Computing the Low-Elevation Variant of the Haines Index for Fire Weather Forecasts

BRIAN E. POTTER

Pacific Northwest Research Station, USDA Forest Service, Seattle, Washington

JULIE A. WINKLER, DWIGHT F. WILHELM, AND RYAN P. SHADBOLT

Department of Geography, Michigan State University, East Lansing, Michigan

XINDI BIAN

Northern Research Station, USDA Forest Service, East Lansing, Michigan

(Manuscript received 14 March 2007, in final form 11 June 2007)

ABSTRACT

The Haines index is used in wildfire forecasting and monitoring to evaluate the potential contributions of atmospheric stability and humidity to the behavior of plume-dominated wildfires. The index has three variants ("low," "mid," and "high") that accommodate differences in surface elevation. As originally formulated, the low variant is calculated from temperature observations at the 950- and 850-hPa levels and humidity observations at 850 hPa. In the early 1990s the National Weather Service implemented a new mandatory level for radiosonde observations at 925 hPa. Following this change, measurements at 950 hPa became less frequent. An informal survey of several forecast offices found no formalized adjustment to the calculation of the low Haines index to take into account the nonavailability of 950-hPa measurements. Some sources continue to use 950-hPa temperature, usually interpolated from 925-hPa and surface temperatures, to calculate the low Haines index. Others directly substitute the 925-hPa temperature for the originally specified 950-hPa value. This study employs soundings from the central United States when both 950- and 925-hPa levels were available to investigate the impact of different calculation approaches on the resulting values of the low variant of the Haines index. Results show that direct substitution of 925-hPa temperature for the 950-hPa temperature can dramatically underestimate the potential wildfire severity compared with the original formulation of the Haines index. On the other hand, a low-elevation variant of the Haines index calculated from the interpolated 950-hPa temperature is usually in close agreement with the original formulation of the index.

1. Introduction

According to the Interagency Agreement for Meteorological Services (National Weather Service Policy Directive 10-4, available online at http://www.weather.gov/directives/sym/pd01004curr.pdf), National Weather Service (NWS) forecast offices are responsible for a variety of fire products, which include routine fire weather forecasts and red flag watches and warnings. Primary components for the fire weather forecasts and criteria for red flag warnings vary among forecast offices. In general, surface-based measurements such as wind and humidity are employed. The Haines index (Haines 1988) is one of the few above-ground parameters often included as part of these products.

Originally named the lower atmosphere severity index, the Haines index is an integer from 2 to 6 intended to measure the likelihood of plume-dominated fires becoming large or displaying erratic behavior. The index includes a stability (A) component and a moisture (B) component. The A component reflects the lower-tropospheric environmental lapse rate, and the B component is the dewpoint depression for a specific pressure level. The Haines index converts each of the components to an ordinal value of 1, 2, or 3 based on prescribed threshold values (Table 1). Summing the components results in a Haines index ranging from 2 (very low potential of large or erratic plume-driven behavior) to 6 (very high potential).

Corresponding author address: Brian E. Potter, Pacific Wildland Fire Sciences Lab, 400 N. 34th St., Ste. 201, Seattle, WA 98103.
E-mail: bpotter@fs.fed.us

DOI: 10.1175/2007WAF2007025.1

TABLE 1. Calculating the Haines index (modified from Haines 1988)

Elevation	Stability (A) component: Calculation	Stability (A) component: Categories	Humidity (B) component: Calculation	Humidity (B) component: Categories
Low	950-hPa temperature − 850-hPa temperature	$A = 1$ if <4°C $A = 2$ if 4°–7°C $A = 3$ if ≥8°C	850-hPa temperature − 850-hPa dewpoint	$B = 1$ if <6°C $B = 2$ if 6°–9°C $B = 3$ if ≥10°C
Mid	850-hPa temperature − 700-hPa temperature	$A = 1$ if <6°C $A = 2$ if 6°–10°C $A = 3$ if ≥11°C	850-hPa temperature − 850-hPa dewpoint	$B = 1$ if <6°C $B = 2$ if 6°–12°C $B = 3$ if ≥13°C
High	700-hPa temperature − 500-hPa temperature	$A = 1$ if <18°C $A = 2$ if 18°–21°C $A = 3$ if ≥22°C	700-hPa temperature − 700-hPa dewpoint	$B = 1$ if <15°C $B = 2$ if 15°–20°C $B = 3$ if ≥21°C

To take into account variations in surface elevation, Haines created three variants of the index (referred to as "low," "mid," and "high") and designated regions in the United States where the different variants are more appropriate (Fig. 1). The variants use temperature and dewpoint observations from mandatory levels of radiosonde observations, with the exception that the low variant uses temperature observations at the nonstandard 950-hPa level in addition to temperature and dewpoint observations at the 850-hPa mandatory level. At the time Haines formulated the index, radiosonde reports commonly included observations at 950 hPa. However, in the early 1990s the NWS introduced a new mandatory level at 925 hPa, and after that time measurements at 950 hPa became much less frequent.

