REGIONAL VARIABILITY OF CAPE AND DEEP SHEAR FROM THE NCEP/NCAR REANALYSIS

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ABSTRACT

Variations in the distributions of parameters that lead to deep moist convection from the National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) 42 year global reanalysis dataset have been analyzed for 3 domains. Although the variability of the distribution of convective parameters is a little higher in the Eastern United States, the Central United States adequately represents the distribution of both domains, and therefore serves as a comparison to the South American domain. CAPE has been roughly increasing in the Central United States since the late 1960's while South America has been exhibiting a downward trend in CAPE over the period. In fact, from 1970 to 1999 the two regions have exhibited very different characteristics when it comes to the distribution of CAPE. Deep shear in the presence of CAPE has not changed throughout the reanalysis period. Therefore, the increase of the product of CAPE and deep shear can be contributed to the increase of CAPE in the Central and Eastern United States.

1. INTRODUCTION

From the perspective of a convective forecaster, it is vital that one understands the environmental conditions in which he/she expects convection to occur. Using the ingredients based forecasting technique that Doswell et al. (1996) described to forecast flash floods, one can employ parameters that are relevant to convection, or perhaps deep moist convection, to develop a conceptual model that would resemble an environment favorable for the development of such events. This is sufficient from a day to day forecasting point of view, but the proposal is to try to understand the distribution of convective environments. In turn, this study will not be useful in predicting the environment on a day to day basis; however, it will be especially useful in determining which areas are climatologically favorable for convective environments. This will also allow one to analyze how frequent, and what times of the year a forecaster would expect a convectively favorable environment. Brooks et al. (2003) have taken the first step towards trying to understand the global distribution of convectively favorable parameters.

This paper will look at the variability of these distributions, including the change of their spatial and temporal characteristics. This will be done by analyzing trends of convectively important variables for three domains. It will then be valuable to compare and contrast the parameters across domains to determine the variability of each data set.

2. BACKGROUND

In order to get a sense of what past environments resemble, especially the vertical profile, it is useful to analyze data from the National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) global reanalysis dataset.

Kalnay et al. (1997) describes this 42 year reanalysis project. Researchers desire to use observed data for analysis, but the spatial and temporal sampling of observed soundings are not adequate enough to allow thorough analysis of regions. On the other hand, reanalysis provides spatial and temporal continuity in the form of spacing of 1.875° longitude by 1.915° latitude and soundings taken every six hours at 00 UTC, 06 UTC, 12 UTC, and 18 UTC. Reanalysis does have a problem with filtered observations however.

Brooks et al. (2007) analyzed mean annual cycles of thermodynamic parameters and described possible correlations. That study helped build the foundation for the current project of looking for the variability of the distributions of convective parameters. The 2002 IPCC Workshop on Changes in Extreme Weather and Climate Events report (IPCC 2002) states that reanalysis techniques will be vital in determining how convective parameters vary and how they will affect our future climate. Because of the unreliability of reports in our society, attention must turn to the environments that lead to convection.

Lee (2002) showed that reanalysis data provides a good approximation of convectively important parameters when compared to collocated observed soundings. One such parameter useful in accessing stability of the atmosphere is Convective Available Potential Energy (CAPE). CAPE is a useful discriminator of convective environments. Deep layer shear[1] values as well as CAPE, can give a much better idea of the environments potential to accommodate deep moist convection. Deep shear is valuable for determining organizational features of the convective environment. Therefore, this study utilizes CAPE and deep shear to analyze trends of convective environments.

[1] In this case deep layer shear is measured as the difference between the magnitude of the 6 Km vector and the surface vector. This is not the definition of shear, but since the height difference from the surface to 6 km is the same, our definition resembles the definition of shear.

3. METHODOLOGY

This study will focus on the 42 year reanalysis data set (1958-1999) and look for annual variability of thermodynamic parameters that would be typical of a preconvective environment. Reanalysis data provides standard 6 hr intervals of best estimate profiles for the atmosphere for 18,048 points on the globe. So far, this study has focused on three main areas: The Central United States, Eastern United States, and Southeastern South America. Each area has domain of 15 ° latitude by 15° longitude. This geographic area produces 72 points in both the Central and Eastern United States regions. The North American regions will have approximately 4.4×10^6 soundings. The South American dataset only has 64 points because of the placement of the domain, but still has about 3.9×10^6 soundings. It is important to note that for this study we will disregard all soundings with zero CAPE in all regions because we do not wish to look at the probability of CAPE occurring, we want to analyze the variability of CAPE.

