Final Report for Joint Fire Science Program Project 03-1-1-37

Project Title: Atmospheric Fire Risk (Haines Index) in a Changed
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Introduction

Previous studies of wildland fire potential under a perturbed climate have focused on potential changes in near-surface atmospheric parameters (e.g., temperature, humidity, and precipitation) and vegetation changes. However, above-ground atmospheric conditions, such as atmospheric stability, also play a critical role in fire behavior, especially for larger fires. This study employed the widely-used Haines Index as a measure of above-ground conditions relevant to wildland fire and investigated the potential changes in the Haines Index over the next 100 years. The analysis is based on simulations from the most recent version of the National Center for Atmospheric Research (NCAR) Community Climate System Model (CCSM3.0), and considers potential future changes in the frequency, magnitude, and duration of periods with high fire potential. An additional important component of this work was the development of a 40-year (1961-2000) baseline climatology of the Haines Index against which projected future changes can be compared.

Synopsis of Key Research Findings

The findings of this study revolve around three themes: 1) the climatology of the Haines Index for North America, 2) methods for calculating the low elevation variant of the Haines Index, and 3) future changes in wildfire potential as measured by the Haines Index and its individual components (i.e., environmental lapse rate and dewpoint depression). The major research objectives and findings for each theme are summarized below. Further details of the analysis along with example output are provided in the *Narrative* that follows the *Deliverables Crosswalk Table*.

1) Historic (1961-2000) Haines Climatology

A baseline climatology is essential in order to validate simulations from Global Climate Models (GCMs) and to compare future changes in the Haines Index. In addition, a long-term climatology is useful for fire managers to evaluate observed and short-range forecasted values of the Haines Index. To meet these needs, we developed a climatology of the Haines Index for the period 1961-2000 for North America. The climatology was derived from NCEP/NCAR reanalysis fields, which are a hybrid of atmospheric observations and short-range simulations from a global forecast model. The climatology is displayed as a web-based, easy-to-use atlas. The atlas includes over 3,000 maps of the mean, median, standard deviation, and percentiles for the lapse rate and dewpoint depression components used to calculate the index and for the Haines Index itself. The atlas also includes the frequency and persistence of moderate and high Haines Index values. The climatology provides numerous insights on the nature of the Haines Index. In general, the climatology indicates that the ability of the Haines Index to discriminate between days with unusual stability and humidity conditions varies spatially across North America. In particular, it is often difficult to isolate the influence of atmospheric circulation on fire potential because of the strong association of large index values with elevation. The discriminatory power of the Haines Index is least in the westernmost portion of the low elevation Haines region, specifically in eastern Oklahoma and Texas, and in the Central Plains where the mid elevation variant of the Haines Index typically is used. For example, in the mid elevation region, large index values (e.g., values of 5 or 6) are not able to distinguish days with typical stability and humidity conditions from those with unusual conditions.

2) Sensitivity of the Low Elevation Variant of the Haines Index to Calculation Method

As originally formulated, the low elevation variant of the Haines Index is calculated from temperature observations at the 950-hPa and 850-hPa levels and from humidity observations at 850 hPa. In the early 1990s the National Weather Service discontinued recording data at 950 hPa as part of their standard upper-air observation, instead implementing a new standard level at 925 hPa. Since this change, there has not been an accepted method for calculating the low variant of the Haines Index. Some forecast and fire management offices directly substitute the 925-hPa observation for the 950-hPa value, whereas others interpolate the 950-hPa value from surrounding observations. Because we needed to compute the Haines Index from records that only included 925-hPa temperatures, we investigated the impact of different calculation approaches on the resulting values of the low variant of the Haines Index. Results show that direct substitution of the 925-hPa temperature for the 950-hPa temperature can dramatically underestimate potential wildfire severity compared to the original formulation of the Haines Index. On the other hand, a low elevation variant of the Haines Index calculated from interpolated 950-hPa temperature is usually in close agreement with the original formulation of the index.

