LOW-LEVEL TEMPERATURE, MOISTURE AND WIND PROFILES PRECEDING MAJOR WILDLAND FIRES

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Abstract

Representative soundings from 74 major wildland fires in the United States were analyzed to determine if characteristic temperature, moisture, and wind patterns were discernable prior to the occurrence of extreme fire behavior. In a previous study, 0000 UTC soundings were used to develop a Lower Atmosphere Severity Index (LASI). In this study, the same LASI was applied to 1200 UTC soundings. The humidity component of the LASI was comparably low for the 1200 UTC data, indicating that dry conditions in the lower atmosphere seem to be a necessary factor prior to the occurrence of extreme fire behavior. In contrast, the low-level lapse rates showed significant variation between 1200 and 0000 UTC with the 1200 UTC soundings showing less instability. Destabilization of the atmosphere due to solar heating during the day was seen as the cause of the differences, and this made the LASI values at 1200 UTC less valuable as predictors. The analysis of low-level wind profiles showed regional differences. In the eastern half of the country where most fires occurred in the spring, strong low-level winds and winds increasing with height were common. Conversely, in the mountainous sections of the west where most fires occurred in the summer, low-level wind profiles at the radiosonde sites often indicated weak winds throughout the atmosphere. These fires seemed to be controlled more by local or topographically-induced winds and by convection over the fire.

1. Introduction

Fire behavior is a critical factor in the control of wildland fires. Spread rates and intensity are crucial not just for the eventual containment and extinguishing of the fire, but also for the safety of the fire control personnel. Weather factors are of paramount importance in controlling fire behavior. Besides determining fuel conditions, meteorological factors also physically affect the fire. Since fires are three dimensional phenomena, the vertical structure of the lower atmosphere must also be considered as well as the standard surface conditions.

Haines (1988) developed a Lower Atmosphere Severity Index (LASI) for wildland fires. This index combined two factors which could influence fire behavior: the vertical lapse rate and the amount of moisture in the air. The vertical temperature structure of the lower atmosphere would influence the convection over the fire. Steep lapse rates, indicating instability, would enhance the convection over the fire, thus increasing the chances of extreme or erratic behavior. The amount of moisture in the lower atmosphere was seen only as a factor influencing fuel moisture at the surface, not as a direct factor affecting convection. Therefore, low humidity values are a contributing factor to extreme fire behavior. This is in contrast to moist convection such as thunderstorms where low-level moisture contributes latent heat and aids the convective column development.

Since the fires in Haines' study occurred at various elevations, he used different levels to indicate the low-level lapse rates. Depending on the actual elevation of the fire, either the 950 to 850-mb temperature difference, the 850 to 700-mb difference, or the 700 to 500-mb difference was used. As indicators of moisture content, he used either the 850 or 700-mb temperature and dewpoint difference. The actual LASI that Haines developed is shown in the following equation:

$$\text{LASI} = a\,(T_{p1} - T_{p2}) + b\,(T_p - T_{dp}) \qquad (1)$$

where T is the temperature at two pressure surfaces (p1, p2), T_p and T_{dp} are the temperature and dewpoint at one of the levels (all temperatures in °C) and a and b are weighting coefficients given equal value for this study.

Haines calculated LASI values for 74 fires in the United States utilizing 0000 UTC data. These are late afternoon or evening soundings and should usually represent actual conditions when the extreme fire behavior was noted. A vast majority of the fires occurred on days with steep lapse rates and low humidities. Comparisons with the Standard Atmosphere and with a simple climatological data set computed for this study showed that these extreme fire conditions were indeed abnormal. Approximately 5% of all fire season days fell into the high-index category of the LASI, but 45% of days with large fires or erratic fire behavior were in this category.

The current study differs from Haines' work in two ways. First, 1200 UTC data over the United States were analyzed. These are the morning soundings and would represent typical data available to fire weather forecasters who are trying to predict fire conditions later in the day. As previously mentioned, the LASI was developed using 0000 UTC data when extreme fire behavior was actually occurring. A goal of this study is to see if the instability and dryness of the lower atmosphere, common during the occurrence of extreme fire behavior, is discernable 12 hours earlier. This will be accomplished by examining the 1200 UTC LASI values to see if these are as high as the 0000 UTC numbers.