An informal survey of several NWS forecast offices found no formalized adjustment to the calculation of the low Haines index to take into account the nonavailability of 950-hPa measurements. Furthermore, the ability of alternative calculation methods to reproduce the original Haines index has not been systematically evaluated. Given the popularity of the Haines index for fire weather forecasting, this lack of a standardized calculation procedure can lead to considerable confusion when using the low variant of the Haines index in operational situations. Incident meteorologists, fire behavior analysts, or incident commanders may not know how the index value they received was computed. To address this concern, three different approaches to calculating the low variant of the Haines index are com-

FIG. 1. Haines index regions. The region of the United States where the low variant of the Haines index is recommended is not shaded, the light shading highlights the area where the mid variant of the Haines index is recommended, and the dark shading represents the area where the high variant of the Haines index is recommended (modified from Haines 1988).

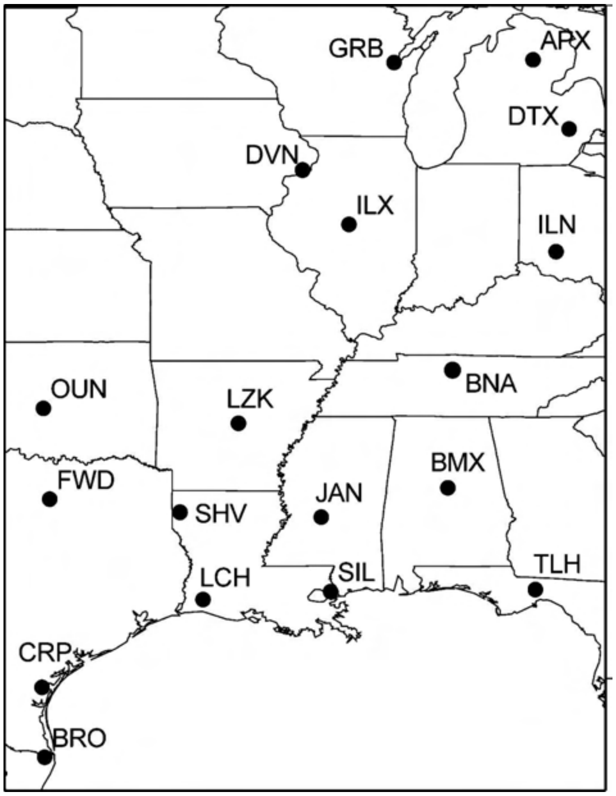

FIG. 2. Radiosonde stations used in this study.

pared, and the significance to operational fire weather forecasting is summarized.

2. Data and methods

Comparison of alternative calculation methods for the low-variant Haines index required upper-air soundings with temperature observations at both the 950- and 925-hPa levels. Twice-daily (0000 and 1200 UTC) soundings for 1958–2000 at 18 radiosonde stations (Fig. 2) within the low-variant region were searched for observations at both pressure levels. These stations are a subset of rawinsonde stations located in the central United States that were used by two of the authors for a previous research project (see Walters et al. 2008) and that were carefully analyzed for station relocations and missing observations. Although the stations do not cover the entire low-variant region, they do have considerable longitudinal and latitudinal variations and likely are representative of the differences in 950- and 925-hPa temperature found within the low-variant region. A total of 80 974 soundings were included in the analysis; the majority came from the period 1992–97, shortly after the time the 925-hPa level was introduced as a mandatory level (Fig. 3).

Three alternative calculation methods were evaluated, and the resulting values were compared with those calculated using the original index formulation. The first two methods were in operational use at the beginning of this study. The third method is a feasible alternative and is included for thoroughness. However, to our knowledge, it has not yet been used operationally. The first method (referred to below as HI925) directly substituted the 925-hPa temperature in place of the 950-hPa temperature with no change in the thresholds for the A component. The second method (HI950INT) used a log-pressure interpolation between the temperatures (T) at the surface and 925-hPa levels,

$$T_{950} = T_{\mathrm{sfc}} + \frac{\ln(p_{\mathrm{sfc}}) - \ln(950)}{\ln(p_{\mathrm{sfc}}) - \ln(925)} \times (T_{925} - T_{\mathrm{sfc}}), \tag{1}$$

