The Productivity & Sustainability of Southern
Forest Ecosystems in a Changing Environment
by Mickler & Fox

37. Regional Climate Change in the Southern United States: The Implications for Wildfire Occurrence

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Fires have always been an important factor in determining the composition of forests worldwide, but particularly in the southern United States. Wildfires were a common occurrence in American forests in the early twentieth century. Before 1930, wildfires typically accounted for the burning of eight to twenty million hectares (ha) in the United States each year. By the early 1940s, wildfires were still responsible for the annual burning of over eight million ha. Over 90% of the area burned during this time was on privately owned lands, primarily in the southern United States (Fedkiw, 1989). Between 1950 and 1980, the hectares burned by wildfires steadily decreased as the area receiving organized protection increased and the intensity of the protection efforts increased (Peterson, 1982). In recent years, the total area burned by wildfires in the United States has diminished to about one to two million ha per year (USDA Forest Service, 1992). Although the decrease in the number of hectares burned by wildfires across the United States has been significant over the last seventy years, the relative importance of wildfires in the southern United States in relation to other regions of the United States is significant. More hectares are burned by wildfires in the southern United States than in any other region of the country. A notable exception occurred in 1988 when the severe drought that affected many of the central and Rocky Mountain states contributed to the massive wildfires that occurred in the Rocky Mountain region. Between 1984 and 1990, wildfires in the southern region of the United States accounted for 20 to 43% of all hectares burned in the United States.

Wildfire occurrence is also much more common in the southern United States than in other parts of the country. The southern and northeastern regions are dominated by human-caused wildfires, and the southern region alone accounts for roughly 53% of all wildfires occurring in the United States, excluding Alaska. Even lightning-caused fires were more common in the southern region over the entire seven-year period between 1984 and 1990 than in any other region, excluding Alaska.

Regardless of the cause of wildfires in the southern region or any other region, the occurrence of severe wildfires depends to a large degree on the atmospheric conditions present before, during, and after the time of ignition. The prospect of future global or regional climate changes resulting from an increase in atmospheric carbon dioxide (CO_2) concentrations has raised concerns about how large-scale changes in the atmosphere associated with a changed climate will affect regional wildfire occurrence. Alteration of the large-scale mean thermal structure of the atmosphere resulting from increased CO_2 concentrations has the potential for affecting the dynamics of the atmosphere across the entire spectrum of scales that govern atmospheric processes. Inherent in these changes are interactions among the scales that could change, resulting in an alteration in the frequency of relatively short-term weather systems that enhance the probability of wildfire occurrence. Indeed, climatic variability and extreme weather events (e.g., drought, flood, extreme heat, fire-weather development) are much more important factors for wildfire occurrence than the effects of systematic climate change (e.g., long-term and large-scale temperature and precipitation trends) (Fosberg et al., 1993).

Given the importance of wildfires in the southern United States, this chapter describes some of the recent research efforts that have examined many of the critical atmospheric interactions with southern wildfire occurrence and the implications of regional climate change on the future development of fire-weather systems. The following sections provide an overview of present and recent research dealing with large-scale atmospheric circulation, temperature, and moisture patterns associated with severe wildfires in the region, useful atmospheric variables as indicators of severe fire potential in the region, soil-moisture effects on southern fire-weather development, El Niño/southem oscillation effects on fire occurrence in the southeastern United States, and potential changes in lightning-caused wildfires in the region.

Synoptic Circulation, Temperature, and Moisture Patterns

Atmospheric conditions play a critical role in affecting the severity of wildfires and the probability of their occurrence in the southern United States, as well as the rest of the country during specific times of the year. Figure 37.1 shows the distribution of severe wildland fires in the south-central and southeastern United States by month for years 1971 to 1984 and 1987 to 1991. Although severe wildland fires in the south-central United States typically occur during the months of March and April, severe fires in the southeastern United States generally occur

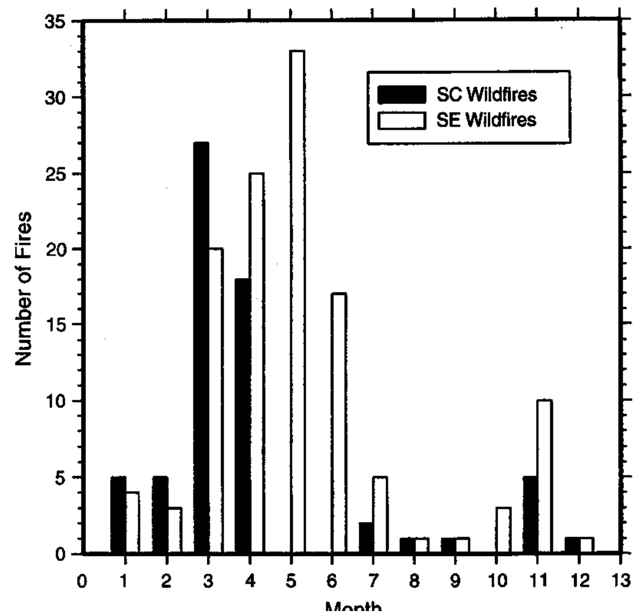

Figure 37.1. Number of wildfires burning more than 400 ha in the south-central United States (i.e., Texas. Oklahoma, Kansas, Missouri, Arkansas, Louisiana) and the southeastern United States (SE: Mississippi, Alabama, Georgia, Florida, South Carolina, North Carolina, Kentucky, Tennessee, Virginia) from 1971 to 1984 and 1987 to 1991.

