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FIRE WEATHER

# A LOWER ATMOSPHERE SEVERITY INDEX FOR WILDLIFE FIRES

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### ABSTRACT

*Dry, unstable air increases the probability that wildland fires will become large and/or erratic. This paper describes an atmospheric index for these fires, based on the environmental lapse rate of a layer of air coupled with its moisture content. In low-elevation regions of the United States, the index is derived from a lapse rate value using 950- to 850-mb temperature differences and a temperature–dew-point spread at 850 mb. At mid-elevations, the index uses 850- to 700-mb temperature differences and the 850-mb temperature–dew-point spread. In the high-elevation western regions, a similar calculation uses a 700- to 500-mb lapse rate value and the temperature–dew-point spread at 700 mb.*

*A preliminary comparison of the low-elevation variant of the index with climatology showed that only 5% of all fire-season days fell into the high-index class. A similar comparison for the high-elevation region showed 6% of all fire-season days in the high-index class, but 45% of days with large and/or erratic wildfire in that class.*

## 1. INTRODUCTION

Over the past 25 yr or so, dozens of *stability indices* have been devised to measure the atmosphere with respect to potential convective activity and thunderstorms. Two of the more popular, the K Index (2,3) and the Lifted Index (3,4,5), are transmitted over the national facsimile network to interested forecast units.

Almost all these indexes use various forms of two elements measured by radiosonde soundings in the lower atmosphere—temperature and dew point. This allows computation of two important features, the lapse rate and the moisture content of appropriate atmospheric layers and levels.

Some fire-weather forecasters have attempted to use these stability indexes as indicators of the potential for increased wildfire severity, but these indicators have generally failed. Thunderstorm development requires high atmospheric moisture content, but wildland fire activity decreases with increasing moisture. Consequently, the design of these indexes is incompatible with their use for fire activity prediction.

Fire-weather specialists have identified lower atmosphere parameters that may increase fire severity. For example, Davis (6) examined surface to 1,525-m lapse rates at upper air stations near 70 large fires and found that half of his sample burned "... when the air mass was classed as absolutely unstable." Byram (7) reconstructed the wind profiles near 17 "blowup" fires and concluded that a low-level jet or decrease of windspeed with height favored such fire development.

In a comprehensive analysis of 98 large fires, Brotak (8) computed values for 11 upper air features. He found that low moisture (93% of the cases) and a 950- to 850-mb temperature difference greater than the standard atmosphere (92% of the cases) were associated with almost all severe fires in the eastern United States. Following these leads, the present analysis concentrated on developing a lower atmosphere severity index (LASI) for wildland fire based on values of environmental lapse rates and moisture. Development of a vertical wind profile component also was attempted, but not included in the final index for reasons outlined in a later section of this paper. Because of elevation differences across the United States, three combinations of atmospheric layers and levels were used to construct three variations of the LASI.

## 2. METHODS

Fire data were obtained by contacting wildland fire management units and requesting information on their worst fire situations over 20 yr. Returns provided information from 30 States on 29 major fires in the west and 45 fires in the east. Twelve of the eastern fires were also included in Brotak's analysis (8); all other fires were independent of previous lower atmosphere summaries.

Data from one to three radiosonde stations closest to each fire were examined to determine air mass lapse rates and moisture values over the fire area. The National Climatic Data Center provided radiosonde information for these fire periods. The 0000 GMT temperature and wind profiles for the evening on which the fires were reported were constructed for one of three layers between 950- and 500-mb, depending on surface elevation.

Brotak and Reifsnyder (9) suggested that the levels and layers used as input to a wildland fire severity indicator be high enough above surface to avoid the major diurnal variability of surface temperature and surface-based inversions. Our procedure lessens the diurnal effects, although there is no way to totally negate that influence.

