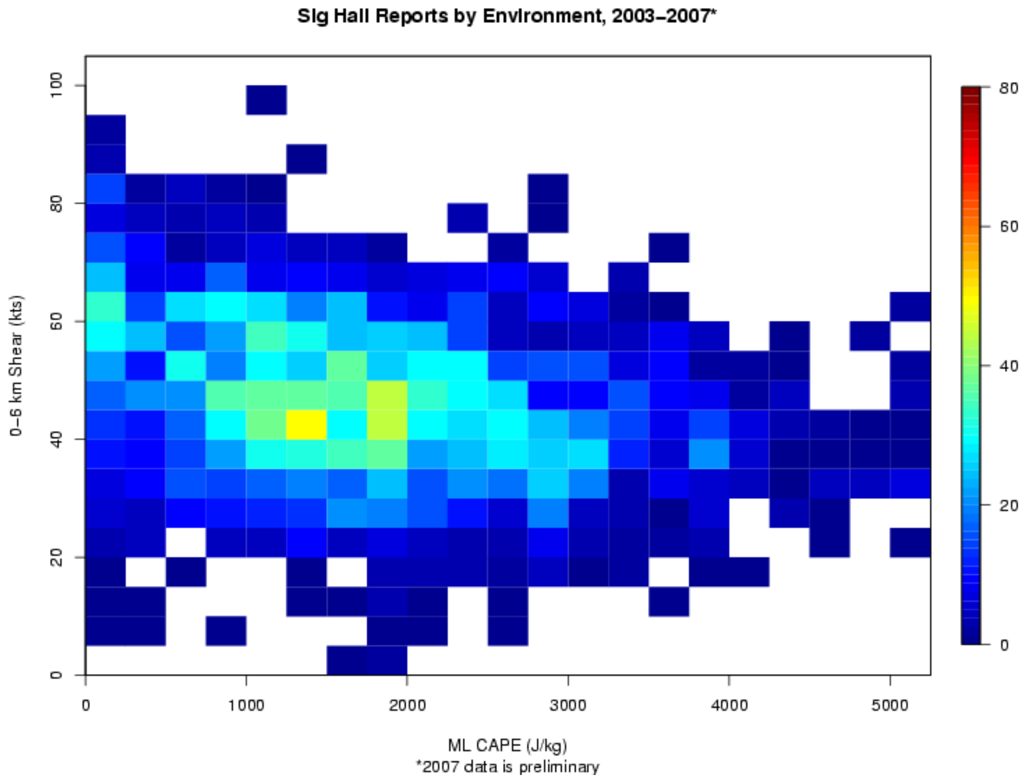

Figure 5b. . Distribution of significant (at least 2” in diameter) severe hail reports for 2003-2007, binned by values of ML CAPE and 0-6 km bulk shear. Values are computed by associating each report with the appropriate hourly surface analysis grid values.

