P8.8 A CLIMATOLOGY OF MESOSCALE CONVECTIVE COMPLEXES IN THE UNITED STATES

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1. INTRODUCTION

Several annual mesoscale convective complex (MCC) climatologies have been compiled since Maddox (1980) strictly defined the MCC criteria over two decades ago. These previous studies have largely been independent of each other and therefore have not established the extended spatial and temporal patterns associated with these large, quasi-circular, and, typically, severe convective systems. This deficiency is primarily due to the complexity of archiving enough satellite imagery to accurately record each MCC based on Maddox's criteria. As a result, this study utilizes results from each of the MCC climatologies compiled between 1978 and 1999 in order to develop a more complete climatology of these storms. Within the 22-year study period, MCC summaries were compiled for a total of 15 years. These 15 years of MCC data are employed to establish estimated tracks for all documented MCCs. These data are also used to determine MCC populations and densities on a monthly, seasonal, annual, and multi-year basis. Subsequent to developing an extended climatology of MCCs, the study ascertains the spatial and temporal patterns of MCC rainfall and determines the precipitation contributions made by MCCs over the central and eastern United States.

2. BACKGROUND

Characteristically, a mesoscale convective system (MCS) is an assemblage of thunderstorms organized on a larger scale than its individual building blocks (i.e., storm cells) in which the individual convective storms within the system act in concert to generate flows and features that facilitate the organized complex. For this study, the focus is exclusively on a particular type of large, long-lived MCS that exhibits a quasi-circular cloud shield, the MCC. MCCs are strictly defined by Maddox (1980) and classified according to cloud-top characteristics observed in infrared (IR) satellite images. MCC criteria include critical cloud-top temperature threshold values of –32°C and –52°C that must meet specific spatial and temporal size requirements. The severe weather and precipitation MCCs produce impacts a majority of the United States, therefore, many (e.g., forecasters, farmers) may benefit from a better understanding of MCC characteristics and any patterns associated with these significant convective systems.

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A number of past studies (Maddox et al. 1982; Bartels et al. 1984; Rodgers et al. 1983, 1985; Tollerud and Collander 1993; Anderson and Arritt 1998, 2001) have investigated the spatial and temporal distribution of MCCs over the United States for specific years to provide a record of their occurrences. Furthermore, research has shown that MCSs and MCCs produce a substantial quantity of the precipitation required for the growing season over the Midwest and the Great Plains (Maddox et al. 1979; Fritsch et al. 1986; Tollerud and Collander 1993). In addition, it is well understood that seasonal and/or annual variation in the number and density of MCSs and MCCs has a strong impact on the total seasonal and/or annual rainfall over these regions, which, in turn, produces conditions ranging from drought episodes to flooding events (Fritsch et al. 1986; Kunkel et al. 1994; Anderson and Arritt 1998, 2001).

3. DATA AND METHODOLOGY

Constructing an accurate MCC climatology can be a difficult task even if data are continually gathered as each event occurs. Attempting to reconstruct such climatologies of the past based on archived satellite data is essentially unfeasible due to the sparse availability of historical satellite imagery, especially prior to the 1990s. Therefore, many studies only include a few years at a time (e.g., Augustine and Howard 1988, 1991; Anderson and Arritt 1998, 2001) or are limited in their spatial scope (e.g., Tollerud and Collander 1993). To study an MCC climatology of reasonable extent, one must spend years collecting and archiving data or use results from several past climate studies. This study employs the latter method. In doing so, 15 years of MCC data for the entire eastern two-thirds of the United States are examined. This allows for a more comprehensive analysis of the temporal and spatial characteristics of MCCs than have previously been published.

4. RESULTS

To better represent and understand the climatology of MCCs, 15 years of MCC data for the eastern two-thirds of the United States are examined in this study. The large spatial and temporal component of this study allows for a clearer examination and comprehension of the MCC climatology of the United States.

4.1 *General Characteristics*

In examining yearly totals (Figure 1), there is a large amount of interannual variability associated with MCCs. Tollerud and Rodgers (1991) suggest that some of the variability is produced by satellite-based, methodological alterations. Before 1985, most analyses of IR satellite imagery were performed manually. Conversely, since 1985, the methods used to measure MCC size, which is based on satellite imagery, have been substantially automated (Augustine 1985; Tollerud and Rodgers 1991). Furthermore, it is also possible that satellite imagery may not have always been available during the early years of the study period. Thus, some cases may have been missed altogether. Tollerud and Rodgers (1991) suggest that there may be a 10 to 15 % undercount [relative to the new automated system and criteria introduced by Augustine (1985)] in the years prior to 1985. Further investigation of the variability based on changes in procedures used to detect and classify MCCs is beyond the scope of this investigation. Consequently, for this analysis, the tabulations made during the 15 years in which MCC summaries are available have been uncritically accepted. In all, 538 events were documented during the 15 years. However, 11 of these events were removed from our dataset due to missing data fields (e.g., missing initiation location and/or time). Thus, this study encompasses 527 events over 15 years for an average of over 35 MCCs per year.