to obtain a value for the 950-hPa temperature. Here, the subscripts "950" and "925" refer to values at the 950- and 925-hPa levels, respectively, and "sfc" refers to a value at the surface. Finally, the third method (HI925THRES) substituted the 925-hPa temperature for the 950-hPa temperature, but also adjusted the originally proposed thresholds of the A component. The new thresholds are three-quarters of the range of the original values (Table 1), given that the layer from 925 to 850 hPa is approximately three-quarters the depth of the original layer. Thus, the new thresholds are 3° and 6°C, compared with the original values of 4° and 8°C. Note that while the HI950INT method uses log-pressure interpolation between the surface and 925 hPa, the HI925THRES approach is mathematically equivalent to a linear (in pressure) extrapolation of the 850–925-hPa temperature lapse rate downward to the 950-hPa level. Figure 4 illustrates the three different calculation methods.

3. Comparison of computation methods

For each sounding with observations at both 925 and 950 hPa, the index values calculated using the three alternative approaches were compared with the value obtained from the original low-variant formulation of the Haines index. Comparisons were performed separately for 0000 UTC, 1200 UTC, and both time periods combined. In the discussion below, only the comparisons for 0000 UTC are highlighted because 1) Haines originally designed the index for the 0000 UTC time period and 2) differences between the computational

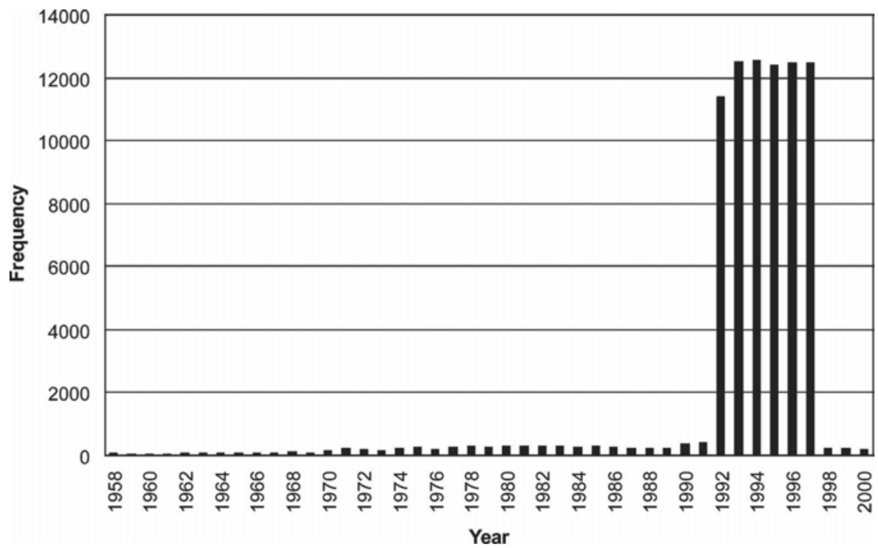

FIG. 3. Number of soundings by year with 950- and 925-hPa temperature observations.

methods and the original formulation were larger at 0000 UTC compared with 1200 UTC.

As a first step in evaluating the different methods, we computed traditional error statistics assuming that the index value from the original formulation is the "true" value. Only the 0000 UTC soundings with original index values of 5 or 6 (i.e., high or very high fire potential) were included in the error rate calculation as these are the values of greatest interest to the fire community. The error rates, E, are simply the percentage of time when the alternative methods yielded a value either larger or smaller than the original index and are expressed by

$$E = \frac{n(A \neq O)}{N} \times 100, \qquad (2)$$

where N indicates the total number of soundings at a location with an original Haines index value of 5 or 6 and $n(A \neq O)$ indicates the number of those soundings for which the alternative method index value does not equal the original method index value.

A comparison across all of the stations revealed that, for more than 65% of the 0000 UTC soundings with original index values of ≥5, the temperature difference between the 950- and 925-hPa pressure levels was between 1.5° and 2.5°C (Fig. 5). This relatively modest

