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Extreme temperature days in the south-central United States

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ABSTRACT: Extreme temperature days in the south-central United States can have significant impacts on energy demand, agriculture, and human comfort. In this paper an extreme day is defined as a day that exceeds 1 standard deviation of the long-term average temperature for that day. Using this methodology, similar numbers of extreme days are found to occur in each season. Sixteen stations are selected from the Historical Climate Network Daily (HCN/D) record to represent conditions across a 6-state region. Significant interseasonal and interannual variability are found in the time-series of extreme days at all stations. In winter approximately 10 to 15 warm and cold days occur each year. However, neither type of event persists for long periods of time. This pattern is indicative of the vigorous atmospheric circulation that moves fronts and air masses through the midlatitudes during this season. Winters with a high frequency of cold days are associated with large-scale meridional circulation over North America, while zonal flow in winter produces more frequent warm days. In summer cold days occur regularly each year but cold events are short-lived. Warm events, however, follow a very different pattern. Warm day frequency is much more variable in the summer, and warm events tend to persist for longer periods of time when they do occur. Large-scale circulation differences between summers with frequent warm and cold days are weak, indicating that regional-scale patterns of subtropical flow and the expansion of the Atlantic Subtropical High are most likely important forcing factors in summer. Over this century there is a long-term trend toward more frequent cold days in all seasons. However, this trend may be reversing in the past decade.

KEY WORDS: Extreme temperature · Climate variability · South-central United States

1. INTRODUCTION

Many areas of society are susceptible to the effects of extreme temperatures. Unusually high summer temperatures raise power demand for air conditioning, increase heat stress on crops, and may create dangerous conditions for human health (e.g. Posey 1980, Mearns et al. 1984, Riebsame et al. 1986, Kalkstein 1993). Low winter temperatures may cause damaging frosts and freezes, increase heating demands, and may disrupt transportation (e.g. Changnon 1979, Rogers & Rohli 1991). Larger societal impacts are associated with these unusual extreme events than with small variations or changes in the mean (Wigley 1985). Effective climate impact studies must include information on extremes as well as the average conditions (Katz & Brown 1992). There is a critical need to understand the variability and persistence of extreme temperature days to enhance climate impact studies and to act as a baseline for global climate change scenarios.

High mean temperatures characterize the climate of the south-central United States. Summer maximum temperatures regularly exceed 30°C throughout the region and winter minimum temperatures rarely fall below 0°C. Locations in western Texas and Oklahoma tend to show more intra-annual variability which is characteristic of their more interior location. Summer maxima average 36°C, and mean winter minima fall as

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low as -2°C in this region. Less information is available on the geographic pattern of extreme days (Rohli & Keim 1994). A climatology of extreme temperature day variability is necessary in order to assess the impacts of temperature days across the south-central United States. Such a climatology can be used to monitor signals of climate change as events become more or less frequent. Future climate change may first become apparent as a shift in the frequency of extreme events (Mearns et al. 1984); it is the changes in these events that will drive society's response to climate change in the future (Parry & Carter 1985).

The geographic pattern of extreme temperature days is produced by air mass movement and circulation patterns. Extreme low temperatures are associated with the incursion of continental polar air accompanying anticyclones tracking southward in winter (Rohli & Rogers 1993). Conversely, maritime tropical air from the Gulf of Mexico and continental tropical air from northern Mexico advected by southwesterly currents on the western edge of the Atlantic Subtropical High regularly bring warmer air in summer (Henderson 1994). The frequency and persistence of these days is likely to differ between locations in the south-central United States, between warm days and cold days, and between seasons. This paper examines this variability, creates a climatology of extreme days, links extreme days to large-scale circulation anomalies, and examines trends through time.

2. DATA AND METHODS

Extreme temperature days were identified by using daily maximum and minimum temperature values. Long-term daily temperature records are available through the Historical Climatology Network Daily (HCN/D) data set compiled by the National Climate

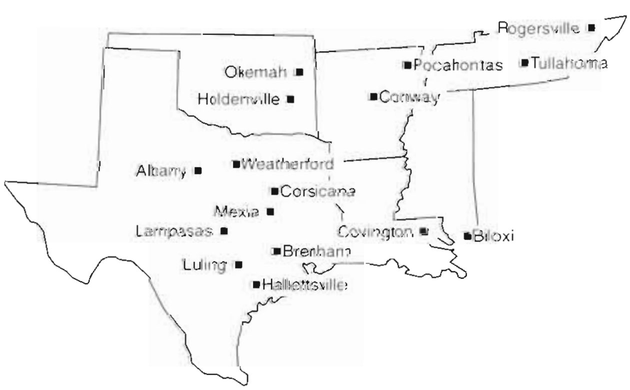

Fig. 1. South-central United States study area with 16 HCN/D station locations

Data Center (NCDC) and distributed through Oak Ridge National Laboratories (Hughes et al. 1992). The HCN/D is composed of stations chosen for their long-term consistent record with minimal data inhomogeneities, including infrequent station moves, small instrument biases, and little urbanization. There are 138 HCN/D stations available for the conterminous United States. This study uses the 16 stations located within the south-central states overseen by the Southern Regional Climate Center (Texas, Oklahoma, Arkansas, Louisiana, Mississippi, and Tennessee) (Fig. 1). The spatial distribution of these stations was not optimal. Large gaps are evident in western Texas and in northern Louisiana and Mississippi. However, a visual analysis of daily temperature during individual years showed that nearby stations display very similar patterns. In fact, even such distant stations as Covington, LA, and Tullahoma, TN, have similar patterns of daily extremes though the absolute values are somewhat different. These results indicate that even though the 16 stations used in this study are not evenly distributed, they can provide a reasonable picture of regional temperature events.

Daily maximum and minimum temperatures were extracted for the period 1901–1987. The 16 stations chosen for the analysis contained very little missing data; the average missing was 4% with a maximum of 15% at Okemah, OK, most of which occurred early in the record. In later analyses any season with more than 2 weeks of data missing was treated as missing for that year at that station in order to avoid biasing the statistics.

There are a variety of ways to define an extreme day. Common methods include counting days below or above specific thresholds such as 0 or 32°C (e.g. Vedin 1990, Changnon 1993, Rohli & Keim 1994), or determining temperature departures beyond certain values. However, these methods often limit the study to certain periods of the year. For example, extreme days defined as days below 0°C occur only in winter, and daily departures of greater than 5°C rarely occur in the summer in the south-central United States. This study needed a more comprehensive method of defining extreme days that could produce both warm and cold days in all seasons. Average daily maximum and minimum temperatures were calculated for each day of the year over the 88 yr study period. The standard deviation of each day's maximum and minimum was also calculated. An extreme warm day was defined as a daily maximum that exceeded 1 standard deviation above the average daily maximum for that day while an extreme cold day was defined as a daily minimum that exceeded 1 standard deviation below the average daily minimum for that day (Fig. 2). Similar numbers of warm and cold extreme days were determined for each season using this method. This methodology does assume a normal distribution of maximum and minimum temperatures. Skewness problems in the data were evident at a number of stations. Generally maximum temperatures were negatively skewed in summer, especially in Texas, and minimum temperatures were negatively skewed in winter, especially at stations near the Gulf Coast. Negative skewness in temperature maxima is not a large problem since extreme warm days are defined by the right-hand side of the distribution. However, negative skewness in temperature minima may overemphasize extreme cold days in winter along the Gulf.

