2.2 A CLIMATOLOGY OF THE HAINES INDEX FOR NORTH AMERICA DERIVED FROM NCEP/NCAR REANALYSIS FIELDS

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1. INTRODUCTION

Originally introduced in 1988 as the “Lower Atmospheric Severity Index,” the Haines Index characterizes the potential impact of dry, unstable air on wildfire behavior and growth (Haines, 1988). In particular, the Haines Index provides a measure of the likelihood of plume-driven fires becoming large or displaying erratic behavior. Although imperfect, the Haines Index remains a widely-used tool in wildfire forecasting and monitoring. However, a comprehensive, long-term climatology of the Haines Index does not currently exist. The few previously-published climatological analyses have generally been confined to short time periods and/or limited geographical areas (e.g., Werth and Werth, 1998). Consequently, fire managers either do not have a “baseline,” or at best only a limited baseline, to compare observed and forecasted values of the Haines Index. Instead, they must rely on personal experience gained in the field. A comprehensive climatology of the Haines Index is required in order to understand what is “normal” and to be able to evaluate historical variations and potential future changes in the atmospheric component of wildfire risk. To address this need, we have prepared a 40-year (1961-2000) climatology of the Haines Index for North America. The climatology focuses on annual, seasonal, and monthly variations in the frequency and characteristics of the Haines Index. In addition to standard statistical summaries, we explicitly consider the temporal persistence of the Haines Index.

2. DATA AND METHODS

Briefly, the Haines Index is computed from lower-tropospheric temperature and dewpoint temperature and has three different versions (referred to as “low,” “mid,” and “high”) that take into account variations in surface elevation. The Haines Index includes a stability (A) component and a moisture (B) component that are weighted equally. The A component represents the environmental lapse rate (i.e., the change of temperature with height), whereas the B component is the dewpoint depression for a specific pressure level. For both components, the calculated temperature and humidity differences are categorized into three groups that are assigned an ordinal value of 1, 2, or 3. The limits for the A and B categories differ by Haines Index variant and are summarized in Table 1. The A and B components are then summed, and the resulting Haines Index has a range from 2 (very low risk of large or erratic plume-driven behavior) to 6 (high risk). For brevity in this paper, we use “risk” and “fire risk” in the text below to mean the risk of an existing plume-driven fire becoming large [over 1000 acres by Haines’ (1988) usage of the term] or displaying erratic behavior.

We derived our climatology from reanalysis fields developed jointly by the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR). The NCEP/NCAR reanalysis is a global data set with a spatial resolution of 2.5^o latitude by 2.5^o longitude (Kalnay et al., 1996). The reanalysis fields were produced using a global data assimilation system that was frozen in time. Input to the assimilation system includes observations from multiple sources but primarily from radiosondes, satellites, ships, and aircraft. The NCEP/NCAR reanalysis fields include temperature and humidity (along with several other variables) at the standard atmospheric levels and are available four times per day (0000, 0600, 1200, 1800 UTC). We chose the reanalysis fields over the original radiosonde observations because of their greater and more uniform spatial coverage and because of concerns about the quality of the radiosonde data. The large number of discontinuities in radiosonde time series at individual stations due to station relocations and changes in sensors can make the

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Table 1: Calculating the Haines Index*

Elevation	Stability (A) Component		Moisture (B) Component	
	Calculation	***Categories***	***Calculation***	***Categories***
Low	950hPa 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 temperature	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 temperature	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 temperature	B = 1 if <15°C B = 2 if 15-20°C B = 3 if ≥21°C

* *Modified from Haines, 1988.*

radiosonde record difficult to use for climatological analysis [see Winkler (2004) for a summary of the heterogeneities in the radiosonde record]. Although the reanalysis fields extend back to 1948, we only used the period from 1961-2000 because a considerably larger number of observations, particularly satellite and aircraft observations, were included in the later period assimilation runs. We limited our analysis to 0000 UTC, as this is the time period for which the Haines Index was originally developed.

The Haines Index was designed to use readily-available temperature and dewpoint temperature for atmospheric standard levels. The one exception to this is the low variant of the Haines Index which uses temperature at the 950-hPa level as part of the calculation. At the time the Haines Index was formulated, the 950-hPa level, although not a standard level, was a commonly-reported pressure level. However, with the establishment of the 925-hPa standard level in the mid 1990s, measurements at the 950-hPa level are no longer regularly reported, and this level is not included in the NCEP/NCAR reanalysis fields. Following the recommendation of Potter *et al.* (2005), we used a log-pressure interpolation scheme to estimate the 950-hPa temperature from the temperatures at the surrounding 1000-hPa and 925-hPa standard levels.