This study will also investigate the variability of CAPE for the three domains previously stated and then begin to compare the distributions across regions. It will not only analyze the variability of CAPE across the 42 year period, but will look at deep shear in the presence of CAPE e.g. (If the CAPE is greater than 1,000 J Kg^{-1}, what is the deep shear value?) This allows one to understand the variability of environments with instability and organizational features that become more important when dealing with severe convection.

Based on the parcel theory, extreme values of CAPE give the preconvective environment a better chance to produce severe convection in the form of stronger updrafts. For this reason we will look at the 90^{th} percentile CAPE values for all three domains. The 90^{th} percentile in this study is the value that is exceeded by only 10 percent of the soundings. By observing the 90^{th} percentile across all domains, one can get a sense of the variability of each domain, trends within domains, and even global scale relationships between regions. Developing this kind of distribution across a 42 year period allows researchers to understand the interannual variability of convective environments. Understanding the past variability of our climate is essential if we are ever to try to understand what convective environments will resemble in the future.

4. RESULTS

4.1 Annual Distribution of CAPE

The Central United States is one of the regions with the most frequent combinations of CAPE and deep shear (Brooks et al. 2003). The Central United States domain consists of 30 to 45 degrees north and 105 to 90 degrees west. Figure 1 depicts the annual distribution of CAPE in the Central United States. The plot shows that for any given sounding, the y-axis corresponds to the probability of exceeding the x-axis CAPE value. This type of chart allows one to interpret the annual cycle of CAPE in the Central United States.

The domain for the Eastern United States encompasses 30 to 45 degrees north and 90 to 75 degrees west. This domain is usually associated with smaller CAPE values on average due to steep lapse rates existing in the Central United States just east of the Rocky Mountains in the spring season are often less dramatic when they reach the Eastern United States. Since lapse rates are often a big contributor to CAPE, values tend to be slightly lower in the Eastern United States. It is interesting to observe how thermodynamic parameters change as you move further east, away from the Rocky Mountains. For this reason, the Eastern United Sates will serve as a good comparison by which to look at the Central United States. Although it does not produce nearly as many convectively favorable environments (high CAPE & Shear) as the Central United States does, it does have more soundings with CAPE than the Central United States. 43 percent of soundings in the Eastern United States have CAPE as opposed to only 37 percent of the soundings in the Central United States.

Brooks et al. (2003) includes an updated figure showing a maximum of severe environments just east of the Andes Mountains in Southeastern South America. Since this project used a 15 degree by 15 degree box for the United States, the same size box will be used for South America to help keep the size of the populations similar. A box from 20 degrees to 35 degrees south and 65 degrees to 50 degrees west gives a similar 15 degree by 15 degree box in to which we can make comparisons to the United States. The United States data set housed 72 points in the 15 degree by 15 degree box, while the same sized South American box only contained 64 points. This is not significant due to the fact of the large dataset; therefore, it should not have immense impacts on the outcome of this study. This region is an area of interest for this study because of its high frequency of severe environments (Brooks et al. (2003) and its topographic similarities with the Central United States (located just east of the Andes Mountains). This region is an area of interest for its comparison across hemispheres. Because this region is in another hemisphere, it will not be affected by the same synoptic features like the two North American domains will be. If there are relationships between these regions in opposite hemispheres, it will be due to global features and circulations rather than synoptic scale features.

Figure 2 shows the annual distribution of 90^{th} percentile CAPE values for the three domains. The Central United States peaks in CAPE values in June while the Eastern United States peaks in the July period. Since South America is in the southern hemisphere, its peak is around the November timeframe. This figure also shows the much larger range of values in the United States as compared to South America. This could be due to the latitude differences of the two regions, which would suggest that South America has CAPE a higher percentage of the time than the United States. This is true as South America has some sort of CAPE in 50 percent of the reanalysis soundings as compared to the 37 and 43 percent in the United States respectively.