Once the long-term climatology of extreme days was established, the interseasonal and interannual variability of extreme temperature days was examined. It should be noted, however, that this method cannot be directly adapted to climate impacts. Extreme days in summer will generally consist of smaller departures than during the winter because of the lower variability of temperatures in the warm season. Nevertheless, important regional patterns of variability were revealed in all seasons using this methodology and absolute departures can always be determined on a station by station basis for impact analysis in the future.

Links between extreme days and atmospheric circulation anomalies were examined using the 1977-point National Meteorological Center (NMC) grid covering the Northern Hemisphere. 500 mb data covering the period 1950–1987 were extracted for a grid over North America and the adjacent oceans. Seasons in which an unusually high number (greater than 1 standard deviation above the mean) of cold days were experienced across the region and seasons with unusually frequent warm days were each composited. Difference maps between cold day composites and warm day composites were used to reveal areas where large seasonal circulation changes are coincident with the formation of extreme temperature days in the south-central United States.

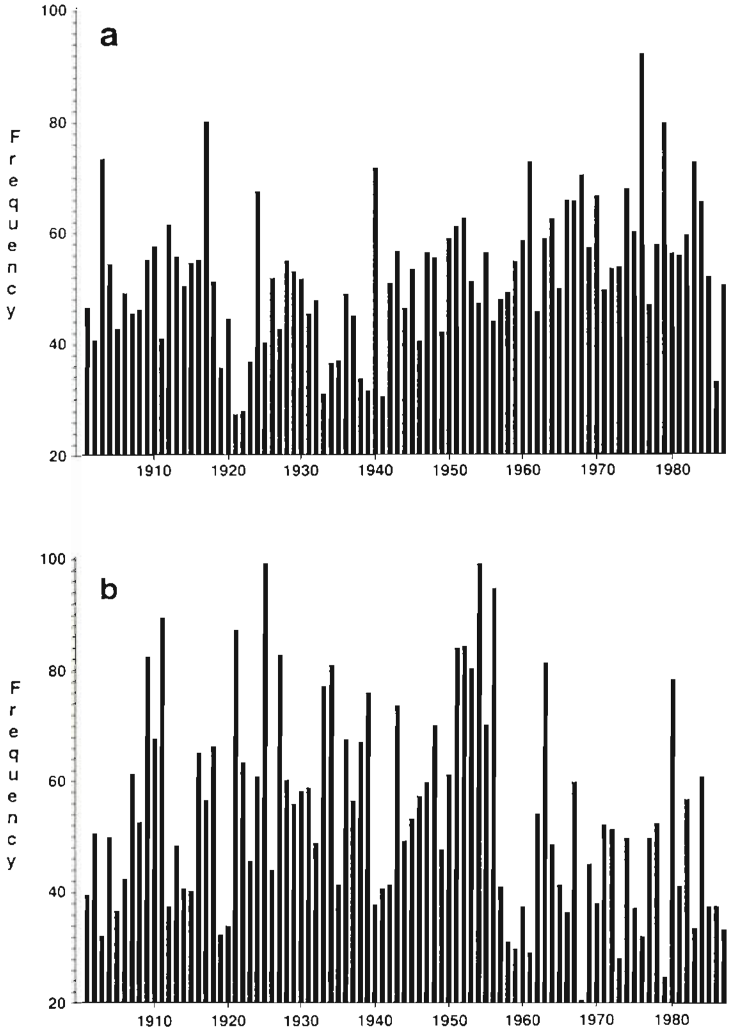

Fig. 3. Average frequency of (a) extreme cold days and (b) extreme warm days for the 16 stations illustrating the considerable interannual variability

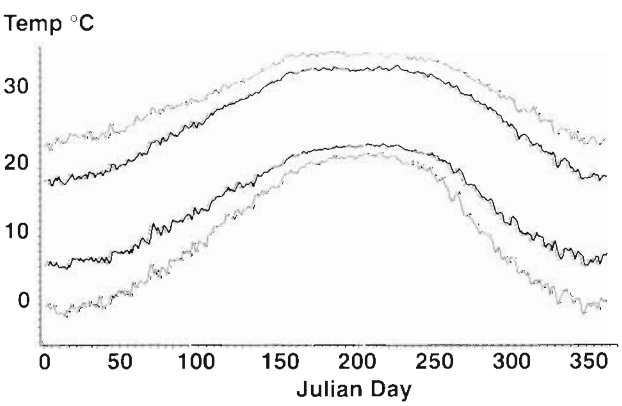

Fig. 2. Daily minimum and maximum temperature patterns (thick lines) and +1 standard deviation of daily maxima and −1 standard deviation of daily minima (thin lines) for Covington, LA

3. RESULTS

Considerable interannual variability of extreme days exists in all seasons (Fig. 3). In some years very

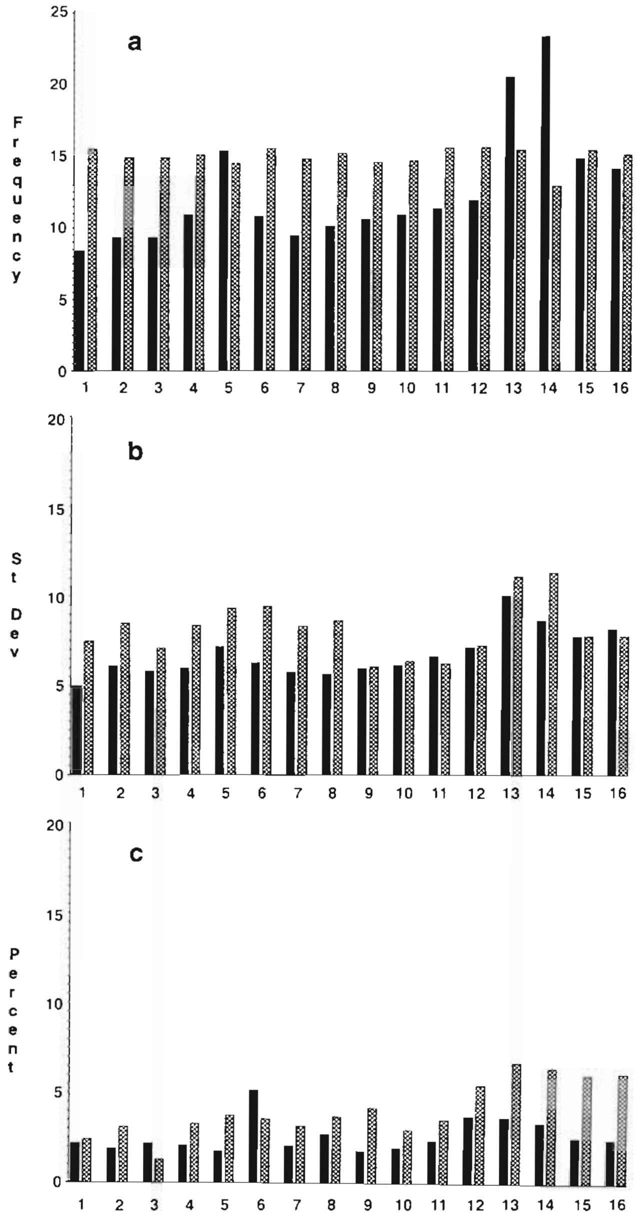

Fig. 4. Climatology of winter (DJF) extreme temperature days showing (a) mean frequency, (b) interannual standard deviation of frequency, (c) percentage of events lasting longer than 5 d. Solid bars indicate cold events and hatched bars indicate warm events. Station numbers run from west to east: 1 = Albany, 2 = Lampasas, 3 = Weatherford, 4 = Luling, 5 = Hallettsville, 6 = Brenham, 7 = Mexia, 8 = Corsicana, 9 = Holdenville, 10 = Okemah, 11 = Conway, 12 = Pocahontas, 13 = Covington, 14 = Biloxi, 15 = Tullahoma, 16 = Rogersville