As mentioned above, the climatology focuses on annual, seasonal, and monthly variations in the frequency and characteristics of the Haines Index. All analyses are in map format and will be published eventually as an electronic atlas. The atlas will include, at a minimum, maps for the low, mid, and high variants of the Haines Index for the:

- average value of the environmental lapse rate between the two levels used in the stability (A) component
- average value of the dewpoint depression used in the humidity (B) component
- average value of the Haines Index
- frequency (expressed as a percentage) of Haines Index values of ≥4, ≥5, and =6
- average number of days of consecutive 0000 UTC Haines Index values (i.e., mean run length) of ≥4, ≥5, and =6
- maximum number of days during the 40-year study period with consecutive 0000 UTC Haines Index values (i.e., maximum run length) of ≥4, ≥5, and =6.

The climatological maps presented here for each variant of the Haines Index include most of North America rather than only the geographic region for which the variant was originally designed (see Fig. 1). Our rationale is that the original coarse geographic regions mask considerable variation in topography. For example, the extreme west coast of the United States falls within the "high" Haines Index region, even though elevations are low along the coastline. Also, the mid and high variants provide useful information on midlevel stability and humidity in the eastern U.S. where the low variant is typically used, and likewise the high variant can be useful for the Central Plains of North America. However, readers should interpret the Haines Index variants outside the region for which they were originally intended with caution, and values should be ignored for those locations where the standard pressure levels used in the calculation are commonly located "underground." [The temperature for "underground" pressure surfaces in the reanalysis is interpolated from the surface temperature assuming a constant moist adiabatic lapse rate. On the other hand, dewpoint temperatures are simply held constant (Ebisuzaki, 2005).]

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 medium 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).

3. RESULTS

Because of space constraints, we only present a subset of the climatological analyses here. For each of the three Haines Index variants, we include maps of the mean environmental lapse rate, dewpoint depression, and Haines Index; the frequency of Haines Index values equal to 6 (i.e., high risk); and the maximum run length of Haines Index values equal to 6. Only climatological maps for the summer season (June, July, and August) are shown for the mid and high variants, as this is the season of greatest wildfire risk for the regions where these two variants are most suited. For the low variant, we show the annual climatology, as the season of greatest fire risk varies considerably across eastern North America.

3.1 *"Low" variant of the Haines Index*

The spatial variation in the magnitude of the vertical temperature gradient between the 950-hPa and 850-hPa levels is small across eastern North America (Fig. 2). For most of the region, the temperature difference falls between 4 and 6^{o}C. This value translates to an average A component value of 2 (Table 1). Exceptions are northeastern Canada where the average environmental lapse rate is smaller, between 2 and 4^{o}C (equivalent to an A component of 1), and eastern Oklahoma and Texas where larger values of 6 to 8^{o}C (an A component of 3) are found.

Larger spatial gradients exist in the mean values of the 850-hPa dewpoint depression in eastern North America. In general, the average dewpoint depression increases from north to south. The highest average dewpoint depressions are along the Gulf Coast and are on the order of 10 to 12^{o}C, corresponding to a B component of 3. Dewpoint depressions are smallest in northeastern Canada where average values of 6 to 9^{o}C correspond to a B component of 2.

The average values of the Haines Index are smallest (approximately 3.0 to 3.5) in northeastern North America and the Great Lakes region. Larger average Haines Index values of around 4.0 in the southeastern United States reflect the generally larger dewpoint depressions in this area, whereas the average Haines Index values of approximately 4.5 in eastern Texas and Oklahoma are primarily a function of lapse rate. Note that the average values of the Haines Index in the northeastern portion of North America fall within the "very low" fire risk category, whereas in the extreme western portion of the low Haines Index region the average values approach the "moderate" fire risk category. For comparison, the rudimentary climatology Haines (1988) created using observations for 1981 at only two radiosonde locations (Salem, Illinois and Winslow, Arizona) had a median value in the "low" risk category.