Variations in actual MCC totals per year are observed with an obvious peak of MCC activity in 1985 and 1986, when 58 events occurred each year. 1978, 1987, and 1999 are all above the average of 35.1 events with 41, 44, and 47, respectively. The only years with notably fewer events are 1981 and 1984 with 19 and 20 events, respectively.

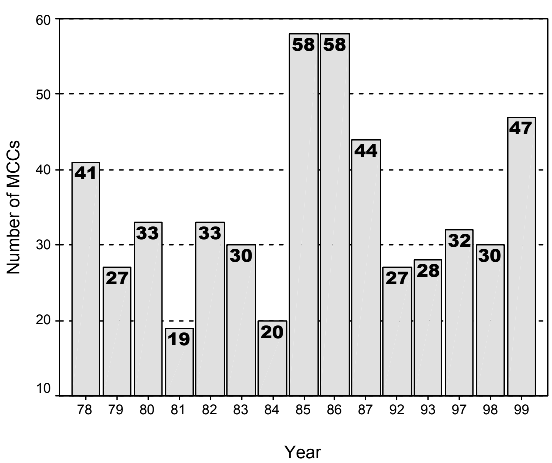

Figure 1. Number of MCCs per year for the 15 years of MCC tabulations.

MCCs are definitive warm-season events with a maximum number of events occurring during May, June, July, and August. In fact, over 86 % of the events documented in the 15-year study occurred during this four-month period. This indicates that high instability, which is at a maximum during the summer months due to greater heat and humidity in the lower troposphere, is the key factor in generating more of these large convective systems. Undoubtedly, transition-season months have lower energies available for the generation of MCCs and, therefore, are less frequented by the systems. In addition to less thermal energies for MCCs, transition seasons have more frequent cyclone activity, which implies more linear forcing for convection and less capping to confine convective development to a particular region (as is typically the case during the warm season). Monthly, MCCs tend to peak in June with an average of nearly 9 MCC events occurring per year during this month. However, when looking at June on an annual basis, MCCs vary from 4 events in 1984 to 18 events in 1985, further indicating that MCC frequency can vary greatly interanually. July is the second greatest MCC frequency month with over eight events annually averaged while May is frequented by over seven events annually.

When examining the average size of the maximum -52ºC MCC anvil by month (not shown), the spring-transition season, especially April, is noticeably different than that of the later warm-season period. In addition, MCCs that occur in April persist, on average, longer than any other month. Tollerud and Rogers (1991) found the same discernable size and duration patterns when they examined a number of years of MCC data. They hypothesized that differing dynamical mechanisms may cause the large differences in the sizes of these events. In general, April and May MCCs tend to develop in regions of stronger forcing from vigorous springtime synoptic-scale circulations. Moreover, Tollerud and Rodgers (1991) suggest that April and May MCCs have a tendency to be in closer proximity to the Gulf of Mexico which might provide them with an easier and more dependable access to low-level moisture, that, in turn, may induce larger cloud-anvil shields. These two factors may cause springtime MCCs to be larger in size and longer in duration than those in the latter part of the warm season.

MCCs have a distinct diurnal pattern of development and evolution. The convective system typically reaches MCC criteria between 00 and 02 UTC. Thereafter, the MCC continually grows until reaching maximum anvil extent around 06 UTC. Subsequently, the MCC begins a lengthy decay until, on average, the system falls below MCC criteria around 13 UTC.

