OVERVIEW OF CURRENT RESEARCH ON ATMOSPHERIC INTERACTIONS WITH WILDLAND FIRES

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Abstract: Changes in the large-scale mean thermal structure of the atmosphere have 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 regional weather systems conducive to fire occurrence. In support of the Northern Stations Global Change Research Program, we have designed a research program to examine the interactions of large-scale atmospheric processes with regional fire-weather systems. This paper provides a summary of four studies that have been performed or are in progress that address some of the fundamental characteristics of regional fire-weather systems and their behavior in response to larger-scale atmospheric conditions.

INTRODUCTION

Atmospheric processes span a wide range of temporal and spatial scales. Ambient micrometeorological conditions as well as micrometeorological conditions generated by wildland fires play a significant role in affecting small-scale physical processes like wildland fire behavior. On the other hand, the frequency of occurrence of severe wildland fires is influenced by larger-scale atmospheric processes like synoptic and mesoscale circulations, precipitation patterns, climatic variability, and extreme weather events. In recent years, there has been considerable attention paid to the prospect of a globally warmer climate due to increases in atmospheric greenhouse gases. Altering the large-scale thermal structure of the atmosphere has the potential for affecting the dynamics of the atmosphere across a multitude of temporal and spatial scales, including those scales that characterize synoptic and regional circulations and regional climate/weather variability. In fact, climate variability and the effects of synoptic and mesoscale weather events with their associated circulation, temperature, and moisture patterns have a much greater influence on the frequency of severe fire occurrence than any global-scale temperature trends. In assessing the potential impact of a changed climate on wildland fire occurrence, it is critical that we examine the secondary effects of climate variability and the tertiary effect of individual weather events (Fosberg et al. 1993).

We have designed a research program to specifically address the mechanisms by which synoptic-scale atmospheric processes, particularly middle-tropospheric circulations, control regional weather systems that are conducive to severe fire occurrence. By examining some of the fundamental characteristics of these atmospheric fire-weather systems, their development, and their interactions with larger-scale atmospheric processes, we will be in a better position to assess the importance of secondary and tertiary effects of climate change in affecting severe fire occurrence. Our research approach for examining regional fire-weather systems and their interactions with larger-scale atmospheric processes includes the following four studies: 1) synoptic circulation, temperature, and moisture patterns during severe wildland fires, 2) surface pressure pattern relationships with fire occurrence in the northeastern U.S., 3) atmospheric synoptic effects on the mesoscale dynamics of fire-weather systems, and 4) simulations of soil-moisture and vegetation effects on fire-weather development.

STUDY 1: SYNOPTIC CIRCULATION, TEMPERATURE, AND MOISTURE PATTERNS DURING SEVERE WILDLAND FIRES

As a first step in examining the relationship of large-scale atmospheric processes to regional fire occurrence, Heilman (1995) performed a series of empirical-orthogonal-function (EOF) analyses on the observed 500 mb geopotential height anomaly fields and 850 mb temperature anomaly fields at the onset of severe wildland fires (i.e.

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those fires that resulted in the burning of more than 1000 acres) between 1971-1991 in six different regions (NW, NC, NE, SW, SC, and SE) of the continental U.S. The EOF analyses were used as tools to identify the prevalent middle tropospheric synoptic circulation and temperature patterns that characterize severe fire occurrence on a regional basis.

For severe wildland fires occurring in the northeastern U.S. (typically in the spring and autumn months), defined as the region extending eastward from Wisconsin and Illinois to the Atlantic coast, two middle tropospheric circulation patterns were found to be predominant at the onset of the fires. The first circulation pattern is characterized by a 500 mb ridge centered over the western half of the U.S. accompanied by a prominent trough over the eastern U.S. and southeastern Canada, resulting in the transport of cool dry air into the northeastern U.S. This circulation pattern in the middle troposphere produces cooler than normal temperatures at the surface over much of the northeastern U.S., but relative humidity values can be anomalously low. This dryness contributes to the atmospheric conduciveness for severe wildland fires in this region. The second pattern is characterized by a strong 500 mb ridge over the eastern half of the U.S. or off the eastern U.S. coast, with the western and/or central states dominated by a 500 mb trough. Average temperatures and relative humidities in the lower atmosphere over the northeastern U.S. under this type of middle tropospheric circulation pattern are anomalously high and low, respectively. The presence of a middle tropospheric ridge over the eastern U.S. is conducive to the surface Bermuda high pressure system that can block the northward transport of Gulf moisture into the northeastern U.S. if it is displaced westward of its normal position.

Specific synoptic circulation, temperature, and moisture patterns prevalent in the middle and lower troposphere at the onset of severe wildland fires in the other regions of the U.S. were also identified. For all regions, the middle tropospheric circulations identified in this study as being associated with severe fire occurrence led to drier than normal lower atmospheric conditions over much if not all of the specific region of interest. Circulation patterns obtained from the EOF analyses were compared with similar but subjective analyses performed by Schroeder et al. (1964), and the results were found to be quite similar. Results from this study are being used to examine how specific synoptic circulation patterns influence the development and evolution of regional fire-weather episodes, and will be used in future studies that will assess the potential impact of large-scale circulation changes in the atmosphere associated with a globally changed climate on the frequency of future wildland fire occurrences.

STUDY 2: SURFACE PRESSURE PATTERN RELATIONSHIPS WITH FIRE OCCURRENCE IN THE NORTHEASTERN U.S.

