282. **TRENDS IN HEAVY PRECIPITATION IN THE SCIPP REGION OF THE SOUTHERN U.S.A**

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1. INTRODUCTION

The recent Intergovernmental Panel on Climate Change (IPCC) report (2007) suggests that increasing global average temperatures will very likely lead to changes in the distribution and intensity of extreme events, particularly pertaining to the hydrological cycle. Warmer air is able to hold more water vapor, and thus there is more moisture available for precipitation. This is not uniform over the globe however, local scale precipitation (or lack thereof) is still dependant on the local environmental conditions, which change depending on pressure, wind direction, surface conditions, season, upper level flow, large scale teleconnections (such as ENSO) and other factors. However, an enhanced hydrological cycle could produce variable precipitation of generally greater intensity (i.e. when it rains, it rains harder, and when it is dry, this dryness may persist for longer). A number of studies support this change in the distribution of precipitation events and their intensity based on model scenarios and observational record, e.g. Kunkel et al. (1999), Groisman et al. (2004), Karl and Knight. (1998).

This paper examines whether there have been changes in the frequency of 1-day heavy precipitation events in the Southern United States over the past 60-100 years, using data from individual raingauge stations and climate divisions. The area of interest for this study focused specifically on the region covered by the 'Southern Climate Impacts Planning Program' (SCIPP), which includes the states of Arkansas, Louisiana, Mississippi, Oklahoma, Tennessee and Texas.

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SCIPP seeks to identify regional weather and climate hazards, working with local stakeholders and governments to assess vulnerability and inform policy that promotes adaptation and mitigation of these hazards. Precipitation timeseries for 176 stations across the six states are examined individually for trends, where 'heavy' precipitation is a fixed threshold between 1.5 and 3 inches/day, depending on location, as overall precipitation amounts and frequency increase further south and east in this region. We then examine spatial trends across each climate division at thresholds between 0.01 and 5 inches/day on both annual and seasonal timescales. A partial duration timeseries of the top 0.3% of events (by magnitude) from 1948-2008 are also constructed for stations within each state to examine changes in high magnitude events over this 60-year period. These simple techniques will allow us to identify robust signals for precipitation changes. This paper is composed of the following: In section two our data and methodology are described in more detail. Section three presents our results, while section four places our results into context using extant literature and our understanding of the local climate. Finally, section five briefly introduces social and policy implications of projected precipitation, especially those related to flooding.

2. DATA AND METHODOLOGY

2.1 DATA ACCESS, QUALITY AND CAVEATS

Data are obtained from the cooperative network of raingauges. The cooperative network, operated by the National Weather Service and the National Climatic Data Center (NCDC), is a vital component of the climatological record of the United States. It uses observations from the general public in both official and unofficial capacities. The raingauge network is made up of official coop stations, with once daily observations, typically at 12Z, but sometimes 18Z or 06Z. Each individual station has a different record length and many of the stations have short and/or incomplete records. For the first part of this work, which looks at time-series from individual raingauges, each station must have satisfied the following criteria: 1) The record must extend longer than 60 years and 2) Data at each location must be equal or greater than 95% complete. For the second part of the study, both short-term and long-term records are used to compile total frequency of heavy and very heavy rainfall event occurrence over each individual climate division.

Measurement of rainfall using raingauges is common practice, however, there are a number of ways that measurement error can occur. Common errors for standard 'tipping bucket' raingauges include poor situation of the gauge, close to buildings or other obstacles, clogging of the gauge, poor calibration or changes in instrumentation, and human error. Since this study is looking at trends in certain rainfall thresholds over time, absolute magnitudes of errors are less important than their changes over time, which could lead to bias. We believe that these are not significant and so will proceed under that assumption.

Another caveat with the data set is its low temporal resolution. Since measurements are made only once per day, there is little information specifying the sub-period over which the precipitation event occurred, or whether the event continues over two days of measurement, despite being less than 24 hours duration. Events that are spread over two measurement periods are almost always underestimated in intensity. Unfortunately, these problems cannot be solved using the current dataset and so we must set them aside for this study. In addition, we do not compensate for the different times of measurement, which we believe does not have a great impact on our results since we are not directly comparing measurements from different stations. We also assume that the time of measurement does not introduce significant bias in rainfall totals (this assumption may be somewhat limited in periods of strong diurnal convective forcing, but such events are very localized and make up only a small proportion of heavy precipitation occurrences).

2.2 METHODOLOGY

Early formulations of this study intended to use regional and nationwide maps of 'return period rainfall' (RPR): The maximum amount, or depth, of precipitation statistically possible at a given location in a given temporal period. Return periods are typically defined from 2-500 years. RPR values are determined by fitting precipitation data with at least a 100-year record, ideally to an extreme value distribution for maximum recorded values over different durations, and then extrapolating out to determine expected magnitudes of high end events. RPRs are popular tools for hydrologists and engineers. When constructing a road, Dam, suburb, etc. such facilities must, by law, be able to withstand extreme events, and RPRs are used as guidelines on the expected magnitude of extreme precipitation. Return period rainfall charts are available for the entire United States (NWS Technical Paper 40), but are very low resolution and not useful on a regional scale. The United States Geological Survey published state RPR analysis for Oklahoma and Texas in 1999, but other states within the region of interest did not have any similar studies to reference. In addition, different publications use different methodologies such that none are directly comparable. This made the use of return period thresholds as standards for defining heavy rainfall at each station difficult to implement outside of Oklahoma and Texas. Time constraints did also not allow calculation of RPRs across the region for this study. The methodology turned instead to using a simple approach to define precipitation depth thresholds. Using the approximate annual average precipitation for each location, we created simple definitions of 'heavy' and 'very heavy' daily precipitation. For semi-arid west and southwest Texas, 'heavy' is defined as 1.5 inches/day and 'very heavy' as 3 inches/day. For the central region of Texas, through Oklahoma, these increase to 2 and 4 inches/day respectively, and 2.5 and 5 inches for Arkansas, Tennessee, Mississippi, Louisiana and eastern Texas. Although these definitions are subjective, they are comparable to those from other studies, e.g. Kunkel et al. (1999) and Karl et al. (1995) use an average of 2 inches per day (or about 50.8 mm) as a National average measure of heavy precipitation, while a study by Groisman et al. (2001) examined trends in precipitation above 101.6 mm/day (or about 4 inches/day) in the upper Midwest. Other studies such as Karl and Knight (1998) consider the upper 10% of the precipitation distribution for a given station or regional average, and for very heavy events the upper 5 or 2.5%, Kunkel et al. (2003) examined trends in events with return periods of 1, 5 and 20 years for daily and multiday precipitation. There are a number of methodologies in place to examine trends, some of which are more rigorous and attempt to be more regionally specific with regard to the definition of 'heavy', 'very heavy' and 'extreme' precipitation and/or the problem being posed (e.g. hydrologic and damage causing flooding events versus simple diagnosis of rainfall trends). Given the time constraints for this study, our approach is simple but our definitions are effective at identifying trends in notable precipitation events.