4.2 *Spatial and Temporal Characteristics*

Calculating densities of various categories (e.g., study period, seasonal, and monthly totals) better illustrates MCC distributions along with MCC migration patterns. This section seeks to determine significant spatial and temporal patterns associated with MCCs in the United States over the 15-year study period. For this purpose, densities are based upon the -32ºC anvil size by interpolating a quasi-linear track between initiation of the MCC (i.e., MCC size criteria met), MCC maximum (i.e., when extent of cloud shield reaches maximum size), and termination (i.e., when MCC size criteria no longer exist) into an area that is outlined by the -32ºC anvil. This allows for a calculation of the

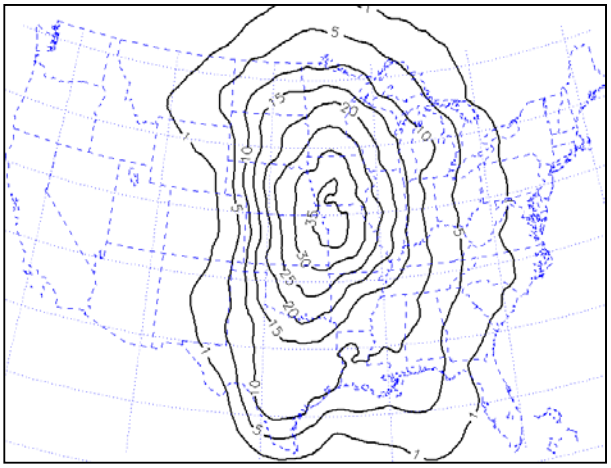

Figure 2. Average number of hours the -32ºC MCC cloud shield is positioned atop a location during a single year. Average is based on 15 years of MCC data. See text for additional information on how densities are calculated.

average number of hours the -32ºC anvil from a convective complex is over a location. Subsequently, densities are determined by how many anvil hours are present over a given area for a specific time period (e.g., month, season, year).

During an average year (Figure 2), MCCs are most likely to occur in the lower Missouri Valley where this region has, on average, 35 MCC anvil hours per year. A north-south axis of greater than 10 MCC hours stretches from southern Texas to the Canadian border while an east-west axis extends from the High Plains to the Ohio Valley indicating that MCCs are primarily a Great Plains phenomenon. In addition to these primary axes, MCCs also affect the Southeast and East Coast, albeit less commonly.

When examining annual MCC totals and densities (not shown) for 1978-1999, the most noticeable component is the consistency with which yearly MCC track densities are concentrated around the borders of Missouri, Kansas, Nebraska, and Iowa. However, there are a few years, particularly, 1982, 1992, and 1999 that do not conform to this pattern. In addition, a few years, primarily 1983 and 1984, do not yield a clear location of maximum densities.

Examining the MCC tracks and densities monthly (only the warm-season is displayed in Figure 3) for the 15-year period reveals a high variability in the spatial distribution of the events. During the month of February, only two events occur with tracks situated in Texas and the other in the southeast region of the United States. Nine MCCs occurred in March and cover an area extending from central Mississippi to southern Minnesota and from western Oklahoma to Ontario, Canada. The highest MCC density in March is positioned primarily over southwest Missouri, parts of southeast Kansas, northeast Oklahoma, and northwest Arkansas. In April, the density values increase by 4.5 times the previous month's values while the density core is positioned over central Mississippi and western Alabama. The coverage area of the 34 MCCs during this month extends primarily from the Gulf of Mexico to the Upper Peninsula of Michigan and from central Texas to Lake Ontario.

The most significant number of MCCs occurs during the warm season of May, June, July, and August (Figure 3). During the late transition and early warm seasons, the number of MCCs during the 15 years increases significantly from 34 in April to 114 during May. Throughout May, the events become more widespread across the Great Plains and Mississippi River Valley of the United States. The increased density core shifts northwestward into southeast Kansas, northeast Oklahoma, northwest Arkansas, and southwest Missouri. Another density core, slightly smaller in coverage area, is located in southern Texas. MCC density continues to increase through June. The density core shifts slightly northeastward into Missouri and, likewise, the broad area of MCC distributions generally migrates in the same direction. MCCs become more frequent in southern Canada as they