between March and June. Secondary peaks in severe wildfire occurrence typically occur in the month of November. There are specific synoptic-scale circulation patterns in the middle troposphere during these months that tend to be associated with severe wildfires in the southern United States. These circulation patterns result in temperature and moisture distributions in the lower atmosphere that enhance the probability of severe fires occurring.

Heilman (1995) expanded upon the work of Schroeder et al., (1964) to examine the prevalent circulation patterns at the onset of past severe fires in six different regions of the United States. Using empirical-orthogonal-function analyses of the observed geopotential heights at the 500 mb pressure level in the atmosphere at the onset of severe wildfires in the United States, it was shown that severe wildfires in the south-central and southeastern United States are associated with three distinct mid-tropospheric circulation patterns. Examples of these patterns are shown in Figures 37.2a,b,c. Severe wildfires occurred on these days in the southeastern United States. The first pattern (Figure 37.2a) is described by a middle tropospheric ridge over the western half of the United States with an accompanying trough over the eastern United States that results in northwesterly to westerly flow over the southeastern United States. This circulation pattern tends to bring cool dry air from Canada into the southern and eastern states. The second pattern (Figure 37.213) is described by a middle tropospheric ridge over the eastern half of the United States, with the western or central states dominated by a

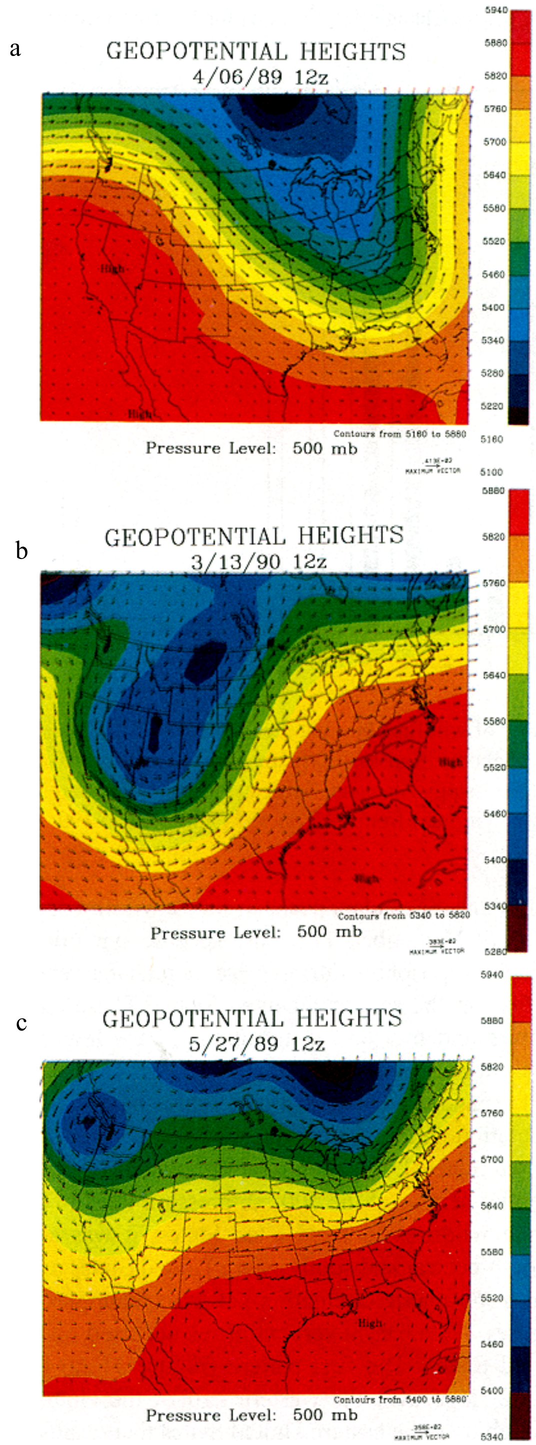

Figure 37.2. Recent examples of three 500 mb geopotential height (contours in meters) and circulation (vectors in m s^{-1}) patterns associated with severe wildfires in the southeastern United States that occurred on: (a) April 6, 1989, (b) March 13, 1990, and (c) May 27, 1989.

middle tropospheric trough. This pattern can be very conducive to the westward shift of the surface Bermuda high-pressure system, leading to hot and dry conditions over parts of the southeastern and northeastern United States. These first two patterns are equivalent to the positive and negative phases, respectively, of the Pacific/North American (PNA) teleconnection pattern (Wallace and Gutzler, 1981) that is responsible for much of the climate variability in the northern hemisphere during the autumn, winter, and spring months (Leathers et al., 1991). The third circulation pattern is shown in Figure 37.2c and is characterized by middle tropospheric zonal flow over the southern regions of the United States.