The frequency of Haines Index values equal to 6 increases from east-to-west across eastern North America. A Haines Index value of 6 at 0000 UTC occurs on less than 0.5 percent of the days per year in northeastern North America and in the southeastern United States. The frequency increases in the Ohio Valley to approximately 1 percent of all days and to 2-3 percent of all days in the Great Lakes region and in Iowa, Illinois, and Missouri. A large gradient is observed farther west, and the frequency of high fire risk days, as indicated by the Haines Index, increases to 10-19 percent of all days in central Oklahoma and Texas.

The spatial pattern for the maximum run length of Haines Index values equal to 6 is very similar to that of the overall frequency. In northeastern Canada and extreme southern Florida, there were no consecutive days during 1961-2000 of Haines Index values equal to 6, meaning that a day with high fire risk was always followed by a decrease in fire risk the following day. Strings of days with high fire risk were also rare along the Atlantic coast of the United States where the maximum persistence was approximately 2 days. Maximum run lengths in

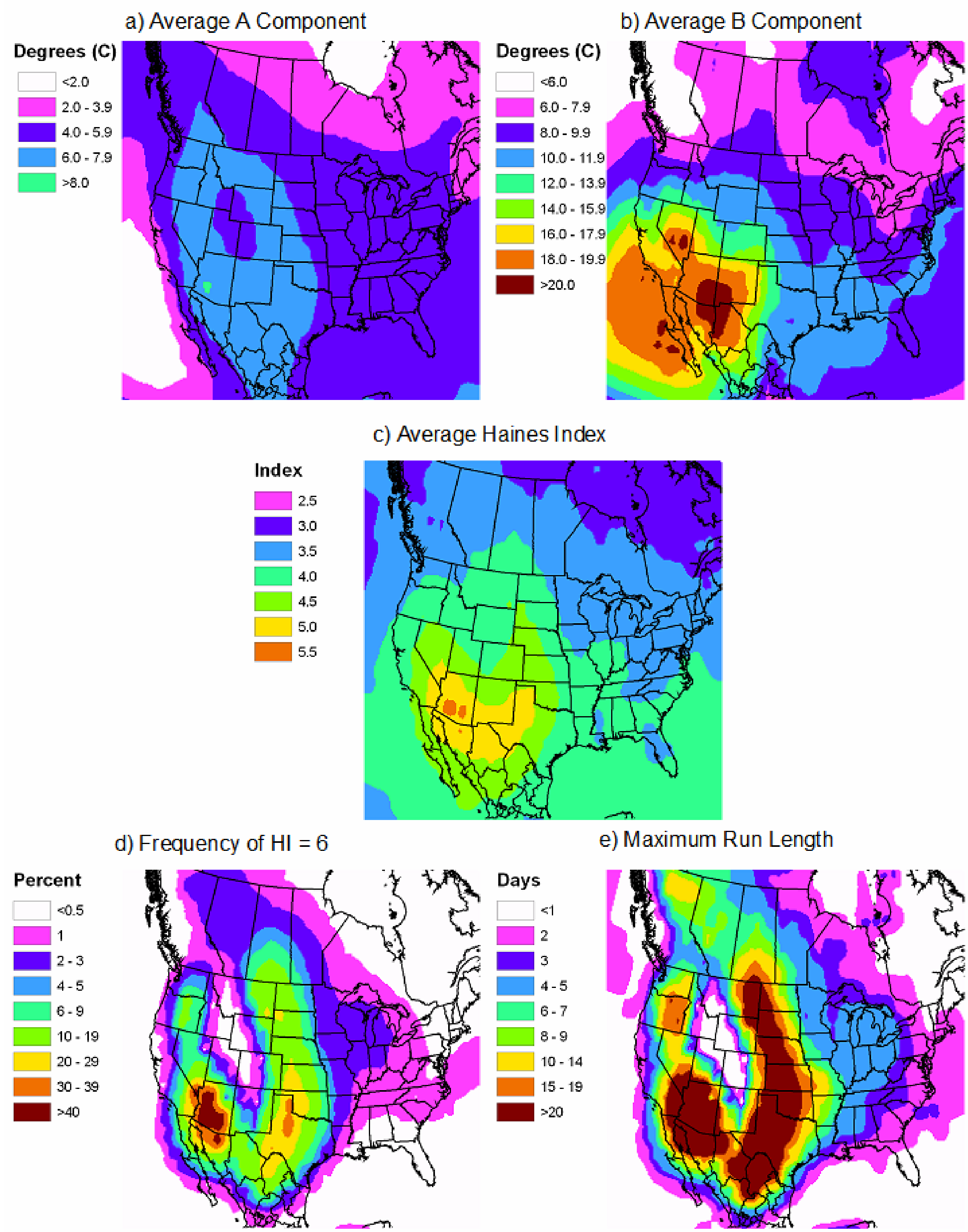

FIG. 2. Climatological characteristics of the low variant of the Haines Index for 1961-2000: a) annual mean environmental lapse rate (950-hPa temperature – 850-hPa temperature) in ^{o}C, b) annual mean 850-hPa dewpoint depression (^{o}C), c) annual mean Haines Index (low variant), d) frequency (as percent of days per year) that the Haines Index (low variant) is equal to 6, and e) maximum consecutive number of days during the 40-year period with Haines Index (low variant) values of 6 at 0000 UTC.

the Great Lakes and Ohio Valley regions were somewhat larger at 4 to 5 days. Farther west, extended periods of high fire risk occurred during the study period with the longest periods (more than 20 days) observed in central Texas and Oklahoma.

3.2 *"Mid" variant of the Haines Index*

During summer, strong east-west gradients in the climate parameters for the mid variant of the Haines Index are found across the Central Plains of North America (Fig. 3), the area in which the mid variant is the most applicable. [The mid variant of the Haines Index is also recommended for the Appalachian region of the United States and Canada (Fig. 1). However, the discussion below focuses only on the Central Plains as summer is not the primary fire season in the Appalachians.] The average environmental lapse rate between the 850-hPa and 700-hPa levels ranges from 8-10^{o}C in northern Minnesota to 12-14^{o}C from northeastern Montana southward to north central Texas. This implies that, except for northern Minnesota, the Central Plains has an average A component value of 3 in summer. Average dewpoint depressions increase westward in summer from approximately 6-7^{o}C (equivalent to a B component of 2) in northeastern Minnesota to over 14^{o}C (B component of 3) in a narrow zone