1.3 A MODEL BASED ANALYSIS OF THE ROLE OF AN UPPER-LEVEL FRONT AND STRATOSPHERIC INTRUSION IN THE MACK LAKE FIRE

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1. INTRODUCTION

Meteorological assessment of wildfire risk has traditionally involved identification of several synoptic types empirically determined to influence wildfire spread. Such weather types are characterized by identifiable synoptic-scale structures and processes. Schroeder et. al. (1964) identified four recognizable synoptic-scale patterns that contribute most frequently to high fire danger over the Great Lakes Region. Two of these weather types, the Hudson Bay High, and the Northwest Canadian High, are regularly observed in conjunction with northwesterly flow at middle and upper tropospheric levels. Such synoptic-scale flow is often associated with the development of upper-level frontal zones and an attendant intrusion of stratospheric air into the troposphere. Properties of stratospheric air such as its high momentum, high values of potential vorticity and low water vapor content, can potentially contribute to fire danger and spread. It is also suggested that the high ozone mixing ratios often observed in the wake of wildfires may be the result of stratospheric intrusions. This paper will investigate the structure and physical processes associated with an upper-level front, which occurred in the vicinity of a documented fire, and propose a role for upper-frontal processes on wildfire behavior.

We employ a fine-scale numerical simulation of the atmospheric conditions associated with the Mack Lake Fire of May 1980, with the motivation to create a Stratospheric Intrusion Index. The index is designed to provide fire managers with a diagnostic tool for assessing the likely influences of upper-frontal activity in wildfire growth.

2. CHARACTERISTICS OF FIRE AND MODEL

The Mack Lake Fire began at 1030 EDT, 5 May 1980 as a prescribed fire in north-eastern Michigan. By 1215, the fire had spotted to become a wildfire, with its major run occurring between 1230 and 1600 EDT. The fire ultimately burned over 24,000 acres, 20,000 of which were forest, and destroyed 44 homes and buildings. With the use of the PSU/NCAR MM5, and 6-hourly gridded data from the NCAR/NCEP Reanalysis Project, we modeled atmospheric conditions influencing the fire. The model was initialized at 0000 UTC May 4, using nested 36km, 12km, and 4km domains, and run for 72 hours. NCEP ADP Global upper-air and surface observations were also used to blend first-guess fields and observations.

3. SYNOPTIC DESCRIPTION

Brotak and Reifsnyder (1977) identified the following synoptic conditions conducive to wildfire spread in the Great Lakes region; a small amplitude trough centered in Canada with a dry surface cold-front that moves in from the north or northwest. In such cases, they found a tendency for the fires to occur in the southeastern quadrant of the upper-level feature. Brotak and Reifsnyder's analysis fails, however, to offer a detailed examination of the structure and processes associated with these upper level troughs. Baroclinic zones in northwesterly flow in the upper troposphere or lower stratosphere are regularly associated with upper-level frontogenesis which leads to stratospheric intrusions. Upper-level fronts are characterized by large horizontal temperature gradients and intense vertical shear. Under the appropriate synoptic-scale conditions, a thermally indirect vertical circulation is induced which tilts isentropes into a more vertical orientation thus intensifying the horizontal thermal contrast. Associated with the subsidence on the warm side of the front is local depression of the tropopause and an intrusion of dry, high momentum stratospheric air into the troposphere, sometimes to very low levels.

The synoptic weather type associated with the Mack Lake Fire is an example of the Hudson Bay High type noted by Schroeder et al. (1964) as conducive to high fire risk in the Great Lakes region. This type is accompanied by northwesterly-flow throughout the middle and upper troposphere. A Hudson Bay high pressure area moved southeastward and influenced Michigan on May 5th. The upper-air pattern also served to guide a surface low southeastward through Ontario (Fig. 1). The dry-cold front associated with the surface low arrived from the northwest and was positioned with the leading edge at the fire location, at 1400 EDT. South of this cold front relative humidity was climatologically very low (24 percent) with unseasonably high temperatures (80°F). Although a clear wind shift accompanied the frontal passage, there was little change in relative humidity or temperature. Winds at 900mb (shown in Fig. 1) are suggestive of an increased wind-speed at the time of the frontal passage. The 500mb chart (Fig. 2) indicates a short wave trough and its associated baroclinic zone were embedded with northwesterly flow over southwestern Ontario and the Great Lakes. The warm edge of this potent middle tropospheric baroclinic zone was associated with very dry air.