Figure 1 shows a map of the United States divided into three regional elevations. Through much of the eastern half of the country, the 950- to 850-mb layer is used with the lapse rate; here surface pressure values are typically much greater than 950 mb. Although 950 mb is not a standard pressure surface, it was used to formulate the low-elevation variant of the index because it produced a superior product in both Brotak's (8) and this analysis. Because of higher elevations in the Appalachian Mountains, extending from Tennessee northeastward to western Maine, along with the western plains region from west Texas northward to Canada, a mid-level variant of the index was designed using lapse rate values between 850- and 700 mb; moisture values were taken from 850-mb data for both of these elevations.

Because of the high elevation of most of the western United States, the 700- to 500-mb lapse rate, coupled with the 700-mb moisture, best represented that situation. A layer at this

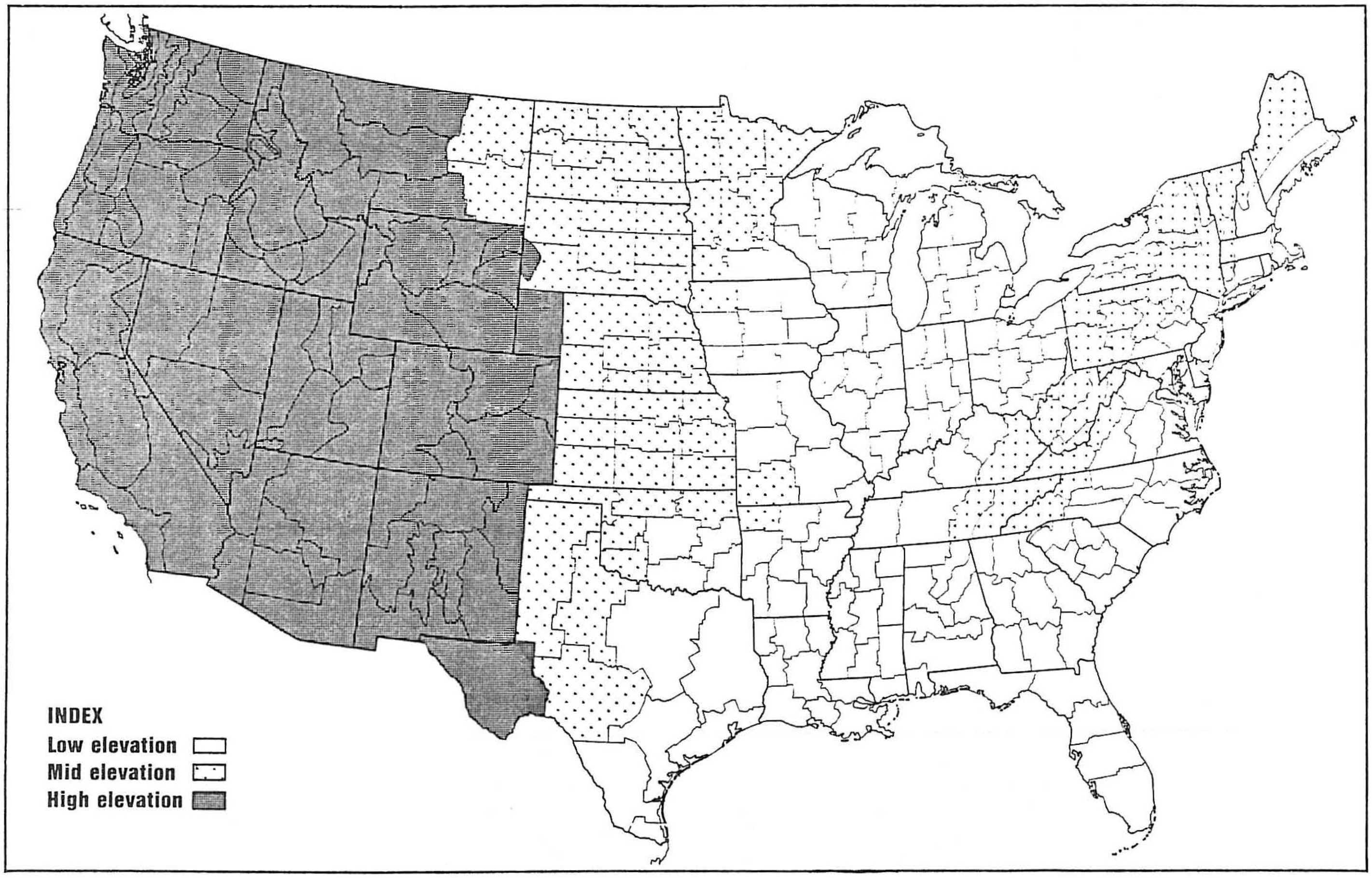


Fig. 1. Map of the United States climatic divisions showing suggested regional application of the LASI. Delineation is based on general surface elevation above sea level.

height was needed because there were problems with western values from lower layers, although fire-weather forecasters use the 850- to 500-mb layer in many situations. Fifteen percent of the fires occurred with surface pressure less than 850 mb. In some cases even the 700-mb level is too low relative to the large forested acreages high in the Rockies and Sierras. Most of the radiosonde stations are located in valleys and, therefore, measure free-air 700-mb temperatures and dew points. The elevated heat sources provided by the mountains are not measured by the observing stations and, therefore, the true, steeper environmental lapse rates caused by the mountains are not observed in the data. In all three regions, the selected layer and level are a compromise among competing factors.

During a few high-elevation fires, isolated cloudiness resulted in high 700-mb moisture values at the radiosonde station measuring the most extreme lapse rate. In those cases, a nearby radiosonde station invariably reported little moisture at that level. Therefore, the lower moisture value was combined with the lapse rate value from the first station to better reflect the true nature of the air mass over the fire.

Lapse rate and moisture were combined into a LASI using:

