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LONG TERM TRENDS IN THE SPATIAL AND TEMPORAL CHARACTER OF PRECIPITATION EVENTS IN THE EASTERN UNITED STATES

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1. INTRODUCTION

During the last decade, numerous high magnitude floods (e.g. Mississippi River Valley 1993, Eastern NC, 1999; Northern IL, 1996; etc.) have caused billions of dollars of damage. These floods are linked to increased frequencies of heavy rain events during the last century (e.g. Karl and Knight 1998). Konrad (2001) identified the spatial scale (i.e. size) of the most extreme precipitation events across different portions of the eastern U.S. and showed that extreme events in three out of four of these regions have experienced increased frequencies across all scales. Furthermore, he demonstrated that a variety of synoptic patterns (e.g. slow moving tropical cyclones, upper-level cyclones, northwest flow outbreaks etc.) are associated with these extreme events and these show significant seasonal and geographical variability.

This study seeks to extend the work of Konrad (2001) by examining a much larger sample of events and determining temporal changes in the frequencies of precipitation events of different intensities. This represents the first stages of an effort to identify the mechanisms that are responsible for the long-term trends in event frequencies, particularly the heaviest events. To carry this out, precipitation events are identified over a 47-year period across 6 regions of the eastern U.S. and assigned to quartile groups according to the greatest mean two-day precipitation totals observed over three spatial scales (2500, 100,000 500,000 km^2, hereafter referred to as small, medium, and large scale, respectively). Temporal trends are identified for each quartile group by event size and region for the period: 1950-1996. A preliminary analysis is made of the long-term variations in the frequencies of synoptic scenarios (e.g. high levels of precipitable water) that support heavy precipitation development. The ultimate goal is to tie changes in the frequencies of “wet” synoptic scenarios to changes in the frequency of the different types of precipitation events.

2. METHODOLOGY

In this study, daily precipitation amounts from the Cooperative Observer Network were used and accessed from the Cooperative Summary of the Day CD ROMs (NCDC, 1997). Two-day precipitation totals from all stations in the cooperative network within the eastern two-thirds of the U.S. were interpolated onto a 279 by 263 grid containing a10 by 10 km grid spacing. This effort was carried out daily, thus providing temporally overlapping, two-day precipitation totals for each day of the 47-year period. Due to the voluminous amount of daily data, the computationally efficient method of Thiessen polygons was used to interpolate the precipitation amounts. The next step in the analysis was to identify regions containing the greatest mean precipitation totals across each of the 3 scales. An automated routine was applied to the daily gridded precipitation fields to identify mean precipitation maxima in space and time (e.g. over two day periods) for each day of the study period. Daily precipitation regions were defined for each of the three scales by determining regional maxima in the mean two-day precipitation totals within the respective circular regions. A moving or floating window approach was applied such that the circular areas at each scale were moved across the study domain (i.e. each area centroid moved systematically, pixel by pixel). The objective here was to identify the region with the greatest precipitation total. Given the computational time required for carrying out this procedure (i.e. calculations at 73,377 pixels over 17,162 days), the moving windows routine was centered only on the population of pixels registering a 2-day precipitation total of at least 2.54 cm. If two precipitation regions at a given scale overlapped spatially within a 2-day time frame (i.e. centroids less than 1000 km apart), the region with the lesser mean totals was eliminated from consideration. This approach yielded 10272, 6935, 4842 precipitation events over the small, medium, and large scales, respectively over the 47 year study period. Konrad (2001) examined a small sample of extreme events and determined that the precipitation regions generally exhibited an elliptical shape at the larger scales and tended towards a circular shape at the smallest scales. This suggests that an elliptical shaped region is more appropriate for estimating mean precipitation totals. With this in mind, mean precipitation totals were estimated within the center half of each circular region for the large and medium scale events (e.g. Fig. 1).

PRECIPITATION TRENDS

Long- term temporal trends (from 1950-1996) in the frequency of precipitation events (Table 1) were identified across six regions of the eastern U. S (Fig. 2). The analysis generally reveals a positive trend in the frequencies of precipitation events across the eastern U.S. between 1950 and 1996; however, there is considerable variability in the nature and strength of these trends by region and event scale (Table 1). Event frequencies have increased markedly in the southern region, especially across the large and medium scales. This contrasts with the adjacent Central region, which has witnessed a drop in overall event frequencies at the large and medium scales. A negative correlation exists between the annual event frequencies of the two regions suggesting that the increased frequencies in the South have occurred at the expense of events in the interior region. The most consistent increases in event frequencies across the regions were identified over the medium scale. Decreases in event frequencies were most prominent at the large scale (i.e. decreases observed in 3 out of the 5 regions).