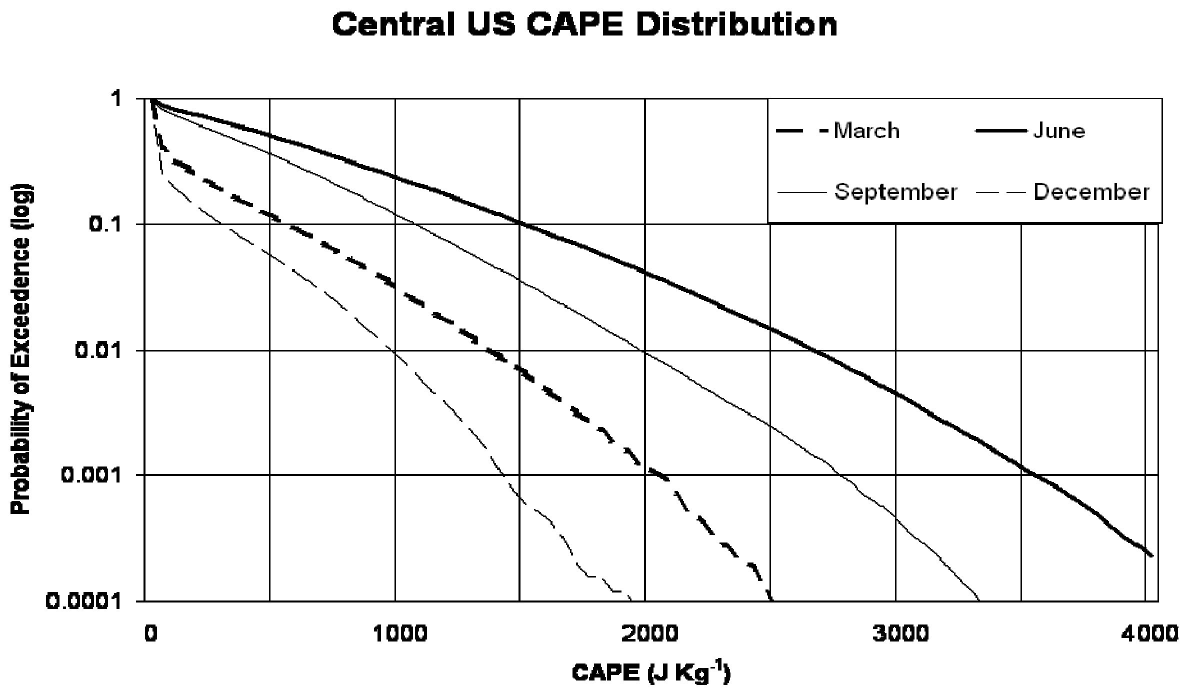

Figure 1: Each line (March-Thick Dashed, June-Thick Solid, September- Thin Solid, December- Thin Dashed) represents the probability that CAPE from a sounding will exceed values on the horizontal axis, given that CAPE is present. For example, the probability that any given sounding in June will exceed 1,500 J Kg^{-1} is 10 percent.

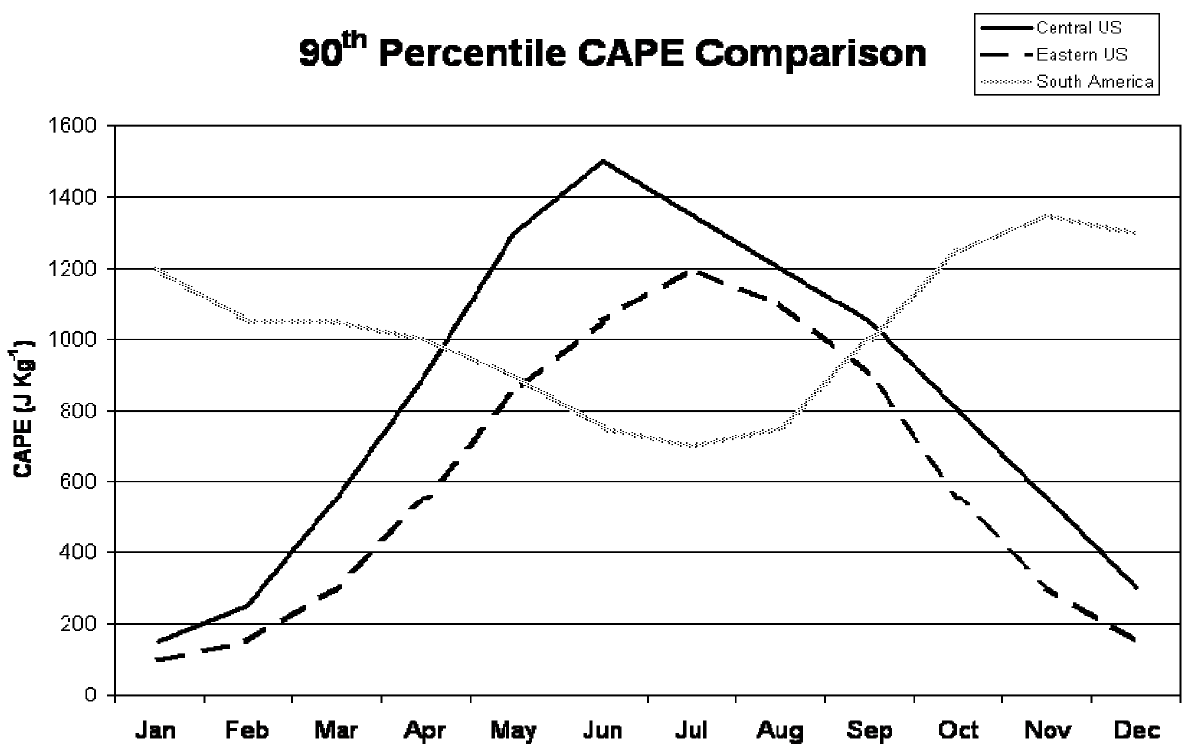

Figure 2: The annual distribution of 90th percentile CAPE values in each region. (Central US- Dark Solid, Eastern US- Dark Dashed, South America- Light Solid). Note the differences in the peaks of the 90th percentile CAPE values and the different ranges of the 90th percentile CAPE values.