For *individual stations* we find each location possessing a different temporal record, some starting around 1900, and some nearer 1940. The entire record of each station was examined, and to facilitate comparison with other station records, the period 1920-2009 and 1948-2009 were examined. For each station, the number of events exceeding a given threshold were summed for each year and plotted as a time series. Individual station analysis has the advantage of examining specific time series and events at point locations, but it does not encompass an area and it misses some events that were not recorded by its specific rain gauge. Therefore, for the *Climate Division* analysis we calculate the total number of precipitation events exceeding specific thresholds between 0.01 and 5 inches/day using data from every active station in each division. The number of events are then normalized by the number of active stations in each year. For climate divisions we assess both the total annual number of events and the seasonal number of events as a fraction of the annual total. Our seasons are defined as DJF: December-January-February (winter), MAM: March-April-May (spring), JJA: June-July-August (summer) and SON: September-October-November (fall). The choice of thresholds reflects the need for consistency across the six states. The lowest threshold of 0.01 inches/day accounts for the total number of rainy days, whilst 2/3 inches/day and 5 inches/day account for 'heavy' and 'very heavy' precipitation over most regions respectively.

Linear trend analysis via a basic Analysis of Variance (ANOVA) is used to determine the statistical significance of the change in the mean number of heavy precipitation events. Significance is defined as a p value less than 0.05, with a 'strong' trend being defined as that with a p value of less than 0.1. Note that the linear model is in general not a good fit to the data; due to the high inter-annual variability, the variance explained is generally less than 20%. Nonetheless, we are principally looking for statistically significant changes in the low frequency component of variation, for which a linear model is not ideal but nonetheless sufficient. To make inferences regarding inter-decadal trends, we also apply a 10-year running mean to the time series.

Finally, we construct our 'partial duration' series by selecting the top 60 events by magnitude during 1948-2008 and binning each event into one of the six decadal intervals over this period. This results in a count of the number of top events per decade for a given station, which is then grouped into a total sum for each state. For this analysis, individual stations, not climate divisions, are used.

3. RESULTS

3.1 INDIVIDUAL STATIONS

Figure 1 shows the distribution of stations with positive trends across the SCIPP region for three time periods between 1900 and 2009. For this analysis no stations had statistically significant negative trends in heavy precipitation. In total, approximately 23% of all stations had a significant positive trend through their total time series, which varied from station to station. This proportion decreased to 15% between 1948 and 2009. There was some spatial consistency in the location of significant trends, which lends support to the reliability of the results. States with the strongest signal for increasing frequency for heavy events from this analysis were Oklahoma through central and east central Texas, into parts of Mississippi, far south Louisiana and eastern and

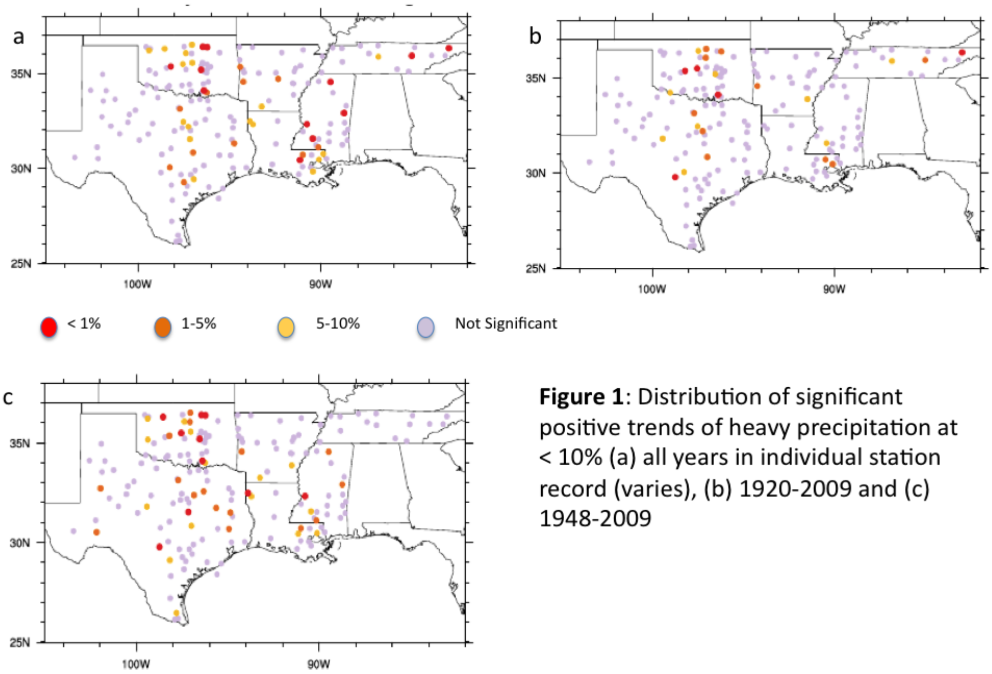

Figure 1: Distribution of significant positive trends of heavy precipitation at < 10% (a) all years in individual station record (varies), (b) 1920-2009 and (c) 1948-2009

southern Arkansas. Tennessee and Arkansas have the lowest proportion of stations with significant trends. We see, therefore, that although there are clear signals for increasing heavy precipitation (as we have defined it) in certain sub-regions, local environmental conditions, high inter-annual variability, and the fact that these are point locations, which may 'miss' many heavy events, tend to mask trends.