Haines examined only low-level lapse rates and moisture. This study would include an analysis of the vertical wind profile. The effects of the change in wind speed with height on wildland fire behavior have been discussed in several previous studies. Byram (1954) stressed the importance of stronger winds at low levels with decreasing winds aloft. Byram believed that such a wind profile over a wildland fire would allow the convective column above the fire to develop more fully. This would increase the fire's intensity and its potential for extreme behavior. Although Byram referred to such wind profiles as having "low-level jets", an interpretation of his work indicates that he was not as much concerned about an actual low-level

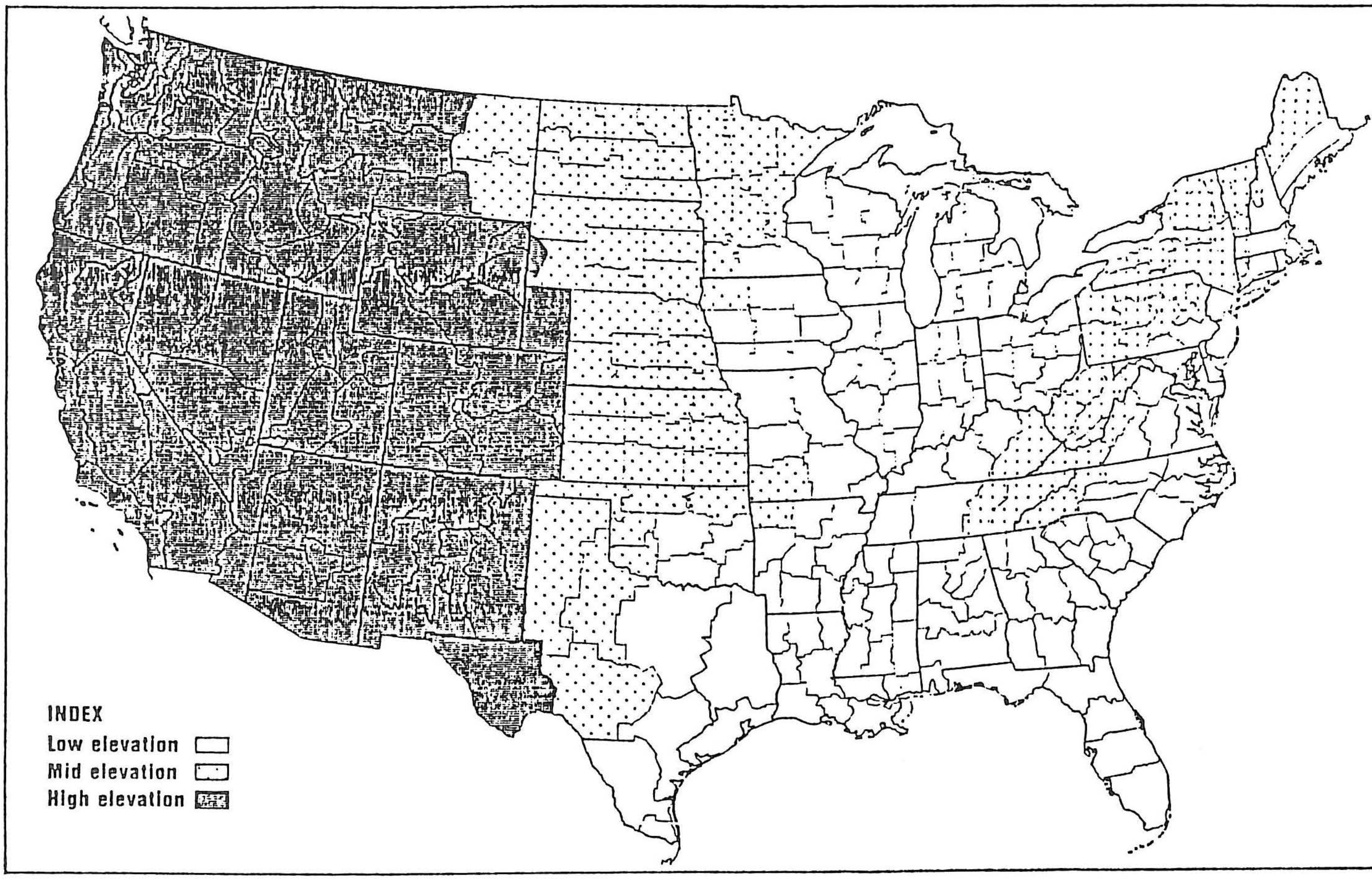

Fig. 1. Map of the United States climatic divisions showing regional elevation aspects of the LASI (Haines, 1988)

wind maximum as he was about minimal amounts of vertical wind shear. It has been long realized that a lack of vertical wind shear allows the development of weaker convective columns such as those associated with non-severe or air mass showers and thunderstorms.

Brotak and Reifsnyder (1977) analyzed 60 fires in the eastern United States. They found that strong winds throughout the vertical profile were common and in most cases wind speeds increased with height. It was their conclusion that fires in the eastern United States, which were mostly at low elevations, were primarily driven by strong winds and that convection above the fire was usually not as important. The current study would examine fires at various elevations and in various terrains to see if any correlations existed with the vertical wind profile, i.e., to see if the fires could be broken down into primarily wind driven with strong vertical wind shear or convection driven with weak vertical wind shear.