3) Future Changes in the Haines Index

Recent simulations from a global climate model (GCM) were used to investigate how the atmospheric component (i.e., stability and dryness) of wildland fire potential may change in the future. The GCM used in the analysis is the NCAR CCSM3.0 model. The simulations were run by the model developers for the period 2000-2099 as part of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment. The simulations employed the A1B greenhouse gas emission scenario which assumes rapid economic growth, high energy demand and a large increase in CO_2 emissions in the early portion of the

21st century, and balanced alternative energy supply technologies. The CCSM3.0 simulations were obtained from NCAR and analyzed two ways. First, the relatively coarse-scale (approximately 1.5^o latitude by 1.5^o longitude) output was analyzed directly. In other words, daily values of the Haines Index were calculated for each grid point over North America and then summarized by 20-year overlapping periods from 2000-2009 out to 2090-2099. Second, meteorologists at the U.S. Forest Service North Central Research Station, in cooperation with this project, used the NCAR CCSM3.0 output to drive a regional climate model (RCM) with a resolution of 36 km. The RCM was run for two time slices: a control period of 1990-1999 and a future time slice of 2045-2054. For both types of analyses, future changes were estimated as “deltas” between a future period and a control (1990-1999) period in order to remove systematic biases in the GCM and RCM simulations.

In general, the GCM and RCM simulations for the 1990-1999 control period capture the overall spatial patterns of the environmental lapse rate (A component) and dewpoint depression (B component) used to calculate the Haines Index. However, the magnitudes of both components, but particularly the dewpoint depression, are larger for the control period compared to observed climatological values. As a result, Haines Index values for the control period generally are larger than climatological values, although the difference is less for the mid elevation variant of the Haines Index compared to the low and high elevation variants. The projections for the future period suggest that changes in wildland fire potential, as reflected by the Haines Index, are more modest compared to changes suggested by earlier studies that focused on surface conditions. Nonetheless, the projected changes as simulated by the NCAR CCSM3.0 model suggest for some locations, especially the mountainous regions of the United States, an elevated wildfire potential. For example, delta values for 2045-2054 imply that the largest changes in the average summertime value of the Haines Index will occur in the Pacific Northwest, Northern Rockies, and south central Canada. Another interesting projection is that, with the exception of Florida, the annual frequency of very high (=6) Haines Index values in 2045-2054 will be smaller than at present in the southeastern United States. On the other hand, the maximum run length of very high Haines Index values is projected to increase substantially over the Ohio Valley region and the central Rockies.

Technology Transfer

As outlined in the initial proposal, multiple approaches were used to disseminate the results of this study, including web sites, paper publications, and oral and poster presentations. The papers and presentations have appeared in both scientific peer-reviewed outlets, to increase scientific scrutiny and review of the findings, and in management-targeted outlets, to ensure that the work is available and understandable to practitioners in the field. Details of the products from this study appear in the following *Deliverables Crosswalk Table*. One technology transfer opportunity not foreseen at the outset was the opportunity to examine and promote the best method to compute the low elevation Haines Index, now that the National Weather Service does not report all of the variables used in the original formulation of the index. This information is being shared with the operational meteorology community and should lead to more consistent calculations across the eastern U.S.

Deliverables Crosswalk Table

Proposed	Delivered	Status
Web sites	1) http://www.haines.geo.msu.edu 2) http://www.airfire.org/haines 3) http://www.haines.geo.msu.edu	(1) Done. This is the general project website. (2) Done. This is the historic climatology atlas. (3) To be completed. Selected maps of the future changes in the Haines Index will be placed on the project website for general use.
Peer-reviewed journal papers	Winkler, J., H. Prawiranata, K., Pirimsopa, X. Bian, and B. Potter, no date. Analysis of future atmospheric fire potential I: NCAR CCSM3 analyses. Proposed outlet: *Journal of Climate*.	In progress
	Bian, X., B. Potter, H. Prawiranata, K. Pirimsopa, J. Winkler, no date. Analysis of future atmospheric fire potential II: Regional climate model analyses. Proposed outlet: *Journal of Climate*.	In progress
	Potter, B.E., J.A. Winkler, D.F. Wilhelm, R.P. Shadbolt, and X. Bian, no date: Computation of the low elevation variant of the Haines Index for fire weather forecasts. *Weather and Forecasting*, in press.	In press
	Winkler, J.A., B.E. Potter, D.F. Wilhelm, R.P. Shadbolt, K.	In print