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

where $T$ is the temperature at two pressure surfaces ($p1$, $p2$); $T_p$ and $T_{dp}$ are the temperature and dew-point temperature at one of the levels. All temperature values are in °C. Weighting coefficients, $a$ and $b$, were given equal value in the computations that follow.

An extensive library search failed to uncover an appropriate climatological summary of data from the lower atmosphere to use in conjunction with this analysis. For example, what are the typical temporal and spatial variabilities of 850- to 700-mb lapse rates? Although Holzworth and Fisher (10) have produced an excellent climatological summary of the lower few kilometers of the atmosphere using rawinsonde observations, their work was directed toward air pollution interests. Their summary is centered on types and incidences of inversions, a feature incidental to the phenomena currently under discussion.

Consequently, a rudimentary climatology was developed for this study using data from an eastern (Salem, IL) and western (Winslow, AZ) radiosonde station for the year 1981. Fire activity (number of fires and area burned) was near normal in U.S. national forests that year (11). Therefore, 1981 appeared to be a representative period. One year of data cannot describe temporal and spatial climatological features across the country, but it can provide a rule-of-thumb to compare to the lower atmosphere lapse rate and moisture values observed during the sampled large-fire occurrences. Until a more extensive climatology is developed, this 1-yr base will be used as a standard.

## 3. RESULTS AND DISCUSSION

### a. Low-elevation index

The low-elevation variant of the index was formed by combining 950- to 850-mb temperature differences with 850-mb temperature–dew-point spreads (Fig. 2). Only 4% of the eastern fires occurred with 950- to 850-mb temperature differences less than 4°C. Another 13% occurred with these temperature differences near the standard atmosphere (≈6°). More than 80% of these fires occurred with temperature differences greater than 8°C, well above the standard atmosphere value. Ninety-three percent of the fires burned with a 950- to 850-mb temperature difference greater than standard atmosphere, almost the same percentage found by Brotak (8). Concurrent temperature–dew-point spreads at 850 mb showed that only 9% of the fires occurred when the spread was less than 6°C, while 69% occurred with the spread greater than 10°C.