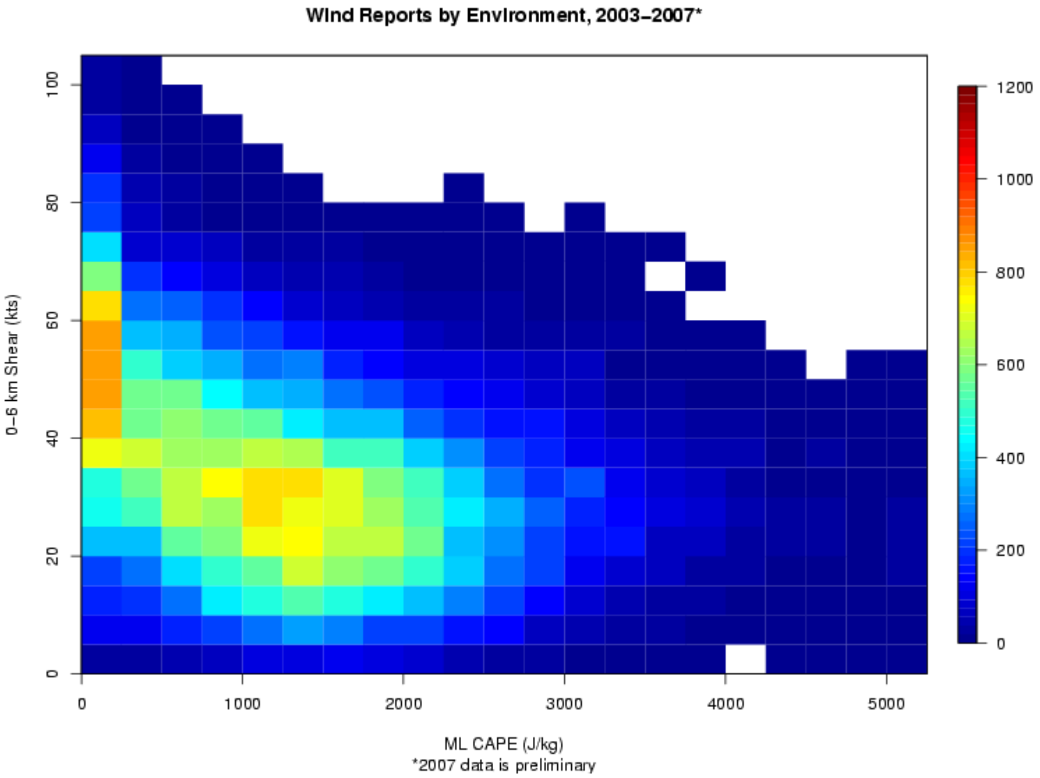

Figure 6a. Distribution of severe wind reports for 2003-2007, binned by values of ML CAPE and 0-6 km bulk shear. Values are computed by associating each report with the appropriate hourly surface analysis grid values.

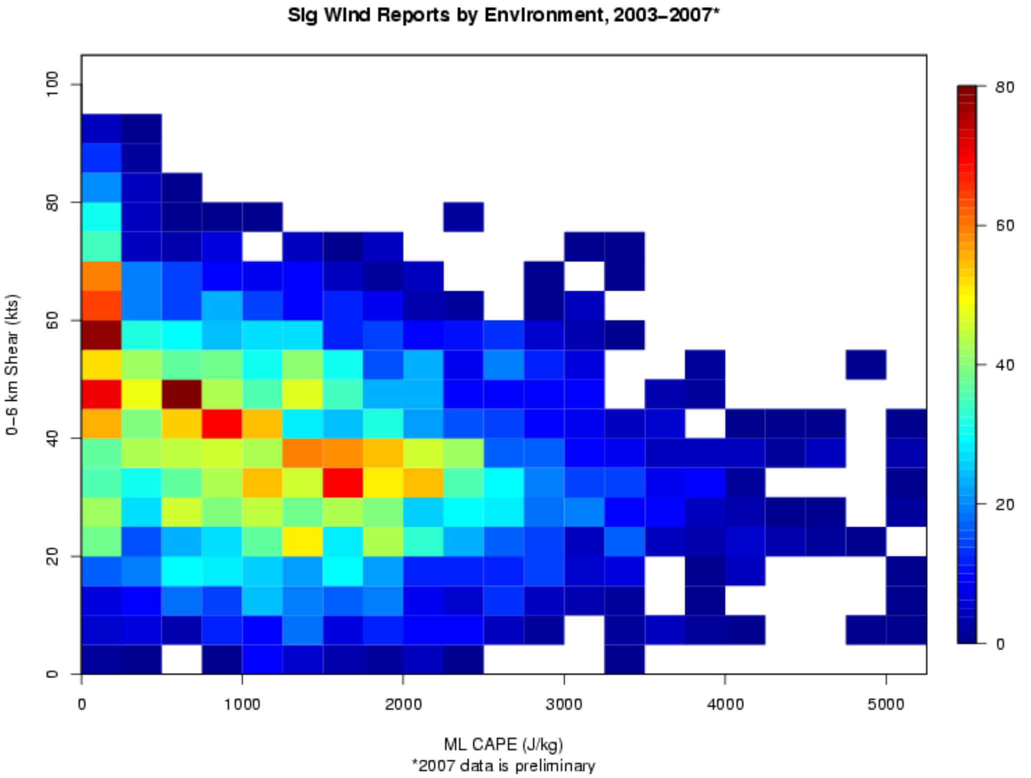

Figure 6b. Distribution of significant (at least 65 kt) severe wind reports for 2003-2007, binned by values of ML CAPE and 0-6 km bulk shear. Values are computed by associating each report with the appropriate hourly surface analysis grid values.