few extreme days occur, while in others more than one fourth of days qualify as extreme days. A climatology of extreme days was created by determining their average occurrence, interannual standard deviation, and persistence by season at all stations. Additionally, we examined seasonal large-scale circulation patterns associated with high frequencies of extreme days.

3.1. Winter

The climatology of winter extreme days is shown in Fig. 4, with station values displayed from west to east. In winter warm (cold) extreme days are experienced when maximum (minimum) temperatures are 5 to 8°C above (below) normal. The average frequency of warm days is 15.1 and of cold days is 12.6 (Fig. 4a). The large number of cold days recorded at Covington, LA, and Biloxi, MS (as well as Hallettsville, TX), is likely a product of their coastal locations. Because these stations are near a large water body and have high average dew points (Henderson 1994), temperatures do not cool off as rapidly at night. Therefore, at these stations, average minimum temperatures are higher, the distribution of minimum temperatures is negatively skewed, and only a weak cold air outbreak is needed to qualify as a cold day. In the western portions of the study region, especially through Texas, the number of warm days exceeds the number of cold days. In the eastern areas though, especially Louisiana, Mississippi, and Tennessee, cold days occur as often as warm days. This eastward increase in the frequency of cold days is most likely associated with the tendency for more frequent upper-level troughing in the southeastern United States than in the Southwest (Harman 1991, Burnett 1994, Davis & Benkovic 1994). Under these conditions, polar anticyclones and associated cold air outbreaks more commonly track through the southeastern United States in winter than more directly south into Texas (Downton & Miller 1993, Rohli & Rogers 1993).

The frequencies reported above are overall averages, and individual years may differ considerably from these values. However, in winter the interannual variability of extreme day frequency is small (Fig. 4b). The average interannual standard deviation is 8.2 for warm days and 6.8 for cold days. There is a slight indication that variability is larger in the eastern portions of the study region than in the west. Again, this is most likely a result of the propensity for strong upper-level troughs to locate over the Southeast in some years. When troughs are present, more cold days are likely, but during more zonal years, warm days are more frequent.

Extreme events (consecutive extreme days) may persist for different lengths of time. Some events may last only 1 day while others may be composed of many extreme days. Climate impacts may be particularly severe during extended runs of extreme days. However, the majority of events at all stations persist for fewer than 5 days. This is especially true in winter which is characterized by few long-lasting events (Fig. 4c). There is a slight tendency for warm events to persist longer than cold events, especially in the east, but this is not pronounced. The winter season has a fairly consistent number of short-lived temperature events. Most winters experience a similar number of events, and the events do not last long. This pattern is consistent with the strong circulation of that season and the frequent passages of cyclones and anticyclones bringing air mass changes through the region. When polar air masses are brought down from the north behind a cold front, they may produce a short cold event, but the temperatures are quickly modified. Entrenched periods of extreme warm and cold periods are relatively rare.

Circulation pattern analysis identifies upper-level flow anomalies that accompany extreme days. A difference map between the 11 winters with a high frequency (greater than 1 standard deviation) of warm days and the 11 winters with a high frequency of cold days is shown in Fig. 5. Clearly, the frequency of extreme days is closely related to the Rossby Wave pattern across North America. The difference map between winters with many warm days and those with many cold days shows centers of large 500 mb height differences that closely resemble the Pacific/North America (PNA) teleconnection pattern (Wallace & Gutzler 1981). Winters with meridional flow and eastern troughing are associated with a higher number of cold days, especially at the eastern stations. Meridional flow steers cyclones and their accompanying cold fronts further south in these years and under extreme meridional flow this region lies entirely on the cold side of the polar front. Zonal winters and winters with reversed meridional flow (a trough in the western United States) experience more frequent warm days. Cyclones more frequently track west of the Appalachian Mountains (Henderson & Robinson 1994) in these winters, leaving the South exposed to warm return flow from the Gulf of Mexico. The zonal or reversed pattern is also more likely to persist for longer periods (Vega et al. 1995) explaining the slight tendency for warm events to persist longer than cold events. Therefore, the amplitude and location of the midlatitude Rossby Wave pattern are closely related to the frequency and variability of extreme temperature events in winter.

3.2. Spring

In spring, the number of warm and cold days is very similar at all non-coastal stations (Fig. 6a). Because the

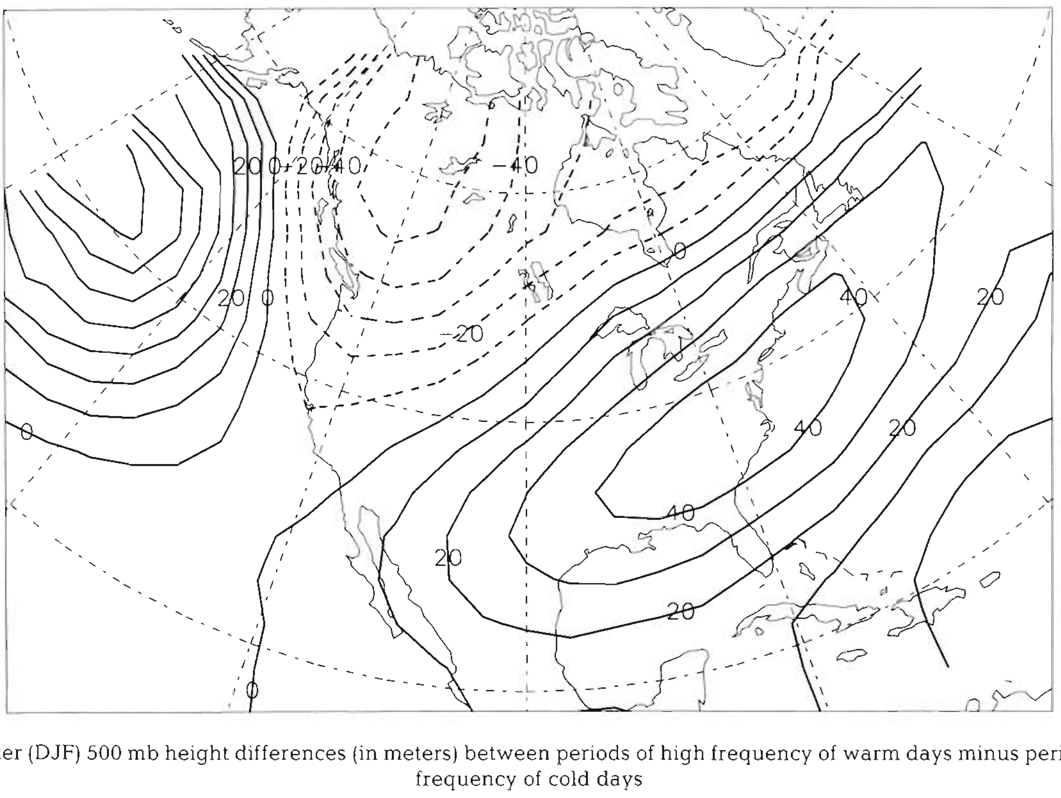

Fig. 5. Winter (DJF) 500 mb height differences (in meters) between periods of high frequency of warm days minus periods of high frequency of cold days

