Climatology of Potentially Severe Convective Environments from Reanalysis

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Introduction / Background

Recent research has indicated that the potential for severe thunderstorm environments may increase under future anthropogenic induced global warming scenarios (Trapp et al. 2007; Van Klooster et al. 2009). The combination of increasing societal vulnerability (Cutter et al. 2003) and severe thunderstorm environment frequency may lead to greater severe thunderstorm hazards in the future. Brooks et al. (2003) took the first steps toward trying to understand the global distribution of severe convective environments using the ingredients-based approach utilized by Doswell et al. (1996); however, no study has focused solely on the distribution and variability of these environments across the U.S. Datasets with relatively high spatial and temporal resolution, such as the North American Regional Reanalysis (NARR; Mesinger et al. 2006), are permitting the examination of historical DMC environments in more detail than previously possible.

This study uses NARR data to examine the variability of significant severe environments across five DMC-active regions in the U.S. In turn, this will allow forecasters to understand the spatial and temporal aspects of DMC environments in their respective region. A climatology of significant severe weather environments for each of the five regions will allow for the discussion of inter/intraregional variability, as well as inter/intrannual variability in single domains. Comparisons of interregional variability are also examined to determine if trends are consistent across multiple domains. This variability is vital to understand if researchers are to make hypotheses about future organized DMC environments in various climate change scenarios. For example, 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. In addition, this study will analyze the relationships between potentially significant severe DMC environments and significant severe weather reports from the Storm Prediction Center's storm report database. This comparison will validate that the climatologies constructed from NARR could serve as proxy guidance for convective report trends under future climate change scenarios.

Methodology

The following variables, valid at 00Z for all days 1979-2009, were downloaded for the entire NARR domain:

•MUCAPE; MUCIN; 500 hPa U,V winds; 10 m AGL U,V winds

Thus, the product of CAPE and deep-layer wind shear can be calculated, and examined in the presence of CIN. Of note is that these are only a few of the fundamental ingredients necessary for DMC development. A lifting mechanism, such as low-level convergence and forced ascent associated with a boundary, was omitted in this study due to the large spatial variability and high dependence on smaller mesoscale processes. While mesoscale boundaries are certainly important for the localized development of severe convection, it was desirable to develop a larger scale conceptual environment favorable for the development of significant severe weather events (i.e., climatological rather than forecasting perspective).

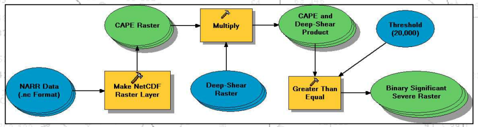

Figure 1. A Geographic Information System (GIS) model was used to examine reanalysis output. This sample section of the model calculates a proximity C composite index similar to Brooks et al. (2003).

While 500 hPa is typically near 5.5 km AGL for regions near sea level, a substantial difference can exist between the two heights AGL. Therefore, the bulk wind shear calculation used in this study tends to result in lower values over the domain when compared to the actual 0-6 km wind difference used in Brooks et al. (2003), especially over high terrain where the surface is substantially closer to 500 hPa. Therefore, it is likely that the resulting index climatologies will be conservative in depicting regions that are favorable for the development significant severe weather, especially on the higher terrain. While fixed-level winds are not available in the NARR above 10 m AGL, we are in the process of interpolating NARR sounding data to calculate the true 0-6 km wind difference value for each grid point.

A Geographic Information System (GIS) model (Figure 1) was used to examine and manipulate NARR output for five regions (Figure 2). Each region is roughly 1.6 × 10^6 km^2 and contains 1,550 grid points. Analysis of spatio-temporal variability was examined using ArcGIS 9.3.1 spatial tools. First, raster images are grouped by year and summed to create annual spatial climatologies for environments with 1) MUCAPE values ≥ 2,000 J kg^{-1}, 2) MUCAPE × Deep-layer wind shear values ≥ 20,000 (C composite index), and 3) MUCAPE × Deep-layer wind shear values ≥ 20,000 in the presence of MUCIN ≥ -75 J kg^{-1}. Next, raster files are organized by month to analyze the annual cycle. Gridded significant severe environments undergo a Gaussian (3 × 3) low-pass filter to help smooth the data and reveal spatial patterns.

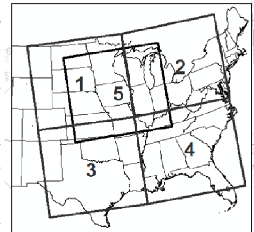

Figure 2. Five regions examined in this study. 1) Northern Plains; 2) Great Lakes; 3) Southern Plains; 4) Southeast; 5) Midwest.

Results

Similar to results shown in Brooks et al. (2003) (cf. their Figure 6; most areas east of the Rocky Mountains experience five or more days per year with CAPE values ≥ 2,000 J kg^{-1}[Figure 3]). While the 2,000 J kg^{-1} threshold is arbitrary, DMC forecasters generally regard this value as moderate environmental instability. In a simplistic way, CAPE is a function of surface θ_e and mid-tropospheric lapse rates. The frequency of days with CAPE values ≥ 2,000 J kg^{-1} are maximized near the Gulf Coast where the proximity to surface moisture plays a dominant role in large CAPE environments. The combination of CAPE and deep-layer wind shear, as assessed via the C composite index, serves as a good discriminator between severe and significant severe weather environments (B03).

