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MULTISCALE EXAMINATION OF FIRE OCCURRENCE IN VERMONT

Eric C. Evenson and Daniel P. St. Jean[1]
NOAA/National Weather Service
Burlington, Vermont

Joshua D. Smith
Lyndon State College
Lyndonville, Vermont

1. INTRODUCTION

In the spring of 2000, NOAA's National Weather Service (NWS) in Burlington, Vermont (BTV) assumed responsibility of fire weather forecast operations across much of Vermont and northern New York. Past fire weather events in Vermont are examined for two purposes: to furnish the fire weather user community with quality products and services, and to provide BTV operational forecasters with a better understanding of local fire weather processes. We develop a climatology of fire occurrence in Vermont from 1991 to 2001 that displays seasonal and geographical distribution, typical causes, and acreage impacted by the fires. In addition, composite charts depicting synoptic scale weather conditions during Vermont's peak fire weather season are examined. Finally, monthly and seasonal precipitation deficiencies are evaluated to determine if any correlation exists between antecedent dry conditions and peak fire seasons.

2. METHODOLOGY

This study uses an eleven-year database of fire occurrence in Vermont (1991-2001), provided by the Vermont Department of Forests, Parks, and Recreation to develop climatologies of seasonal and geographical distributions, typical causes, and acreage impacted by the fires. In addition, this database is utilized to examine days in which fires were reported during the months of April and May, the peak fire season in Vermont. Surface observations from BTV, as well as the Weather Information Management System (WIMS) data from various points in Vermont, were used to determine: a) the minimum surface relative humidity (hereafter SRH) values and b) typical wind speed and direction over the area on each day that fires were reported. The events were divided into two categories: days with SRH less than 30

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[1] Current affiliation - NOAA/NWS Charleston, SC

percent and days with SRH greater than 30 percent. The 30 percent SRH criteria is chosen because it is a critical value with respect to local red flag criteria. Red flag criteria consist of meteorological parameters (winds 13-23 kt and SRH less than 30 percent), long term dryness, and the vegetation status (the dryness of the fuels and their resulting ability to burn) that all combined result in increased fire danger.

Of the 268 cases when at least one fire was reported per day in both April and May, 73 (27 percent) cases had SRH values at or below 30 percent, with 195 (73 percent) cases having SRH values above 30 percent. Surface level features from the 268 cases (i.e. fronts, high and low pressure) were examined from the NOAA National Center for Environmental Prediction (NCEP) reanalysis datasets (Kalnay 1996) and categorized by the location of surface pressure systems and their proximity to Vermont. From the 268 cases and the SRH values, six composites of mean sea-level patterns were found and their frequency is displayed in Fig. 1. The definitions of each pattern are as follows: Pattern 1 (SRH < 30 percent) has high pressure to the west and a trough to the east of Vermont (Fig. 8b). Pattern 2 (SRH < 30 percent) has broad area of high pressure over New England (not shown). Pattern 3 (SRH > 30 percent) has high pressure to the west and low pressure to the east of Vermont (Fig. 9b). Pattern 4 (SRH > 30 percent) has high pressure to the east and low pressure to the west of Vermont (Fig. 10b). Pattern 5 (SRH > 30 percent) has low pressure to the north and high pressure to the south of Vermont (Fig. 11b). Lastly, Pattern 6 (SRH > 30 percent) has high pressure to the north and low pressure to the south of Vermont (Fig. 12b). Once these surface composite patterns were identified, individual cases (days of reported fires) are examined to determine a prevailing wind speed and direction.

A program was written to create composite charts of mean sea-level pressure and 500-hPa heights for the seven cases. The composite charts were developed for an initial time (t-0) valid at 1200 UTC on the days with reported fires. In addition, composite charts were generated at 24 and 48 hour intervals (t-24 and t-48) prior to the 1200 UTC time period. Deviations from the climatological mean (the period from 1961-90) as well as statistical significance were also calculated for the three time periods.

To determine if a correlation existed between fire occurrence in April and May and antecedent precipitation during a specific period of time, a linear regression analysis was computed on the data. The regression analysis fits a least-squares line to the data which yields the correlation coefficient for the two variables. The correlation coefficient measures the relation between these two variables. A value of 1.00 represents perfect correlation, while a value of 0.00 represents no correlation. A correlation of at least 0.68 would potentially yield some predictability to Spring fires based on previous months' precipitation.

The data used to test the correlations were monthly and seasonal precipitation deficiencies from the three typical climatic regions in Vermont: the Champlain Valley, Southern Vermont, and North Central and Northeast Vermont (Fig. 2). Twenty-six NWS cooperative observer data sites were available in these regions for analysis of precipitation deficits. Percent of normal precipitation was calculated for each site in each region. Those values were then averaged to obtain regional percent of normal precipitation values. The seasonal time periods evaluated were as follows:

a.) November through March for the winter season
b.) April and May for the pre-greenup time period
c.) June through October for the summer and early fall months
d.) September through November for the fall period
e.) October and November for an additional fall period.