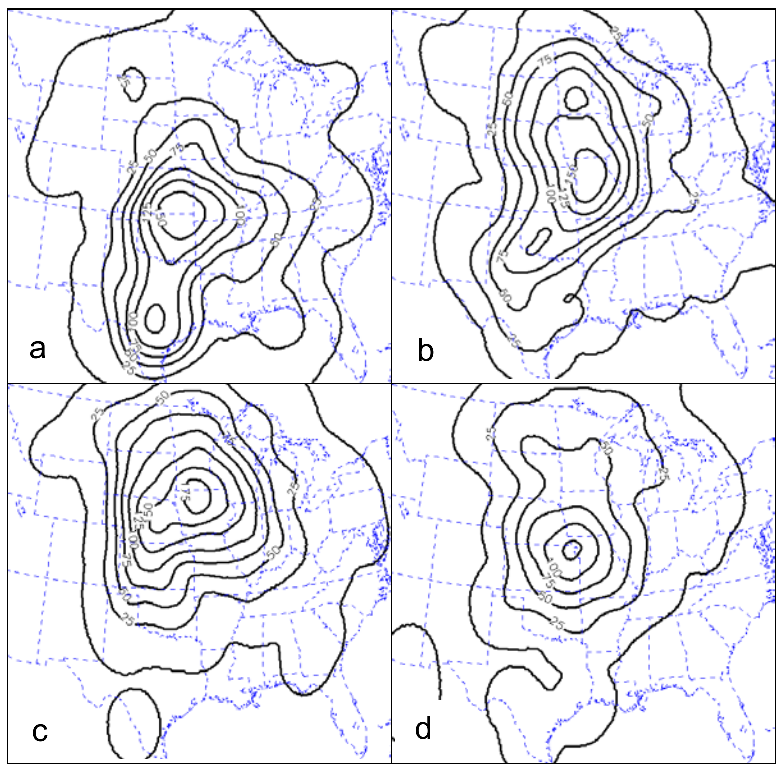

Figure 3. Number of hours the -32ºC MCC cloud shield was over the U.S. during May (a), June (b), July (c), and August (d) for the 15 years tabulated.

diminish around the Gulf of Mexico with some MCCs situated east of the Appalachian Mountains. During the month of June, MCCs reached their highest total of 133 and, subsequently, July marks the initial decline with the MCC totals dropping to 125 events for the month. The MCC density becomes most concentrated over northern Iowa and southern Minnesota. MCCs become less frequent in the southern and eastern regions of the United States and occur more often in the Northern Plains and Upper Midwest regions. During August, the total number of MCCs drops significantly to 82. Accordingly, MCC density also decreases during this month but at a more moderate rate. The area with the highest density shifts south-southwestward into the northeast corner of Kansas, and the width of the coverage area decreases whereas the north-south coverage area generally remains the same.

Both the density and the total number of MCCs decrease significantly in September (not shown). During this period, the density core is located over northern Illinois, southern Lake Michigan, and northwest Indiana while, in addition, a smaller core with the same density value is noticeable over northern Wisconsin. During October and November, there is no significant location of maximum MCC density due to the rarity of events during these months. In October, only five MCCs occurred over the entire study period, and only one MCC event occurred in November, which extends from northern Louisiana to central Alabama. Lastly, December and January have no recorded MCCs during the period of study.

4.3 *Additional Analysis*

The years 1992-93 and 1997-99 are further investigated to establish how many MCCs, on average, engender derechos. Only 13% of the MCCs during this five-year period produced widespread windstorms that met the Bentley and Mote (1999) criteria for derechos. This indicates that derechos are typically produced by convective systems that are smaller in scale and/or more linearly oriented than quasi-circular MCCs.

Finally, monthly, annual, and 15-year MCC precipitation totals are calculated for this study to reveal temporal and spatial MCC precipitation estimates. The frequency of MCC events and percentages of total rainfall contributed by MCCs varies greatly on a year-to-year basis (not shown). However, in general, regions throughout the Great Plains received upwards of 18 % of their annual warm-season precipitation from MCCs. On average, precipitation contributions, densities, and event numbers from MCCs peak during June and July across the Middle and Lower Missouri and Upper and Middle Mississippi Valleys. Nonetheless, significant warm-season MCC precipitation contributions may be found from the Gulf of Mexico to the Canadian border.

5. SUMMARY AND CONCLUSION

In conclusion, this study attempts to quantify the spatial and temporal aspects of MCCs in the United States by examining 15-years of these large convective systems. Results indicate that there is a considerable amount of yearly and even monthly variability in the location and frequency of MCC events that, in turn, has substantial impacts on the hydrological and severe weather climates of the central and eastern United States – specifically during the warm season.

In addition, this climatology of MCCs has deciphered the role of MCC precipitation in the central and eastern United States. It has also detected regions (e.g., the Central Plains) that are most dependent upon MCC rainfall and how, generally, MCC rainfall is advantageous for growing season precipitation within these regions. This analysis suggests that the elimination of MCC rainfall may have substantial impacts on the moisture balance throughout the central and eastern United States. Finally, MCCs were determined not to be prolific derecho producers, with only 13 % of the MCC events documented during five years in the 1990s yielding derechos.

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