3.2 CLIMATE DIVISIONS

Figure 2 shows the distribution of climate division trends in total number of precipitation events between 0.01 and 5 inches/day between 1948 and 2009. For the total number of rainy days/year (panel a), much of the northern and western portions of the region exhibit significant positive trends. In other words, in these regions, the number of rainy days has been increasing since 1948. On the other hand, southern parts of the region, including much of the Texas Gulf Coast, indicate that the overall number of rainy days has been decreasing. Above 2 inches/day (panel b) most locations show positive or no trends, especially in Oklahoma, West Texas and northern portions of Arkansas, Louisiana and Mississippi. A couple of locations on the Louisiana Gulf coast show significant decreasing trends. Above 3 inches/day (panel c) the only significant trends are positive and are concentrated mainly in western portions of the region, specifically Texas, Oklahoma and Mississippi. Above 5 inches/day (panel d) very few divisions have significant trends (largely due to the low frequency of such events, so linear trend analysis is less reliable) but there is a signal for increasing event frequencies in east Texas and Western Oklahoma and Texas Panhandles. This spatial analysis finds regional trends to be much more prominent than the station analysis. A qualitative comparison between Figure 1(c) and Figure 2 for events between 2 and 3 inches/day shows some consistency between them in terms of location, which is expected, nonetheless, discrepancies arise from the aforementioned high variability and local climate influences that lead to increased 'noise' in individual station records.

3.3 SEASONAL TRENDS

Figure 3, 4, 5 and 6 show the distribution of trends between 0.01 and 5 inches/day for DJF, MAM, JJA and SON respectively. In order to establish a baseline with which to compare these seasonal trends, climatological distributions of precipitation for each season were constructed for each state and each threshold. Due to the large land area and distinct change in climatological characteristics, Texas was split into two components: east and west. Contributions by each climate division were weighted by area. For all states, peak precipitation occurred during JJA, but generally high amounts of precipitation also occurred during MAM and SON, and DJF for the gulf coast states and Tennessee. Figure 7 shows these distributions as a schematic, also indicating the observed changes in seasonal precipitation since 1948. Although there is a large amount of variability across climate divisions and between seasons, we summarize the broad results below for each threshold:

3.3.1 *Precipitation > 0.01 inch/day*

The only statistically significant trends occurred during JJA and SON. The data is suggestive of a shift of rainy days from JJA to SON, due to positive trends in rainy days in SON alongside negative trends in JJA events for parts of Oklahoma, while decreasing trends in North and Eastern Texas JJA precipitation remain uncompensated for by other seasons (see Fig. 2). Trends are largest over the northern sections of the region, specifically west and north Texas, Oklahoma and Arkansas.

3.3.2 *Precipitation > 2 inches/day*

The most notable trends include an increase in DJF events in parts of Oklahoma. Trends in MAM are very few and mostly negative but fall below statistical significance. In JJA, eastern Oklahoma trends are negative, a couple of divisions in this region reach significance. SON trends are largely positive and are most substantial over Arkansas, far western Tennessee, northern Mississippi and western and northern Louisiana. Thus, for this threshold, relative fractions of precipitation events have increased in DJF for Oklahoma (balanced slightly by decreasing trend during summer, JJA in eastern Oklahoma) and in SON for parts of the northeast sections of the region.

3.3.3 *Precipitation > 3 inches/day*

As for the 2-inches/day threshold, parts of Oklahoma, extending into western and northeastern Texas show significant increases in the proportion of winter events. Northern and central Texas also indicates an increase in the proportion of JJA events. Conversely, parts of northern Texas show significant decreases in the proportion of spring events. During fall, the significant trends are all positive and concentrated in Arkansas, Mississippi, Louisiana and Tennessee. The results are suggestive of a shift in events characterized by more heavy precipitation events in Oklahoma and northern Texas during the winter, as well as portions of the eastern states during the fall. Meanwhile, there is a reduction in spring heavy rainfall in parts of northeastern and central Texas.

3.3.4 *Precipitation > 5 inches/day*

Significant trends are more sporadic spatially at this threshold given the limitations of establishing linear trends with sparser data. DJF shows a significant increase in the proportion of events for northern Texas especially. There are a couple of climate divisions in Mississippi that indicate marginally significant decreases in the proportion of events attributable to this season. MAM shows sporadic and generally weaker trends, nearly all of which are negative. JJA is similar in general, the only significant positive change in the proportion of events is far west Texas, which also experiences a significant decrease in the proportion of events occurring during SON, a possible season shift of extreme precipitation in this region. Most trends in SON are again positive and once more concentrated in eastern sections of the region, albeit shifted slightly west of the 3 inches and 2 inches/day trends.

3.4 TEMPORAL DISTRIBUTION OF HIGH MAGNITUDE EVENTS

Figure 8 shows the distribution of top magnitude events per decade for each state in the region. For all states, the majority of high magnitude precipitation events occurred during the latter part of the period, especially 1988-07. These results are suggestive of an increase in high magnitude events since 1948, the