In a companion study to the middle tropospheric circulation analyses performed in study #1, Takle et al. (1994) examined surface pressure patterns and circulations corresponding to reduced precipitation, high evaporation potential, and enhanced forest-fire danger for a portion of the northeastern U.S. Analyses of daily surface weather maps resulted in the identification of eight surface pressure or weather patterns (Yarnal 1993) that describe distinctive flow situations over the northeastern U.S. throughout the year. Three particular surface pressure patterns were found to occur most frequently during severe fires in the four-state region of West Virginia, Ohio, Pennsylvania, and New York: 1) an extended region of high surface pressure over the eastern and central U.S., with light surface winds, 2) a high pressure system situated off the Atlantic coast (Bermuda high pressure system) resulting in southerly flow over the eastern U.S., and 3) a high pressure system centered over the western Great Lakes region with northerly surface flow over the northeastern U.S. Of these pressure patterns, the Bermuda high pressure pattern was found to be associated with a disproportionately large amount of fire-related damage in the West Virginia area. Evaporation and precipitation data indicate that these three patterns along with a fourth pressure pattern described by a high pressure system centered over the northern Gulf of Mexico all lead to drying conditions over the northeastern U.S. and enhance fire potential.

Simulation results from the Canadian Climate Centre's (CCC) general circulation model (GCM) for the present climate and a doubled atmospheric CO_2 climate were examined to determine whether there may be a tendency for more surface pressure patterns conducive for fire occurrence in the northeastern U.S. to develop under increased atmospheric CO_2. The results of the CCC GCM suggest a tendency for increased frequency of "drying" pressure patterns in the northeastern U.S. under a globally changed climate, although the results were not statistically significant.

STUDY 3: ATMOSPHERIC SYNOPTIC EFFECTS ON THE MESOSCALE DYNAMICS OF FIRE-WEATHER SYSTEMS

Determining the role of synoptic-scale atmospheric processes in affecting severe fire occurrence in a particular region of the country requires a fundamental understanding of the atmospheric dynamics associated with mesoscale or regional fire-weather systems. Mesoscale weather events that produce atmospheric conditions favorable for severe wildland fires develop and evolve, to a large extent, in response to the larger-scale circulation, temperature, and moisture patterns identified in studies #1 and #2. The development and evolution of mesoscale weather events conducive for fire occurrence can be examined through the use of atmospheric mesoscale modeling techniques that can also translate atmospheric conditions into estimates of fire risk.

As a precursor to actual mesoscale simulations of fire-weather episodes, a suitable but simple index of severe fire risk based on surface atmospheric conditions was developed by Potter (1995). He performed statistical analyses of eight meteorological variables on fire days and non-fire days throughout the U.S. and found that surface dew-point depression is the best overall discriminator of fire and non-fire days. A fire-weather index suitable for implementation in atmospheric mesoscale models for fire-weather simulation was then developed by Potter (1995) and is based on elevation-adjusted dew-point depression values at the earth's surface. Unlike other indices of fire-weather, this index does not require upper-air measurements and can be easily measured at any location. This index has been implemented in the Regional Atmospheric Modeling System (RAMS) (Pielke et al. 1992), a sophisticated computer model used for simulating atmospheric processes with spatial scales on the order of 2-2000 km. Mesoscale simulations of specific fire-weather episodes are currently being performed with RAMS to examine how typical large-scale circulation, temperature, and moisture patterns associated with regional fire occurrence influence the development and evolution of mesoscale weather systems that favor severe wildland fires. The new fire-weather index developed in this study serves as a useful tool for examining the spatial and temporal characteristics of fire-weather systems as they evolve over different regions of the country and for determining the potential for severe wildland fires.

STUDY 4: SIMULATIONS OF SOIL-MOISTURE AND VEGETATION EFFECTS ON FIRE-WEATHER DEVELOPMENT

The development of regional fire-weather systems in response to the large-scale atmospheric circulation, temperature, and moisture fields is also influenced by atmospheric processes taking place at the earth's surface. Surface fluxes of heat and moisture can modify air masses and alter the atmospheric dynamics of weather systems that tend to enhance or inhibit the occurrence of severe fires. In particular, the presence of inhomogeneous distributions of soil-moisture and vegetation can significantly influence circulations and the heat and moisture budgets in the lower atmosphere, which in turn can lead to modifications in the overall impact of the larger-scale circulation, temperature, and moisture fields. Fast (1994) examined some of the fundamental characteristics of the atmospheric secondary circulations that can result from different soil-moisture and vegetation distributions. He also examined their impact on the lower atmospheric temperature and moisture fields which are very important variables in determining wildland fire potential.

Fast (1994) performed a series of numerical simulations with RAMS for the May 5-17, 1989 and October 25-November 16, 1987 periods when severe wildland fires occurred in Minnesota, Florida, and West Virginia, and abnormally dry and wet soil conditions existed in various regions of the eastern half of the country. For these particular periods, the simulations indicated that the use of realistic soil-moisture significantly affects the near-surface temperatures and moisture fields, and affects the cloud cover, precipitation, and wind speeds to a lesser extent. The largest effects due to soil-moisture usually occur at locations where the soil is sufficiently moist, but there are occasions when moisture evaporated from wet soil can be transported downwind and affect locations that are characterized by much drier soils. Soil-moisture variations were found to have a significant impact on local diurnal temperatures and relative humidities, with wet soils decreasing daytime temperatures and increasing daytime humidity values. The simulations also indicated that surface vegetation moderates the transfer of water from the soil to the atmosphere. Vegetation reduces the amount of water evaporated into the atmosphere where the soil is wet, and increases the amount evaporated where the soil is relatively dry. Changes in the lower atmospheric temperature and moisture fields resulting from soil-moisture and vegetation variations were also found to affect the Lower Atmospheric Severity Index (LASI), an indicator of suitable conditions for severe fire occurrence (Haines 1988). Numerical simulations suggest that the LASI is usually reduced over moist-soil regions, so that the potential for wildland fires is diminished. The LASI was found to be mostly affected by evapotranspiration which reduces the dew-point depression within the atmospheric boundary layer.

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