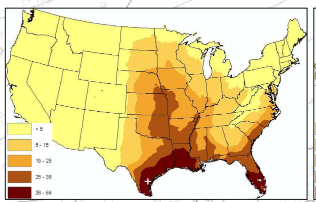

Figure 3. The average (1979-2009) number of 00 UTC NARR soundings per year with MUCAPE values ≥ 2,000 J kg^{-1}. White "+" indicates maximum grid-cell value.

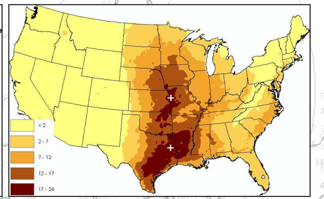

Figure 4. 1979-2009 average number of 00 UTC significant severe environments per year from the NARR. White "+" symbols indicate maximum grid cell values.

Therefore, since supercells are responsible for a majority of significant severe convective weather hazards (Doswell et al. 1993; Doswell 2001), the product of CAPE and deep-layer wind shear serves as a proxy climatological supercell environment. While similar, large CAPE environments (Figure 3) show some important differences from significant severe weather environments (Figure 4). While locations along the Gulf Coast and Southeast exhibited maximum frequencies for large CAPE environments, these locales are now relative minimums for significant severe weather. The shifting of the mean position of favorable deep-layer shear is evident in the annual cycle of significant severe weather environments (Figure 5; Figure 6). From a large-scale perspective, adequate deep-layer shear environments tend to be most frequent in the eastern and northern parts of the U.S., while large CAPE environments are most frequent in the south central U.S. As a result, the area most favored for significant severe weather occurs in the eastern Great Plains where these two ingredients frequently overlap.

Annual Cycle of Significant Severe Environments

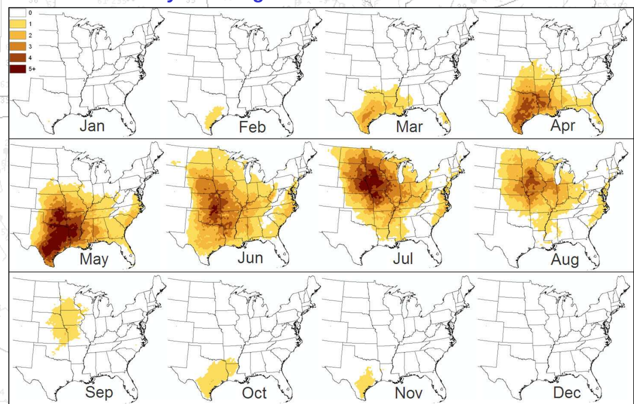

Figure 5. Average days per month with C composite parameter values ≥ 20,000 from the NARR based on the period 1979-2009.

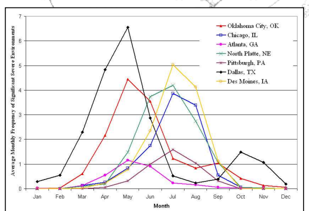

Figure 6. Annual cycles of significant severe weather environments for various U.S. cities for the period 1979-2009 from the NARR.

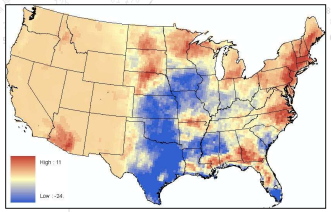

Figure 8. 1988 significant severe weather environment departure from the 1979-2009 average. Red/blue areas correspond to above/below average environments respectively.

Significant Severe Environment Variability

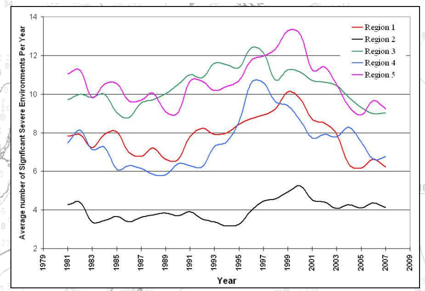

Figure 7. Regional variability of average annual significant severe weather environment frequency. 5-year running means are plotted for the period 1979-2009.

All regions (except Region 2) show a decreasing trend in the number of significant severe weather environments since the late 1990s (Figure 7). Predictably, Region 2 has remained mostly unchanged given it is a "low frequency" region. While the trend for most regions is decreasing, it is not out of the range of earlier frequency values experienced in the late 1980s. In addition, it appears that some regions are inherently linked when it comes to significant severe environment frequency. For example, Regions 1 and 5 behave similar due to their close proximity, while Regions 3 and 4 also have comparable trends. Given the similar latitudinal nature of Regions 3 and 4, the related trends are likely a function of deep-layer wind shear (e.g., subtropical jet stream during cool season).

While regional mean analysis is useful to examine trends over time and allows one to compute a base average to compare to, departures and trends are likely occurring across numerous spatial and temporal scales. In addition, the atmosphere is not restricted to a "user defined domain." To illustrate this point, a departure map (Figure 8) was created for a a year relative to the mean dataset period.

Discussion

Results indicate that there has been little change in significant severe weather environments over the past 30 years in all analyzed regions. Significant severe environments from reanalysis show a strong annual cycle similar to that of observed reports and thus can serve as proxy of locations that would favor significant severe weather during a given time of the year. Additionally, the C composite index underestimates the potential for significant severe weather on the High Plains. This is likely a result of the way deep-shear is calculated in this study (10 m – 500 hPa wind difference) as 500 hPa is substantially closer to the surface on the higher terrain. This terrain bias is in the process of being corrected by calculating the 0-6 km AGL bulk shear as it is not a NARR variable.

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