Each regional sub-sample was further divided into quartile groups on the basis of the precipitation totals. The heaviest precipitation events (i.e. top quartile) displayed the most consistent increases in frequencies; in particular, 4 out of the 6 regions showed increases across all scales. These increases were most marked at the small scale, especially in the regions adjacent to the Atlantic and Gulf of Mexico (i.e. the Northeast, Southeast, and South). A spatial analysis indicates that many of these events occurred along the coastline. On the medium scale, the Northeast and South were the only regions reporting a significant positive trend in the frequency of heavy events. On the large scale, slight positive trends were indicated in the Southeast and South regions; however, the Midwest region showed the most marked trend over the study period.

In order to assess the synoptic mechanisms that are potentially playing a role in the precipitation increases, it is useful to first examine the seasonality of the identified trends. This will provide some indication of the general seasonal circulation pattern (e.g. warm season convective, cool season cyclonic etc.) that can be tied to the precipitation increases. Since the small-scale heavy precipitation events show the most prominent temporal increases, their trends with respect to tseason are highlighted here. In the Midwestern region, heavy precipitation events occur mostly between May and September. Comparisons of the first (1951-1973) and second (1974-1996) halves of the study period reveal marked increases in heavy events during the latter half of the summer and relatively modest decreases during the late spring and early summer. In the Southern region there is much less seasonality in the heavy precipitation regime. The positive trends in heavy event frequencies are therefore spread out more broadly across the season. Most evident is a negative trend in the heavy rain frequencies during the month of September. This can be attributed at least partially to a decreased frequency of landfalling tropical cyclones along the Gulf Coast during the later half of the period. Over the Northeast and Southeast regions, heavy precipitation events also show a broader seasonal distribution (March-October) and the temporal trends are correspondingly distributed rather evenly across the season. The Central region displays a double peak (i.e. early spring and summer) in the seasonal distribution of small-scale heavy precipitation events. Increased heavy rain frequencies are more evident in the summer months. Since the northern portion of the Central region is immediately downstream of the Midwest, it is probable that there is some connection between the summer increases in heavy rain frequencies in the two regions.

ASSOCIATIONS BETWEEN PRECIPITATION AND SYNOPIC TRENDS

Konrad (2001) showed that a variety of synoptic patterns can produce heavy rain events during a given season (e.g. tropical cyclone, slow-moving upper-level cyclone). These “wet” synoptic patterns display much regional variability; for example, mesoscale convective systems (MCSs) are typically tied to heavy rain in the Midwest but contribute much less farther east. In contrast, tropical cyclones contribute significantly to heavy rain frequencies in the Northeast and Southeast regions, especially the most extreme events. It should also be noted that many heavy rain events during the summer months are not associated with any distinctive synoptic circulation, but rather develop on the mesoscale in a moist, unstable environment. Although the circulations that can lead to heavy rain vary quite a bit, ongoing research suggests that many of the heavier precipitation events during the summer months are tied to exceptionally high values of precipitable water. In fact, precipitable water appears to the most effective field on a synoptic scale for discriminating heavy events (i.e. distinguishing the 4th quartile of the sample from the remainder). To see if there are any connections between precipitable water and heavy rain frequencies, it is useful to assess the long-term trends in precipitable water values. To carry this out, twice-daily NCEP reanalysis data were obtained and precipitable water fields extracted for the period between 1953 and 1996. Comparisons of mean precipitable water values for the May through September period between the early (1974 and earlier) and late (post-1974) portions of the study period, however, reveal slight decreases in precipitable water over most of the United States. Additionally, the number of days in which precipitable water reached various levels (1.2" and 1.6") was found to decrease between the early and late years of the study period. This suggests that increases in heavy precipitation are more associated with long-term changes in the dynamic climatology of the region (e.g. increased frequencies of synoptic disturbances that provide dynamic lift). Present work is being undertaken to investigate this possibility.

The heavy rain sample investigated in this study appears to exhibit clustering with respect to time, that is, a relatively small number of years and/or months contain a majority of the events. The floods in the Mississippi River Valley in 1993 provide a prime example as numerous heavy rain events were observed during a single season. A temporal analysis of events is presently being undertaken to quantify the temporal clustering of events.