extending from extreme western South Dakota to northwest Texas. Average summertime Haines Index values range from approximately 3.5 in northern Minnesota to 5.5 in northwestern Texas. The large average Haines Index values in the western part of the mid Haines region result from both large environmental lapse rates and large dewpoint depressions, and suggest that on average the extreme western Central Plains has a moderate to high risk of plume-driven fires during summer, at least as measured by the Haines Index. These averages are higher than the median values in the Haines (1988) climatology. Approximately 60% of his climate days fell into the "very low" category, i.e., Haines Index values of 2 or 3.

Not surprisingly given the relatively large average values during summer, Haines Index values equal to 6 are frequent in the Central Plains, except in northeastern Minnesota, where values of 6 at 0000 UTC are observed on less than 3 percent of all summer days. Elsewhere, the frequency of days with a high risk for plume-driven fires increases from approximately 5 percent of all summer days in the eastern Central Plains (eastern Dakotas to central Texas) to over 40 percent of all summer days in the western Central Plains (northeastern Montana to northwestern Texas). Maximum run lengths during the study period range from 3 or few days in northeastern Minnesota to over 20 days in the western portion of the Central Plains.

3.3. *"High" variant of the Haines Index*

Summertime average environmental lapse rates for the high version of Haines Index exceed 16^{o}C across western North America (Fig. 4). These larger values, compared to the temperature differences for the low and mid variants, reflect the thicker layer (700 hPa to 500 hPa) over which the high variant of the Haines Index is calculated. The largest values are located in the Great Basin along the border between Utah and Colorado. Here the average environmental lapse rate is $\geq$22^{o}C which corresponds to an A component value of 3. The largest dewpoint depressions are over the coast, particularly in northern and central California where the average 700-hPa dewpoint depression exceeds 21^{o}C (equivalent to a B component of 3). Summertime average dewpoint depressions are relatively small (<14^{o}C; B component of 1) over northwestern Canada, the Northern Rockies, and the Front Ranges of the Rocky Mountains. Larger average values (15-20^{o}C; B component of 2) are found in the Great Basin, especially southwestern Utah and southern Nevada.

Summertime average Haines Index values fall within the "very low" or "low" categories for much of western North America. Average values are lowest in western Canada, the Pacific Northwest, and the Northern Rockies, primarily because of high humidity at 700 hPa in these areas. Average Haines Index values in excess of 4.0 are found in the Great Basin, specifically Utah, where both the environmental lapse rate and the dewpoint depression tend to be relatively large.