These circulation patterns that are associated with severe wildfires in the south-central and southeastern United States produce lower atmospheric temperature and moisture patterns that enhance the probability of fire occurrence if fuel conditions are adequate. Figures 37.3a,b,c and Figures 37.4a,b,c show the corresponding average lower atmospheric temperature and relative humidity anomalies over the United States when severe wildland tires occurred in the southeastern United States from 1971 to 1984 and 1987 to 1991. The first circulation pattern (Figure 37.2a) resulted in lower than normal 850 mb temperatures over the eastern half of the United States, with maximum temperature anomalies occurring over the Ohio River Valley. Average temperature anomalies at 850 mb over the southeastern United States ranged from – 1 °C in Florida to about – 5 °C in Kentucky (Figure 37.3a). The second circulation pattern (Figure 37.2b) resulted in warmer than normal temperatures at 850 mb over all the eastern United States. Average temperature anomalies reached about 5 °C over the northeastern United States, and decreased southward to about 1 °C over southern Florida (Figure 37.3b). The zonal circulation pattern over the southern United States (Figure 37.2c) resulted in positive 850 mb temperature anomalies over the southern half of the United States, with the southeastern Upited States experiencing average temperature anomalies of 1 to 2 °C (Figure 37.3c). For all three circulation patterns, lower-than-normal relative humidity values occurred over at least a portion of the southeastern United States (Figures 37.4a,b,c). The average lower atmospheric moisture anomalies associated with the second circulation pattern (Figures 37.2b and 37.4b) indicate that although this pattern tends to produce dry atmospheric conditions over most of the Atlantic coast states and eastern Great Lakes region, the states west of Alabama, Tennessee, and Kentucky typically experience higher-than-normal relative humidity values. It is not uncommon for significant portions of the south-central and southeastern United States to experience higher-than-normal relative humidity values under the second circulation pattern. The location of the Bermuda high-pressure system under this particular circulation pattern determines where the northward transport of Gulf moisture will occur and those southeastern and northeastern states that will be cut off from the supply of Gulf moisture.

The average lower atmospheric temperature and relative humidity anomalies occurring during severe wildland tire episodes in the south-central United States over the same time period for each of the three identified circulation patterns are shown in Figures 37.5a,b,c and Figures 37.6a,b,c, respectively. The temperature