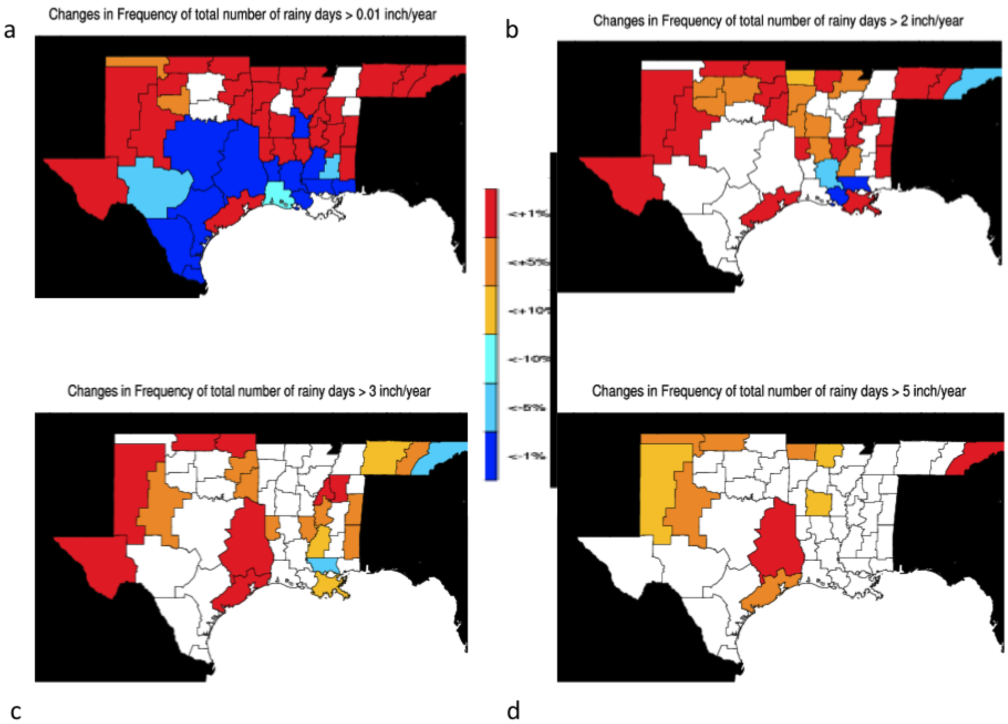

Figure 2: Trends in the number of days of rain above thresholds from 0.01 to 5 inches/day for each climate division across the SCIPP region. Negative (positive) trends are shown in blue (red). Trends < 5% ($p < 0.05$) are statistically significant, but the figure also includes trends at $p < 0.1$ (10%). Areas without any notable trends are shaded in white.

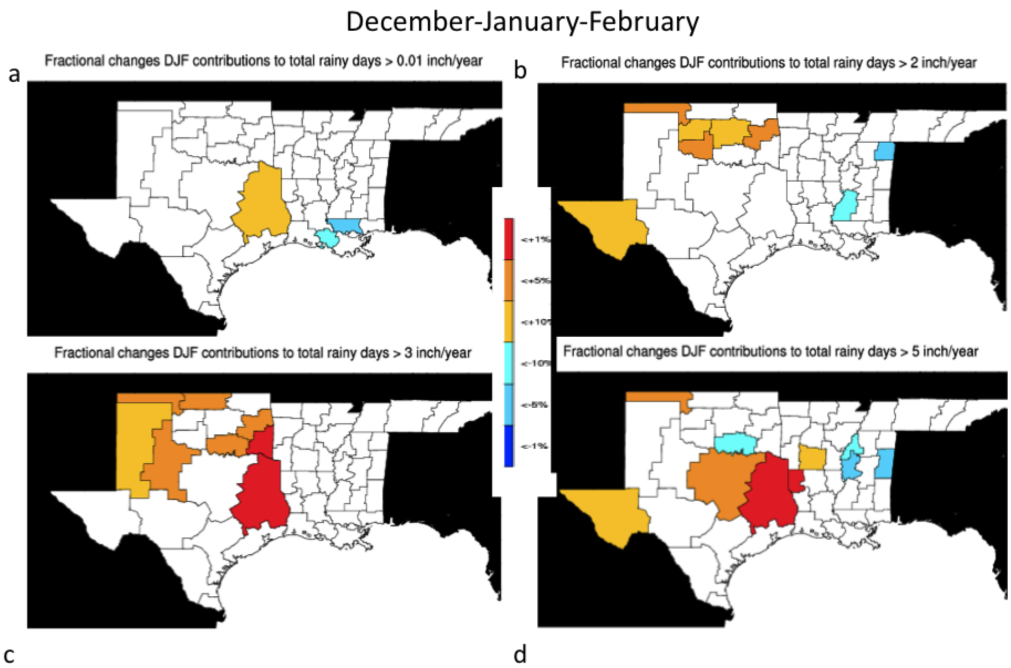

Figure 3: As figure (2) but for trends during December-February (DJF) of the number of days with precipitation between 0.01 and 5 inches/day

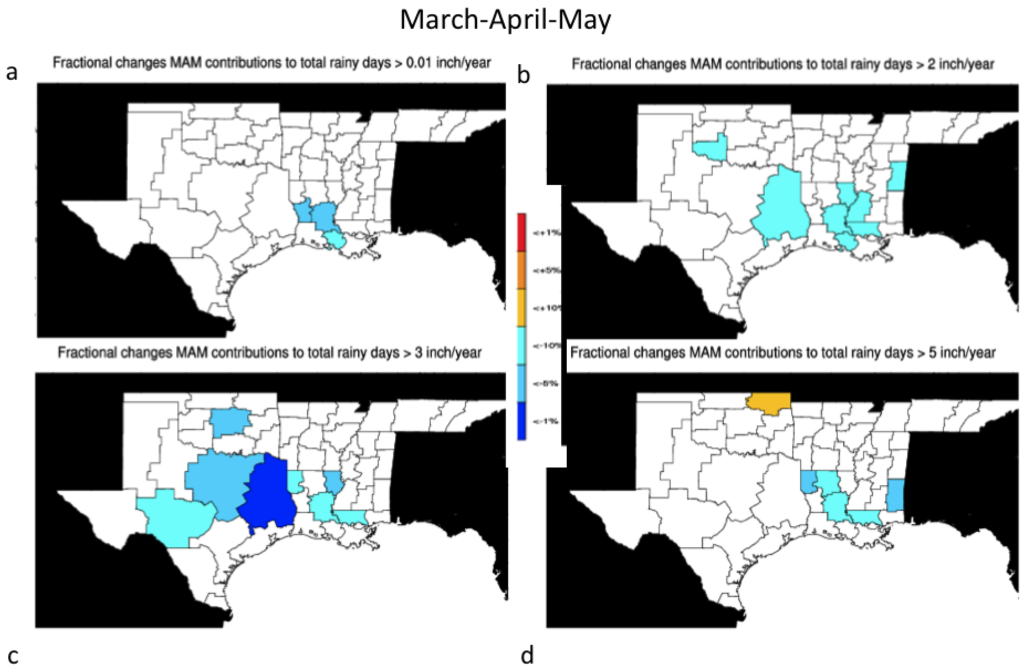

Figure 4: As figure (3) but for March to May (MAM)