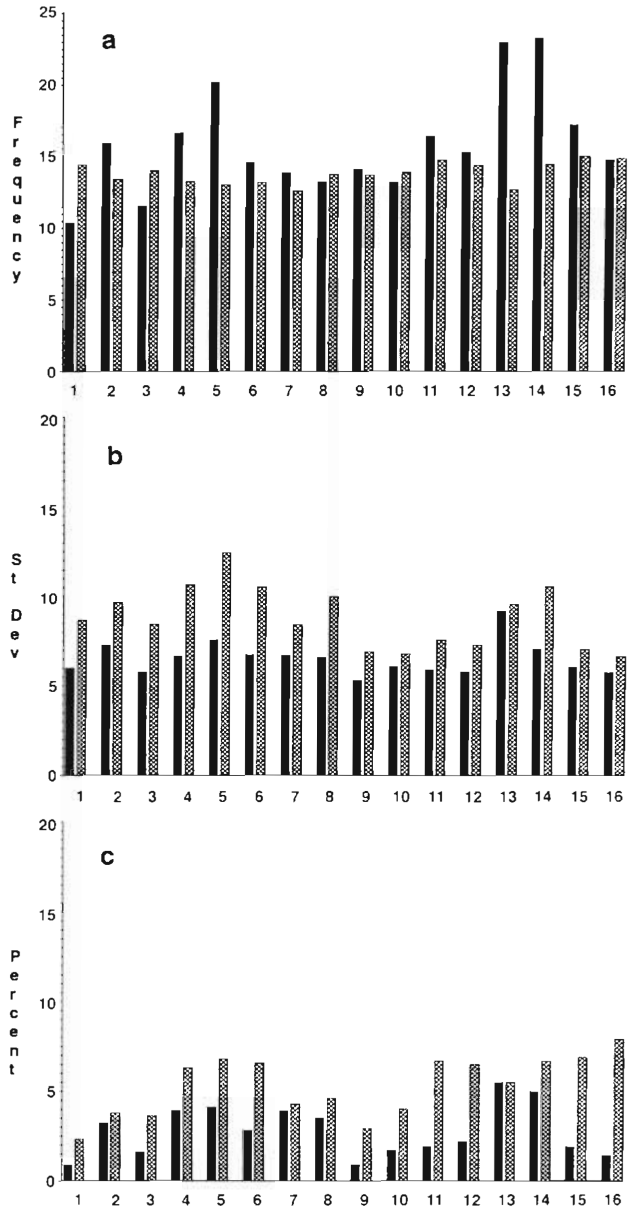

Fig. 6. Climatology of spring (MAM) extreme temperature days showing (a) mean frequency, (b) interannual standard deviation of frequency, (c) percentage of events lasting longer than 5 d. Solid bars indicate cold events and hatched bars indicate warm events. Station numbers run from west to east: 1 = Albany, 2 = Lampasas, 3 = Weatherford, 4 = Luling, 5 = Hallettsville, 6 = Brenham, 7 = Mexia, 8 = Corsicana, 9 = Holdenville, 10 = Okemah, 11 = Conway, 12 = Pocahontas, 13 = Covington, 14 = Biloxi, 15 = Tullahoma, 16 = Rogersville

departure needed to cause a cold day is smaller in spring than in winter, extremely cold outbreaks of air are not necessary; extreme days are more likely a result of late-season frontal passages. Interannual variability of warm days is slightly larger than in winter (Fig. 6b). Interannual standard deviations are 8.9 for warm days and 6.6 for cold days. Variability of warm days exceeds that of cold days in the western stations indicating that, in some years, early strengthening of the subtropical high may advect more warmer air mass events into the west. Persistence of extreme days also increases slightly in spring, but the percentage of events lasting longer than 5 days is still relatively small (Fig. 6c).

A difference map of 500 mb circulation during years of unusually frequent warm days and cold days shows large anomalies centered over the Mississippi Valley and the Gulf of Alaska (Fig. 7). The pattern is very similar to the winter pattern with slight shifts in the major anomaly regions. Rossby Wave patterns in mid-latitude circulation are still the major controlling feature. As the circumpolar vortex retreats, slight spatial variability of the polar jet stream position alters regional flow. During transitional seasons, extended exposure to continental polar air on one side of the polar front, or maritime tropical air on the other, explains a large portion of extreme temperature day variability. Upper-level ridging is more common over the south-central United States during years with an unusually large number of warm days. Conversely, late-season upper-air troughs in this region produce higher frequencies of cold days.

3.3. Summer

The summer pattern of extreme day frequency closely resembles the winter pattern (Fig. 8a). In the eastern portion of the study region, the number of warm and cold days is relatively similar. In the west, however, the number of warm days far outnumbers the number of cold days. In summer the temperature departure needed to produce an extreme day is very small (1 to 3°C). In this case the increase in the ratio of warm days to cold days is probably associated with the strengthening of the Atlantic Subtropical High in the west and the consistent advection of hot, dry, continental tropical air into the region from Mexico (Henderson 1994).

In summer the standard deviation of cold day frequency (6.2) has not changed considerably from the other seasons (Fig. 8b). However, the interannual variability of warm days is much larger. An average standard deviation of 13.4 indicates that the frequency of warm days is highly variable, especially in Texas, Oklahoma, and Arkansas. In some years there are almost no warm days, while in other years half of the days exceed maximum temperature thresholds. This finding is most likely related to the strength of the Atlantic Subtropical High in a particular summer. With