3. RESULTS

a. Vermont Fire Climatology

Figure 3 shows an annual distribution of reported fires in Vermont from 1991 through 2001. The average of this eleven year period yields 151 fires per year. The most fires (238) occurred in 1995 and the least (31) in 2000. A monthly distribution of known fires in Vermont (Fig. 4) clearly delineates a peak fire season during the months of April and May. During the eleven year period of concern, there were 268 cases where at least one fire occurred in the months of April and May. On average, the months of April and May account for 73 percent of all fires within a given year. Even in a year such as 2000, when only 31 fires were reported, 58 percent of those fires were in the months of April and May. The months of April and May in Vermont are typically considered the "pre-greenup time of year". Pre-greenup conditions exist before the leaves become fully developed on trees. Dead fuels, any non-living organic matter that will burn, are maximized during this period and have the greatest potential to burn. Dunham and Vallee (2001) noted the highest frequency of fire occurrence across Massachusetts and Rhode Island is also in the spring during this critical pre-greenup period. Although the fall season (October and November) can have a buildup of dead fuels from the leaves falling off the trees, no distinct signal is noted in the data to support a strong secondary maximum.

The geographical distribution exhibiting the location of known fires by county in Vermont from 1991 through 2001 is shown in Figure 5. Washington county reported the most fires (206) while Grand Isle county recorded only 12. Figure 6 represents the amount of acreage burned during the eleven year period. Most fires were less than five acres (91 percent). In addition, over half (59 percent) were less than one acre and 56 percent of the fires were less than or equal to a half acre. Only two fires in the time period of concern were over 100 acres. Figure 7 displays the causes of fires in Vermont from 1991 to 2001. The most common cause of fires was burning debris (brush and trash for example) at 51 percent. Lightning accounted for only two percent of fires within the period.

b. Composite patterns

Pattern 1, with surface high pressure to the west of Vermont and a surface trough over the Canadian Maritimes (Fig. 8b), accounts for 88 percent of all fire events with SRH less than 30 percent. The 500-hPa pattern is also shown in Figure 8a. The composites are at initial time (t-0), valid 1200 UTC on the days fires were reported in April and May. The 500-hPa pattern (Fig. 8a) shows a trough axis over Maine and eastern Canada with a broad ridge west of Vermont. The 500-hPa trough is 30-40 meters lower over the area than the climatological mean, and is statistically significant at the 95 and 99 percent confidence intervals. This suggests the 500-hPa trough is two to three standard deviations deeper than the climatological mean. At the surface, the trough over the Canadian Maritimes and the high pressure system to the west of Vermont were statistically significant at the 95 and 99 percent confidence interval respectively. This surface pattern would allow drier air to move into Vermont (and surrounding areas) from Canada. In addition, the pressure gradient between these two systems may be substantial enough to promote north to northwest surface winds generally on the order of 13 to 28 knots (kts). The drier air and winds described above would likely enhance the potential for fire spread. Pattern 1 at time intervals of t-24 and t-48 (not shown) showed no statistical significance at the 95 and 99 percent confidence intervals for both the surface and aloft.

Pattern 2, with a broad area of surface high pressure over New England, is comprised of only 9 cases where the SRH is less than 30 percent (not shown). This limited number of cases suggests this pattern is not statistically significant and will therefore not be discussed in this study.

With respect to patterns associated with SRH greater than 30 percent, four composites are developed. Pattern 3, with surface high pressure to the west and surface low pressure to the northeast of Vermont, is the most common pattern of these cases (49 percent of all cases with SRH greater than 30 percent; Fig. 9b). The t-0 500-hPa (Fig. 9a) composite shows a trough axis across western Quebec. Heights are at least 30 meters lower than climatology, with statistical significance at the 95 percent confidence interval. This feature also shows statistical significance (95 percent confidence interval) at the t-48 time period (Fig. 9a). The surface features also exhibited statistical significance at the 95 and 99 percent confidence interval at time t-0 (Fig. 9b). As with Pattern1, winds were typically on the order of 13 to 28 kts and from a north and/or northwest direction. Winds of this magnitude could have an impact on fire spread.

Pattern 4, with surface high pressure to the east and surface low pressure to the west of Vermont, accounts for 26 percent of all cases with SRH above 30 percent, and is noticeably different than the patterns previously discussed. Figure 10a shows a 500-hPa pattern with an upper level ridge over Vermont and northern New England and an upstream upper level trough over the Upper Midwest at the t-0 time period. Both features exhibited statistical significance at the 95 and 99 percent confidence interval. The corresponding surface pattern at t-0 (Fig. 10b) shows statistical significant with respect to the surface high and low pressure systems (both at the 95 and 99 percent confidence interval), and a tight pressure gradient between these two features. The surface low pressure system over the Upper Midwest is also statistically significant (95 and 99 percent confidence interval) at t-24 hour time period (Fig. 10b). The south to southwest surface winds associated with this pattern were typically on the order of 13 to 28 kts with gusts to 38 kts across Vermont and the surrounding region, thus enhancing the potential for fire spread.