	Piromsopa, and X. Bian, 2007: Climatological and statistical characteristics of the Haines Index for North America. *International Journal of Wildland Fire*, 16, 139-152.	
Management-level papers	Potter, B.E., J.A. Winkler, K. Piromsopa, R.P. Shadbolt, D.F. Wilhelm, and X. Bian, no date. A 40-year climatology of the Haines Index. Proposed for a General Technical Report or *Fire Management Today*. Potter, B.E., J.A. Winkler, D.F. Wilhelm, R.P. Shadbolt, 2007: Computing the low elevation Haines Index. *Fire Management Today*, 67, 40-43.	In progress In print
Conference Proceedings	Winkler, J.A., B.E. Potter, R.P. Shadbolt, D.F. Wilhelm, X. Bian, and K. Piromsopa, 2005. A climatology of the Haines Index for North America derived from NCEP/NCAR reanalysis fields. *Preprints*, Sixth Fire and Forest Meteorology Symposium/19th Interior West Fire Council Meeting, American Meteorological Society, Canmore, Alberta, Canada. Potter, B.E., J.A. Winkler, D.F. Wilhelm, R.P. Shadbolt, 2005: Computation of the low elevation Haines Index. *Preprints*, Sixth Fire and Forest Meteorology Symposium/19th Interior West Fire Council Meeting, American Meteorological Society, Canmore, Alberta, Canada.	Done Done
Conference presentations (oral and poster	*Conference presentations on <u>future</u> changes in wildland fire*	

presentations)	*risk:*	
	"Future climate and the Haines Index as simulated by the NCAR CCSM3.0 general circulation model" (B. J. Winkler, H. Prawiranata, K. Piromsopa, and X. Bian). Seventh Fire and Forest Meteorology Symposium. American Meteorological Society, October 2007. (Oral presentation)	Scheduled for October 2007.
	"The Impact of Climate Change on Fire Weather as Predicted by a Regional Climate Model" (X. Bian, B. Potter, K. Piromsopa, H. Prawiranata, and J. Winkler). Seventh Fire and Forest Meteorology Symposium, American Meteorological Society, October 2007. (Poster presentation)	Scheduled for October 2007.
	"Regional Climate Change Impact on Fire Regimes in Midwest and Eastern United States" (X. Bian, W. Heilman, S. Zhong and J. Winkler). Seventh Fire and Forest Meteorology Symposium, American Meteorological Society, October 2007. (Poster presentation)	Scheduled for October 2007.
	Conference presentations on the climatology of the Haines Index:	
	"A Climatology of the Atmospheric Component of Wildland Fire Risk" (D.F. Wilhelm, B.E. Potter, J.A. Winkler, and R.P. Shadbolt). 102nd Annual Meeting of the Association of American Geographers, Chicago, Illinois, March 2006. (Oral presentation)	Done

	"A Climatology of the Haines Index for North America derived from NCEP/NCAR Reanalysis Fields" (J.A. Winkler, B.E. Potter, R.P. Shadbolt, D.F. Wilhelm, X. Bian, and K. Piromsopa). Sixth Fire and Forest Meteorology Symposium/19th Interior West Fire Council Meeting, American Meteorological Society, Canmore, Alberta, Canada, October 2005. (Oral presentation) *Conference presentations on the calculation of the low Haines Index:* "Computation of the Low Elevation Haines Index for Wildfire Risk" (B.E. Potter, J.A. Winkler, D.F. Wilhelm, and R.P. Shadbolt). 102nd Annual Meeting of the Association of American Geographers, Chicago, Illinois, March 2006. (Poster presentation) "Computation of the Low Elevation Haines Index" (B.E.Potter, B.E., J.A. Winkler, D.F. Wilhelm, R.P. Shadbolt). Sixth Fire and Forest Meteorology Symposium/19th Interior West Fire Council Meeting, American Meteorological Society, Canmore, Alberta, Canada, October 2005. (Poster presentation)	Done Done Done
Presentations to user groups	Presentation of results to Program Meteorologists and Intelligence Officers from Geographic Area Coordination Centers at a meeting or	Scheduled for November 2007