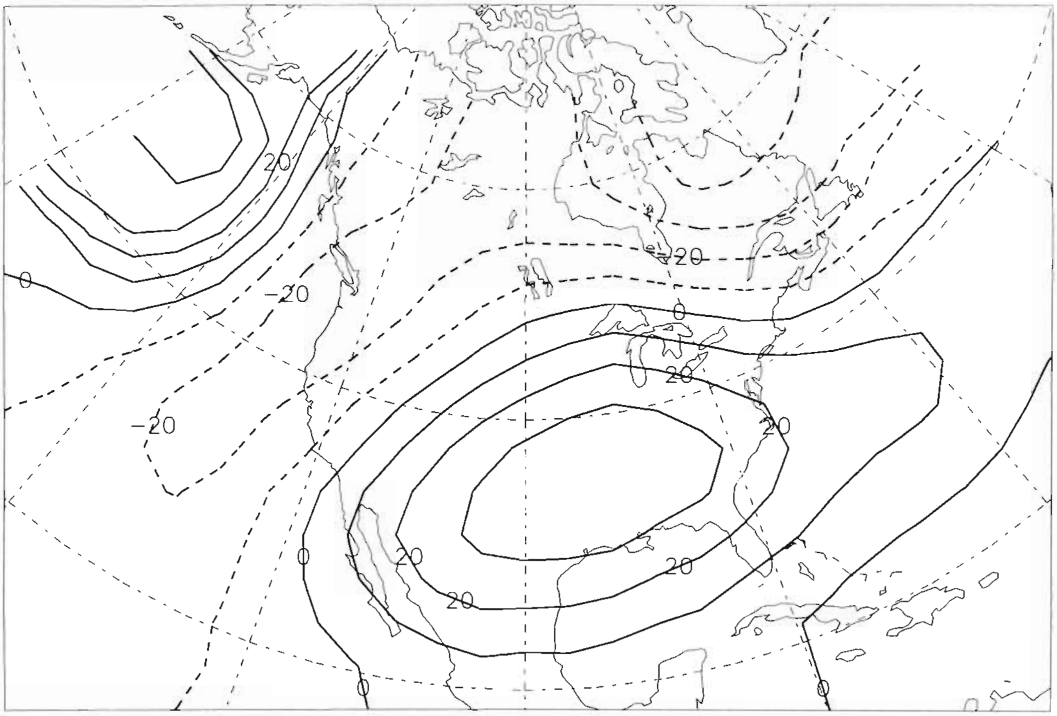

Fig. 7. Spring (MAM) 500 mb height differences (in meters) between periods of high frequency of warm days minus periods of high frequency of cold days

a strongly entrenched high extending far to the west, advection of warm, southern air is enhanced and cloud cover is suppressed, leading to high afternoon temperatures. During summers in which the Atlantic Subtropical High is weakened or displaced eastward, southerly advection of air masses is reduced and more frequent frontal passages are possible.

In summer few cold events last longer than 5 days (Fig. 8c). Fronts moving through the southern region in this season are generally less frequent (Morgan et al. 1975) and are often weak, causing temperatures to cool only moderately. In a matter of days the air masses are modified and warmer conditions will again prevail. Conversely, warm events can persist for much longer periods of time. At many of the western stations, the percentage of warm events lasting more than 5 days exceeds 10%, twice the percentage of cold events. Summer was also the season that showed the greatest variability in warm days. However, when warm days do occur they tend to persist for long periods of time.

Only very small geopotential height differences between seasons of many warm days and many cold days occur in summer (Fig. 9). Most likely this is a result of smaller scale circulation features that are responsible for extreme temperature day variability in this season. In the case of warm outbreaks, the Aleutian Low is somewhat weakened, and an arm of the Atlantic Subtropical High extends into the Gulf of Mexico and the southern United States. Rapid expansion of the subtropical high in early summer dominates the average weather patterns of the southern United States (Davis et al. 1997). The strengthening of the subtropical high implies enhanced subsidence over the area, producing clearer skies and increased afternoon insolation. This expansion of the Atlantic Subtropical High in some summers in combination with local synoptic situations creates season-long anomalies that produce a high number of persistent events. In other summers this pattern may not be established, and very few warm extreme days are experienced. Additional research needs to be done on the role of subtropical flow at more regional scales to confirm this hypothesis.

3.4. Autumn

Autumn patterns of extreme day frequency (Fig. 10a) resemble those of spring since, during the time of transition between tropical summer and continental winter, the position of the polar front is crucial to the advection of warm and cold air. Consequently, there is very little difference between the frequency of warm or cold days across the region.

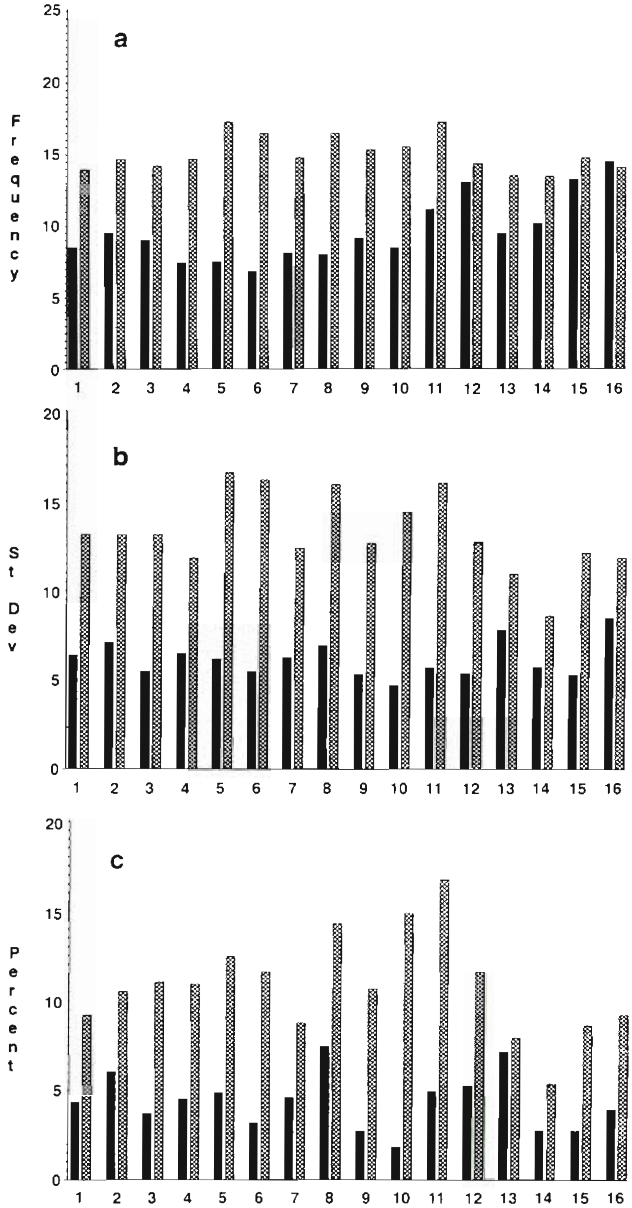

Fig. 8. Climatology of summer (JJA) extreme temperature days showing (a) mean frequency, (b) interannual standard deviation of frequency, (c) percentage of events lasting longer than 5 d. Solid bars indicate cold events and hatched bars indicate warm events. Station numbers run from west to east: 1 = Albany, 2 = Lampasas, 3 = Weatherford, 4 = Luling, 5 = Hallettsville, 6 = Brenham, 7 = Mexia, 8 = Corsicana, 9 = Holdenville, 10 = Okemah, 11 = Conway, 12 = Pocahontas, 13 = Covington, 14 = Biloxi, 15 = Tullahoma, 16 = Rogersville

The high variability of warm days during summer does not last long. By autumn interannual standard deviations of warm and cold days are again very similar, 9.6 and 7.3 respectively (Fig. 10b). The variability of extreme days is slightly larger than that of spring. During these transitional seasons the frequency of extreme temperature days is more consistent. The imbalance between the persistence of cold and warm events also disappears in autumn (Fig. 10c). Both warm and cold events show higher persistence percentages. The highest percentage of events persisting longer than 5 days is found in the west and along the Gulf Coast.