Pattern 5, with surface low pressure to the north and surface high pressure to the south of Vermont, comprises 13 percent of all cases with SRH above 30 percent. The 500-hPa composite at time t-0 shows a fairly zonal westerly flow over Vermont (Fig. 11a). The trend at 500-hPa from t-48 to t-0 is for the upper level ridge to flatten and this is statistically significant at all three time periods (95 percent confidence interval). The surface pattern at t-0 (Fig. 11b) shows a low pressure system just north of Lake Superior. As was the case with the 500-hPa flow, this surface feature also shows statistical significance (95 and 99 percent confidence intervals) at t-24 and t-48 hours (Fig. 11a). This type of pattern brings a westerly surface wind to Vermont and the surrounding areas with speeds on the order of 13 to 28 kts, which could aid in the development of fire spread.

Pattern 6, with surface high pressure to the north and surface low pressure to the south of Vermont, makes up 12 percent of all cases having SRH values greater than 30 percent. No statistical significance is noted on the 500-hPa (Fig. 12a) composite valid at time t-0. The surface composite valid at t-0, which shows a general north to northeast flow over Vermont, does have a statistically significant (95 and 99 percent confidence intervals) high pressure system over the eastern Canada (Fig. 12b). This surface pattern will be conducive for relatively drier air, SRH between 30 and 40 percent, to spread in from Canada on north to northeast winds. Wind speeds were typically in the 4 to 13 knot range. As was the case with Pattern 1, no statistical significance at the 95 and 99 percent confidence interval were noted on the t-24 and t-48 time intervals (not shown).

c. Monthly/Seasonal Precipitation Deficiencies

The correlation between fire occurrence and antecedent precipitation is examined. Statistical correlation coefficients are calculated for the seasonal time periods noted in the methodology section of this paper. A value of one (zero) suggests there is exact (no) correlation between precipitation deficiencies and fire occurrence. The correlation values are as follows.

November through March: 0.13
April and May: 0.38
June through October: 0.01
September through November: 0.18
October through November: 0.14

These data suggest that no definitive correlations exist between seasonal precipitation deficiencies and enhanced fire occurrence.

4. CONCLUSION

Synoptic and climatological information was generated from an eleven year database (1991-2001) of known fire occurrences in Vermont. Several important facts became evident from the database, including an average of 151 fires per year in Vermont, and the peak fire season occurring in April and May. These two months accounted for 73 percent of all fires within a given year, and represent the pre-greenup time of year when dead fuels are maximized and have the greatest potential to burn. In terms of the size of fires in Vermont, 91 percent of fires are less than 5 acres, and 59 percent of all fires are less than one acre. With respect to the cause of fires, just over half (51 percent) were from burning debris, while lightning accounted for only two percent of fires.

NCEP reanalysis data was utilized to create composite charts of mean sea level pressure and 500-hPa heights. These composite charts were categorized into six different patterns based on SRH values and mean sea level pressure patterns. Deviations of the composite charts from climatology and statistical significance fields were also examined.

The composite charts showed the synoptic scale weather patterns typically associated with fire occurrence in April and May. Of the six patterns identified, three proved to be the most prevalent with at least 50 cases. Pattern 1, comprised of 88 percent of all cases with SRH less than 30 percent, included a regime where a west to northwest flow of air aloft allowed highpressure at the surface to build toward Vermont from the northwest. A discernable pressure gradient from the high pressure building in from the northwest and low pressure to the east of Vermont helps to advect a drier air mass from Canada into the region. Pattern 3 accounting for 49 percent of all cases with SRH above 30 percent, is similar to Pattern 1 with respect to position of surface and upper air features, and would suggest that the surface winds may have an impact on fire spread. Pattern 4, made up of 26 percent of all cases with SRH above 30 percent, has winds aloft from the west or southwest with a deepening low pressure system at the surface to the west or southwest of Vermont. This pattern is conducive to producing stronger winds on the order of 13 to 28 kt over the area. All three patterns described above are crucial in potentially creating red flag conditions over the area, of which low SRH and strong winds are the two meteorological parameters that go into assessing the potential for red flag conditions (long term dryness and the vegetation status comprise the other elements). Recognizing such patterns and understanding their impact will be instrumental in providing the necessary products (fire weather watches or red flag warnings) and services to the local fire weather user community.

Finally, monthly and seasonal precipitation deficiencies were examined. A correlation coefficient was calculated to establish the existence of any correlation between dry weather and fire occurrence. The data suggests no statistical correlations exist between dry weather and fire occurrences.

Future study of fire weather conditions in Vermont should include an examination of fire occurrence in other months of the year and an incorporation of fuel moisture data.

ACKNOWLEDGMENTS

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Figures

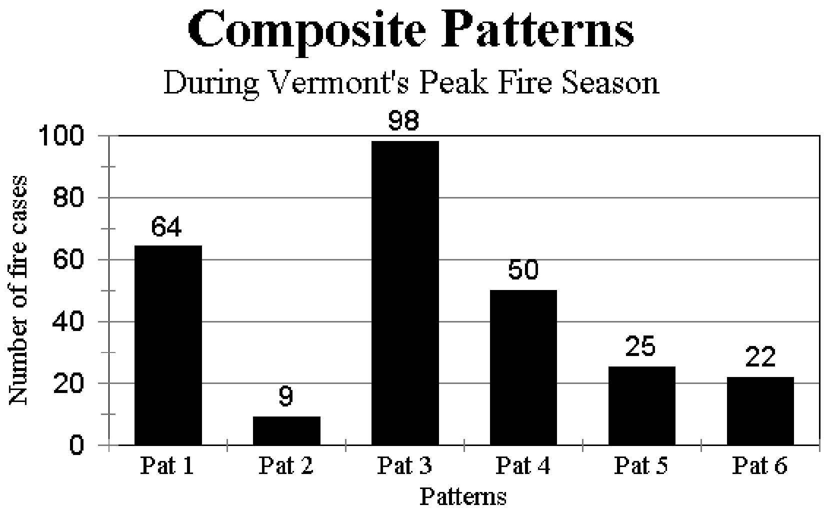


Figure 1 Number of fire cases per composite pattern during peak fire season (April and May) in Vermont from 1991 to 2001.