2. Data

The fires examined were the same used in Haines' study. These consisted of 29 major fires in the western United States and 45 fires in the eastern United States. Soundings from one to three nearby radiosonde sites were analyzed to determine both the vertical temperature and wind profiles. The 1200 UTC data were used which represented conditions in the morning prior to the extreme fire behavior.

To allow for the varying elevations, Haines divided the United States into three broad regions as shown in Fig. 1. For much of the eastern part of the United States (low elevation), the 950 to 850-mb temperature difference and the 850-mb dewpoint depression were examined. For the Appalachian Mountains and much of the Great Plains (mid elevation), the 850 to 700-mb temperature difference and the 850-mb dewpoint depression were used. For the western third of the United States (high elevation), the 700 to 500-mb temperature difference and the 700-mb dewpoint depression were analyzed. The surface and 700-mb wind speeds were examined for all of the fires.

The lapse rate component was broken down into three categories for each region again following Haines (1988). For a reference point, the Standard Atmosphere (NOAA et al. 1976) lapse rate was used. The standard value for the 950 to 850-mb temperature difference is ~6°C, for 850 to 700-mb it is ~10°C, and for 700 to 500-mb it is ~17°C. The LASI was computed using the following

$$\text{LASI} = A + B \qquad (2)$$

where A is the lapse rate component and B is the moisture parameter. The actual component values were calculated according to Table 1.

3. Analysis

Table 2 shows the breakdown of the fires into the various lapse rate, humidity, and LASI categories. The moisture component of the LASI, either the 850 or 700-mb dewpoint depression, was comparably low for both the 1200 UTC data used in this study and the 0000 UTC data used by Haines. Therefore, dry

Table 1. LASI Component Calculations

	Low Elevation	Mid Elevation	High Elevation
A	*950–850 Δ T*	*850–700 Δ T*	*700–500 Δ T*
1	< 4	< 6	< 18
2	4–8	6–11	18–22
3	> 8	> 11	> 22
B	*850 $T–T_d$*	*850 $T–T_d$*	*700 $T–T_d$*
1	< 6	< 6	< 15
2	6–10	6–13	15–21
3	> 10	> 13	> 21

conditions in the lower atmosphere certainly seem to be a necessary factor prior to the occurrence of extreme fire behavior. The analysis of low-level lapse rates did show differences between the two data sets with the 1200 UTC soundings used in this study indicating less instability. Only 14% of the low elevation soundings were decidely unstable at 1200 UTC as compared to 83% at 0000 UTC. The mid elevation soundings were only slightly more unstable with 36% falling into the least stable category in this study in comparison to 58% in the Haines' analysis. The high elevation soundings showed the least difference between 1200 and 0000 UTC. In both studies, nearly 90% of the soundings showed lapse rates greater than the Standard Atmosphere rate.

Low-level lapse rates are significantly affected by the radiation budget of the underlying surface. At night, the surface loses heat, and the lower atmosphere is cooled from below. This produces stable lapse rates at low levels. During the day, the surface gains energy from solar radiation, and the lower atmosphere is heated from below. This produces steep lapse rates and unstable conditions. The result of these processes is a major change in low-level lapse rates from 1200 to 0000 UTC with the 1200 UTC sounding not being particularly representative of conditions later in the day. For the current study, this means that 1200 UTC LASI values were lower and were not as good as predictors of extreme fire behavior.

The computational problems caused by radiational cooling at night could be dealt with if these effects were concentrated in the boundary layer within a nocturnal inversion. Lapse rate calculations could be adjusted for some level above the top of the inversion. The soundings were examined specifically for the occurrence of nocturnal inversions. The lowest levels used to calculate lapse rates were almost always above the nocturnal inversion. Only in three cases did the nocturnal inversion reach the 950-mb level for low elevation soundings. This means that there was no simple quantitative way of allowing for radiational cooling at night and the resultant increase in stability.

As previously mentioned, the LASI variants from the high elevation soundings showed the most consistency from 1200 to 0000 UTC. This is due to the location of the radiosonde station. Often the radiosonde station is at a much lower elevation than the fire site. The 700-mb temperature, which is considered a near surface temperature for the fire site, is a "free air" reading at the radiosonde location and is not as affected by radiational effects of the surface.

The analysis of the 1200 UTC low-level wind profiles also produced mixed results. In only 11 cases did the surface wind reported at the radiosonde site exceed 9 knots. The early morning surface winds at a distant radiosonde station would probably not represent winds at the actual fire site later in the day. Instead, the 700-mb wind speed was analyzed. This would give a better representation of synoptic-scale wind patterns. Strong winds at

Table 2. Percentage of Occurrence of Fires by LASI Variants for 1200 UTC Soundings with 0000 UTC Data in ( ) for Comparison.