REFERENCES

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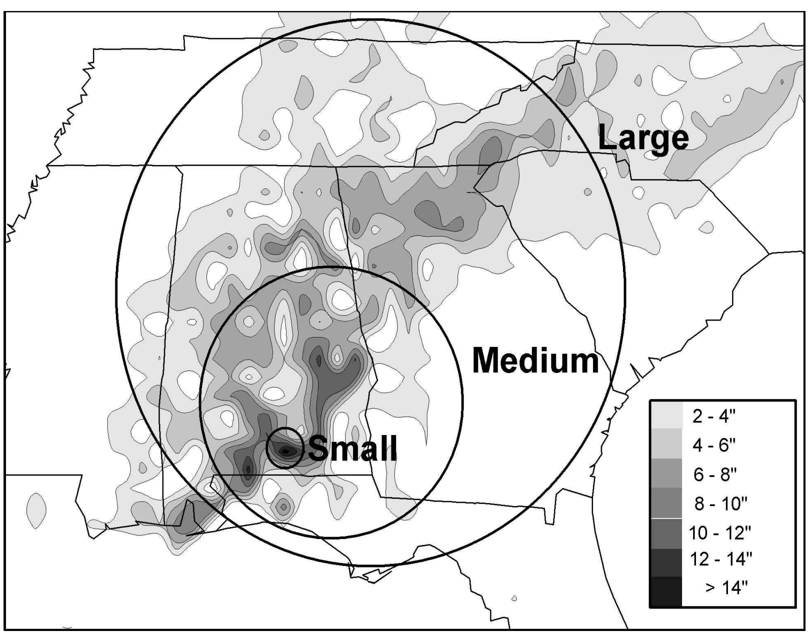

Figure 1. Two-day precipitation totals associated with Hurricane Opal. The circles identify regions in which the heaviest areal precipitation totals were identified.

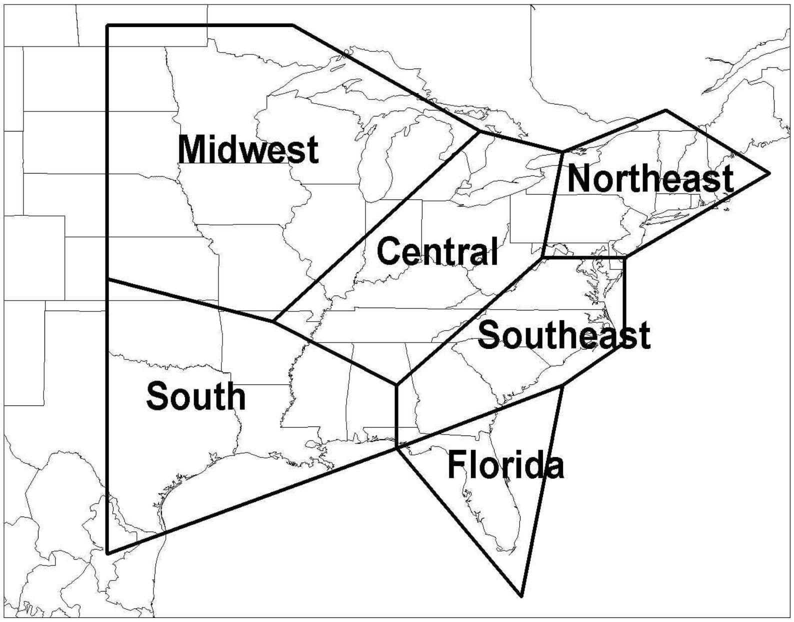

Figure 2. The six regions examined in this study.

Table 1. Correlations between years and event frequencies by region and precipitation quartile.

Midwest	Large	Medium	Small	**Northeast**	Large	Medium	Small
All events	-.10	.16	.26		----	.29	.11
4th quartile	.29	.15	.24	4th quartile	----	.26	.34
3rd quartile	-.17	.00	.05	3rd quartile	----	.04	-.01
2nd quartile	-.16	-.20	.16	2nd quartile	----	.15	-.03
1st quartile	-.14	.29	.19	1st quartile	----	.13	-.05
Central				**Southeast**			
All events	-.24	-.38	.01	All events	-.02	.07	.38
4th quartile	-.09	-.17	.26	4th quartile	.10	.15	.31
3rd quartile	-.12	-.19	-.02	3rd quartile	-.01	.28	.35
2nd quartile	-.14	-.20	.03	2nd quartile	.04	-.18	-.20
1st quartile	-.13	-.05	-.05	1st quartile	-.09	.01	.12
South				**Florida**			
All events	.48	.48	.33	All events			-.10
4th quartile	.13	.23	.35	4th quartile	----	----	-.07
3rd quartile	.30	.26	.32	3rd quartile	----	----	.04
2nd quartile	.31	.41	.15	2nd quartile	----	----	.07
1st quartile	.02	-.07	-.21	1st quartile	----	----	-.21