4.2 Variability of CAPE & Shear

There is need for an understanding of how different convective parameters vary with time so that researchers and forecasters can adjust their approach to studying and forecasting these convective environments. This is accomplished in this study by observing five-year running means to help smooth the data and identify trends. Figure 3 is a plot of the 90th percentile CAPE values for each year for the Central United States. In other words, for any given year, the y-axis value corresponds to the percent of soundings that exceed the 90th percentile value, which in this case is 1,200 J Kg^{-1}. It is easy to diagnose high and low CAPE periods by using these types of charts. For example, in Figure 3 one can see the relatively low CAPE period in the mid 1960's through the 1970's and the reasonably high CAPE period from the late 1980's through the 1990's. This suggests that in the 30 year period from about 1967 to 1998 the number of soundings that reach the 90th percentile CAPE value have increased.

The Eastern United States shows much less in terms of extreme CAPE values as discussed earlier in terms of lapse rates. This is shown in Figure 4: the 90th percentile CAPE value in the Eastern United States is only 900 J Kg^{-1} as opposed to the 1,200 J Kg^{-1} in the central United States. The Eastern United States has also shown the same kinds of increases in CAPE across the same time period, with a hint of higher variability in the data set. Qualitatively, these regions show the same sorts of relationship in terms of CAPE. This is mostly likely the cause of their proximity to each other and synoptic features that impact both regions around the same temporal period. Figure 5 shows the 90th percentile CAPE values for the South American domain. It is interesting to note that this region was above average in terms of 90th percentile CAPE for all of the 1970's. Since 1985, this region has shown signs of decrease when compared to other years. Figure 6 is a distribution of median deep shear values when CAPE is greater than the 90th percentile. This figure shows that there has not been much variation in the deep shear values in the presence of 90th percentile CAPE over the 42 year time period in the Central United States. Besides slightly higher shear in the 1960's and a few interesting years of low shear in the late 1980's, deep shear in the presence of high CAPE values in the Central United States have remained the same.

Brooks et al. (2003) implies that the product of CAPE and deep shear can yield values that are helpful in determining significant severe environments. Essentially if the product of CAPE and deep shear is above a certain threshold, then the environment has the potential to produce significant severe convection. Figure 5 shows the distribution of the 90th percentile product of CAPE and deep shear. It shows similarities of the 90th percentile of CAPE itself. Since median deep shear in the presence of 90th percentile CAPE has stayed relatively the same, the increase in the product of CAPE and deep shear has likely been attributed to the increase in CAPE and not to deep shear.