For a large portion of the Great Basin and the central and southern Rocky Mountains, there is a high fire risk on more than 10 percent of all summer days. In western Colorado, southern Utah, and eastern Nevada, over 20 percent of summer days have Haines Index values equal to 6. In contrast, less than 0.5 percent of all summer days in western Canada, Washington state, and northwestern Oregon report Haines Index values of 6 at 0000 UTC, and the Northern Rockies of the United States experience high fire risk on only 1-5 percent of summer days. The spatial pattern of the maximum run length of Haines Index values of

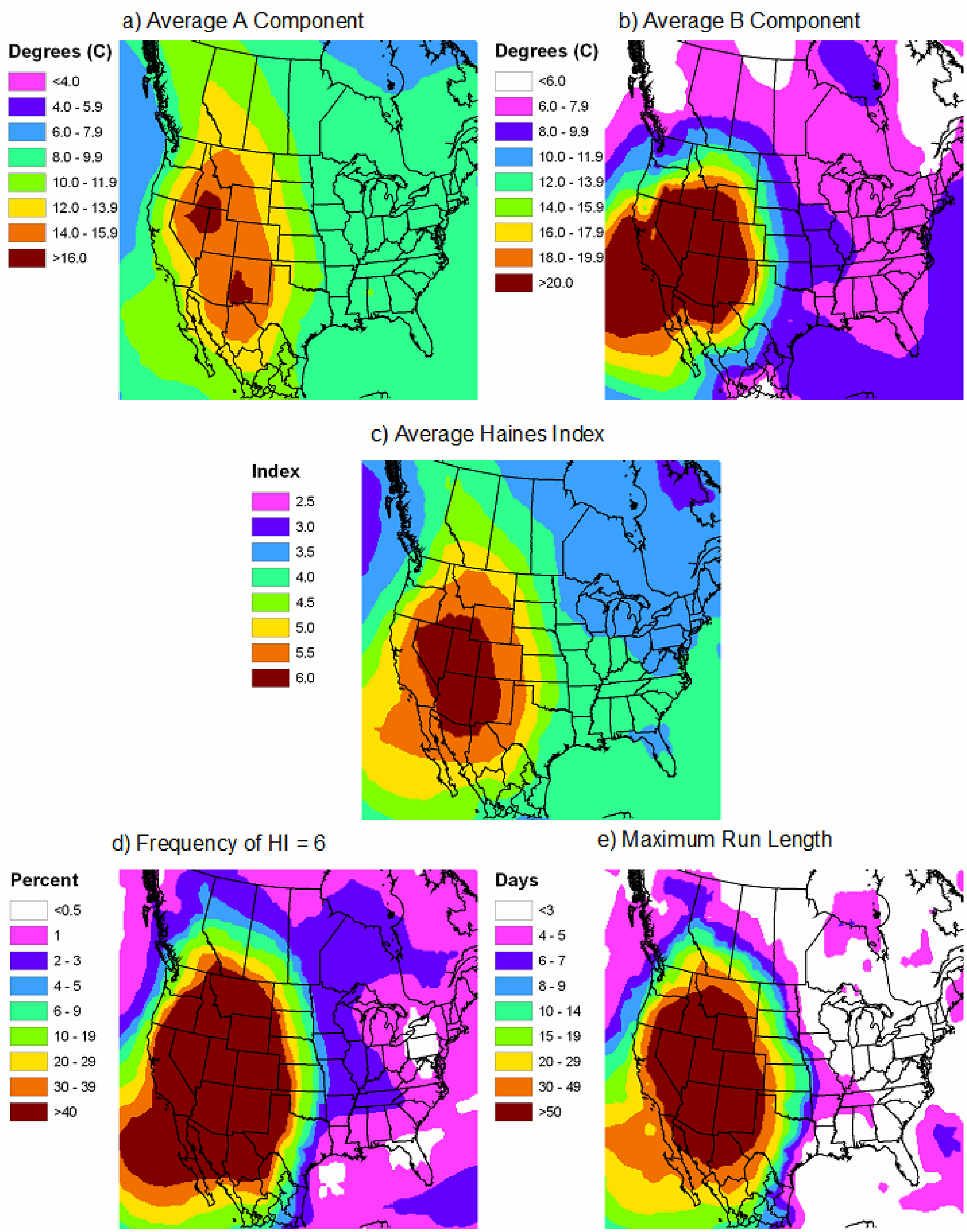

FIG. 3. Climatological characteristics of the mid variant of the Haines Index in summer (June, July, August) for 1961-2000: a) summer mean environmental lapse rate (850-hPa temperature – 700-hPa temperature) in ^{o}C, b) summer mean 850-hPa dewpoint depression (^{o}C), c) summer mean Haines Index (mid variant) , d) frequency (as percent of days per summer) that the Haines Index (mid variant) is equal to 6, and e) maximum consecutive number of days in summer during the 40-year period with Haines Index (mid variant) values of 6 at 0000 UTC.