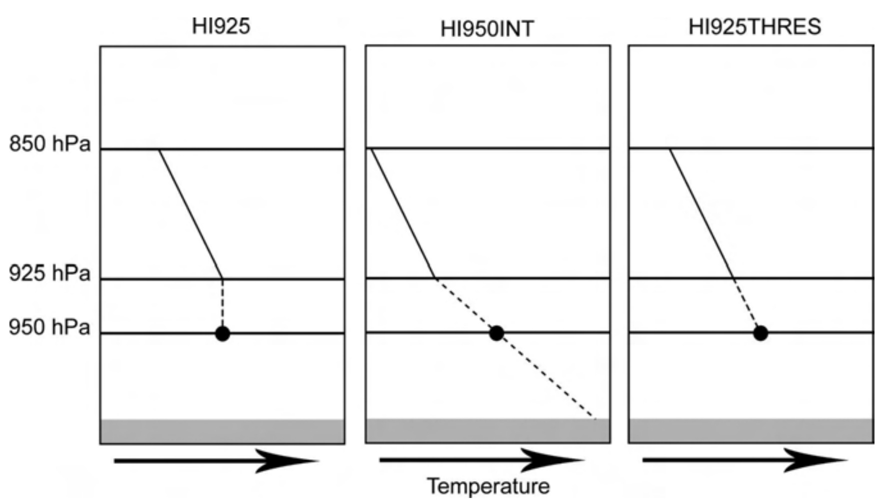

FIG. 4. Illustration of the three options for calculating the low-elevation variant of the Haines index. See text for a description of the calculation methods.

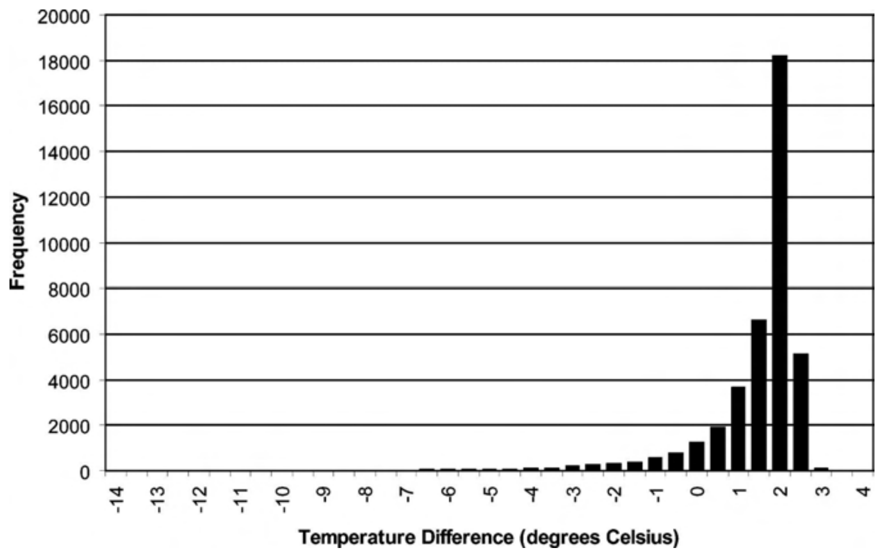

FIG. 5. Difference between the 950- and 925-hPa temperatures at 0000 UTC for all 18 stations used in the analysis.

temperature difference translates into frequent lower index values for the HI925 method because of the use of fixed thresholds in the Haines index calculation. On an annual basis, the HI925 method yielded a lower index value than the original Haines index formulation over 75% of the time (Table 2). In contrast, annual error rates were much smaller, at 8% for the HI950INT and 17% for the HI925THRES computational methods. The accuracy of the methods varies seasonally (Table 2), but for all seasons the error rate is substantially greater for the HI925 method than for either of the other methods. In all seasons, the error rate is smallest for the HI950INT method. The three alternative methods yielded values higher than the original index for 1% or less of the soundings, which is not surprising given the expected decrease in temperature in the lower troposphere.

Traditional error rates such as those given above are not necessarily the most appropriate statistic for evaluating and interpreting the operational significance of the alternative calculation approaches. Rather, fire weather forecasters and managers need to know how

TABLE 2. Error rates for alternative calculations of the Haines index for cases when the original Haines index value at 0000 UTC was a 5 (high fire potential) or 6 (very high fire potential).

		Error rate (%)	
Alternative Haines index computational methods	Season	Frequency that the value for the alternative method was smaller than the original value	Frequency that the value for the alternative method was larger than the original value
Substitution (HI925)	Annual	75	0
	Spring	78	0
	Summer	81	0
	Autumn	74	0
	Winter	68	0
Interpolation (HI950INT)	Annual	8	1
	Spring	3	1
	Summer	4	1
	Autumn	14	0
	Winter	12	0
New thresholds (HI925THRES)	Annual	17	1
	Spring	11	1
	Summer	15	1
	Autumn	19	1
	Winter	23	1