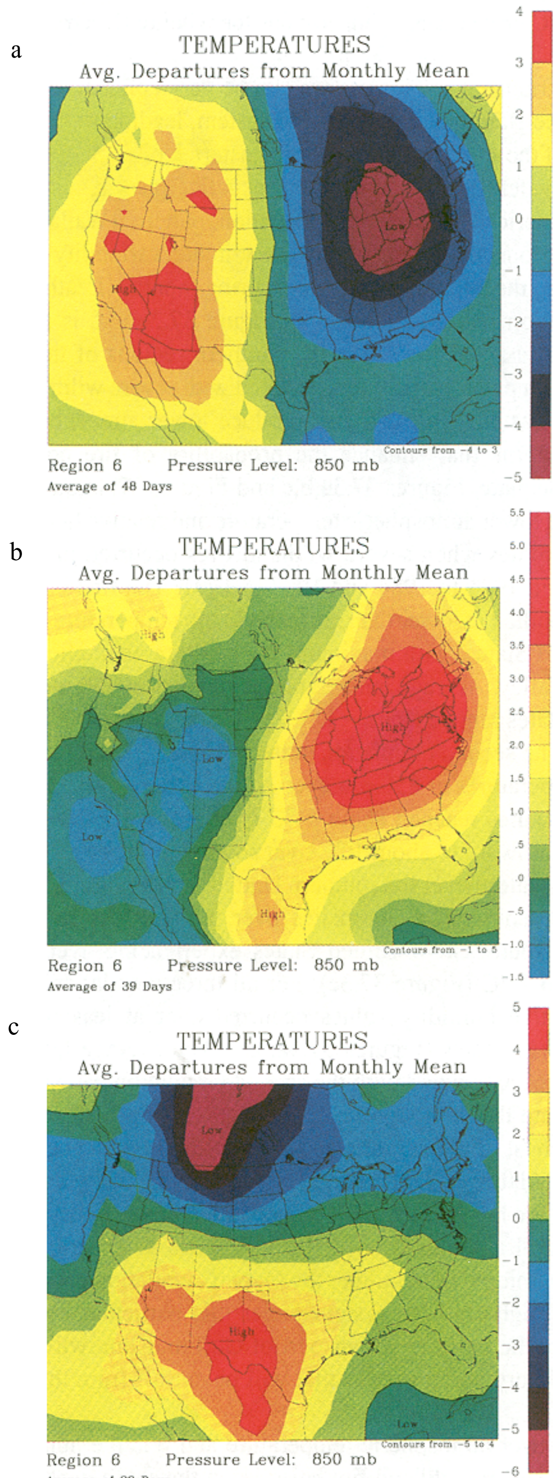

Figure 37.3. Average temperature anomalies (°K) at the 850 mb pressure level during past tire-weather episodes in the southeastern United States having circulation patterns similar to those shown in: (a) Figure 37.2a, (b) Figure 37.2b, and (c) Figure 37.2c.

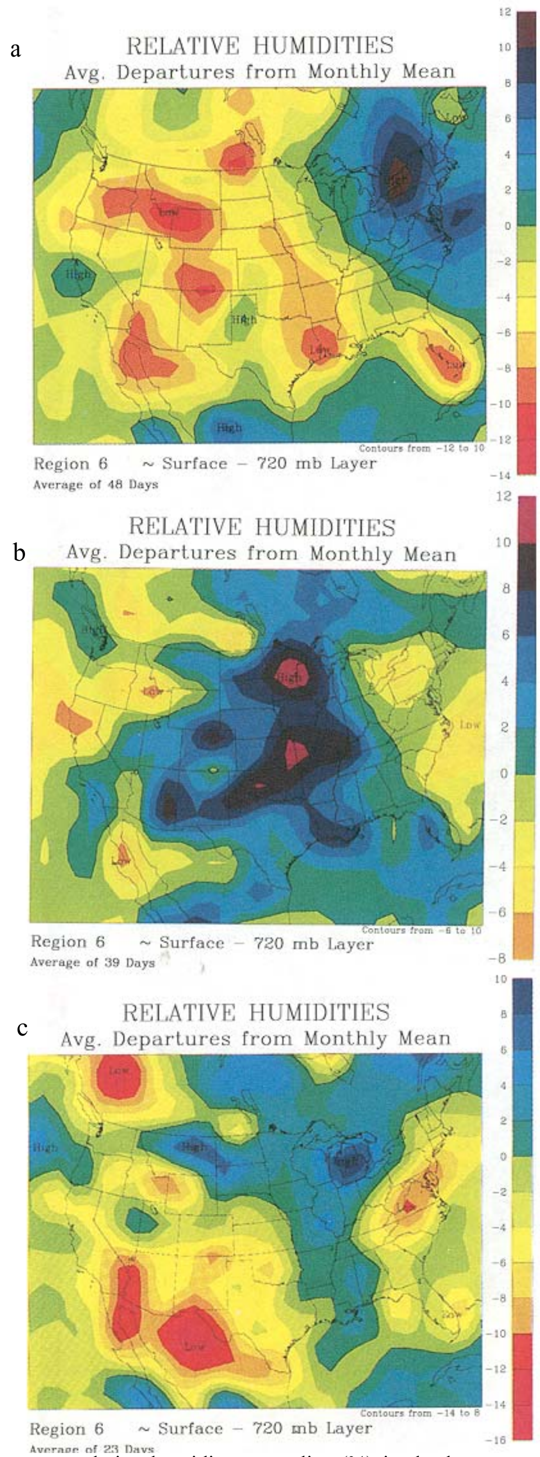

Figure 37.4. Average relative humidity anomalies (%) in the lower atmosphere during past tire-weather episodes in the southeastern United States having circulation patterns similar to those shown in: (a) Figure 37.2a, (b) Figure 37.2b, and (c) Figure 37.2c.