The only circulation signal evident in autumn is a broad zone of higher pressure over interior North America during seasons with many warm day outbreaks (Fig. 11). The subtropical high normally retreats during this season, but a secondary pressure maximum becomes established over the continent (Davis et al. 1997). This area appears to be related to the normal westward shift of the upper-level ridge in autumn (Harman 1991). This ridge may lock into preferred positions at this time, maintaining summer conditions (and thus warm days) longer into the autumn, or may shift earlier, bringing midlatitude air masses and longer lasting cold events. As in summer, the circulation features that produce extreme days are probably found at smaller regional and synoptic scales.

4. TRENDS IN EXTREME EVENTS

If extreme temperature days can have important impacts and are as variable as shown here, then it is also crucial for us to understand their trends through time. Because of growing concerns over global climate change, it is necessary to examine whether any changes in the frequency or magnitude of the extreme temperature days has been taking place during this century. To address this question the number of extreme days in each season was correlated with the year of their occurrence. Results are shown in Fig. 12. Since 1901 the overall temperature trend appears to be downward with more frequent cold days and less frequent warm days at most stations in all seasons (Fig. 3). In interpreting these results it must be noted that although the HCN/D data provide the most homogeneous data set available, changes such as stations moves, thermometer changes, and changing times of observation may account for a portion of this frequency change.

In winter all 16 stations show an increase in cold days through the study period (Fig. 12a). This relationship is statistically significant at the 0.05 level at 6 stations. Any trend in warm days is less identifiable. Nine stations display a decrease in warm days while 6 stations, mostly in Texas, show an increase. The overall trend toward more frequent cold days matches long-term trends toward increased troughing in the southeastern United States (Leathers & Palecki 1992, Davis & Benkovic 1994). However, 2 points should be

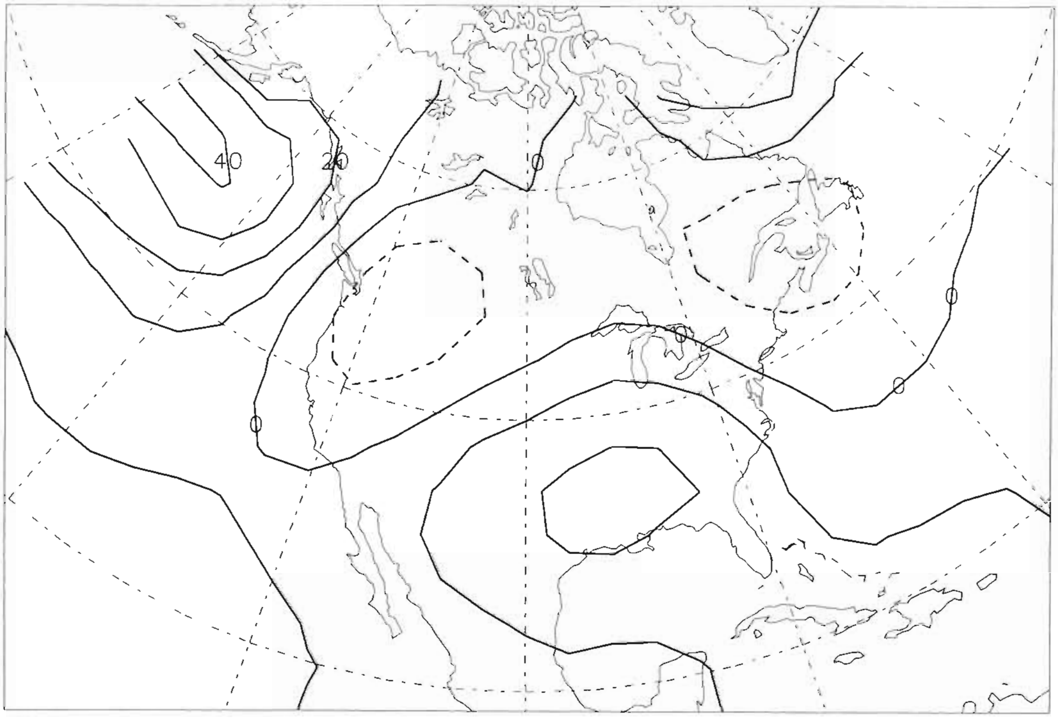

Fig. 9. Summer (JJA) 500 mb height differences (in meters) between periods of high frequency of warm days minus periods of high frequency of cold days

noted. First, some of this increase in cool day frequency may be explained by changing times of observation at the weather stations. Since the 1940s many weather stations in the United States have gone from evening observing stations to morning observations. When observations are made in the morning, a particularly cold day will be double-counted, once on the day of observation and once on the following morning after the thermometer has been reset (Karl et al. 1986). Changing times of observation can not account for the entire temperature decrease however, and a portion of this cooling is also probably real. The second point is that the trends shown here are true for the last 88 yr inclusive. Any change in the trend over the last 10 to 20 yr would not be shown in this data. Indeed, from a visual analysis of the patterns, it appears likely that the trends have begun to reverse in the past decade.

A clear idea of trends in extreme days in spring is not as apparent (Fig. 12b). The majority of stations still show an increasing number of cold days and a decreasing number of warm days through time. However, the patterns are not as clearly defined and trends at fewer stations are statistically significant. Summer shows similar patterns, though more stations are significant (Fig. 12c). The other interesting feature of the summer patterns is that in the eastern portions of the study area, a number of stations have experienced a decrease in both kinds of extreme days. This trend indicates a decrease in the variability of extreme days and may be linked to trends in the strength of the Atlantic Subtropical High (Henderson & Vega 1996).

Differences between the eastern and western stations are apparent in autumn (Fig. 12d). In Texas most stations have experienced an increase in the frequency of cold days. In the east the strongest signal is a sharp decrease in the number of warm days. This result is consistent with the findings of Davis et al. (1997) and Vega (1994) who found that over the last century the strength of the Atlantic Subtropical High has been weakening. With a weaker subtropical high in autumn, the polar jet may advance into the Southeast earlier in the season, decreasing the chances of experiencing very warm, subtropical days. It should be remembered that this trend is for the entire century and there is some indication that the trend has been reversing in the last decade.

