11B.4 A CLIMATOLOGY OF ENVIRONMENTAL PARAMETERS THAT INFLUENCE SEVERE STORM INTENSITY AND MORPHOLOGY

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1. INTRODUCTION

Improved knowledge of how large-scale environmental characteristics regulate convective storm morphology and intensity is crucial to weather forecasters. Prior numerical and observational studies have identified many of the environmental parameters that influence convective storm structure. These studies have shown enhancement of storm intensity and longevity with increasing convective available potential energy (CAPE), provided the ratio of CAPE to kinetic energy in the ambient shear is within a certain favorable range (Weisman and Klemp 1982). Environments outside this optimal range of CAPE and shear values have been referred to as being either CAPE-starved or shear-starved. The shapes of buoyancy and shear profiles (McCaul and Weisman 2001) can also significantly influence the storms, with compression of parcel buoyancy into the lower troposphere being capable of boosting updraft overturning efficiency and thus partially compensating for lack of CAPE in CAPE-starved regimes.

Furthermore, McCaul and Cohen (2002; hereinafter MC02) showed that overturning efficiency in simulated storms is strongly suppressed when the moist layer depth, represented by the level of free convection (LFC), is very small, and that outflow dominant storms are likely when the mixed layer depth, represented by the lifted condensation level (LCL), is large. They also showed that outflow dominance could be prevented in a high-LFC environment if the LCL was low, and the air between the LCL and LFC was not too dry. Other research has shown that a drier midtroposphere has also been found to encourage stronger surface outflow.

Based on their study of cloud simulations, MC02 proposed that a parameter space of at least eight dimensions must be considered in order to understand the basic behavior of convective storms. The eight parameters used by MC02 included CAPE, altitude of maximum buoyancy, LCL height, LFC height, midtropospheric relative humidity, precipitable water and two parameters of the wind profile (one describing bulk shear, the other the shape of the shear profile). Past studies have examined the statistics of a few of these parameters (Johns et al. 1993; Rasmussen and Blanchard 1998). A common finding in these studies was that severe storms can occur in environments having a wide range of CAPE and bulk shear values, with scatterplots generally showing a negative correlation between CAPE and shear. However, these studies are limited in the sense that they have examined only undifferentiated statistics, without controls on each of the other parameters.

Unfortunately, environments with similar values of one parameter can support storms that can be quite different if other parameters differ. Likewise, different values of one parameter can be associated with somewhat similar storm structures if other key parameter values are properly chosen. For example, greater lower tropospheric buoyancy enhances storm size and strength in a CAPE-starved environment, but can have quite different effects for a shear-starved environment, all other things being equal. Analysis of undifferentiated statistics makes interpretation of relevant physical effects difficult, because the existence of correlations between many of the parameters in observational data conflicts with the need to keep other things equal. The present study attempts to attack this problem by laying the groundwork for a more careful analysis of storm environments within the context of the eight dimensional space conceived by MC02.

Here we will document the spatial variations of the eight basic parameters and some other potentially important variables, for the entire Continental United States (CONUS) region, using all available sounding data archived during the period 1950-2000. Scatterplots of pairs of parameters are also constructed and compared, both for data unconstrained and constrained with respect to values of the other six key parameters.

2. METHODOLOGY

The climatology of the key environmental parameters is constructed based on analysis of quality-controlled rawinsonde observations from the Comprehensive Aerological Reference Data Set (CARDS; Eskridge et al., 1995), using all U. S. sites and a few other neighboring sites in Canada and Mexico. These rawinsonde observations are carefully quality-controlled to eliminate errors. We do not restrict our study only to soundings that are known to have been associated with severe storms, although such soundings are included in our dataset. The key parameters are then evaluated for each of the edited soundings in the dataset, and written to time series files for scatterplot analysis. These data are then processed to produce monthly means and extremes of each parameter for both 00 UTC and 12 UTC times; the results are then objectively analyzed to a regular grid. For station pairs that are closely collocated but span different time periods, the monthly

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statistics of each member of the pair are examined, and if their statistics are not significantly different, they are merged to create a longer data record for one of the sites in each pair. This obviates the need to maintain separate records and plotting points for stations such as Oklahoma City and Norman, Oklahoma.