a

b

c

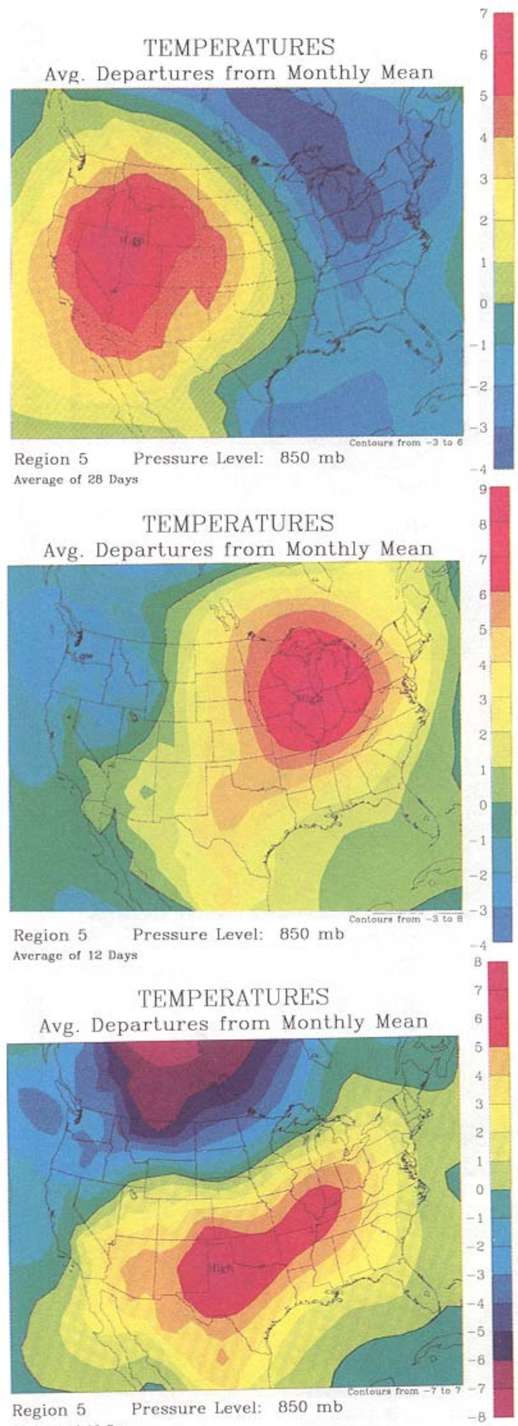

Figure 37.5. Average temperature anomalies (°K) at the 850 mb pressure level during past tire-weather episodes in the south-central United States having circulation patterns similar to those shown in: (a) Figure 37.2a, (b) Figure 37.2b, and (c) Figure 37.2c.

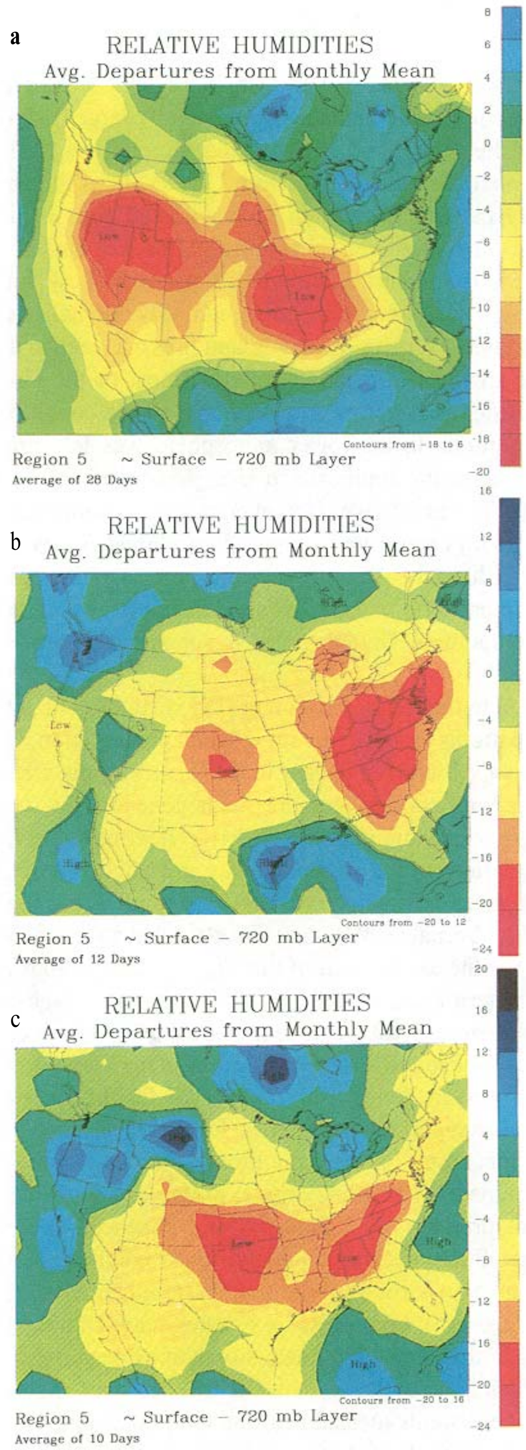

Figure 37.6. Average relative humidity anomalies (%) in the lower atmosphere during past fire-weather episodes in the south-central United States having circulation patterns similar to those shown in: (a) Figure 37.2a, (b) Figure 37.2b, and (c) Figure 37.2c.

patterns are similar to the patterns shown in Figures 37.3a,b,c, although the magnitudes of the computed anomalies are generally larger in Figures 37.5a,b,c because of the smaller sample size of wildland fire episodes in the south-central United States compared to the southeastern United States. The average relative humidity anomaly patterns associated with wildland tires in the southeastern (Figures 37.4a,b,c) and south-central (Figures 37.6a,b,c) United States and corresponding to the three identified circulation patterns show some differences, particularly in the spatial extent of negative humidity anomalies over the eastern half of the United States. When severe wildland fires occurred in the south-central United States for all three circulation patterns, most of the United States was characterized by drier-than-normal, lower atmospheric conditions. The spatial extent of dry conditions in the lower atmosphere was less pronounced when severe fires occurred in the southeastern U.S, particularly under the circulation patterns shown in Figures 37.2b,c. However, each circulation pattern associated with tires in the south-central and southeastern United States results in lower-than-normal relative humidity values over some portion of the regions. The significance of lower atmospheric moisture as an indicator of the potential for wildfire occurrence in the southern United States is supported by Potter (1995, 1996) as well.