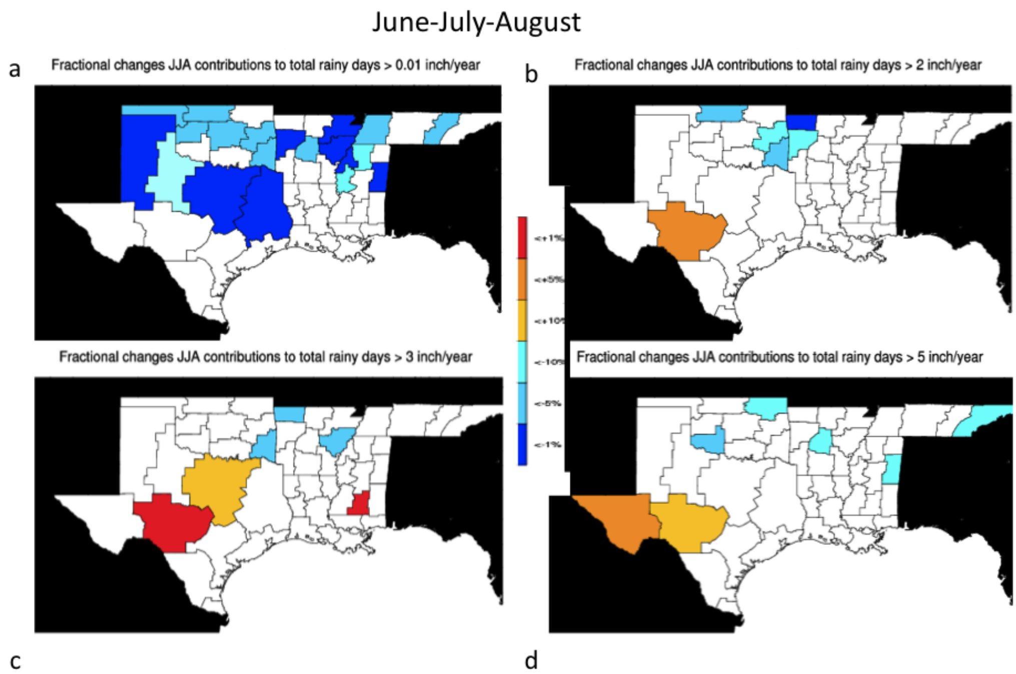

Figure 5: As figure 3 but for June to August (JJA)

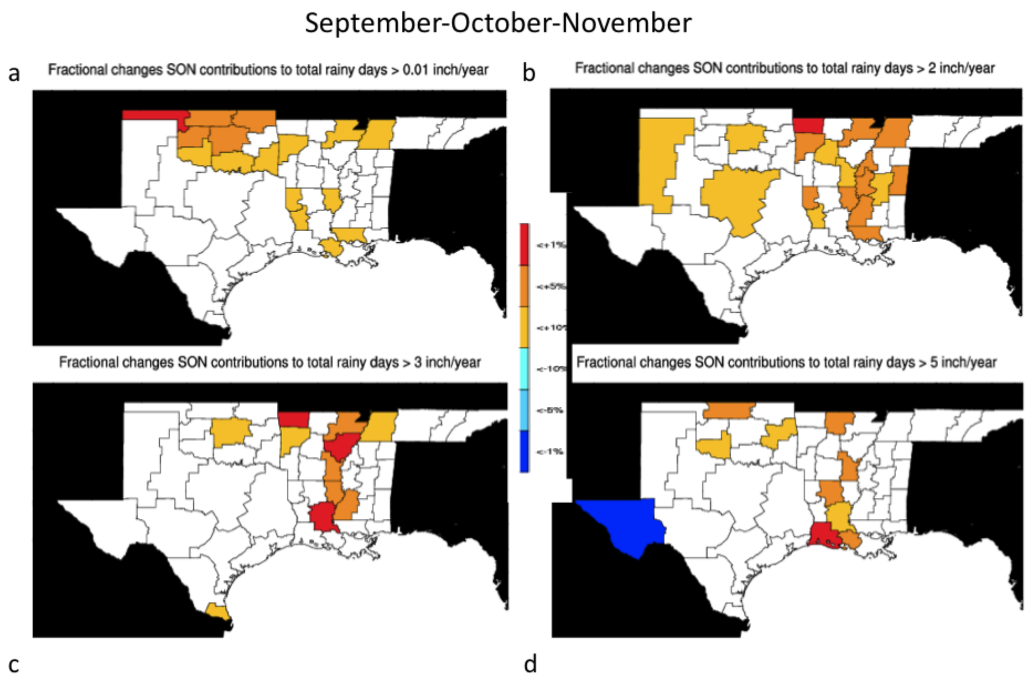

Figure 6: As figure 3 but for September-November (SON)