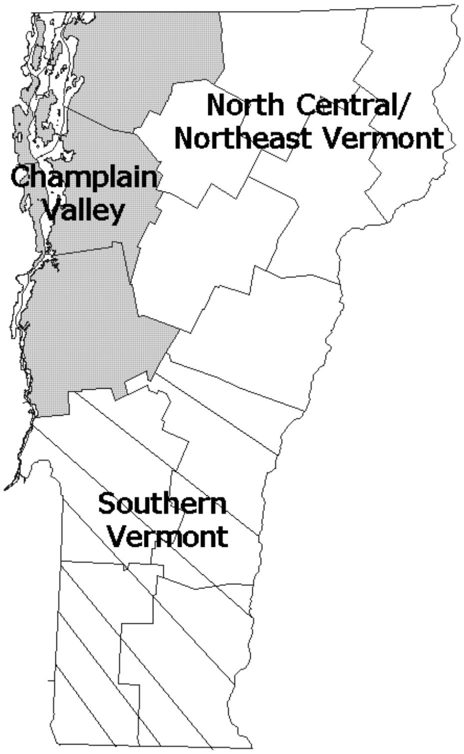


Figure 2 Typical climatic regimes across Vermont.

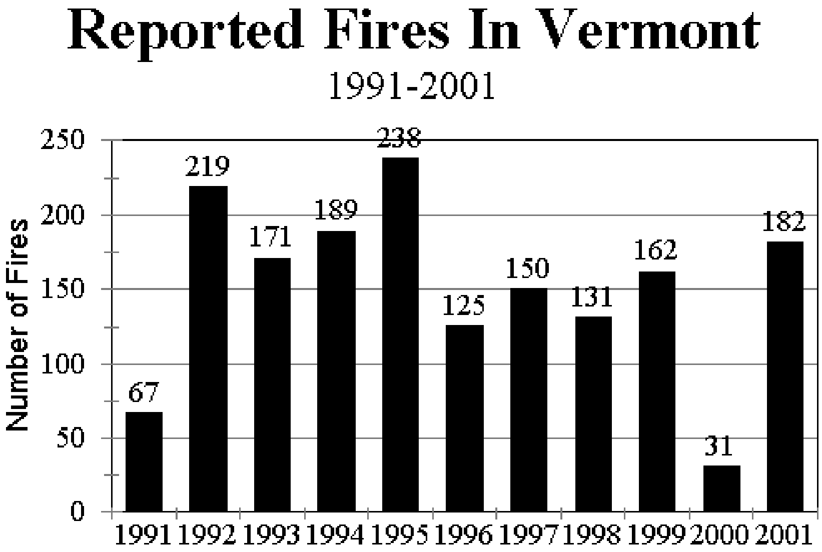


Figure 3 Number of reported fires by year in Vermont during the period from 1991 to 2001.

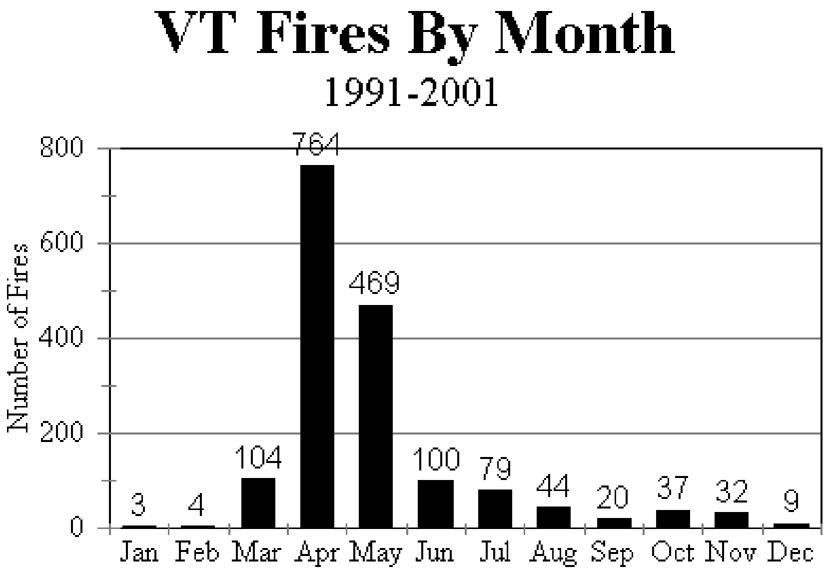


Figure 4 Number of reported fires by month in Vermont during the period from 1991 to 2001.