	workshop (B. Potter) “Forty Years of Context for the Haines Index” (J.A. Winkler, B.E. Potter, D.F. Wilhelm, R.P. Shadbolt, K. Piromsopa, and X. Bian). Eastern Area Modeling Consortium, U.S. Forest Service North Central Research Station, East Lansing, Michigan, June 2006. (Oral presentation) “Atmospheric Fire Risk in a Changed Climate” (J.A. Winkler, B.E. Potter, X. Bian, K. Piromsopa, R.P. Shadbolt, and D.F. Wilhelm). Eastern Area Modeling Consortium, U.S. Forest Service North Central Research Station, East Lansing, Michigan, June 2006. (Oral presentation) “Atmospheric Fire Risk in a Changed Climate” (J.A. Winkler, B. Potter, X. Bian, K. Piromsopa, R. Shadbolt, and D. Wilhelm). Presentation to the Joint Fire Science Principal Investigators Meeting. San Diego, CA, November 2005. (Oral presentation) “Atmospheric Fire Risk in a Changed Climate” (J.A. Winkler). Paper presented at the Eastern Area Modeling Consortium, U.S. Forest Service North Central Research Station, East Lansing, Michigan, June 2005. (Oral presentation)	 Done Done Done Done

NARRATIVE

1) Haines Index Climatology

As noted above, at the start of this project a comprehensive, long-term, and spatially-extensive climatology of the Haines Index did not exist for North America. The development of a baseline climatology was added to the project work plan, as a climatology is essential for evaluating any future changes in the Haines Index. At the time the proposal was written, we thought that earlier analyses of radiosonde (i.e., balloon) observations would be sufficient for a baseline. However, these analyses, when examined in detail, were incomplete and questions were raised regarding the accuracy of some of the previous analyses. Also, given the long-term need in the predictive services community for a Haines Index climatology, we elected to not only develop a baseline climatology, but to also expend the additional effort to compile the climatology into a accessible, web-based atlas. The additional climatological analyses along with the substantial cartographic work to present the analyses in an understandable and attractive format represent a large time investment, but one that we feel was worthwhile.

The climatology focuses on annual, seasonal, and monthly variations in the characteristics of the Haines Index. Several different parameters were included in the climatology including standard statistical measures such as mean, median, standard deviation, and percentiles. In addition, frequency and persistence measures are provided for Haines Index values ≥4 ('moderate' or greater potential of plume-dominated fires), ≥5 ('high' or 'very high' potential), and =6 ('very high' potential). All analyses are in map format and are displayed on an Albers map projection.

Examples from the 3000+ maps in the web atlas are shown in Figure 1. These maps illustrate the types of inference that can be made regarding the spatial and temporal variations of the Haines Index. For example, the maps in Figure 1 show that:

- The low elevation variant of the Haines Index was ≥5 on 30 to 60% of all days in eastern Oklahoma and Texas, suggesting that even moderately high values of the low Haines Index are not particularly good discriminators of atypically favorable conditions for large or erratic plume driven fires in this area (Figure 1a).

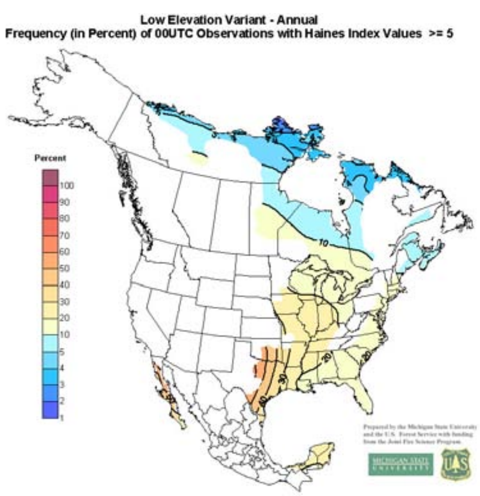
- For many areas of the eastern United States, a day with very high fire potential is unlikely to be followed by a second such day (Figure 1b). In contrast, extended (>20 days) periods of very high fire potential were observed in central Texas and Oklahoma.

- A strong east to west gradient in the mean value of the mid elevation variant of the Haines is found across the Central Plains of North America (Figure 1c). Average values range from approximately 3.5 in northeastern Minnesota to 5.5 in northwestern Texas.

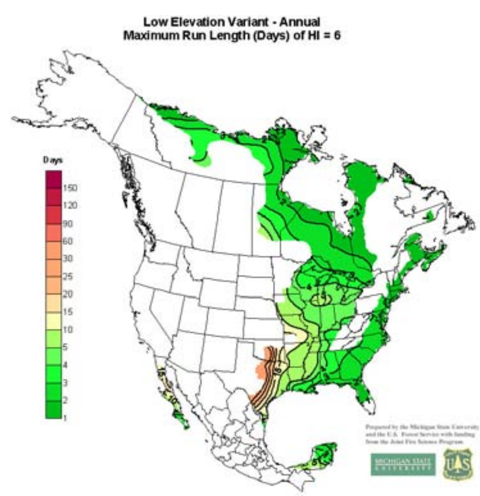
- The large average values of the mid elevation variant of the Haines Index in the western portion of the Central Plains result from both large environmental lapse rates and large dewpoint depressions (Figure 1d).