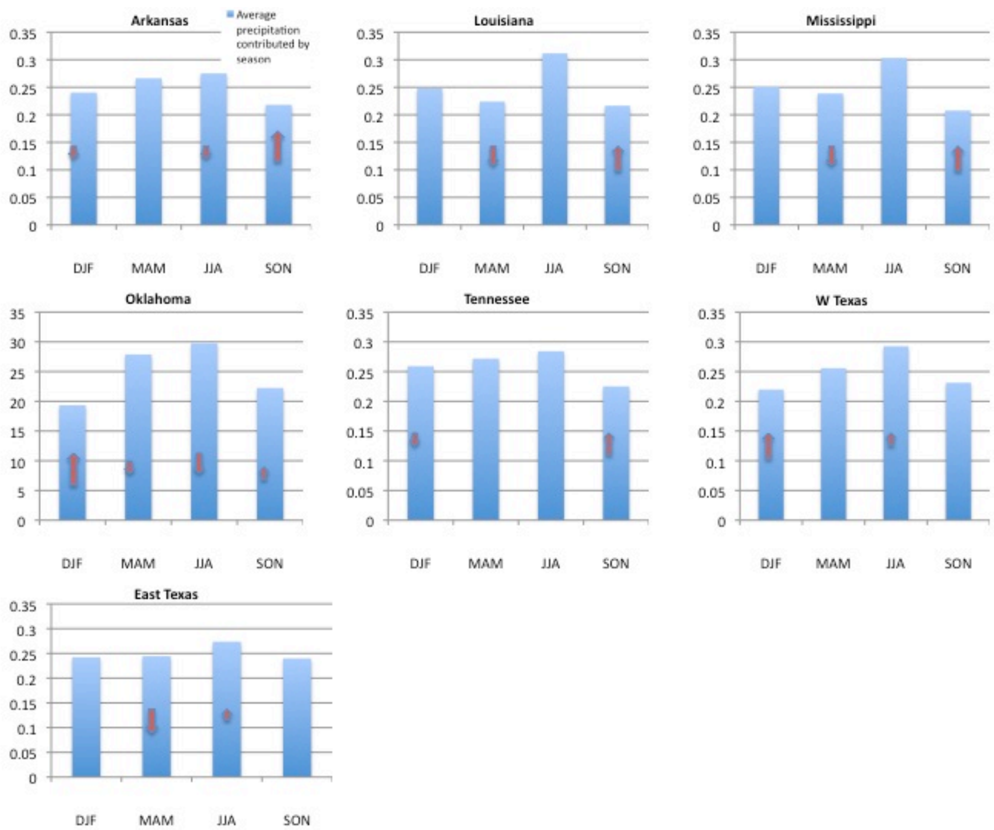

Figure 7: Average fractional contributions to total annual precipitation by season (Oklahoma units in percent). Arrows are a schematic representation of the direction and magnitude of observed changes between 1948 and 2009. Upward (downward) arrows indicate an increase (decrease) in the seasonal contribution to the total number of heavy precipitation events (2-3 inches/day). Long arrows denote a significant change, medium arrows indicate at least half of the climate divisions within that state having strong or significant trends, and short arrows indicate about one quarter of climate divisions within that state having strong or significant trends.

precise value of which varies from station to station. Further work would also ideally consider periods prior to 1948, as we cannot discount the role of natural variability on a 60-year timescale, but a 100-plus year dataset would allow us to make stronger inferences regarding the role of anthropogenic climate change. Nonetheless, the signal for a sustained period of higher heavy precipitation event frequencies since the 1980s over much of the SCIPP region appears clearly throughout this analysis and is consistent with climate change projections of an enhanced hydrological cycle.

3.5 ROLE OF CLIMATE VARIABILITY

Long-term trends in precipitation may reflect a changing climate, however, they may also be dominated by interannual and interdecadal variability in annual average precipitation. Since our precipitation record extends predominantly between 1920/1948-2009, long-term natural variability versus climate change signal is not necessarily clear. Moreover, increasing trends since mid century may be simply a result of a drier mid century versus latter century. For example, Kunkel et al. (1999) and Karl et al. (1998) note that the 1930s and 50s were generally dry across much of the contiguous US, whereas the 1980s and 90s were quite wet. Thus a trend between 1950 and 2000 may show a significant positive trend, but from 1900-2000 this linear trend may actually disappear if earlier parts of the century were also wetter. In addition to a linear trend analysis, applying a 10-year moving average smoother allows higher frequency variations to be identified. The aforementioned national average interdecadal variability is generally also reproduced for this region, indicative of a positive association between heavy precipitation frequency and total annual precipitation, especially in the more arid regions of western Texas and Oklahoma. We also note that for most stations, the frequency of heavy precipitation actually declines on average during 2000-2010. This is not unexpected given the unprecedented wetness of the 1990s, however, it does indicate the large role of natural variability in moderating regional trends.

4. DISCUSSION

4.1 COMPARISONS TO OBSERVATIONAL STUDIES

Our analysis has established a variable but clear signal for an overall increase in heavy precipitation events over the past 60 years for the south central US. In the literature, most trend analysis has traditionally considered the Contiguous U.S (Groisman et al. 2004, Kunkel et al. 1999, Karl et al. 1998), but in some cases considers sub-regions of the country with similar annual precipitation means and climatological characteristics. This study is one of the first to examine trends in precipitation across the SCIPP domain, however, in the Karl et al. (1998) analysis, the southern region, similar to the SCIPP states (minus Tennessee), showed a statistically significant increase in > 2 inch/day precipitation during 1910-1995 that exceeded the national average trend. Their analysis also suggested that over half (about 53%) of the total increase in precipitation amounts that had been observed nationally was contributed by the upper 10% of the precipitation distribution. Clearly, however, there may be substantial regional differences. Along the Gulf coast states, Groisman et al. (2004) suggested that trends may in some cases be masked by the high interannual variability contributed by tropical cyclones. In this analysis there was a signal for increasing heavy events in these states, but it was not consistent across the state and was least evident within about 50 km of the coast, which lends support to conclusions in Groisman et al. Groisman et al. (2004) thus split up tropical cyclone related precipitation from other events, finding no significant change in the amount of precipitation contributed by tropical systems despite an increase in the frequency of heavy precipitation (> 2 inches/day) unrelated to tropical cyclones.

Some studies, including the aforementioned, also considered the seasonal changes in precipitation. For much of the country, on average, the greatest increases in the number of days with precipitation (> 0.01 inch in this paper) occurred during spring and autumn. For the frequency of heavy events, the seasonal distribution was most noticeable