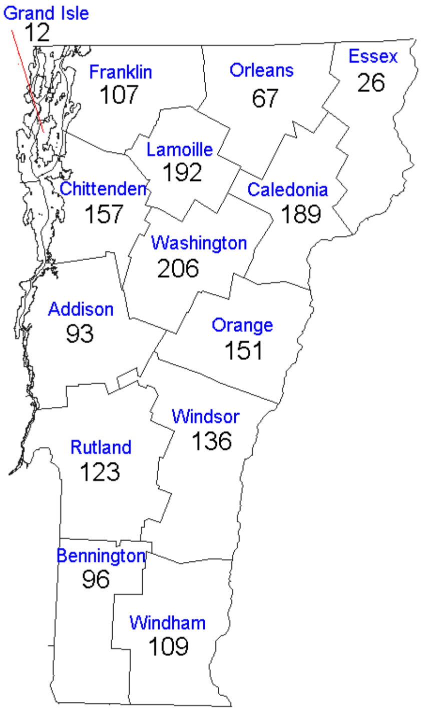


Figure 5 County distribution of reported fires in Vermont from 1991 through 2001.

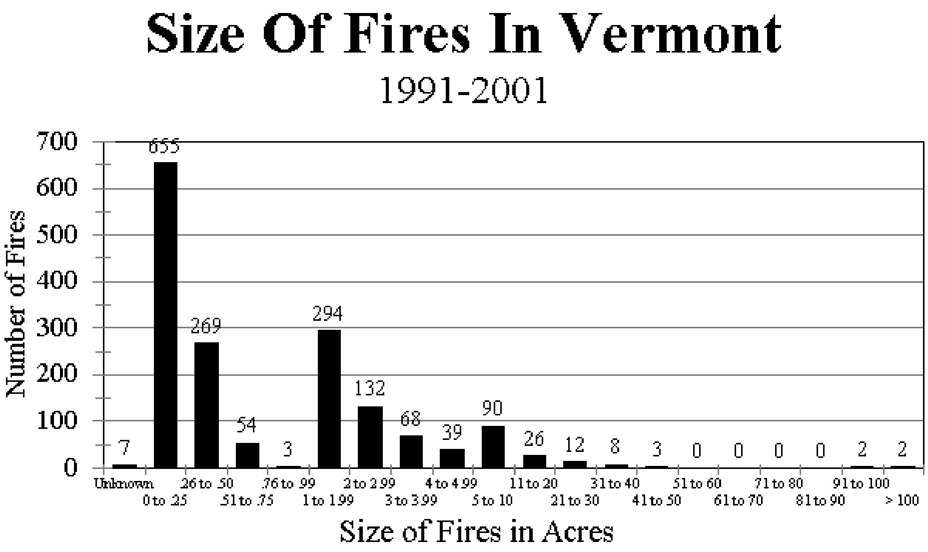


Figure 6 Distribution of reported fires by acreage in Vermont from 1991 through 2001.

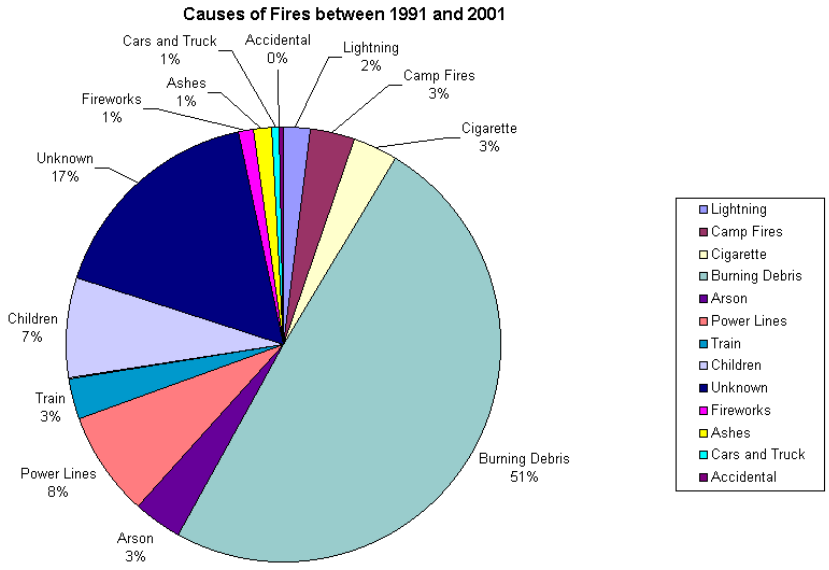
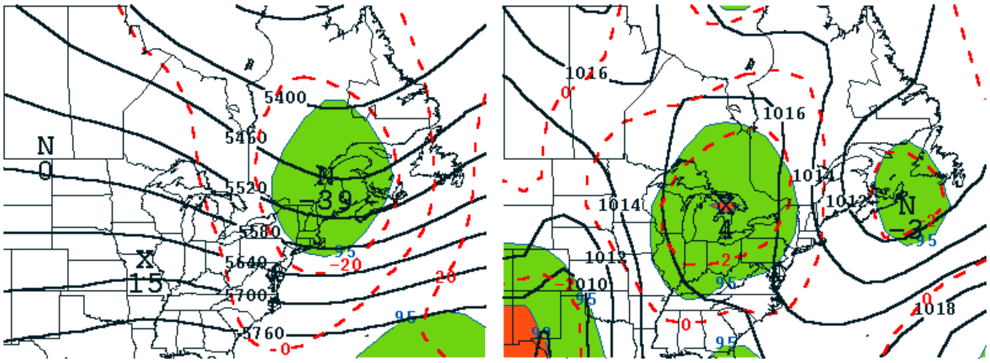


Figure 7 Causes of fires in Vermont from 1991 through 2001.