Low Elevation (21 fires)		
950–850 mb Δ T	**850 ($T - T_d$)**	**LASI**
< 4: 24% (4%)	< 6: 10% (9%)	2–3: 14% (2%)
4–8: 62% (13%)	6–10: 19% (22%)	4: 24% (13%)
> 8: 14% (83%)	> 10: 71% (69%)	5: 57% (34%)
		6: 5% (51%)
Mid Elevation (28 Fires)		
850–700 mb Δ T	**850 ($T - T_d$)**	**LASI**
< 6: 7% (7%)	< 6: 0% (9%)	2–3: 4% (6%)
6–11: 57% (35%)	6–13: 32% (31%)	4: 25% (16%)
> 11: 36% (58%)	> 13: 68% (60%)	5: 43% (45%)
		6: 28% (33%)
High Elevation (25 Fires)		
700–500 mb Δ T	**700 ($T - T_d$)**	**LASI**
< 18: 12% (13%)	< 15: 4% (7%)	2–3: 4% (10%)
18–22: 48% (34%)	15–21: 24% (17%)	4: 24% (21%)
> 22: 40% (53%)	> 21: 72% (76%)	5: 44% (24%)
		6: 28% (45%)

this level could induce strong surface winds later in the day with turbulent mixing. In addition, the 700-mb wind would given an idea of the vertical wind speed profile. Strong winds at this level would probably indicate strong wind shear and wind driven fires at the surface. Weak winds at 700 mb would probably indicate weak wind shear and convection dominated fires.

As shown in Table 3, there are definite regional differences in these data. Over ¾ of the high elevation fires in the west occurred with 700-mb wind speeds less than 20 knots. This does not necessarily mean that the surface winds at the fire site were light. Certainly, topographic and other local effects could produce stronger surface winds in the mountains. The lack of strong winds aloft is probably a function of the time of year. As shown in Table 4, most of the western fires occurred in the summer when overall pressure patterns are weak. The worst conditions in terms of low fuel moisture also usually occur under an upper-level ridge which favors weak synoptic-scale winds. Fires in the west seem to follow Byram's model where convection over the fire is an important factor. In contrast, ⅔ of the mid-elevation fires occurred when the 700-mb wind speed exceeded 20 knots. In addition, 6 of the 8 times when the 700-mb wind speed was 19 knots or less, low-level jets were noted, i.e., wind speeds exceeded 20 knots below the 700-

Table 3. Number and Percentage of Fire Occurrences by 700-mb Wind Speed (wind data not available for 4 fires)

700 Mb WS (kts)	Low El. Fires	Mid El. Fires	High El. Fires
0–9	1 (5%)	0	7 (28%)
10–19	7 (33%)	8 (33%)	12 (48%)
20–29	8 (38%)	7 (29%)	5 (20%)
30–39	3 (14%)	7 (29%)	0
40–49	2 (10%)	0	0
50–59	0	2 (8%)	0
60–69	0	0	0
70–79	0	0	1 (4%)

Table 4. Number of Fires by Elevation and Month

	J	F	M	A	M	J	J	A	S	O	N	D
Low Elevation	1		6	9	2	1		2	1			
Mid Elevation				12	2		5		4	1		
High Elevation					1	8	4	9	5		1	

mb level. These fires seemed to fit into Brotak and Reifsnyder's model of wind driven fires. The majority of these fires occurred in the spring and fall (Table 4) when weather systems are stronger. Surprisingly, the low elevation eastern fires showed less correlation with strong winds at 700 mb, and low-level jets were not a factor.

4. Summary and Recommendations

The LASI developed by Haines for classifying atmospheric conditions during periods of extreme fire behavior utilizing 0000 UTC soundings was not as useful in predicting these conditions using 1200 UTC data. The stabilization of lapse rates due to radiational cooling at night seems to be the main problem. One possible solution would be to use a predicted afternoon surface temperature to do the calculations with the 1200 UTC soundings. Another possibility is to compare the 1200 UTC values with climatology. This study could only use as reference points the Standard Atmosphere lapse rate and the 0000 UTC results from Haines' study. It would be best for a local climatology for each radiosonde station be developed for the most accurate comparisons.

The analysis of low-level wind profiles showed definite regional differences. The mid-elevation fires in the eastern half of the United States and to a lesser extent the low-elevation fires there occurred with strong winds and strong vertical wind shear at low levels. These fires, which occurred mainly in the spring, seem to be primarily wind driven. In the west, where the lowest fuel moistures often occur in the summer, strong winds on the synoptic scale are rare. These fires seem to be controlled more by local or topographically induced winds and by convection over the fire.

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