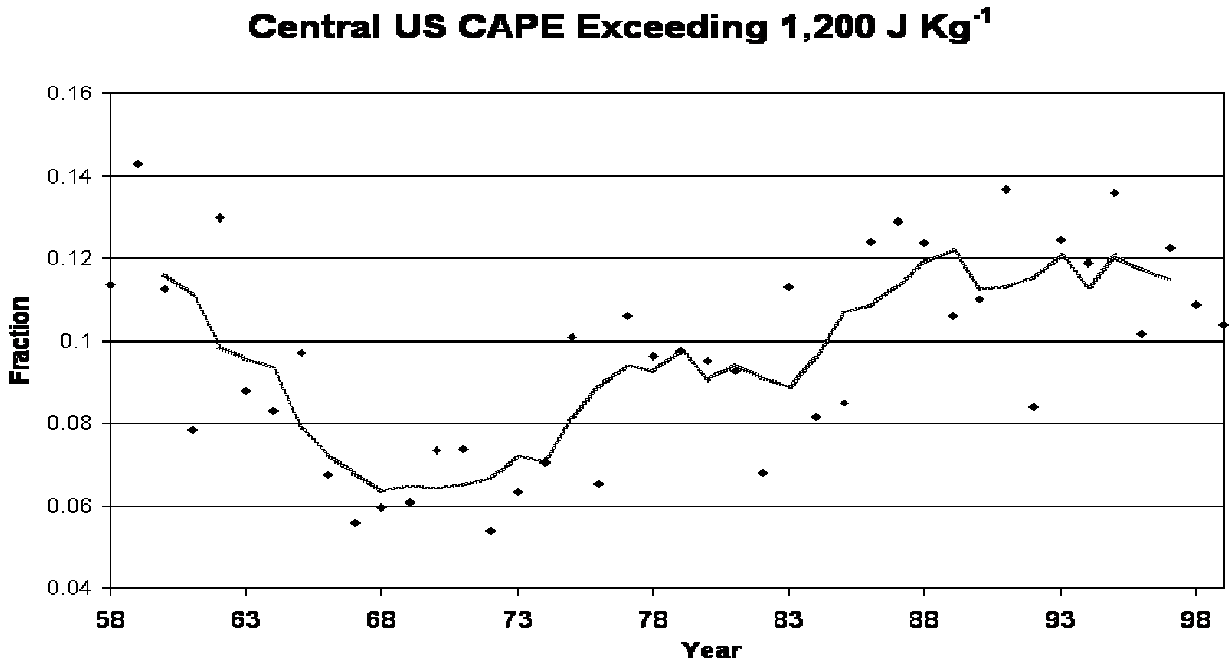

Figure 3: Distribution of percent of soundings that exceed 1,200 J Kg^{-1} (90^{th} percentile). Solid line indicates the five year running mean. For example, about 12 percent of soundings exceeded 1,200 J Kg^{-1} in 1988.

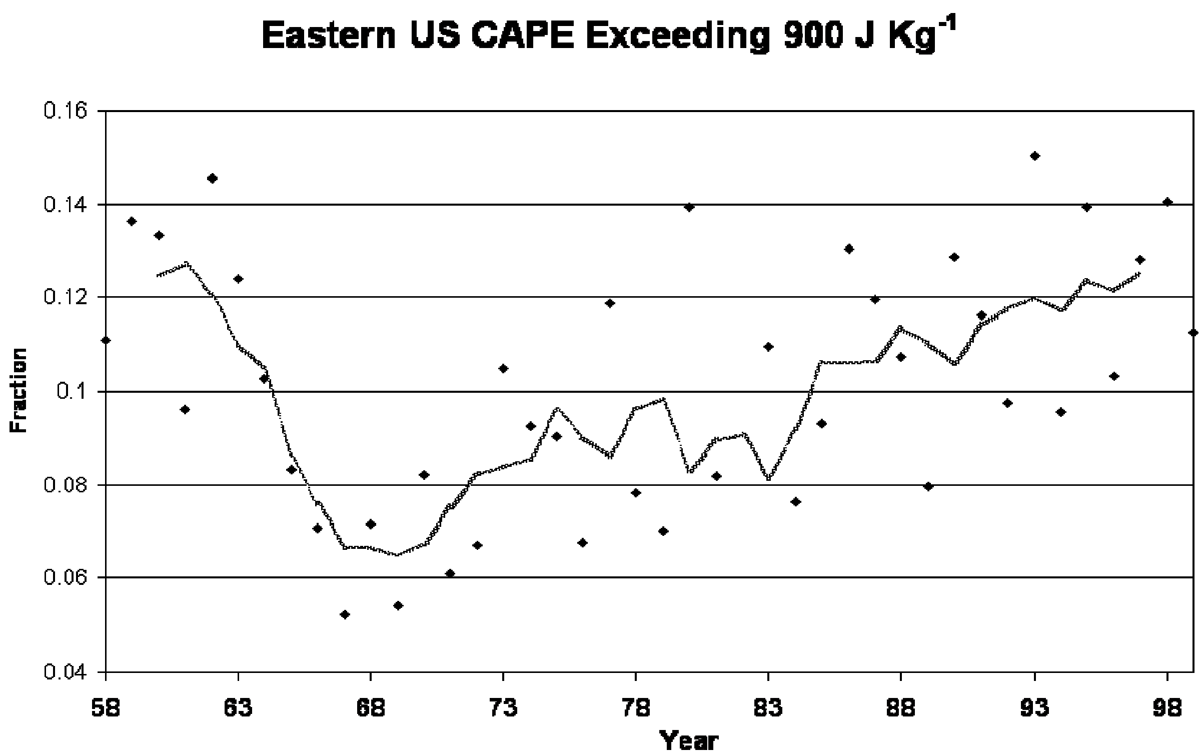

Figure 4: Same as Figure 3 except for the Eastern United States. Note the difference of the values of the 90^{th} percentiles for the regions.