In order to determine whether the magnitude of the temperature departures on extreme days has been increasing, the average anomaly of extreme warm days and extreme cold days was calculated for each season. These average anomalies were then correlated

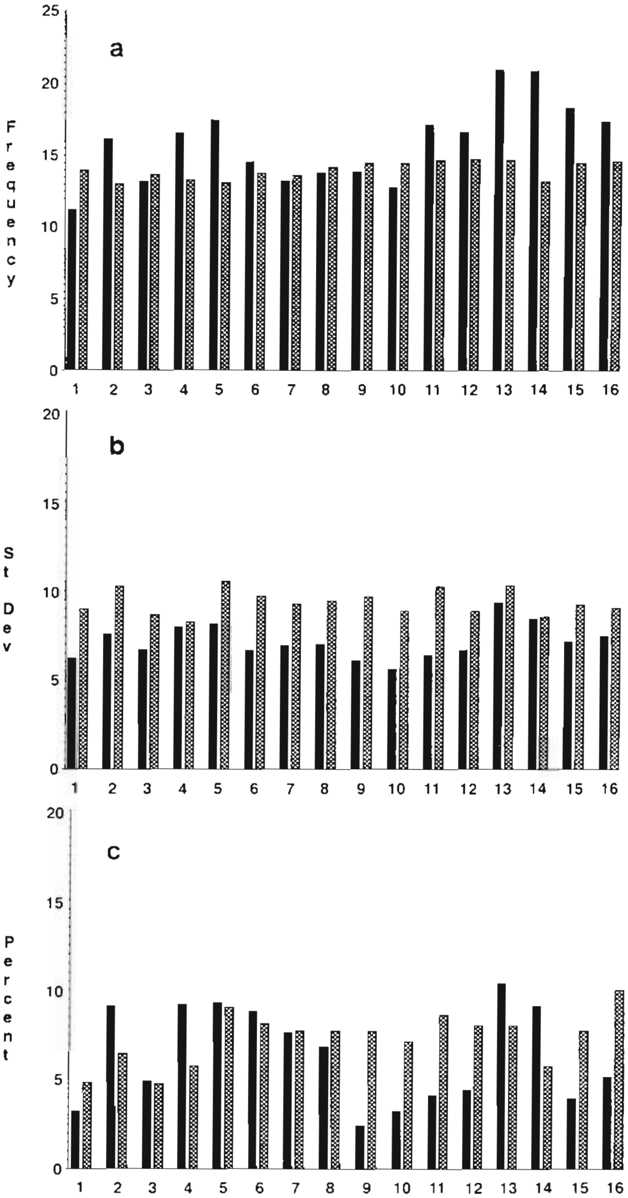

Fig. 10. Climatology of autumn (SON) extreme temperature days showing (a) mean frequency, (b) interannual standard deviation of frequency, (c) percentage of events lasting longer than 5 d. Solid bars indicate cold events and hatched bars indicate warm events. Station numbers run from west to east: 1 = Albany, 2 = Lampasas, 3 = Weatherford, 4 = Luling, 5 = Hallettsville, 6 = Brenham, 7 = Mexia, 8 = Corsicana, 9 = Holdenville, 10 = Okemah, 11 = Conway, 12 = Pocahontas, 13 = Covington, 14 = Biloxi, 15 = Tullahoma, 16 = Rogersville

with the year of their occurrence. No significant trends were found. Although there has been a change in the frequency of extreme temperature days at many stations, the magnitude of the temperature departures has not changed.

5. CONCLUSIONS

Extreme temperature days are an important element of the climate of the south-central United States. Using a definition of extreme days based on daily means and standard deviations, warm and cold days occur on average 10 to 15 times each season. In winter these days represent temperature departures of more than 5°C, while in summer a departure of less than 3°C is often sufficient to produce an extreme day. Cold days have a small interannual variability and events rarely last more than 5 consecutive days. They tend to occur more frequently in the eastern portion of the study region. Warm days experience a much greater interannual variability in summer and autumn when warm events also tend to last significantly longer than cold events.

Extreme temperature days are potentially important in all seasons. The regular pattern of short-lived cold events in winter can adversely affect agriculture and energy demand, but rarely last long. More importantly, warm days in summer do not occur as regularly. However, when the proper synoptic situation becomes established, warm events can persist for many days. This has obvious implications for human health and comfort, energy demand and water need.

Over the past century the number of extreme cold days has been increasing at many stations in all seasons. In winter, more frequent Southeast troughing accounts for the increase in cold days and the concurrent decrease in warm days. In summer and autumn, a decrease in the number of warm days in the east may indicate changes in the strength of the Atlantic Subtropical High. Any future change in extreme days will be driven by these types of circulation changes. Therefore, it is important to identify significant flow patterns associated with extreme temperatures. Results indicate that during winter, midlatitude Rossby Wave flow is more important, while subtropical flow tends to determine extreme day frequency in summer. Interannual variability is highest during the seasons dominated by subtropical flow, and is lower in the seasons dominated by midlatitude flow. Every year will experience similar numbers of cold days and warm days in the non-summer seasons controlled by large-scale Rossby Wave patterns. However, warm days in summer, which can be the most important for heat stress and energy consumption, are highly variable and more closely linked to subtropical and regional circulation. This result indicates the importance of the Atlantic Subtropical High for the southern climate. Further research on the variability and the influence of this feature is needed to understand the causes of extreme temperature days in the summer

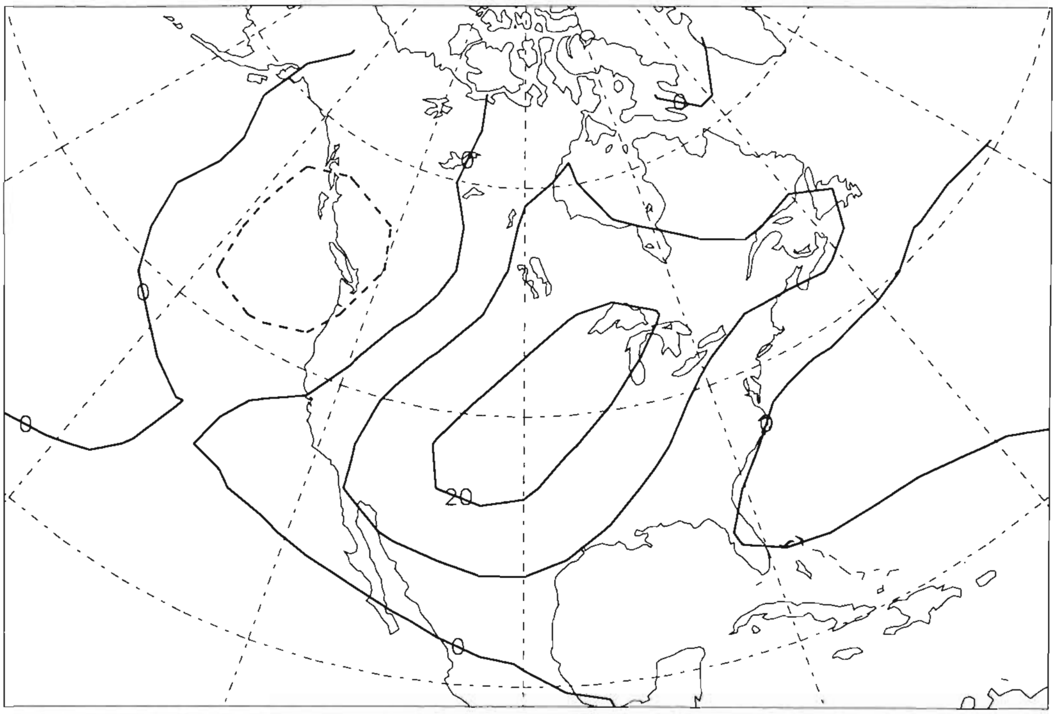

Fig. 11. Autumn (SON) 500 mb height differences (in meters) between periods of high frequency of warm days minus periods of high frequency of cold days