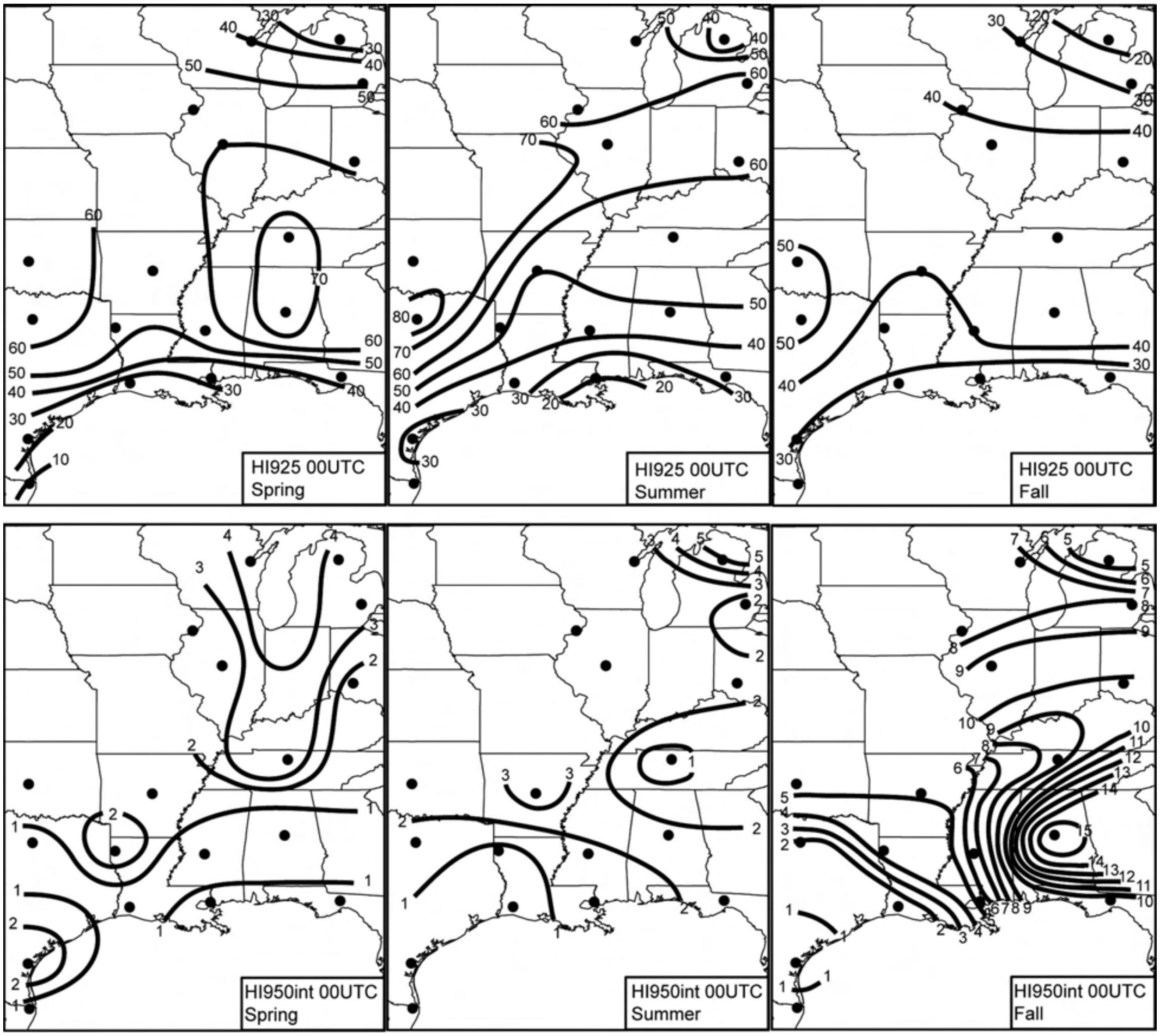

FIG. 6. Seasonal underestimation percentages for the HI925 (top row) and HI950INT (bottom row) computation methods of the low variant of the Haines index for index values of 4.

often the value they obtained from an alternative method is likely to understate the potential (as indicated by the original index formulation) of a large or erratic plume-dominated fire, especially as the original index values are no longer available to them because of the lack of 950-hPa temperature measurements. To evaluate this, we calculated the ratio (expressed as a percentage) of the number of times the index value for an alternative method was a 4 but the value of the original low variant index was a 5 (numerator) to the total number of occurrences of index values of 4 for an alternative computational method (denominator). This value, which we refer to as the underestimation percentage P_u, can be written as

$$P_u = \frac{n(\mathrm{A4O5})}{n(\mathrm{A4})} \times 100, \qquad (3)$$

where $n(\mathrm{A4O5})$ indicates the number of soundings for which the alternative method yielded a 4 when the original method gave a 5 and $n(\mathrm{A4})$ indicates the number of soundings for which the alternative method yielded a 4. The analogous calculation was also performed for alternative index values of 5.