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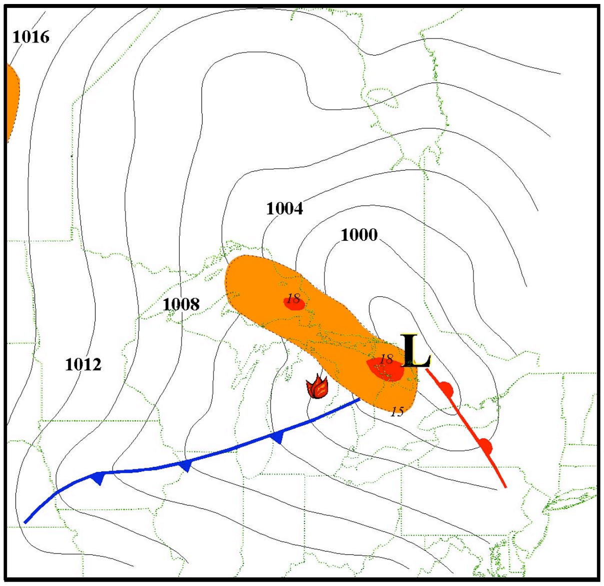

Fig. 1 Sea-level isobars (solid lines) and 900 hPa isotachs from the 44 h forecast of the MM5 simulation valid at 1400 EDT 5 May 1980. Frontal symbols indicate positions of surface fronts while fire icon indicates the location of the Mack Lake Fire.

4. STRATOSPHERIC INTRUSION AND FIRE INTERACTIONS

The robust horizontal potential-temperature gradient evident in Fig. 2 is clear evidence of the presence of a well developed upper-level front at 1400 EDT. By this time, the front had evolved to a state where the trough in the isentropes lagged the trough in the isohypses, implying geostrophic cold advection, in the presence of cyclonic horizontal shear, along the length of the front. Such a configuration has been shown by Keyser and Shapiro (1986) to be an upper-frontogenetic signature. A maxima in quasi-geostrophic descent at 500mb (Fig. 3), was centered over the arrowhead of Minnesota along the base and western side of the trough testifying to the robustness of the descent of the extremely dry stratospheric air deep into the troposphere.

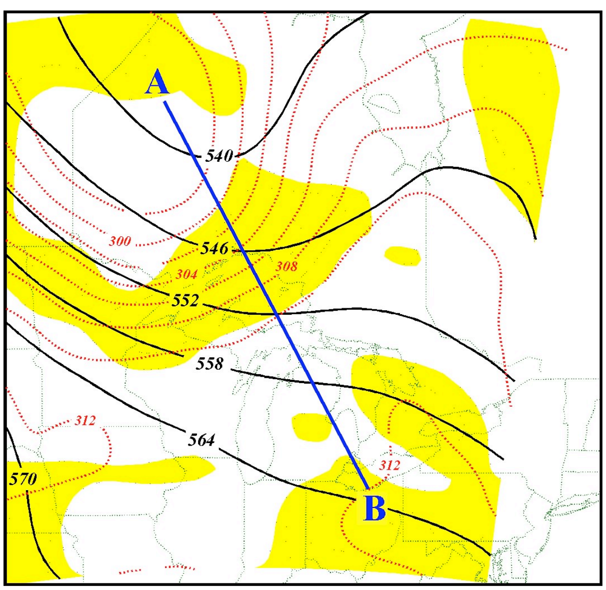

Fig. 2 500 hPa geopotential height, temperature and relative humidity (RH) from the 44 h forecast of the MM5 valid at 1400 EDT 5 May 1980. Isotherms (dashed lines) are contoured in K and contoured every 2 K. Geopotential height (solid lines) contoured every 60 m. RH shaded where values are less than 30%. Cross-section along line A-B is shown in Fig. 4.

The depth of this dry air can be gauged by considering a vertical cross-section through the front and fire location at 1400 EDT. The cross-section intersects the front, a region of maximum downward vertical motion at 500mb, as well as the driest air associated with the front at this level. The cross-section shows an intrusion of air, low in relative humidity ahead of the upper-front and descending tropopause. The dry air extends downward to almost 800mb, and is positioned just to the northwest of the fire. The upper-level jet is located directly above this dry-air intrusion and above large values of subsidence, suggestive of the positive momentum transport downwards towards the fire. The large area of descent in the region of the dry-air intrusion testifies to the downward mixing of dry, high-momentum air that characterizes the upper frontogenetic process. The 1.5 PVU contour of potential vorticity is indicative of the sloping tropopause boundary with stratospheric air above it. Relative humidity values