The lapse rate and moisture values were combined to form the low-elevation variant of the index with four adjective ratings: very low (possibility of severe fire conditions), low, moderate, and high (Fig. 2C). The analysis showed that only 2% of the fires occurred on days classed as very low, while 51% of the fires occurred on days classed as high. On the other hand, the climatological analysis showed that 75% of the days of the fire season were classed as very low or low, while only 5% of the days were classed as high.

## b. Mid-elevation index

The mid-elevation variant of the index (Fig. 3) was based on a finding that only 7% of the fires occurred when the 850-to 700-mb temperature spread was less than 6°C, while 58% occurred with a spread of 11°C or greater. Almost two-thirds of the fires listed in the data base burned with a 850- to 700-mb temperature difference greater than standard atmosphere (≈10°). Three-fourths of the fires listed in Brotak's data base (8) burned under similar conditions. Concurrent temperature–dew-point spreads at 850 mb showed that only 9% of the fires occurred when the spread was less than 6°C, while 60% occurred when the spread was greater than 13°C. Although the moisture in this LASI was calculated from the same data base as the low-elevation index, there are some tabulation differences because data from up to three radiosonde stations were examined for each fire. In some cases lapse rates were greater at another nearby station with the mid-elevation index. This required use of that new station's moisture value at 850 mb.

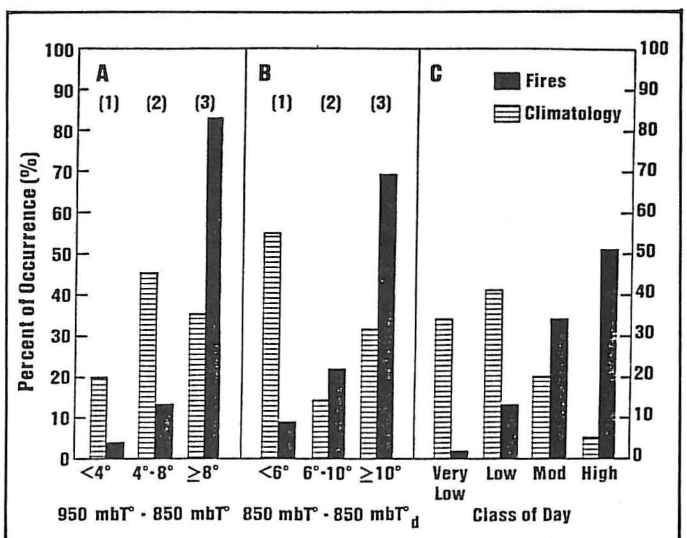


Fig. 2. Low-elevation variant of the LASI: observation levels, temperature thresholds, and performance characteristics. Section A shows the temperature difference between the levels. Section B shows temperature–dew-point spreads. Section C shows the percent of occurrence of the class of day. Factors 1, 2, and 3 indicate the percent of occurrence of the various temperature groupings.

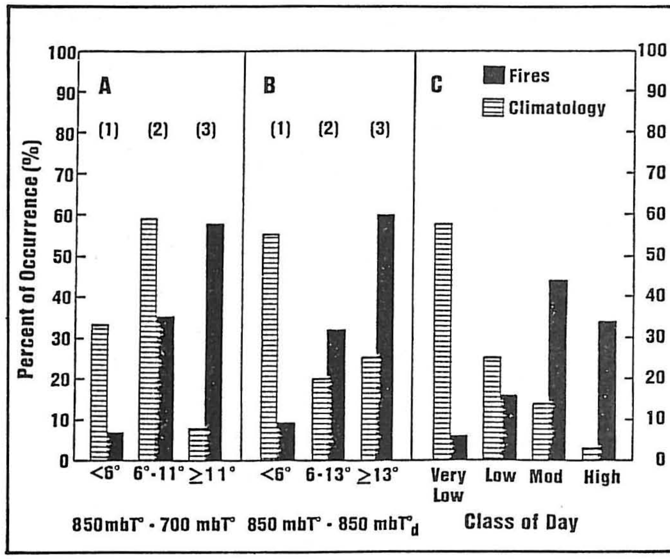


Fig. 3. Mid-elevation variant of the LASI: observation levels, temperature thresholds, and performance characteristics.