Distinct spatial and seasonal patterns exist in P_u (Fig. 6). (The figure omits winter because of the lower fire hazard over most of the study area during this time of year.) For the HI925 method, the percentage of index values of 4 (moderate fire potential) that should have been a 5 (high fire potential) is smallest (10%–40%) along the Gulf Coast during all three seasons and increases northward, where P_u exceeds 60% in northern Texas and eastern Oklahoma for all three seasons and exceeds 70% in Tennessee and Alabama during spring. Farther north, in the Great Lakes region, P_u values again decrease to around 20%–40%. These differences likely represent spatial variations in the 950–925-hPa lapse rate. Underestimation percentages are smaller for the HI950INT method, with values of 5% or less across most of the study area. In other words, 0000 UTC values of 4 for the HI950INT index match the values of the original index formulation over 95% of the time. Plots for the HI950THRES method are not shown, as values of P_u for this method were intermediate between those of the other two methods.

Spatial variations in P_u for the HI950INT method are small. An exception is the large (over 15%) underestimation percentages for the HI950INT method at Birmingham, Alabama (BMX), during autumn. An HI950INT index value less than the original index indicates that the interpolated 950-hPa temperature is colder than the observed temperature, which in turn implies a smaller environmental lapse rate for the surface–950-hPa layer compared with the surface–925-hPa layer (keeping in mind that the interpolated 950-hPa temperature is computed from observations at the surface and at the 925-hPa level). Hence, strong low-level stability must be more frequent during autumn at Birmingham compared with the other radiosonde locations. To test this, the environmental lapse rates for the surface–950-hPa and the surface–925-hPa layers were computed for autumn soundings at Birmingham and at a nearby station [Shreveport, Louisiana (SHV)] with a much lower P_u. Surface inversions extending to 950 hPa were present at Birmingham on 62% of the days when the HI950INT index underestimated the value of the original low-variant Haines index. In contrast, none of the days at Shreveport with underestimated values of the HI950INT index were associated with surface inversions, lending credence to the contention that a more stable lower troposphere contributes to the large underestimation percentage at Birmingham. Investigating the reason for the larger number of inversions at Birmingham is beyond the scope of this study, but may result from a combination of local site factors, generally more stable conditions in autumn, or the 0000 UTC observation time falling after sunset in mid- and late autumn.

Generally similar patterns are evident for the seasonal plots of P_u when the value of the alternative indices is 5 (Fig. 7). However, P_u in autumn at Birmingham is much smaller for index values of 5 compared with values of 4. This is likely because of the steeper environmental lapse rates required for index values of 5 (>4°C if the B component is equal to 3 or >8°C if the B component is equal to 2). In contrast, an index value of 4 is possible with a small (<4°C) surface–925-hPa lapse rate as long as the B component has a value of 3.

4. Interpolation considerations

The discussion above clearly indicates that the HI950INT computational method replicates the original low-variant Haines index better than either the HI925 or HI950THRES methods. As mentioned previously, a simple log interpolation of the temperature values at the surface and 925-hPa levels was used to estimate the 950-hPa temperature. This scheme was chosen to minimize data requirements; users only need mandatory upper-air data to calculate the HI950INT index on either a real-time basis or for climatological analyses [see Winkler et al. (2007), for a climatology of the Haines index developed from mandatory pressure levels]. However, fire weather forecasters, especially those at NWS offices, often have initialization and forecast fields available from mesoscale numerical models with fine horizontal and vertical resolutions that can be used for Haines index calculations. In this situation, all variants (i.e., low, mid, and high) of the Haines index are calculated by estimating the temperature and moisture values for the pressure levels used in the index calculations from surrounding sigma levels. Furthermore, on-site interpolation software packages [e.g., BUFKIT (Mahoney and Niziol 1997; Niziol and Mahoney 1997) and the General Meteorological Package (GEMPAK; desJardins and Petersen 1985)] often use a quadratic rather than a log-interpolation scheme in the vertical. Commonly, the quadratic interpolation employs the temperature or humidity values for the two sigma levels below and one sigma level above the pressure level of interest to arrive at an estimated value. To evaluate the potential impact of the different interpolation schemes, the parameters for the low, mid, and high variants (see Table 1) of the Haines index at 0000 UTC were interpolated from simulations for 1 yr (1991) from the fifth-generation Pennsylvania State University–National Center for Atmospheric Research Mesoscale Model (MM5; Grell et al. 1995) driven by National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis fields (Kalnay et al. 1996).