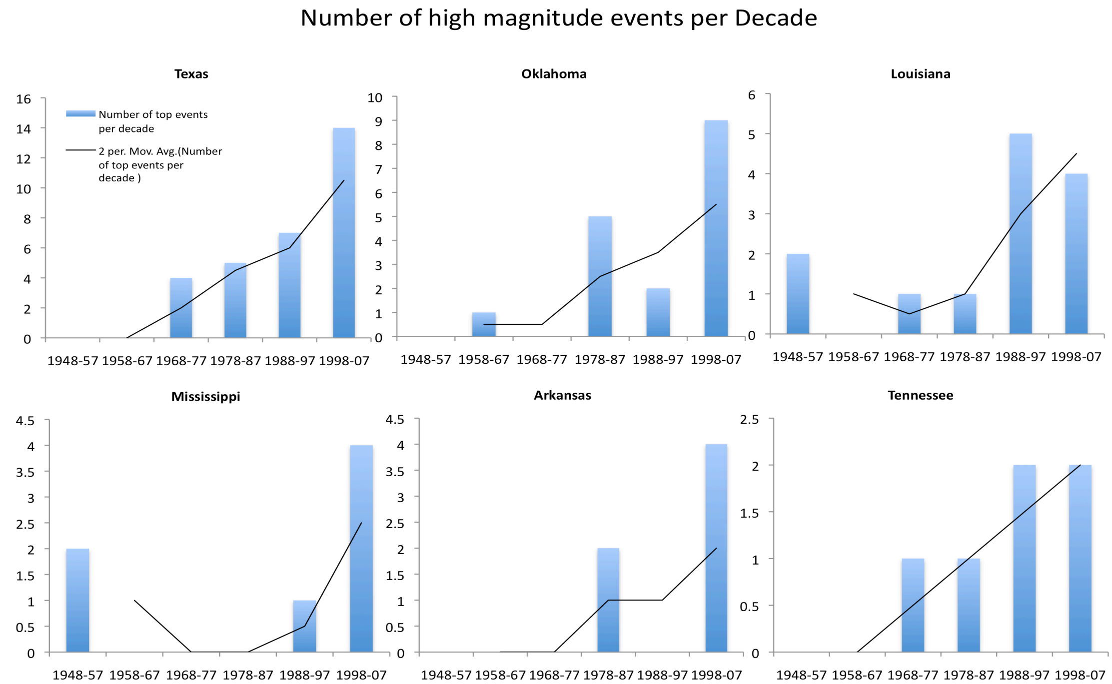

Figure 8: Top 0.3% of events broken down by decade for all stations with strong or significant positive trends in heavy precipitation (arranged from west to east geographically). Note that the y-axis is a count of the number of *stations* with the most number of events in a given decade (e.g. four stations in Arkansas had the largest number of high magnitude precipitation events during 1998-07, and the other 2 stations had their most events during 1978-87)

in the autumn, which supports the findings of this study, where autumn event frequencies at nearly all thresholds are increased in a similar region. A study on changes in heavy precipitation in Texas by Mishra and Singh (2010) showed mixed results. They used the top 5% of the distribution as a measure of heavy rainfall and estimated the magnitude of extreme values by fitting a generalized extreme value distribution to the data, considering trends over a 'pre-climatic' period of 1925-64 and a 'post-climatic' period of 1965-2005. For 1-day precipitation events, shifts toward higher quantile thresholds in the latter period were observed for certain stations in most parts of Texas, while higher values in the earlier period (which would indicate no trend or even a decrease over the 20th century) were concentrated in sub-humid regions near the southern and eastern coast. These results lend some support to those provided in this paper. For the plains regions, studies by Garbrecht and Russell (2002), Garbrecht et al. (2004) show a marked increase in annual average precipitation over the last two decades of the 20th Century. This is also clearly shown in figure 3 for parts of Oklahoma and west Texas, however, the authors do not consider changes in heavy and extreme precipitation.

4.2 COMPSRISONS TO CLIMATE MODEL PROJECTIONS

For the southern U.S, there is some conflict over climate model projections of future precipitation patterns. Most models are able to simulate increased variability of precipitation with increasing carbon dioxide (CO_2), e.g. Mearns et al. (1999) demonstrate this with a nested regional model for a 2xCO_2 scenario. However, models still struggle to accurately capture current precipitation variability and magnitude on the regional scale. As an example of the range of results available for the southern U.S, we refer to a selection of studies for the region. Firstly, a study by Manabe and

Wetherald (1999) suggested general drying of midcontinent regions during summer with increased CO_2/warming. However, a slightly earlier paper by Giorgi (1998) examined $2xCO_2$ scenarios for the main agricultural belt of the Midwest US, finding an overall increase in precipitation. More recently Meehl et al. (2007) found that model projections of future changes in precipitation extremes are greater than changes in overall mean precipitation, which is a result echoed by the IPCC (2007). Further studies, e.g. Meehl (2000) have attempted to relate changes in precipitation to changes in Pacific SST, for example, a shift to a more persistent El Nino like state and its associated circulation patterns over the US (which tends to produce more winter storm systems over parts of the south). Nonetheless, the IPCC (2007) suggests that there is little consistent trend in El Nino amplitude and frequency as simulated by a number of climate models. For the plains, changes in the characteristics of the low level jet (LLJ) could be more significant, as the LLJ is important for moisture transport into the region, with the strength of moisture convergence (and thus precipitation) moderated by the land sea thermal contrast (Augustine and Caracena. 1994). Changes in the magnitude of the land sea contrast may be expected to feedback to changes in the regional circulation and the strength of the LLJ/moisture availability from the Gulf.

As a specific example of a recent regional modeling study, we examine the results of an inter-comparison by the North American Regional Climate Change Assessment Program (NARCCAP, 2005) which uses a suite of nested regional models driven by global reanalysis. The IPCC (2007) suggests that accuracy of these models with respect to simulating recent conditions is good; for a Southern Plains ensemble simulation using 6 RCMs, 82% of all monthly precipitation biases were within ±50%, based on results for a single year (see Mearns et al. 2005). Results of a 2041-2070 minus 1971-2000 changes in both average and heavy precipitation for the Canadian coupled global climate model with a nested regional model show some qualitative similarities with the patterns observed with our results. Although not exactly comparable (due to different thresholds and use of average precipitation versus our rainy day frequency approach), the model produces a notable reduction in summer average precipitation, and an increase in winter and fall precipitation amounts. Thus, we may cautiously state (especially for precipitation thresholds below 3 inches/day) that our results are consistent with at least some future climate change predictions for parts of this region, lending support to the possibility that some of the recent increases in precipitation frequency/intensity may be driven by global climate change.