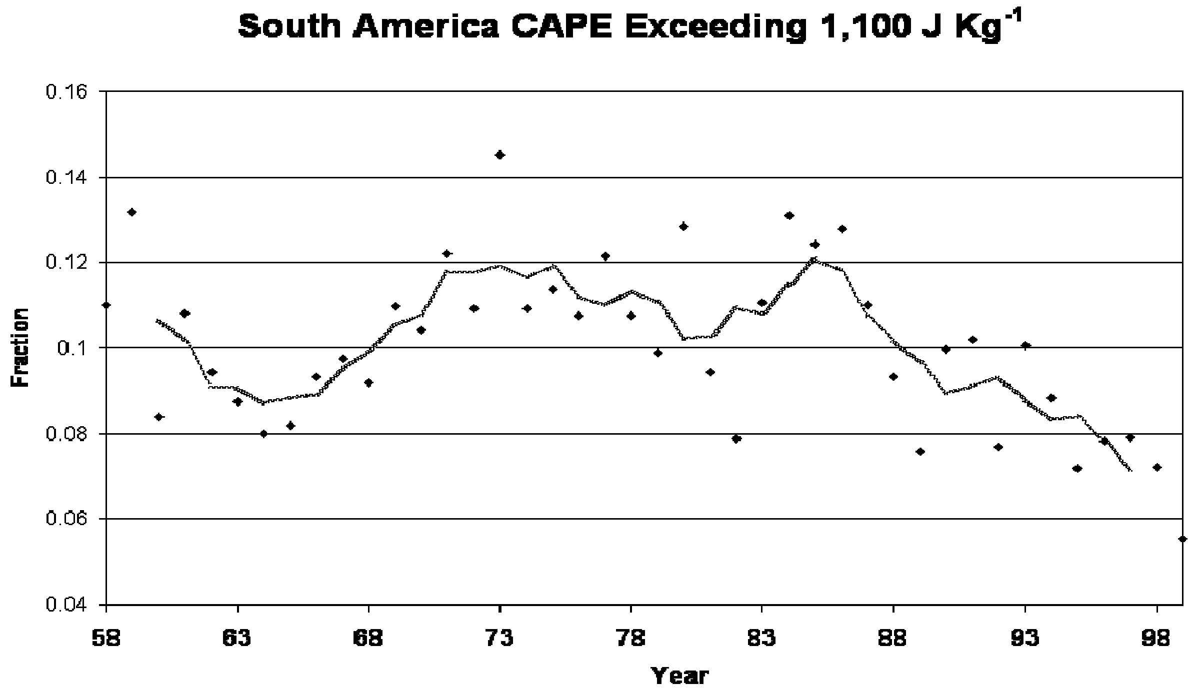

Figure 5: Same as Figure 3 except for South America. Note the difference of the values of the 90th percentiles for the regions.