Combined lapse rate and moisture values also formed the adjective classification for the mid-elevation variant of the index shown in Figure 3. Six percent of the fires burned under a classification of very low, while 58% of the days in the fire season were in that class. Seventy-eight percent of the fires burned when the day was classed as moderate or high, while only 17% of the fire season days were in these classes.

## c. High-elevation index

The high-elevation variant of the index was formed by combining 700- to 500-mb temperature differences with 700-mb temperature–dew-point spreads (Fig. 4). This variant of the index provided a poorer lapse-rate distinction between fires and climatology than did the low- and mid-elevation variants, but did better with the moisture discriminator than the other two.

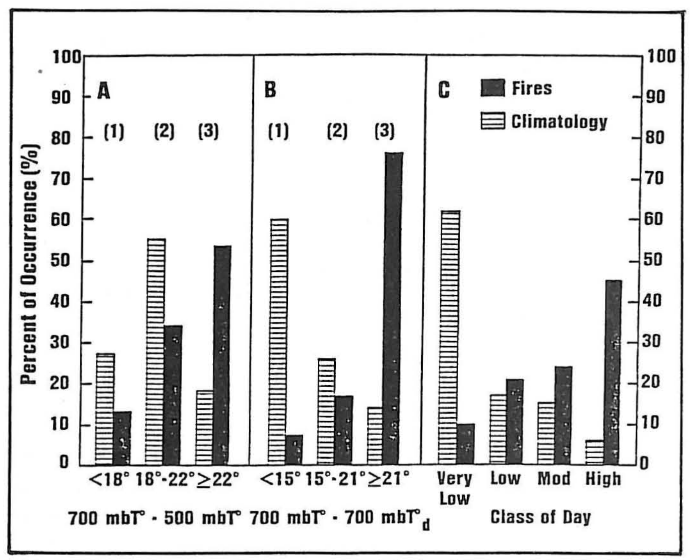


Fig. 4. High-elevation variant of the LASI: observation levels, temperature thresholds, and performance characteristics.

Thirteen percent of the fires occurred when the 700- to 500-mb temperature difference was less than standard atmosphere ($\approx 17°$), while 53% burned with a spread of 22°C or greater. Comparative fire season climatology was 27% in the first-mentioned category and 18% in the latter. Concurrent temperature–dew-point spreads at 700 mb showed that only 7% of the fires occurred when the spread was less than 15°C, while 76% occurred with a spread of 21°C or greater.

Combined lapse rate and moisture values formed a LASI (Fig. 4C) with 10% of the fires occurring when the class of day was very low, in contrast to 62% of the fire-season days in that class. Forty-five percent of the fires were associated with the high class, but only 6% of the climatological summary days fell in that class.

### d. Computing the LASI

Values of any of the three variants of the index can be derived by the following procedure. First, select the proper index variant based on surface elevation (Fig. 1). For example, if the station is at a low elevation, compute the 0000 GMT lapse rate (Fig. 2A) and moisture (Fig. 2B) values:

| | *Factor values* |
|---|---|
| (A) *950 mb T° − 850 mb T°* | |
| less than 4°C | 1 |
| 4° to 8°C | 2 |
| greater than/equal to 8°C | 3 |
| (B) *850 mb T° − 850 mb* $T°_d$ | |
| less than 6°C | 1 |
| 6° to 10°C | 2 |
| greater than/equal to 10°C | 3 |

Second, add the factor values (A + B):

| *(A + B)* | *Class of day (potential for large fire)* |
|---|---|
| 2 or 3 | very low |
| 4 | low |
| 5 | moderate |
| 6 | high |

Computing the index for mid- or high elevations follows the same procedure using the temperature thresholds provided in Figures 3 or 4.