In a study related to the work of Heilman (1995), Takle et al., (1994) examined surface-pressure patterns associated with reduced precipitation, high evaporation potential, and enhanced wildfire danger in the West Virginia area, and compared these observations with surface-pressure fields generated by the Canadian Climate Centre general circulation model (GCMII) (Boer et al, 1992; McFarlane et al., 1992) for simulations of the present climate and a doubled Co, climate. Using the eight synoptic meteorology patterns that tend to influence the eastern United States, as defined by Yarnal (1993) they observed that an extended high-pressure system situated over the eastern half of the United States, a high-pressure system situated off the eastern coast of the United States, and a high-pressure system centered over the western Great Lakes region are the three most common surface-pressure patterns associated with severe wildfires in the West Virginia area. Simulations of surface-pressure fields from the GCMII for the present climate and a doubled CO, climate suggested a tendency for the occurrence of more surface-pressure patterns that result in drier conditions in the northeastern United States under a changed climate. Most of the surface-pressure patterns identified by Takle et al., (1994) that produce dry conditions and enhanced fire potential in the northeastern United States are also conducive to dry conditions and increased tire potential in at least some portions of the southeastern United States. In particular, the increased occurrence of high-pressure systems centered over the Gulf coast of the United States in the changed climate simulations performed by Takle et al., (1994) suggests that the southeastern United States may experience more dry days. High-pressure systems located near the Gulf coast tend to block the transport of Gulf moisture northward over the eastern states. This surface-pressure pattern usually develops in response to mid-tropospheric circulation patterns similar to those shown in Figures 37.3b,c, which have been found to be associated with severe wildfires in the south-central and southeastern United States (Heilman, 1995). Thus, the potential for more fire-weather episodes in the south-central and southeastern United States would probably increase under this scenario.

Atmospheric Indicators of Severe Wildfire Potential

In addition to the studies that have identified those atmospheric synoptic patterns conducive to severe wildfire occurrence in the southern United States, other studies have focused on specific atmospheric variables that are indicative of severe wildfire occurrence. For example, such studies as Byram (1954), Davis (1969), and Brotak and Reifsnyder (1977) examined various atmospheric conditions at or near the earth's surface and their relationships to large wildfires, including neat-surface wind speeds and profiles, frontal positions, and temperature profiles. The conditions generally considered as favorable to large wildfires are dry air and an unstable temperature profile (i.e., temperatures decreasing more than 1 °C for every 100 m increase in altitude). Brotak and Reifsnyder (1977) examined atmospheric profiles for fifty-two fires, more than half of which occurred in the southeastern United States. They concluded that a low-level wind jet often accompanied the occurrence of large wildland tires. They defined this jet as a wind maximum within 3,050 m of the surface where the wind speed is 2.2 m s^{-1} greater than the speed 305 m above or below. They did not examine conditions on nonfire days, hence there is no indication of whether such a jet is also found on days when no fire occurred.

In the most recent study of specific atmospheric variables associated with severe wildfires, Potter (1996) used analysis of variance (ANOVA) to examine how strongly atmospheric conditions differ on the days of large wildfires (over 400 ha) as compared to climatological conditions. Surface temperature, dewpoint depression, relative humidity, wind speed, wind shear, and stability were all considered. There was no indication that temperature at the surface, or stability or wind shear in the lowest 100 to 1000 m are any different when large wildfires occur than at any other time. Surface wind speed and relative humidity showed some tendency to differ from normal on large wildfire days, though not in Florida. Dewpoint depression showed the most significant difference and was most widespread in its ability to discriminate between normal conditions and large wildfire conditions. It was significant all along the southeastern Atlantic coast (from Virginia to Palm Beach, Florida), the region for which the most data were examined. The relationships between the findings of Brotak and Reifsnyder (1977) and Potter (1996) and the potential atmospheric conditions associated with a changed climate are difficult to determine. However, these studies do suggest that changes in the frequency or intensity of weather systems that produce low-level jets or that move dry air masses with large surface dewpoint depressions and low relative humidity values into the southern United States could affect the frequency of severe wildfires there.