(a)

(b)

Figure 8 Pattern 1 500-hPa and surface composite for 64 cases with surface relative humidity less than 30 percent for initial time (t-0) valid at 1200 UTC on the days when fire were reported. A. Geopotential height lines are in solid (contoured every 60 meters), deviation of the composite from the climatological mean is in dashed lines (contoured every 20 meters), and shaded areas represent the 95 (green) and 99 (red) percent statistical significance of the composite field. B. Mean sea level pressure lines are in solid (contoured every 2 mb), deviation of the composite from the climatological mean is in dashed lines (contoured every 2 mb), and shaded areas represent the 95 (green) and 99 (red) percent statistical significance of the composite field.

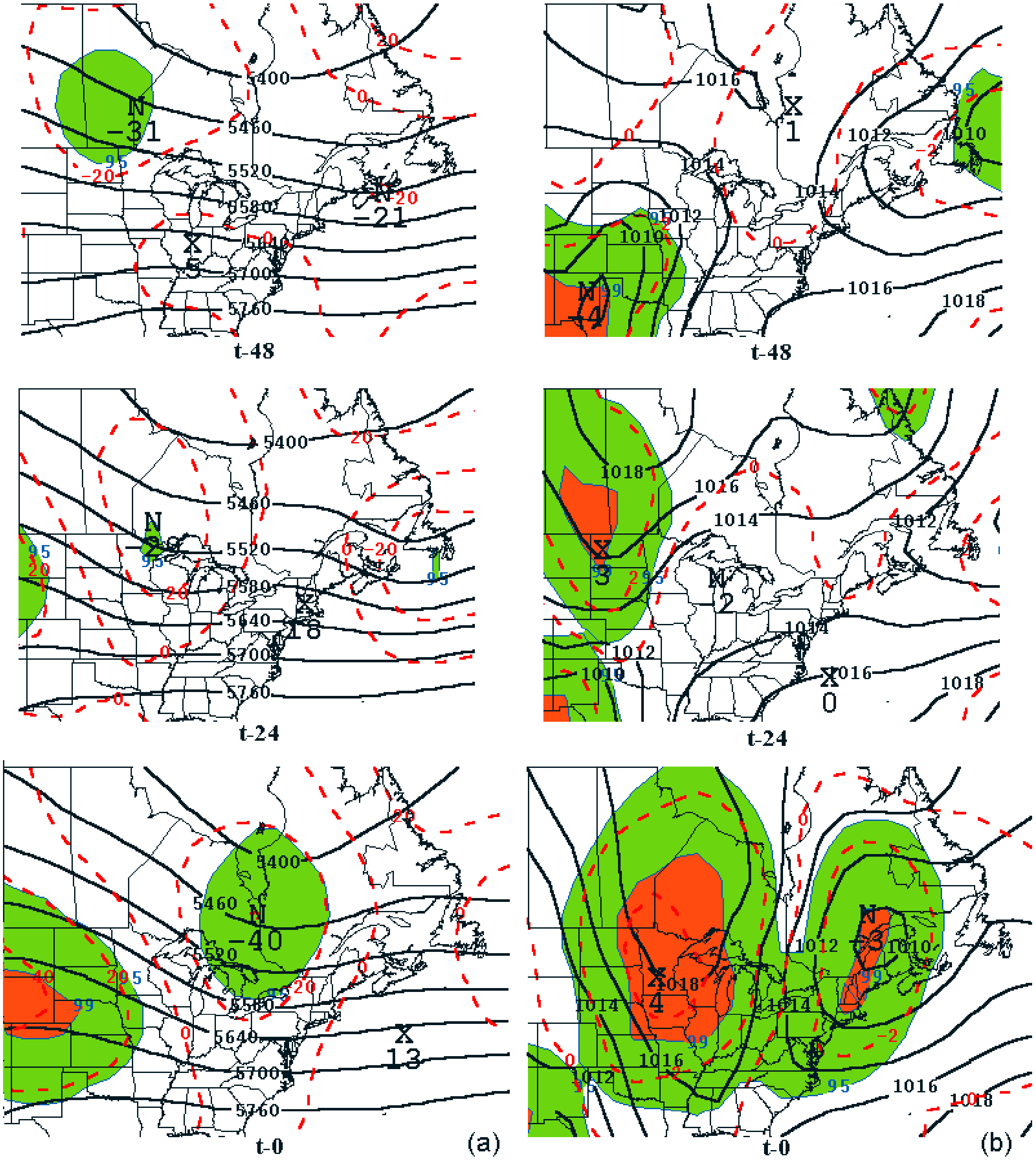


Figure 9 As in Figure 8, but for Pattern 3; 500-hPa and surface composites for 98 cases with surface relative humidity above 30 percent for times t-0, t-24, and t-48 valid at 1200 UTC on the days when fire were reported.