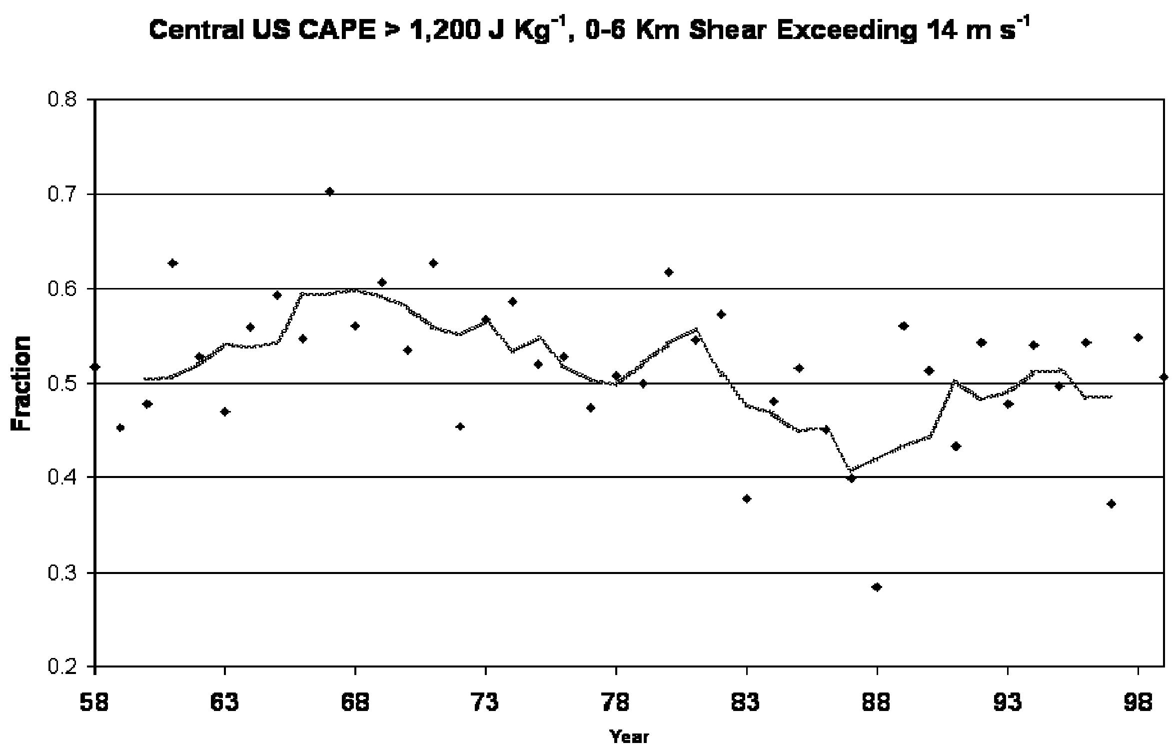

Figure 6: Similar to Figure 3 except with the distribution of Central United States Median Shear in the presence of CAPE greater than 1,200 J Kg^{-1} (90th Percentile). Note the outlier points in 1976 and 1988. 1976 would suggest a very favorable environment for severe weather while 1988 shows that when CAPE was present, shear values were very low.

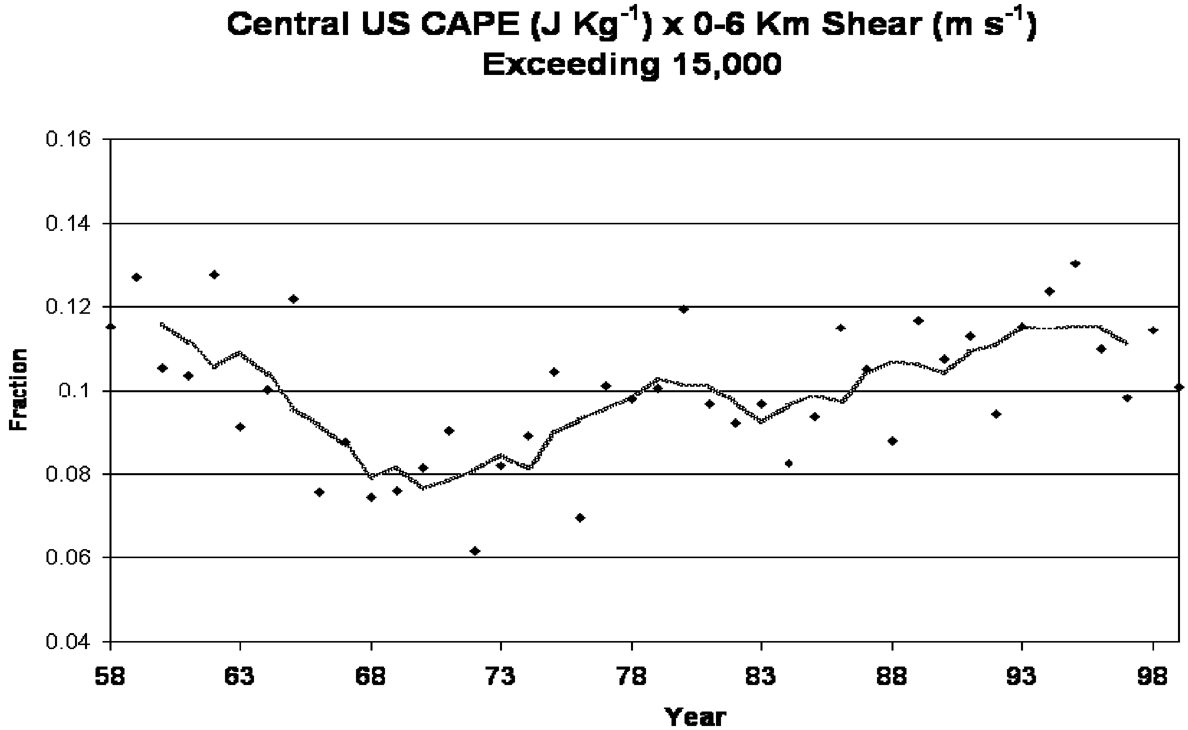

Figure 7: Same as Figure 3, now for the product of CAPE and deep shear.

4.3 Comparison

Since regions of the same size have been used, it is useful to look at how the regions compare to one another. This will be especially helpful in identifying interregional trends or cycles between the regions. Figure 7 shows the comparison of the Central United States 5 year running mean and the South American five-year running mean of 90th percentile CAPE. Note how the samples behaved similarly until 1975 and have since then acted differently from one another. Since this is such a small temporal sample, it is hard to reach a conclusion about the relationship between the two geographic regions, but it brings up an interesting proposal. Just because some regions experience high CAPE values on any given year, high CAPE values may not be achieved elsewhere around the world. In fact, some scientists suggest that the notion of global warming would cause changes around the world that would not have been previously witnessed. For instance, the Central United States may have a really high CAPE year, while South America has a well below average year and vice versa. Because we have not experienced such a change before, it is hard to come to a conclusion about what will happen. For this reason it is important to try to use this reanalysis data to further understand what has happened in the past, so that we can help predict future convective environments.