Soil-Moisture Effects on Fire-Weather Development

Along with the specific large-scale circulation patterns that result in drier-than-normal conditions and enhanced wildfire probabilities in the south-central and southeastern United States, regional soil-moisture variations can also influence the development of fire-weather systems. Fast (1994) and Fast and Heilman (1996) examined the effects of soil-moisture deficits on the atmospheric mesoscale dynamics that influence tire severity. Using the regional atmospheric modeling system (RAMS) (Pielke et al., 1992) a three-dimensional nonhydrostatic mesoscale model, simulations of past fire-weather episodes in the southeastern United States were performed to examine the role of soil moisture and vegetation within and outside the southeastern United States in affecting fire-weather development in the region, as measured by the lower atmospheric severity index (LASI) (Haines, 1988).

Meteorological conditions were simulated during the period May 5 to 17, 1989 when Florida experienced numerous wildfires and moderate to severe drought conditions were observed in central and southern Florida and in the northern Great Plains. During this same period, moderate to severe wet conditions were observed over much of the northeastern United States and in the states north and west of Georgia in the southeastern United States. Circulations in the middle atmosphere during this period were very similar to one particular circulation pattern identified by Heilman (1995) as being conducive for severe wildfires in the southeastern United States (see Figure 37.2a). Sensitivity tests performed with the RAMS model indicated that the addition of soil moisture significantly affects the near-surface temperature and relative humidity fields, and affects cloud cover, precipitation, and wind speeds to a lesser extent. The simulations also indicated that the effects of soil moisture are most pronounced where the soil is sufficiently moist, but the advection of evaporated moisture from wet-soil regions can occasionally increase the relative humidity observed at locations downwind of the wet-soil regions. Daytime surface temperatures and relative humidity values are reduced and increased, respectively, when soil moisture is increased. Vegetation was found to moderate the transfer of water from the soil into the atmosphere. In regions where soil is wet, the presence of vegetation reduces the amount of water evaporated into the atmosphere, and where the soil is relatively dry, the presence of vegetation increases the amount of water evaporated compared to regions with little vegetation. Vegetation also reduces the speed of surface wind through the inhomogeneous roughness and plant lengths that increase the surface friction.

Fast (1994) and Fast and Heilman (1996) found that tire-weather development in the southeastern United States., as measured by the LASI, is affected by soil moisture and vegetation distributions that determine the degree of evapotranspiration in a region. Values of LASI were reduced in areas of significant evapotranspiration because the additional moisture added to the atmospheric boundary layer reduces the lower atmospheric dew point depression, thereby reducing the probability of severe wildfire occurrence. The implication of this phenomenon is that surface evapotranspiration in regions of moist soil or significant vegetation upwind of the south-central or southeastern United States have the potential for reducing the probability of severe wildland fire occurrence in the southern United States because of the advection of low-level moisture. Thus, although large-scale circulation patterns in the middle atmosphere may be conducive to severe wildland fires in the southern United States, regional soil moisture and surface evapotranspiration patterns within and outside the region must also be considered in assessing the potential for severe wildfires in the southern United States and elsewhere.

El Niño/Southern Oscillation Effects

Because severe wildfires are strongly linked to relatively short-term weather events that produce conditions favorable for their occurrence, any large-scale circulation changes in the atmosphere brought about by global climatic forcing factors have the potential for altering circulation patterns in the United States and modifying the normal frequency of weather events conducive to severe wildfires. One particular forcing factor that has a major influence on atmospheric circulation patterns over North America is the El Niño/southem oscillation (ENSO) phenomenon.

El Niño is a term that refers to the periodic extreme warming of surface ocean water in the eastern tropical Pacific Ocean (Wyrtki, 1979). This periodic warming has been shown to be associated with the southern oscillation, a periodic fluctuation in surface pressures observed in the western and eastern Pacific Ocean (Walker, 1928; Bjerknes, 1969). El Niño/southem oscillation events typically occur every three to eight years (Haston and Michaelsen, 1994) and they have been linked to changes in observed midlatitude circulation and weather patterns through atmospheric teleconnections. For example, Horel and Wallace (1981) showed that ENSO events are correlated with below-normal 700 mb geopotential heights in the northern Pacific and the southeastern United States, and above normal-heights over western Canada. Gray (1984a, 1984b) found that the seasonal number of hurricanes and hurricane days was negatively correlated with moderate to strong ENSO events. Ropelewski and Halpert (1986) used monthly precipitation and temperature data from 1875-1980 from sites throughout North America to show that ENSO events are associated with above normal precipitation and below-normal temperatures in parts of the southeastern United States starting in October of ENSO years and ending in March of the following years. Trenberth et al., (1988) identified tropical Pacific sea-surface temperature changes associated with the 1988 La Niña episode as the primary factor responsible for the atmospheric circulations over North America that caused the severe drought in the Great Plains region of the United States. Many other studies have also been conducted in recent years that indicate a relation between ENSO events and climatic and weather variability over the United States and North America.