The estimated temperatures differ little between the two interpolation schemes, with the average absolute differences ranging from only 0.04° to 0.1°C (Table 3). Differences in estimated moisture are also small, on the

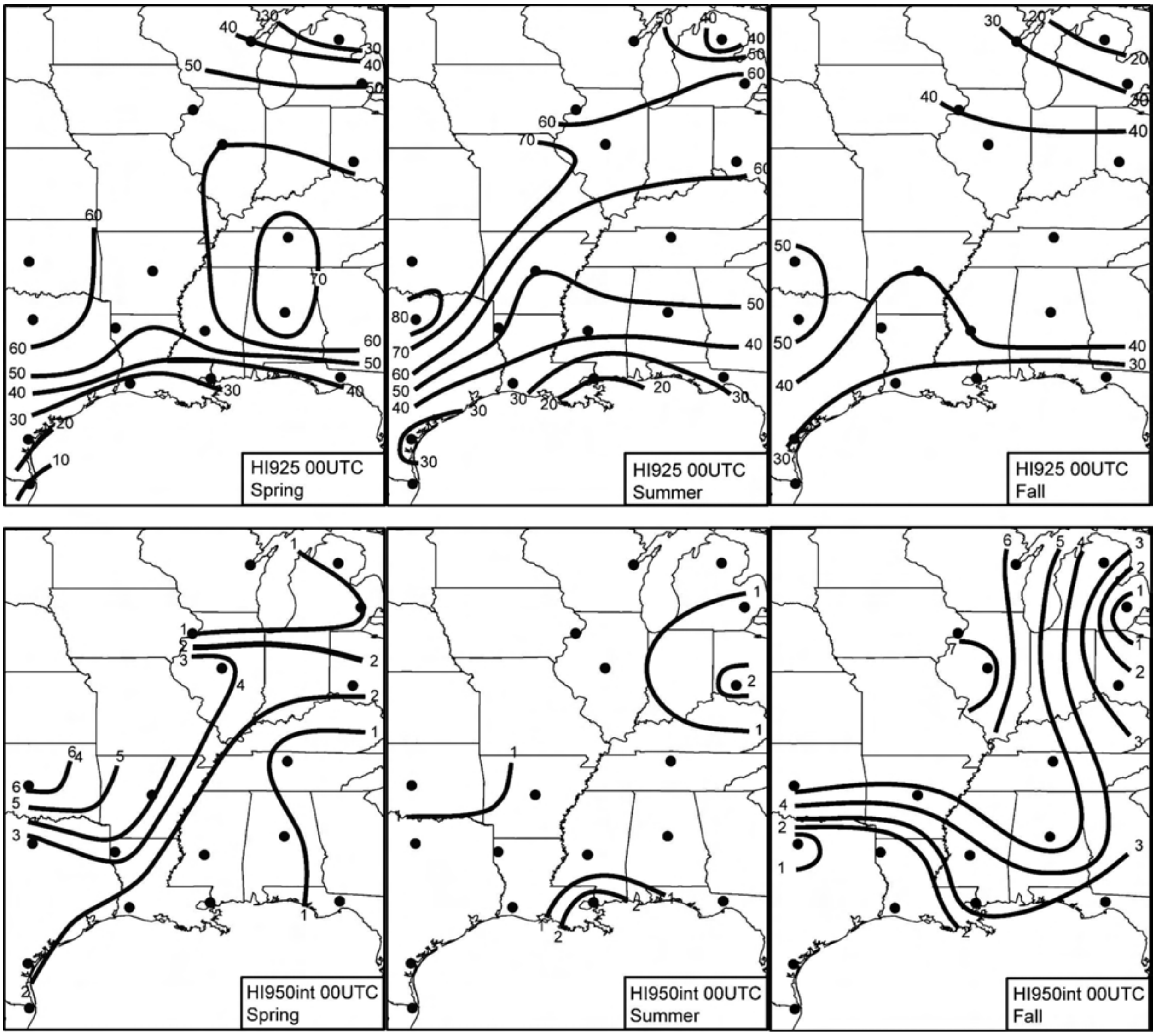

FIG. 7. Seasonal underestimation percentages for the HI925 (top row) and HI950INT (bottom row) computation methods of the low variant of the Haines index for index values of 5.

order of 0.1 g kg^{-1} (note that the moisture comparisons are for specific humidity rather than dewpoint, as specific humidity is used to calculate dewpoint). These small differences suggest that either interpolation scheme is appropriate. However, we found that as many as 15% of the interpolated values from the quadratic scheme fell slightly outside the range of temperature or humidity between the upper and lower sigma levels used in the interpolation. This situation usually occurred when temperature or humidity increased with height. In contrast, the log-interpolated temperature and humidity are constrained to fall between the values on the surrounding sigma surfaces. Consequently, we recommend using a log-interpolation scheme as shown in Eq. (1) when calculating the Haines index from numerical model output.