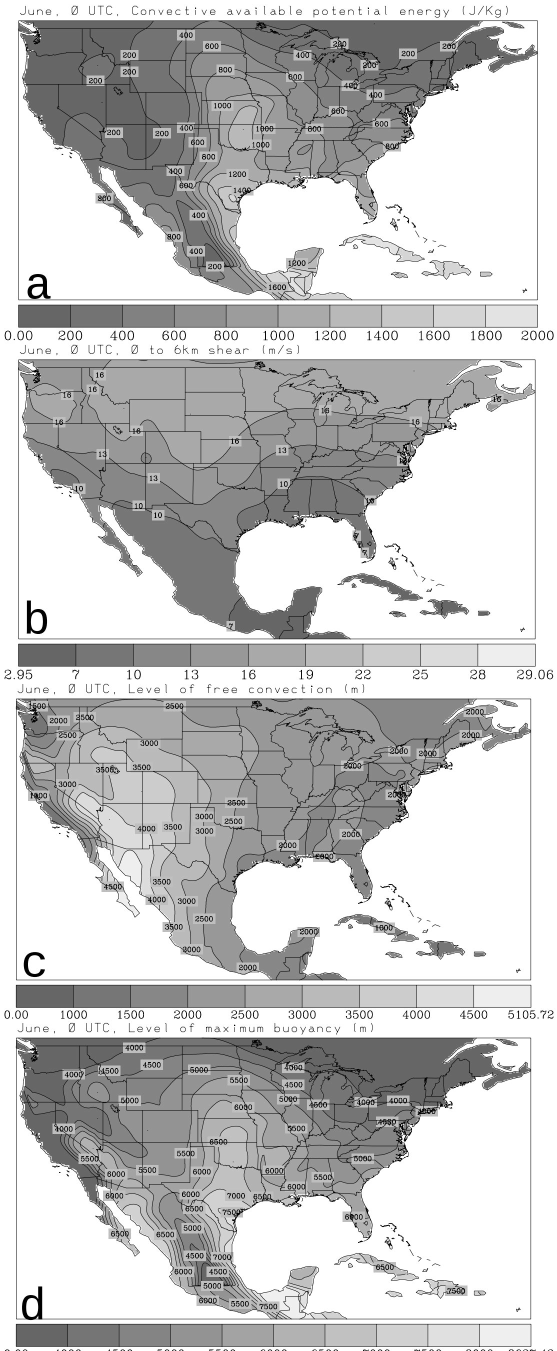

Figure 1. Maps of mean 0 UTC soundingparameters

For simplicity, we have chosen to examine 0-1 km vector shear and 0-6 km vector shear as our key kinematic parameters. Midtropospheric dryness is evaluated in terms of 2-6 km layer-mean dewpoint depression. We also compute a few other parameters of potential importance, namely convective inhibition (CIN), 0-10 km vector shear, and surface pressure, temperature, dewpoint and windspeed. All these parameters may be mapped for any month, and pairs of parameters may be drawn on scatterplots.

3. RESULTS

Maps of most of the key parameters exhibit large spatial and seasonal variations. Taking the month of June as being roughly representative of severe weather season, it is found (Fig. 1a) that mean CAPE at 00 UTC displays a pronounced tongue of large values from Texas northward into the central Plains. At the same time, mean 0-6 km shear (Fig. 1b) shows small values in the Southeast U. S., but enhanced values just east of the Rocky Mountains. The pattern is even more pronounced when 0-1 km shear is examined, especially at 12 UTC (not shown). Large CAPE and shear thus tend to coexist in the mean through much of the central Plains during June, in agreement with the observed high frequency of occurrence of severe weather there.