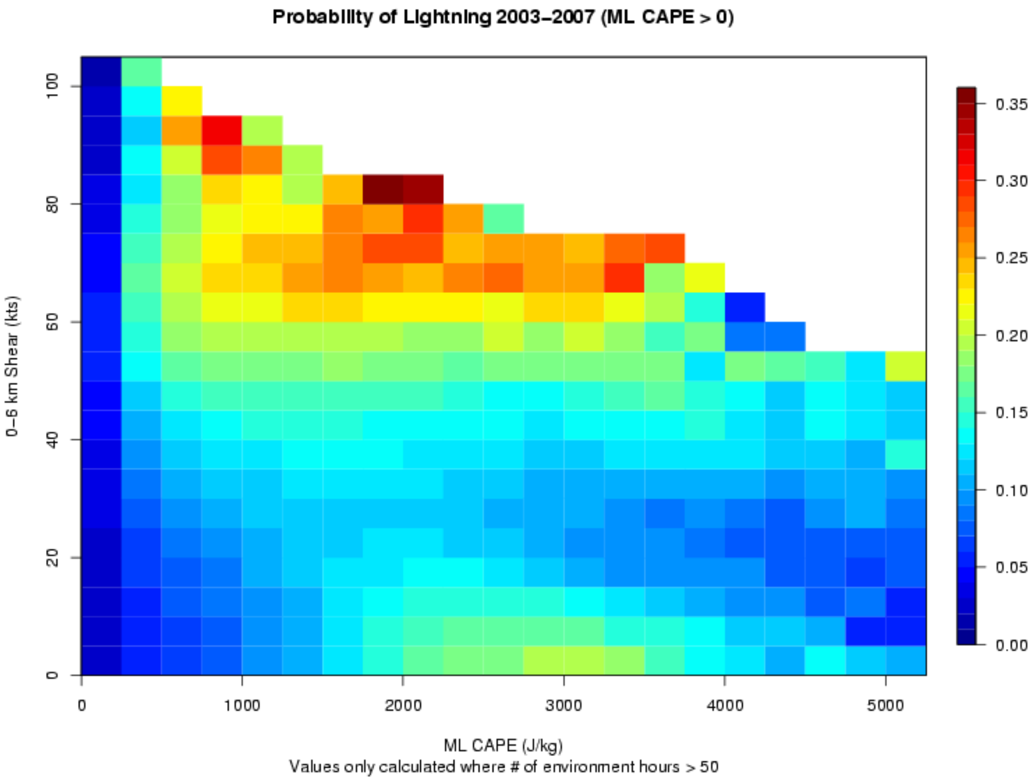

Figure 7. Probability of lightning, given associated values of ML CAPE and 0-6 km bulk shear. Values are calculated from the fraction of hourly surface analysis grid boxes that contained at least one lightning flash (i.e. the values in Fig. 2 divided by the values in Fig. 1). Values are not calculated where the number of environment hours is less than 50.

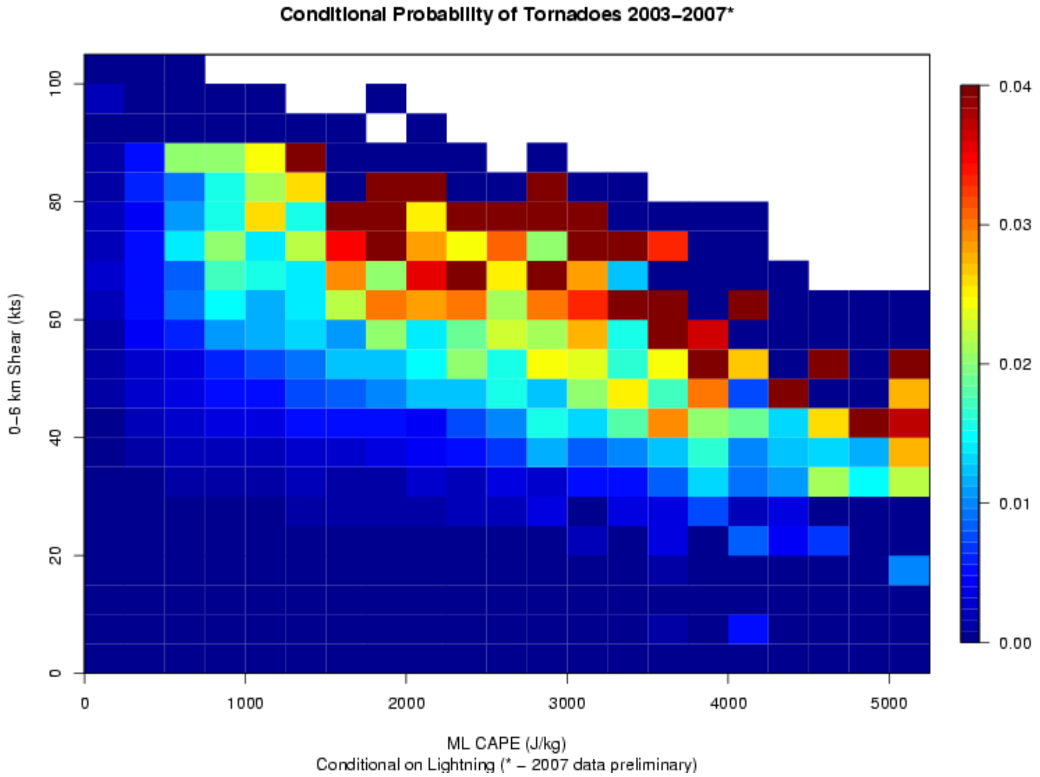

Figure 8. Conditional probability of tornadoes by ML CAPE and 0-6 km shear, given the occurrence of lightning. Values are calculated from the number of hourly surface analysis grid boxes that contained tornado reports divided by the number of boxes that contained at least one lightning flash.