### e. Other considerations

There are two additional areas of immediate interest about operational use of the LASI for fire-weather forecasting. First, the LASI might be strengthened by adding a third term to equation (1) dependent on a low-level wind-speed profile. Initial attempts to include a characteristic vertical wind speed component failed because they were concentrated solely on low-level jets. Only 47% of the eastern fires and 27% of the western fires were associated with that feature in this large fire sample. Brotak and Reifsnyder (9) found 33% occurrence for their data base. They believe that the low-level jet is important in that it increases surface wind speeds and gustiness through the downward transport of momentum, making a bad fire situation even worse. Perhaps a wind term could be included later in an augmented version of the index. However, the disagreement in the literature over the meteorological importance of various wind profiles, coupled with inconclusive results here, necessitates a delay until a clearer picture emerges of the impact of various wind profiles on large wildfires. Among other problems, Byram (7) listed six types of profiles that could be "potential trouble makers," but he described these profiles somewhat subjectively making it difficult to include them as objective components in equation (1). Four profiles included types of low-level jet points, and two displayed a decrease of wind speed with height above surface. On the other hand, the study by Brotak and Reifsnyder (9) found that in addition to a low-level jet, the only characteristic wind profile typically associated with wildland fires was one that included surface wind speeds exceeding 13 kt coupled with 3050-m wind speeds exceeding 34 kt.

If/when a wind component is added to the LASI, it would be prudent to first establish its validity in the low-elevation region. As pointed out by Boise fire-weather meteorologist Carl Groski, the influence of complex terrain in the high-elevation region masks wind's influence. Evaluating a wind term in relatively flat terrain largely negates the problem of land features.

There is a second consideration: the present study was done primarily to establish the validity of meteorological parameters and methods used. Operational factors, though important, were secondary to accomplishing that goal. The 0000 GMT radiosonde observations used in this analysis were made during the evening across the continental United States and, therefore, usually occurred just after the major burning period (middle to late afternoon) had ended. For forecasting, the 1200 GMT (morning) observations might better be used, but this could mean that the results from the analyses shown in Figures 2, 3, and 4 would change to some extent.

Simard *et al.* (12) have recently incorporated the LASI as one component of an Extreme Fire Potential Index. Results from that study will be evaluated after a year of semioperational testing and collection of supporting data. This analysis then will be repeated using 1200 GMT radiosonde information and compared with the present computed values.

## 4. CONCLUDING REMARKS

This study reports on an anlysis of lower atmosphere data in relation to large wildland fires. Although a large number of lower atmosphere studies have been conducted previously, the investigations were directed primarily toward the potential for thunderstorms, downbursts, air pollution, or clear-air turbulence. Fire-weather personnel have developed various guidelines regarding lower atmosphere features and wildland fire, but no one had attempted to construct a formal index or make climatological comparisons.

This is a first effort at constructing a national fire-weather index based on features of the lower atmosphere. Even though it will undoubtedly require further refinement and/or additional components, the index already appears to be a good predictor of the probability of large wildland fire.

## ACKNOWLEDGMENTS

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### NOTES AND REFERENCES

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# Folklore

## "SKY'S BLUE, LET'S PUT ON A HAPPY FACE!"

**by Sue Mroz**

Does the presence of blue skies, sunshine and puffy cumulus clouds have an uplifting effect on the human psyche? I think most of us (unless we're desperate for rain for our crops, etc.) would give a resounding yes! Weatherlores and sayings for centuries have been telling us that high pressure and its attending weather often puts people in a good mood.

Shakespeare said men judge "the state and inclination of the day by the complexion of the sky" and in King Alfred Poems XII it is written: "So it falls that all men are with fine weather happier far."