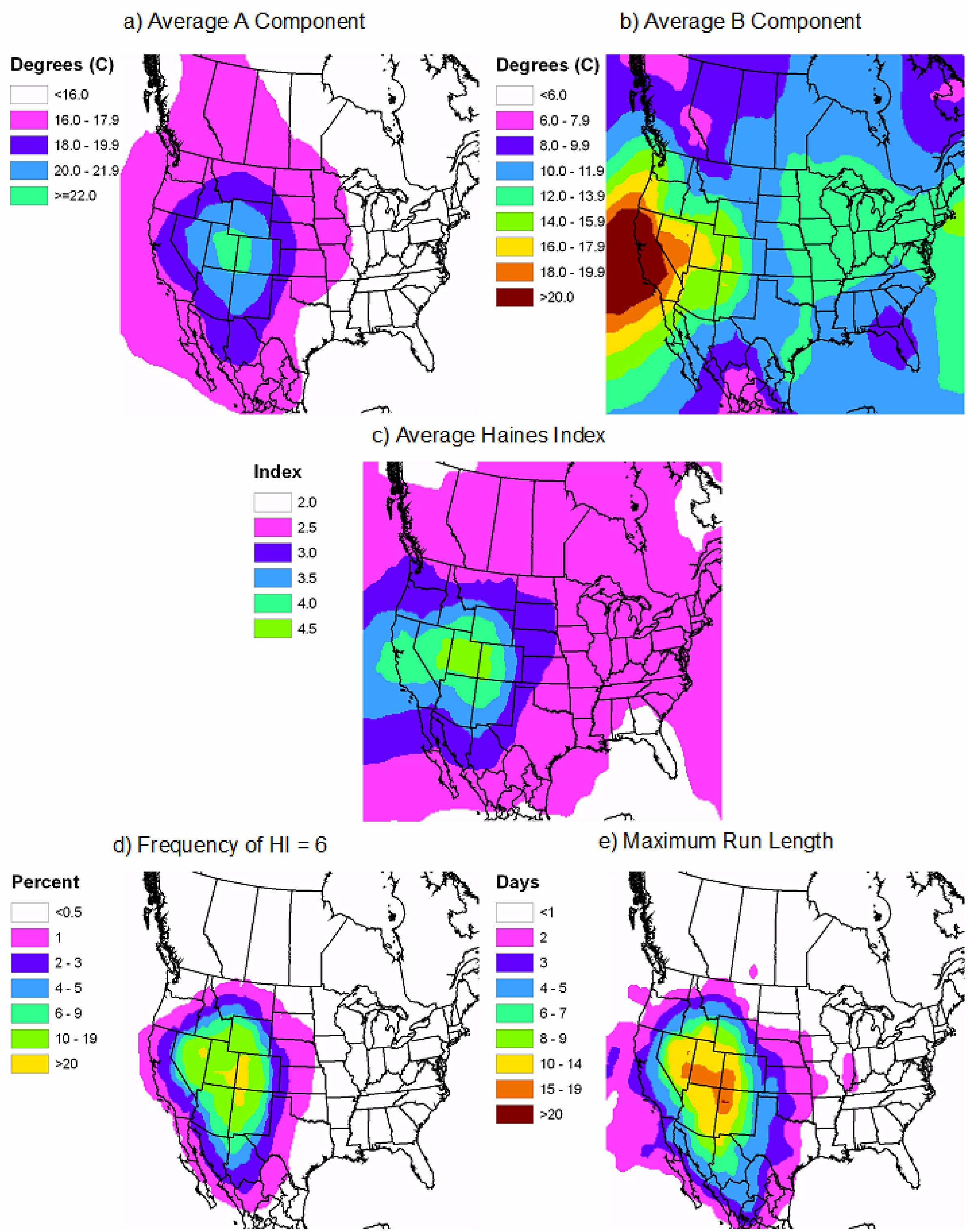

FIG 4. Climatological characteristics of the high variant of the Haines Index in summer (June, July, August) for 1961-2000: a) summer mean environmental lapse rate (700-hPa temperature – 500-hPa temperature) in ^{o}C, b) summer mean 700-hPa dewpoint depression (^{o}C), c) summer mean Haines Index (high variant), d) frequency (as percent of days per summer) that the Haines Index (high variant) is equal to 6, and e) maximum consecutive number of days in summer during the 40-year period with Haines Index (high variant) values of 6 at 0000 UTC.

6 is almost identical to that for the frequency of high risk Haines Index values. Maximum run lengths during 1961-2000 were largest in the Great Basin where they approached 20 days. On the other hand, a high risk day in western Canada was rarely, if ever, followed by a second day of elevated risk.

4. DISCUSSION AND CONCLUSIONS

The climatological analyses presented here, along with those for the additional statistical measures that will be included in the electronic atlas, provide fire managers with useful information for interpreting and evaluating Haines Index forecasts. Inclusion of monthly analyses in the atlas will allow fire managers to focus more precisely on the fire season at their location.

Haines (1988) set the thresholds demarcating values of 1, 2, and 3 for the lapse rate (A) and humidity (B) components so that most fire days fall into the highest (3) category for each component. At the same time, he wanted the final index (A+B) to equal 6 on only a small number of days per year. Adding another restraint, he strove to define an index that used only temperature and humidity measurements at commonly available pressure levels. The climatological maps indicate that the balance among these objectives was not always achieved, particularly in the Central Plains where the mid variant of the Haines Index is used. Only the extreme eastern edge of this region experiences Haines Index values equal to 6 infrequently. For most of the region, values of 6 occur on more than 20 percent (and in some places on more than 40 percent) of summer days. Similar high frequencies are found along the extreme western edge of the low variant region and in the Great Basin where the high variant of the Haines Index is used. A spatially and temporally extensive climatology, as presented here, can help users interpret the meaning and significance of high Haines Index values for their region.