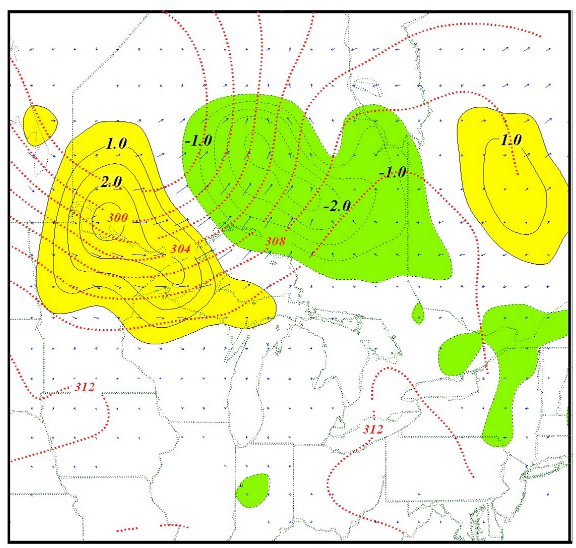

Fig. 3 500 hPa QG ω from a 44 h forecast of the MM5 valid at 1400 EDT 5 May 1980. ω contoured in μbar s^{-1} with solid (dashed) lines denoting positive (negative) ω. Red lines are 500 hPa isotherms contoured every 2 K. Arrows are the 500 hPa $\boldsymbol{Q}$-vectors.

between 10 and 30 percent, coherent with values at the tropopause level, are coincident in Fig. 4 with the 1.5 PVU contour except locally near the upper frontal dry-air intrusion. The combination of subsidence and strong northwesterly winds are thought to be responsible for the high wind-speeds and low relative humidity seen at the ground at the time and location of the fire.

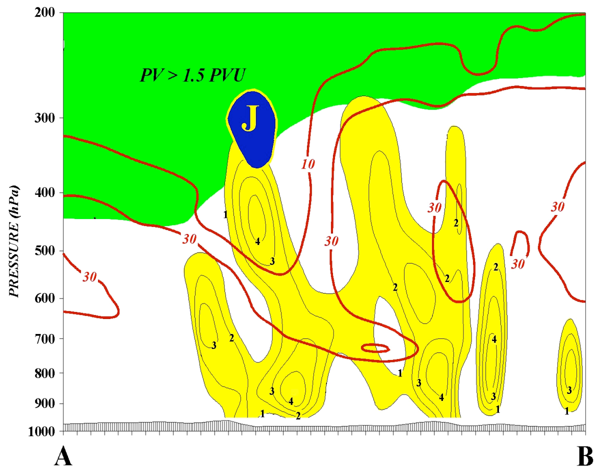

Fig. 4 Vertical cross-section along line A-B in Fig. 2 of positive omega (ω), RH, and PV from the 44 h forecast of the MM5 valid at 1400 EDT 5 May 1980. Omega contoured every 1 μbar s^{-1}. RH values of 10 and 30% contoured in bold line while PV greater than 1.5 PVU is shaded to indicate stratospheric air. Bold “J” indicates the position of the geostrophic wind speed maxima in the cross-section.

5. CONCLUSION

The combination of an intense upper-level front and its associated stratospheric intrusion appear to have contributed to the conditions that were responsible for rapid spread of the Mack Lake Fire. The influence of stratospheric intrusions on wild fires such as this one is not an isolated event. Investigation of other severe wildfires such as, the Air Force Bomb Range Fire (1971), the Double-Trouble State Park Wildfire (2002), and a wildfire in East-Central Alberta Canada all show consistently similar atmospheric conditions to those described in this paper. Analysis of these several cases will be used to formulate a Stratospheric Intrusion Index, which can be used to assess the influence that upper tropospheric conditions will have on fire danger.

6. REFERENCES

Brotak, E. A., and W. E. Reifsnyder, 1977: An investigation of the Synoptic Situations Associated with Major Wildland Fires. *Journal of Applied Meteorology*, **16**, 867-870.

Keyser, D., and M. A. Shapiro, 1986: A review of the structure and dynamics of upper-level frontal zones. *Monthly Weather Review*, **114**, 452-499.

Schroeder, Mark J., 1964: Synoptic weather types associated with critical fire weather. Pacific Southwest Forest and Range Experiment Station, Berkeley, 492p.