5. HEAVY PRECIPITATION AND FLOODING: POLICY IMPLICATIONS

Clearly, a sustained change in precipitation intensity and/or frequency will alter some aspects of the local environment that will require forms of adaptation and mitigation. A projected increase in the overall amount of precipitation could have some beneficial results, for example recharge of groundwater and increased water availability for human use. On the other hand, increasing intensity of precipitation events has the potential to produce an increased risk of flooding, depending on the intensity, duration and timing (e.g. Trenberth 1999). The relationship between heavy precipitation and flooding is nonetheless rather complicated (Kunkel, 2003). The types of precipitation events that cause flooding vary regionally, with the terrain and characteristics of the river basin playing important roles. In the US, river flooding tends to produce the most significant societal effects, since many major US cities are located along major rivers. Flash flooding however can produce serious risk to life and property and disruption of transportation. 1-day heavy precipitation events are most commonly related to small scale flash flooding, exacerbated in regions near small creeks, and in urban areas with poor drainage. Typically, many days to weeks of heavy rain are required to produce river flooding. At the national level, Pielke and Downton (2000) examined the relationship between ten different measures of precipitation and flooding. They found that most of the precipitation measures attained statistical significance, but the best measures nationally were two-day heavy rainfall accumulations and the number of wet days prior to a flooding episode. Since our study examines only one-day events, it may be prudent in the future to examine trends associated with multi-day events. Despite the complex, often non-linear relationship between heavy precipitation and flooding, it stands to reason that changes in precipitation patterns will modify the probability of a region being inundated, especially if the region has an existing flood hazard (Pielke, 1999).

Pielke (1999) among others suggests that there is considerable room for adaptation and/or mitigation of flooding from adoption of new behaviors and policies alone, since many causes and exacerbating factors related to flood severity result from human choice. Currently, common flood policies, originally developed by the National Flood Insurance Program (1970), use statistical definitions of return period rainfall such as the '100 year flood'- the magnitude of a flooding event that has a 1% chance of occurrence on average every year. This threshold is typically used as the upper limit of flood-type that certain structures, e.g. roads and dams, must be able to withstand. It is also used to limit construction in floodplains, such that in many areas, regions can only be developed if they remain outside the extent of the 1 in 100 year flood. This definition suffers from a number of problems, firstly, the general public tends to misunderstand the level of risk associated with such an event, often assuming that it cannot or should not occur more than once in 100 years. In addition, most precipitation records only contain about 100 years of data (often less), so an event is a statistical extrapolation; thus there is often an assumed stationarity. As the above results indicate, there have been substantial changes in precipitation over the 20th Century for some stations and regions. If stationarity is assumed, we almost always end up underestimating the magnitude of a risk (e.g. Mills, 2005). Policymakers must balance a myriad of complex social and economic issues to evaluate the ultimate cost-effectiveness of flood adaptation and mitigation policies. For example, in the case of development in floodplains, current incentives for urban development may appear more favorable than the risk of incurring loss via an uncertain event. In addition, there may be increased demand for housing by the public. The added complexity arises under changing climatic conditions, where suddenly previously accepted standards, (e.g. road drainage codes, floodplain definitions) suddenly become outdated and require reassessment, which takes both time and money. In fact, Pielke (1999) suggests that many regions of the US have not been thoroughly mapped for flood risk at all. Policymakers must therefore be aware of the potential changes to flooding resulting from changes in precipitation, and make judgments about how to incorporate this information in urban planning, transportation and other infrastructure. In addition, there are opportunities to educate the public on flood risks in their region so they may make informed choices. Nonetheless, in many cases due to economic status and other factors, people cannot always choose to live outside of a flood risk area.

6. CONCLUSIONS AND FUTURE WORK

This study has examined trends in observed frequencies of heavy rainfall (1.5-3 inches/day) for individual stations in the Southern US, along with trends in rainfall events between 0.01 and 5 inches/day for each climate division within the region. In the examination of individual stations, only about 23% of stations have positive trends significant at the 5% level, reducing to 15% between 1948-2009. For individual stations, there were no statistically significant decreases in heavy precipitation. Stations with significant trends tended to be clustered in similar locations, which suggested local changes in precipitation, although natural variability tends to dominate most stations in most years. Examination of climate division trends between 1948-2009 indicate overall increases in the number of rainy days for northern and eastern sections of the SCIPP regions, while much of Texas shows a decrease in overall precipitation days but an increase in heavy (3+ inches/day) and very heavy (5+ inches/day) events, especially in far eastern and western Texas. There are no statistically significant negative trends in the frequency of events above 2 inches/day at the 5% level or less anywhere in the region. Seasonal trends in precipitation for each climate divisions indicate in a broad sense (since there is inter-division variability) more significant trends during the summer (JJA) and Fall (SON), where overall frequency of precipitation in JJA decreases but events above 3 inches/day increased (albeit only in central parts of Texas). For SON there is an overall increase in precipitation at all thresholds for parts of Oklahoma and Arkansas, shifting somewhat eastwards into Mississippi at higher thresholds (> 2 inches/day). Winter precipitation between 2-3 inches/day showed an increase over Oklahoma, and parts of north and west Texas, with little trend elsewhere. Finally, examination of a partial duration time-series for stations with trends significant to 20% (p value < 0.2) or less indicates a clear bias of extreme events toward the end of the century, especially the 1990s and 2000s, for all states. Thus overall, there is a clear signal for increased frequency of heavy precipitation events since 1948 and for many stations since the start of their records, some of which date back to about 1900.

This analysis was deliberately simple compared to many current techniques for trend analysis or ascertaining changes toward extreme magnitudes of precipitation, largely due to time constraints. Future work would ideally consider some of the following:

1. Examining trends in multiday precipitation events, especially 2, 3 and 7 day as a companion to the above analysis.
2. Attempt to understand the types of precipitation systems that produce flooding events over the SCIPP region, along with typical observed precipitation magnitudes, precipitation rates and durations.
3. Examine observed trends in precipitation magnitudes most clearly linked to flooding (on scales from flash flooding to larger scale inundation) as determined from (2). Ideally, reliable interpolation techniques should be used to convert individual station time series to gridded regional time series.
4. Examine trends in the frequency of dry days, this was addressed briefly in the above study through examination of number of days with precipitation > 0.01 inches/day for climate divisions but could be extended to a more detailed analysis of station data back to 1900.
5. Prepare a regional 'risk' map, highlighting regions where more substantial trends are evident in historical data, which, along with future climate change projections, may be used by stakeholders for present and future policy decisions.

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