A next step in the analysis is to compare the climatological values for selected grid points in the reanalysis to those for nearby radiosonde stations in order to evaluate the impact of the choice of data set on the resulting climatology. An initial comparison of our results with those of the radiosonde-based six-year climatology of the Haines Index produced by Werth and Werth (1998) for the Western United States reveals striking similarity. In particular, their maps of the frequency of Haines Index values $\geq$5 in the summer months display similar spatial patterns as the summertime map of values equal to 6 for the high variant of the Haines Index shown here. Their analyses, like ours, also point to very large 700-hPa dewpoint depressions in summer over California.

The analyses shown here, along with those that will appear in the electronic atlas, address important considerations for the operational use of the Haines Index. The analyses reveal substantial variations in the climatological characteristics of the Haines Index between and within the three elevation variants. Additionally, important intra-annual variations are seen for a given location.

These variations complicate the use and proper interpretation of the Haines Index. Some users want a "universal method", where the Haines Index is calculated the same everywhere and a value of 6 indicates similar environmental lapse rates and dewpoint depressions regardless of location. For these users, the thresholds for a particular variant of the Haines Index would be kept constant, similar to what is done today. But as illustrated by the results herein, the use of constant thresholds for the A and B components leads to wide variations in the frequency of Haines Index values of 6 from place to place.

On the other hand, some users prefer a "universal meaning", in the sense that Haines Index values of 6 indicate the same percentile of extreme instability and moisture conditions at all locations. This goal is only possible if every location uses unique thresholds for the A and B components. Setting these thresholds would require a major research undertaking including the measurement of temperature and dewpoint temperature a kilometer or more above the surface for an extended period. Furthermore, there is no guarantee that the thresholds determined for a site would remain stable over time. These same concerns lie behind the National Fire Danger Rating System pocket cards. Pocket cards developed for individual forests or parts of the country allow an individual to see what constitute "normal" values of various indices for that place and at various times of the year. The climate atlas of the Haines Index will serve much the same purpose. It will provide context for the fire fighter, manager, or forecaster to understand what today or tomorrow's Haines Index means for their situation.

5. ACKNOWLEDGEMENTS

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