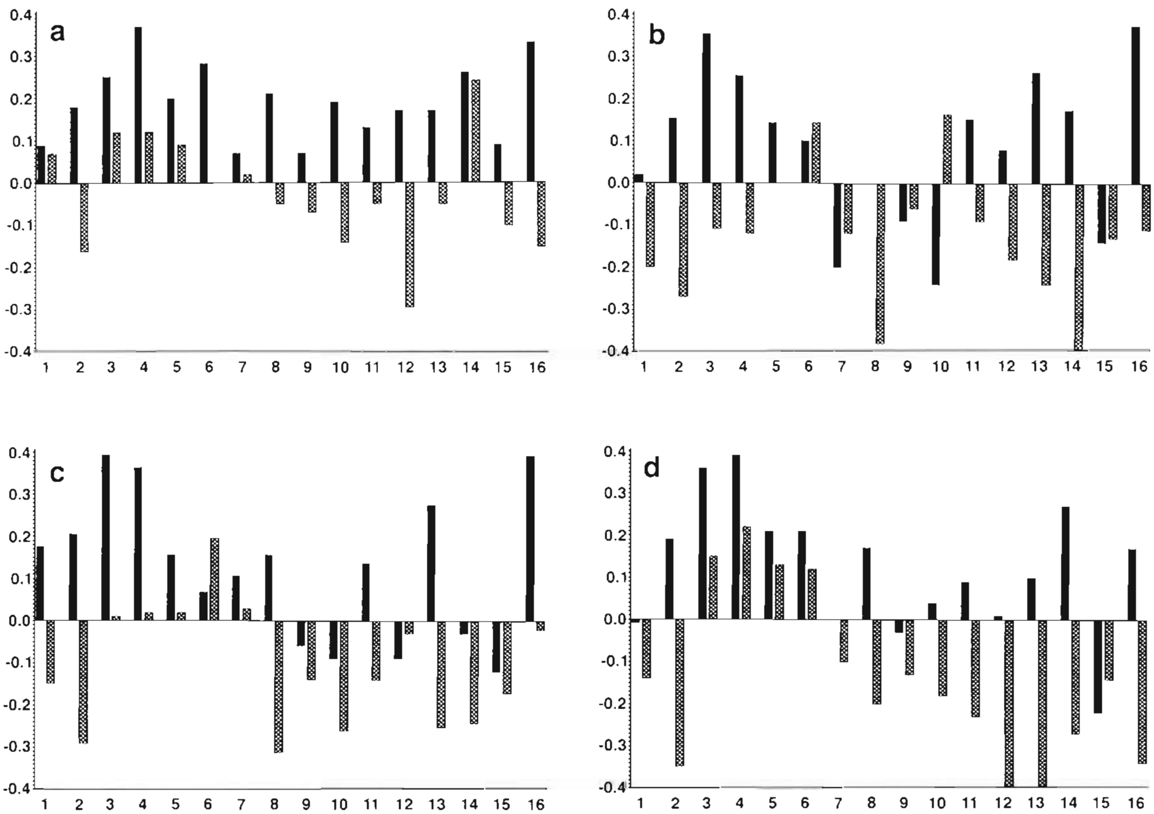

Fig. 12. Correlations between extreme day frequency (solid = cold, hatched = warm) and year demonstrating trends through time for (a) winter, (b) spring, (c) summer, and (d) autumn. Values with an absolute value greater than 0.2 are significant at the 0.05 level

LITERATURE CITED

Burnett AW (1994) Regional-scale troughing over the Southwestern United States: temporal climatology, teleconnections, and climatic impact. Phys Geogr 15:80-98

Changnon D (1993) Variability in high temperature extremes in the southeastern United States. Phys Geogr 14: 599-611

Changnon SA (1979) How a severe winter impacts on individuals. Bull Am Meteorol Soc 60:110-114

Davis RE, Benkovic SR (1994) Spatial and temporal variations of the January circumpolar vortex over the Northern Hemisphere. Int J Climatol 14:415-428

Davis RE, Hayden BP, Gay DA, Phillips WL (1997) The Atlantic subtropical anticyclone. J Clim (in press)

Downton MW, Miller KA (1993) The freeze risk to Florida citrus. Part II: Temperature variability and circulation patterns. J Climate 6:364-372

Harman JR (1991) Synoptic climatology of the westerlies: process and patterns. Association of American Geographers, Washington, DC

Henderson KG (1994) Variations in dew-point temperatures in the southern United States. Phys Geogr 15:23-37

Henderson KG, Robinson PJ (1994) Relationships between the Pacific/North American teleconnection pattern and precipitation events in the southeastern United States. Int J Climatol 14:307-323

Henderson KG, Vega AJ (1996) Regional precipitation variability in the southern United States. Phys Geogr 17: 93-112

Hughes PY, Mason EH, Karl TR, Brower WA (1992) United States Historical Climatology Network daily temperature and precipitation data. Oak Ridge National Laboratory, Oak Ridge, TN

Kalkstein LS (1993) Health and climate change—direct impacts in cities. Lancet 342:1397-1399

Karl TR, Williams CN Jr, Young PJ, Wendland WM (1986) A model to estimate the time of observation bias associated with monthly maximum, minimum, and mean temperatures for the United States. J Clim Appl Meteorol 25: 145-160

Katz RW, Brown BG (1992) Extreme events in a changing climate: variability is more important than averages. Clim Change 21:289-302

Leathers DJ, Palecki MA (1992) The Pacific/North American teleconnection pattern and United States climate. Part II: Temporal characteristics and index specification. J Clim 4: 707-716

Mearns LO, Katz RW, Schneider SH (1984) Extreme high-temperature events: changes in their probabilities with changes in mean temperature. J Clim Appl Meteorol 23: 1601-1613

Morgan GM, Brunkow DG, Beebe RC (1975) Climatology of surface fronts. ISWS-75-CIR122. Illinois State Water Survey, Urbana, IL

Parry ML, Carter TR (1985) The effect of climate variations on agricultural risk. Clim Change 7:95-110

Posey C (1980) Heatwave. Weatherwise 33:112-116

Riebsame WE, Diaz HF, Moses T, Price M (1986) The social burden of weather and climate hazards. Bull Am Meteorol Soc 67:1378-1385

Rogers JC, Rohli RV (1991) Florida citrus freezes and polar anticyclones in the Great Plains. J Clim 4:1103-1113

Rohli RV, Keim BD (1994) Spatial and temporal characteristics of extreme high summer temperature events in the south-central United States. Phys Geogr 15:310-324

Rohli RV, Rogers JC (1993) Atmospheric teleconnections and citrus freezes in the southern United States. Phys Geogr 14:1-15

Vedin H (1990) Frequency of rare weather events during periods of extreme climate. Geografiska Annaler 72A:151-155

Vega AJ (1994) The influence of regional-scale circulation on precipitation variability in the southern United States. PhD dissertation, Louisiana State University, Baton Rouge

Vega AJ, Henderson KG, Rohli RV (1995) Comparison of monthly and intramonthly indices for the Pacific/North American teleconnection pattern. J Clim 8:2097-2103

Wallace JM, Gutzler DS (1981) Teleconnections in the geopotential height field during the Northern Hemisphere winter. Mon Weather Rev 109:784-812

Wigley TML (1985) Impact of extreme events. Nature 316: 106-107

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