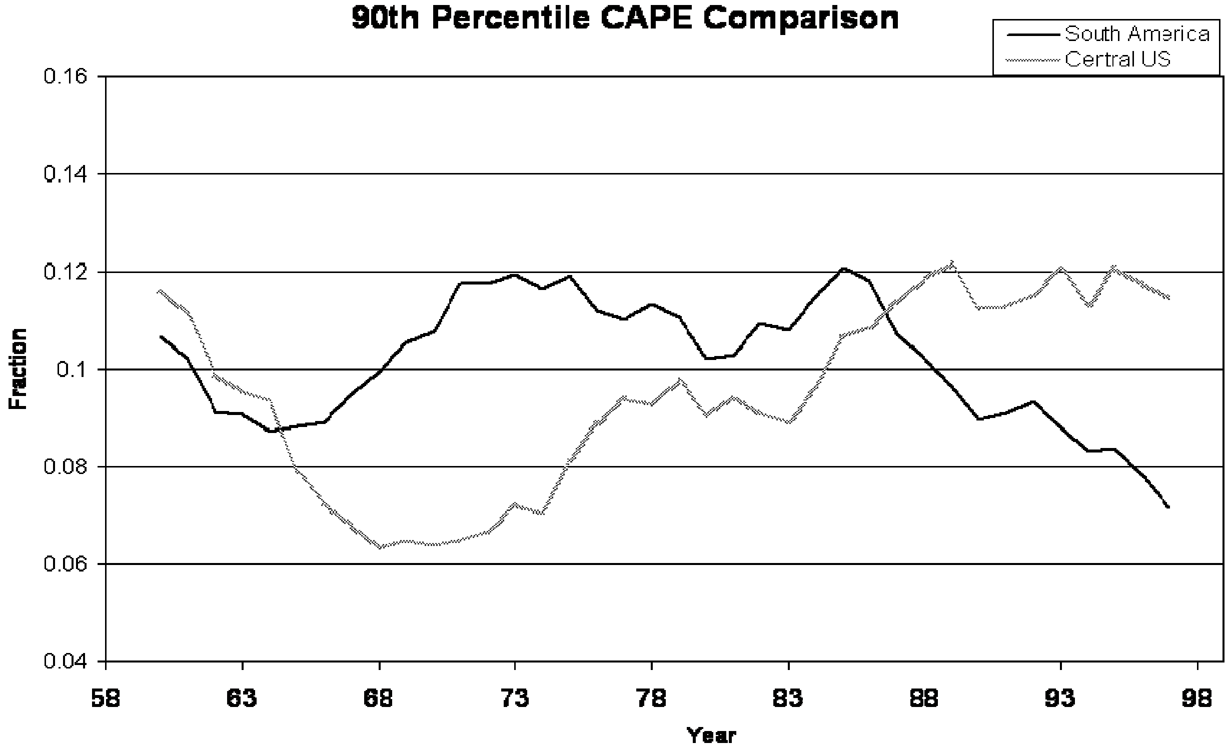

Figure 8: Comparison of the Central United States and South American 90th Percentile CAPE 5 year running means. Note the different behavior since the late 1980's.

5. DISCUSSION

Variability of convective parameters provides forecasters a look into how environments favorable for convection vary in their respectable region. The Central and Eastern United States have shown an increasing trend in the amount of soundings that have surpassed the 90th percentile in the period from July through September. The Central United States shows more variability in the annual distribution of CAPE than the South American domain, which could partly attributed to latitude differences of the regions.

If forecasters want to make an attempt to forecast deep moist convection environments in the future, they must first understand how these environments vary in their respected geographic area. In the Central United States, these environments have been shown to be increasing by relatively stable deep shear values, but increasing CAPE values. In Southeastern South America, deep shear has also been relatively constant, but CAPE values have been decreasing in the last decade. Since convection depends on a wide variety of different variables and processes to occur, it is beyond this study to show that convection was also on the increase or decrease during these years. However, since the environmental conditions that house deep moist convection are being studied, it is possible to show areas that would be more or less favorable to accommodate this type of activity if synoptic or mesoscale processes were in place.

This study needs to examine more regions in order to be able to come to conclusions about global scale cycles.

6. ACKNOWLEDGEMENTS

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