The map of mean LFC height at 00 UTC (Fig. 1c) reveals values less than 2 km east of the Mississippi River, but increasing with distance westward from there; very high mean LFCs of more than 4 km are noted throughout much of the desert intermountain plateau region. Thus moderately high LFCs of 2-3 km tend to coexist with large CAPEs over much of the Plains. MC02 found that LFCs of 2 km or more over well-mixed boundary layers tended to promote highly efficient convective overturning. Thus the combination of LFCs and CAPEs over the Plains is also consistent with the observed maximum in severe storm occurrence there. The map of mean altitude of maximum buoyancy (zbmx; Fig. 1d) shows a minimum in the East and far West and a peak over the Southern Plains. MC02 showed that low values of zbmx tend to enhance convective overturning efficiency in CAPE-starved environments, while high zbmx could reduce the tendency for outflow dominance in storms forming in slightly shear-starved environments. For June, the balance between CAPE and shear is such that most of the U. S. is somewhat shear-starved, so that enhanced zbmx might be expected to encourage the probability of supercell convection. If the mean pattern of tornado occurrences can be said to mirror the distribution of supercells, then the map of June mean zbmx in Fig. 1d is indeed consistent with the apparently enhanced probability of supercells in the Plains.

A scatterplot of CAPE versus 0-1 km shear, when considering only small zbmx soundings (Fig. 2a), shows marked differences compared to that drawn for only large zbmx soundings (Fig. 2b). The full scatterplot (not shown) consists of points filling in the lower-left triangle of the parameter space, suggesting a general negative correlation between CAPE and shear. This is reminiscent of the scatterplots given by earlier investigators for severe storms conditions, but with more weak shear points included. However, Fig. 2a reveals that in the small CAPE, strong shear part of the scatterplot, low zbmx tends to predominate, making efficient and even severe convection more likely there. Likewise, Fig. 2b shows that the large CAPE, weak shear cases tend to have only large zbmx, which was found by MC02 to promote more clearly delineated supercell morphology for shear-starved environments. Many of the points at very small CAPE in Fig. 2b are apparently associated with very high LCL environments, which are not likely to be associated with severe convection. Thus, the data in Fig. 2, in combination with the findings of MC02, offer one possible explanation for how severe storms can occur under widely different combinations of CAPE and shear.

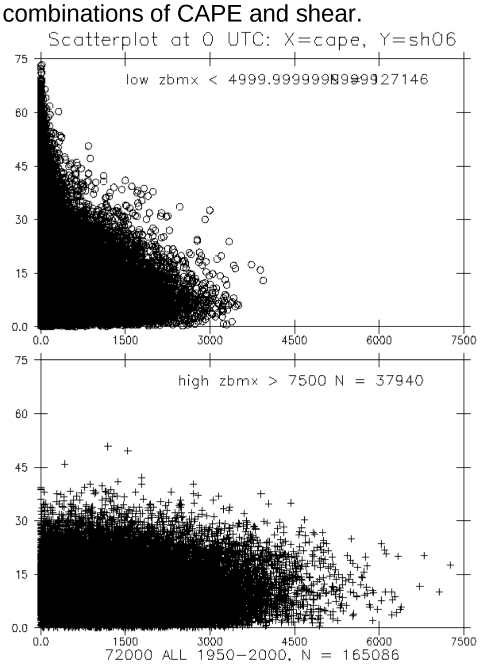

Figure 2. Scatterplots of 0 UTC CAPE vs 0-1 km shear for all CONUS stations, stratified by altitude of maximum parcel buoyancy “zbmax”. (a) zbmax < 5.0 km (b) zbmax > 7.5 km.

4. CONCLUSIONS

Analysis of the eight key sounding parameters identified by MC02 can furnish new insights about the structure of environments that support different types and intensities of convection. The high-shear, small-CAPE portion of previously published scatterplots of severe weather soundings is shown to be associated with situations where the altitudes of maximum buoyancy are low, a condition which has been shown to lead to enhanced storm size and intensity compared to situations having larger altitudes of maximum buoyancy. Conversely, the low-shear, large-CAPE portion of those scatterplots is associated with high altitudes of maximum buoyancy, which have also been found to be beneficial for storm structure in shear-starved environments, all other things being equal. In future work, we plan to analyze the seasonal and interannual variations in the key parameters, document how often the atmosphere visits each part of the eight-dimensional parameter space, identify specific severe weather soundings in our data, and compare the radar and satellite-derived characteristics of observed storms with results from simulations obtained in each portion of the parameter space.

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