5. Conclusions

The results of this study illustrate the implications of using alternative methods for calculating the low variant of the Haines index and are relevant for operational fire weather forecasters and fire managers. We found that Haines index values calculated by directly substituting the 925-hPa temperature for the 950-hPa temperature are usually lower than the value obtained from the original low-variant formulation of the Haines index and are at risk of underestimating the potential for

TABLE 3. Differences in temperature and specific humidity estimated using quadratic and log-interpolation schemes. Comparisons are based on 0000 UTC output from a mesoscale model for 1991.

Pressure level (hPa)	Avg absolute difference between quadratic and log interpolations	Percentage of quadratic interpolations that fell outside of observed range
	Temperature	
950	0.04°C	6.7
850	0.10°C	11.2
700	0.07°C	1.1
500	0.08°C	0.1
	Specific humidity	
850	0.11 g kg^{-1}	15.2
700	0.07 g kg^{-1}	12.1

plume-dominated wildfires. On the other hand, interpolation of the 950-hPa temperature based on surface and 925-hPa temperatures with few exceptions reproduces the original index values. Furthermore, there are distinct spatial and seasonal patterns in the underestimation rates when the 925-hPa temperature is used in the calculation, whereas little spatial and temporal variation is seen for the interpolation method. One limitation of the interpolation method is that locations that frequently experience surface-based isothermal or inversion layers have higher underestimation rates, although they are still smaller than the underestimation rates produced by direct substitution of 925-hPa temperatures. Using 925-hPa temperatures in the index calculation and adjusting the thresholds to account for the generally cooler temperatures at this level, a method that has been proposed in the past but is not, to our knowledge, in use anywhere, fell between the other two methods examined in its ability to replicate the original Haines index values.

The impact of the choice of interpolation scheme was also considered by comparing the log interpolation to a commonly used quadratic scheme. While the absolute differences between the interpolated values were small for the two methods, the estimates from the quadratic scheme often fell outside the range of the values on the neighboring surfaces used for the interpolation. This error most often occurred when temperature or humidity increased with height.

In sum, the sensitivity of the index values to the calculation method requires that a universal calculation method of the low variant of the Haines index be adapted for operational use. An important point to keep in mind when interpreting the results of this analysis is that this study did not address how well the Haines index does or does not correlate with the occurrence of large or erratic wildfires. Such an analysis requires some measure of fire behavior. This study only considered how well alternate methods of computing the Haines index simulated the original method.

Acknowledgments. Joint Fire Science Program Project 03-1-1-37 provided the primary funding for this work. In-kind support was provided by Michigan State University and by the High Performance Computing Facility of the Eastern Area Modeling Consortium at the USDA Forest Service Northern Research Station. Acquisition and initial data quality control of the rawinsonde observations was completed with funds from NSF Grant BCS-0136480.

REFERENCES

desJardins, M. L., and R. A. Petersen, 1985: GEMPAK: A meteorological system for research and education. Preprints, *First Int. Conf. on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology,* Los Angeles, CA, Amer. Meteor. Soc., 313–319.

Grell, G. A., J. Dudhia, and D. R. Stauffer, 1995: A description of the fifth-generation Penn State/NCAR Mesoscale Model (MM5). NCAR Tech Note NCAR/TN-398+ STR, 117 pp.

Haines, D. A., 1988: A lower atmosphere severity index for wildland fires. *Natl. Wea. Dig.,* **13** (2), 23–27.

Kalnay, E., and Coauthors, 1996: The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Amer. Meteor. Soc.,* **77,** 437–471.

Mahoney, E. A., and T. A. Niziol, 1997: BUFKIT: A software application toolkit for predicting lake effect snow. Preprints, *13th Int. Conf. on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology,* Long Beach, CA, Amer. Meteor. Soc., 388–391.

Niziol, T. A., and E. A. Mahoney, 1997: The use of high resolution hourly soundings for the prediction of lake effect snow. Preprints, *13th Int. Conf. on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology,* Long Beach, CA, Amer. Meteor. Soc., 92–95.

Walters, C. K., J. A. Winkler, R. P. Shadbolt, J. van Ravensway, and G. D. Bierly, 2008: A long-term climatology of southerly and northerly low-level jets for the central United States. *Ann. Assoc. Amer. Geogr.,* In press.

Winkler, J. A., B. E. Potter, D. F. Wilhelm, R. P. Shadbolt, K. Piromsopa, and X. Bian, 2007: Climatological and statistical characteristics of the Haines index for North America. *Int. J. Wildland Fire,* **16,** 139–152.