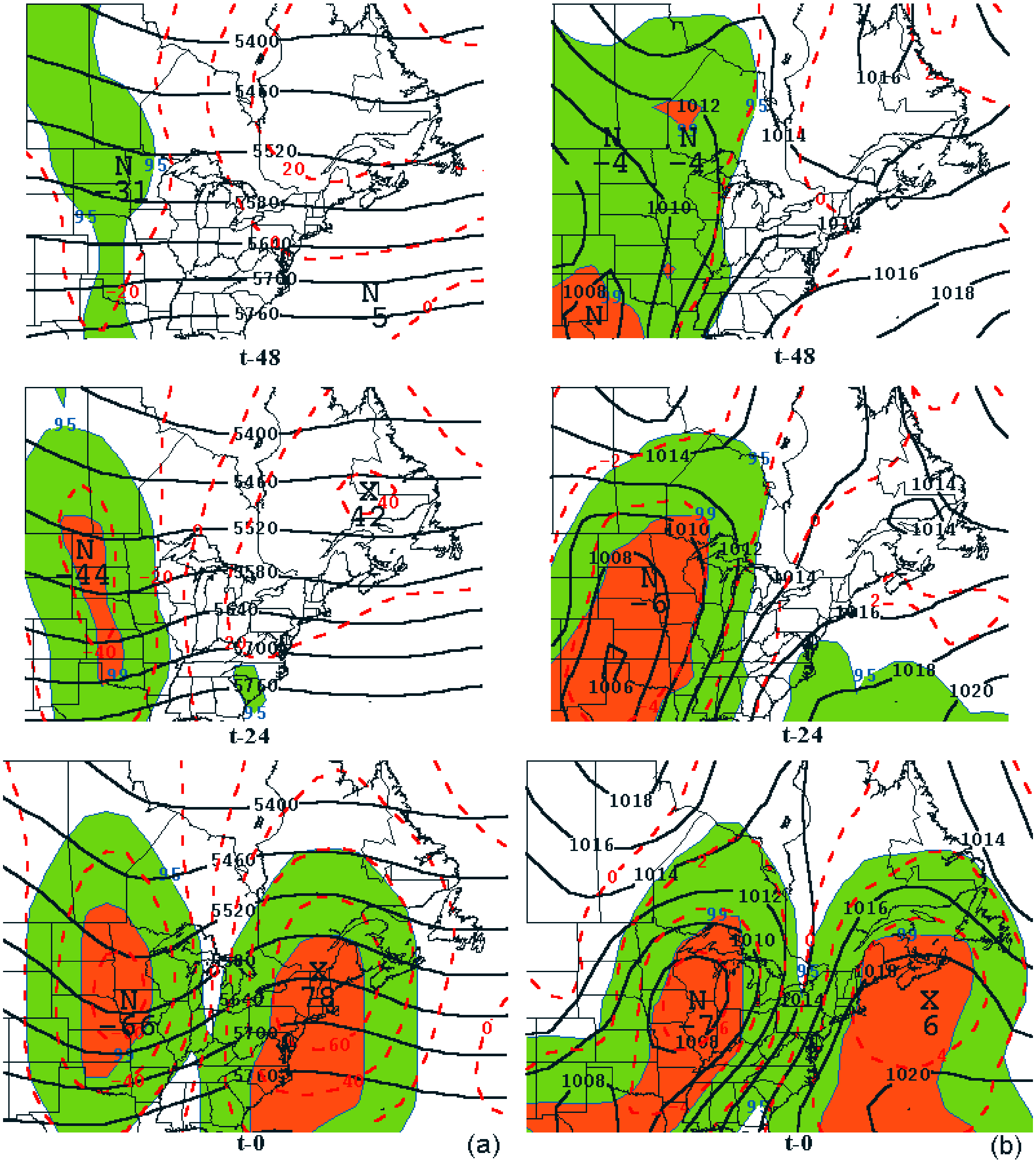


Figure 10 As in Figure 9, but for Pattern 4; 500-hPa and surface composites for 50 cases with surface relative humidity above 30 percent for times t-0, t-24, and t-48 valid at 1200 UTC on the days when fire were reported.