The observed changes in atmospheric circulation and weather patterns associated with ENSO events, particularly trends in precipitation, suggest that ENSO events may influence the probability of severe wildfire occurrence and the number of hectares burned as a result of wildfires in certain regions of the United States. The most notable study examining ENSO/wildfire relationships was performed by Simard et al., (1985a, 1985b). They used fifty-seven years of tire activity data (1926 to 1982) along with El Niño occurrence and intensity level data (Quinn et al., 1978) to identify specific regions of the United States that tend to show changes in wildfire activity during ENSO episodes. It was found that annual tire activity in the southern region tends to decrease during El Niño years, the relation between tire activity and ENSO episodes in the north-central and eastern regions is weak, and that there is no evidence that ENSO episodes affect fire activity in the Pacific or Rocky Mountain regions.

Lightning

Large-scale circulation conditions in the atmosphere also play a role in the development of regional weather systems that produce lightning, a factor in wildfire occurrence throughout the country. Although large wildfires attributed to cloud-to-ground lightning strikes are much more common in the western United States., lightning is responsible for about 1,000 to 3,000 wildfires on Federal, State, and private lands in the southern United States each year (USDA Forest Service, 1992). Lightning-caused wildfires have been responsible for the burning of over 121,000 ha in some years in the southern United States. Changes in global and regional climates could result in increased frequency of weather patterns associated with drought conditions, leading to enhanced fuel dryness, and thunderstorms that generate cloud-to-ground lightning strikes, leading to fuel ignition. Price and Rind (1994) examined the impact of a changed climate resulting from an increase in atmospheric CO, concentration on lightning-caused wildfires in North America and in different regions of the United States, using the Goddard Institute for Space Studies (GISS) general circulation model (GCM) (Hansen et al., 1983). Their modeling study suggested that the number of lightning-caused wildfires in the entire United States could increase by approximately 44% over the present number. The total area burned in the United States was projected to increase by about 78%. For the south-central and southeastern regions of the United States, their modeling study suggested increases on the order of 40 to 50% in the number of wildfires caused by lightning each year. Contributing to these increases is the probable decrease in the average effective precipitation (defined as precipitation minus potential evapotranspiration) over the United States under a changed climate as a result of increased atmospheric CO_2 concentrations (Price and Rind, 1994).

Summary

An overview of present and recent research on atmospheric interactions with wildfire occurrence in the south-central and southeastern United States and the potential implications for fire occurrence in these regions under a changed climate have been presented. Because wildfire occurrence is very dependent on relatively short-term weather events along with fuel conditions, present research has partly focused on identifying the critical atmospheric circulation patterns that lead to enhanced wildfire activity in different regions of the United States., including the Southern Global Change Program (SCGP) study region. The results indicate that there are three specific circulation patterns in the middle atmosphere that are prevalent at the onset of severe wildfires in the south-central and southeastern United States. These circulation patterns produce drier-than-normal conditions over many parts of the south-central and southeastern United States during the spring and fall fire seasons. Examinations of the surface-pressure patterns associated with severe wildfire occurrence in the eastern United States and comparisons with general circulation model simulations under doubled CO_2 conditions tend to suggest the future occurrence of more surface pressure and atmospheric circulation patterns that produce drier conditions in the eastern and southeastern United States. Present-day research substantiates the importance of near-surface moisture (surface dew point depression values) as an indicator of enhanced wildfire activity in the southeastern United States.

Recent research has also focused on the additional effects of vegetation and soil-moisture variations on fire-weather development over the southeastern United States. Research results indicate the importance of soil moisture within and outside the southern United States in affecting fire-weather development in the region. Evaporation from wet-soil regions and the advection of moisture into regions that are much drier tend to reduce the potential for severe wildfire occurrence in the drier regions, as measured by the LASI. The presence of vegetation moderates the transfer of moisture to the atmosphere in wet- and dry-soil areas.

Other research has focused 9 lightning as a causative agent for wildfires. General circulation model simulatidns suggest that the south-central and southeastern United States will experience more lightning-caused wildfires under a changed climate resulting from increased atmospheric CO_2 concentrations.

The periodic fluctuations in sea-surface temperatures in the eastern Pacific Ocean, commonly referred to as El Niño episodes, have also been shown to have a major impact on wildfire occurrence in the southeastern United States. El Niño events tend to reduce wildfire activity in this region. However, it is uncertain what impact periodic El Niño events would have on circulation patterns over the United States and wildfire activity in the southern states under a changed climate because of increased atmospheric CO_2 concentrations.

Given the importance of wildfires in the south-central and southeastern United States, as reflected in the yearly totals of wildfire numbers and hectares burned, there is a need to better understand the potential ramifications of a changed climate and climate variability on wildfire activity in the region. The research results outlined in this chapter provide insight into some of the key atmospheric processes involved with wildfire occurrence in the southern states. They provide the foundation for new studies that are needed to further examine the relationship between those atmospheric processes relevant to large-scale climatic changes and the smaller-scale atmospheric dynamics that are most relevant to regional fire-weather development and wildfire occurrence in the southern states.

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