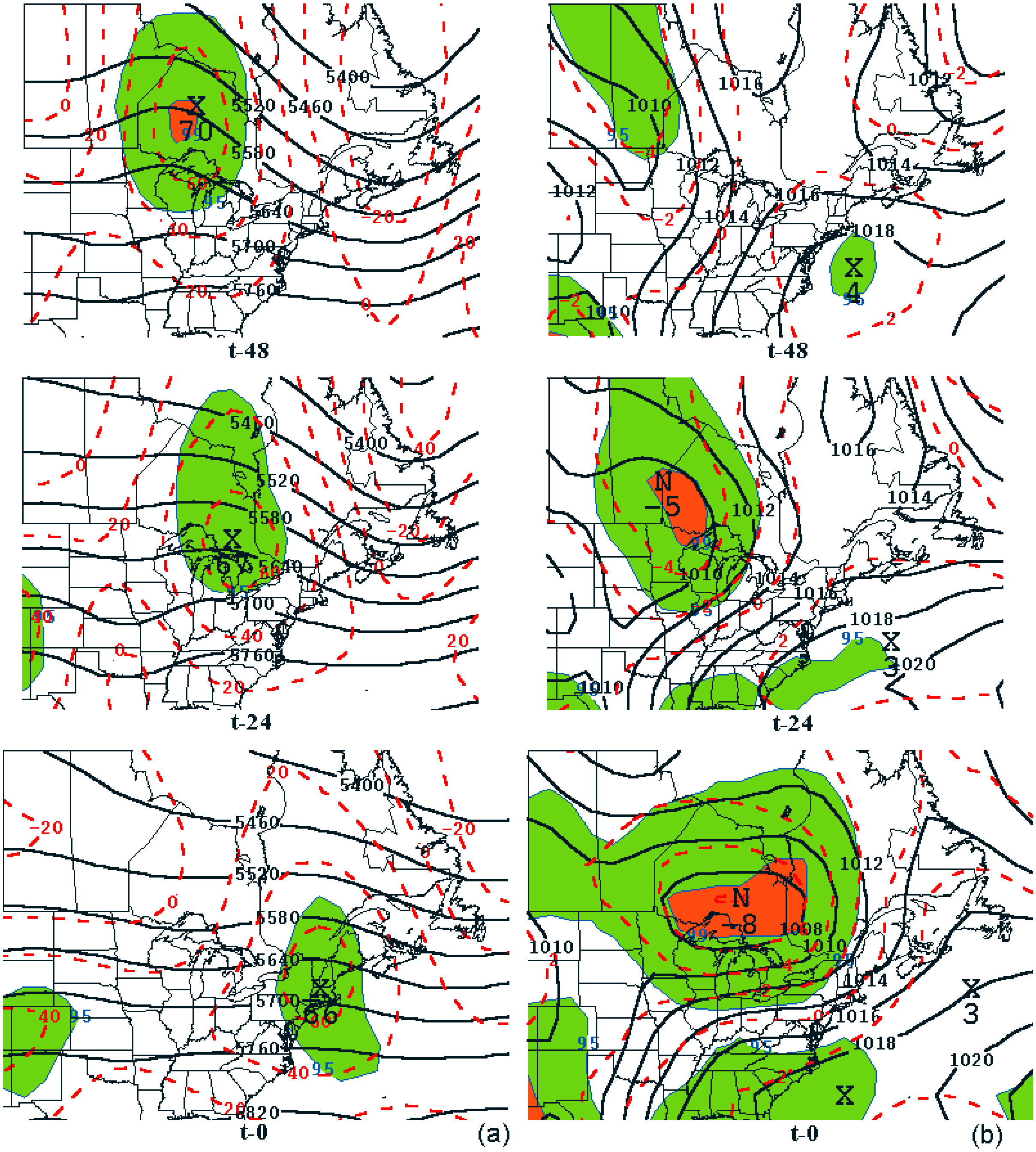
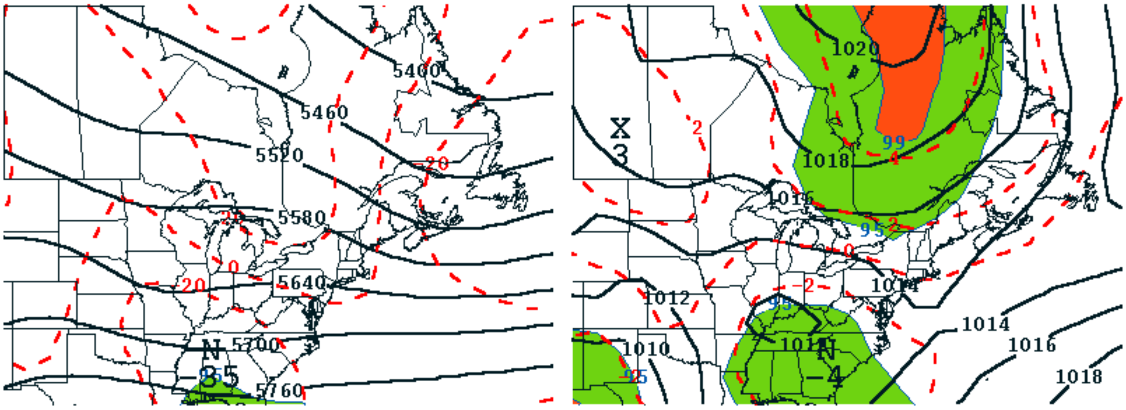


Figure 11 . As in Figure 10, but for Pattern 5; 500-hPa and surface composites for 25 cases with surface relative humidity above 30 percent for times t-0, t-24, and t-48 valid at 1200 UTC on the days when fire were reported.



(a) (b)

Figure 12 As in Figure 8, but for Pattern 6; 500-hPa and surface composites for 22 cases with surface relative humidity above 30 percent for initial time (t-0) valid at 1200 UTC on the days when fire were reported.