- Summertime average values of the high elevation variant of the Haines Index fall within the 'very low' or 'low' categories for much of western North America (Figure 1e). Average values are lowest in western Canada, the Pacific Northwest, the Northern Rockies, and central Mexico primarily because of high relative humidity at the 700 hPa level in these areas. Average Haines Index values in excess of 4 are found in the Great Basin, specifically Utah, where both the environmental lapse rate and the dewpoint depression tend to be relatively large.

- The frequency of very high potential for plume-dominated wildfires is large over western Colorado, southern Utah, and eastern Nevada, where over 20% of summer days have Haines Index values equal to 6 (Figure 1f). In contrast, large Haines Index values are infrequent in western Canada and southern Mexico.



(a)



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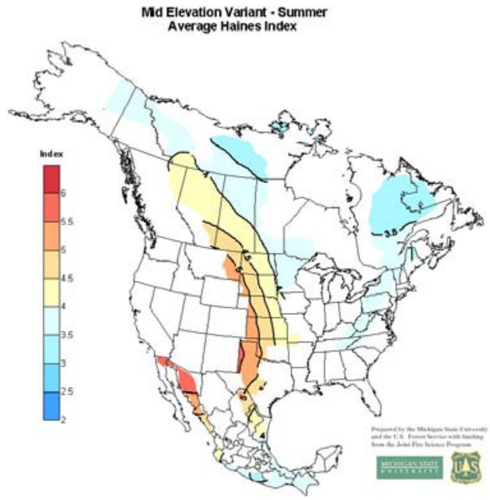

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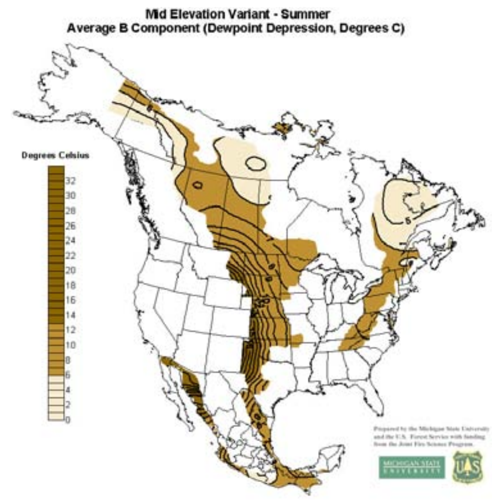

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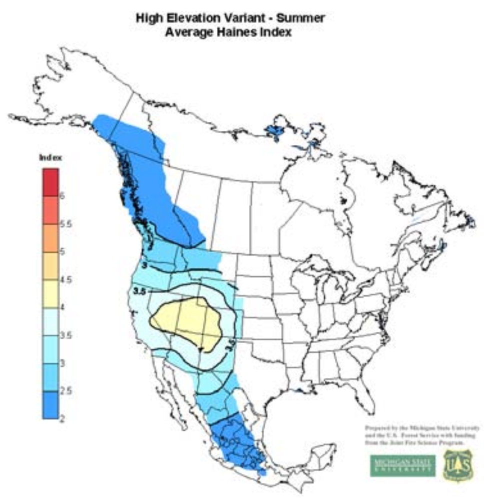

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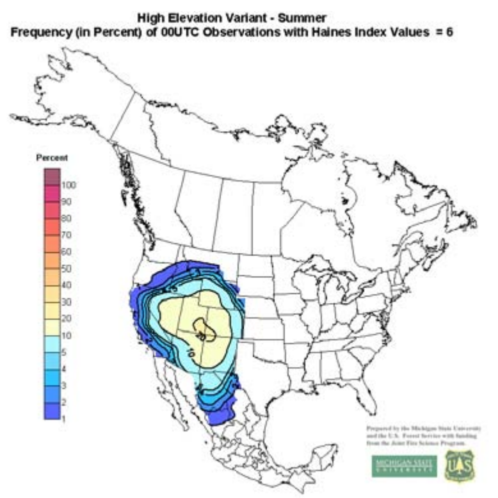


(f)

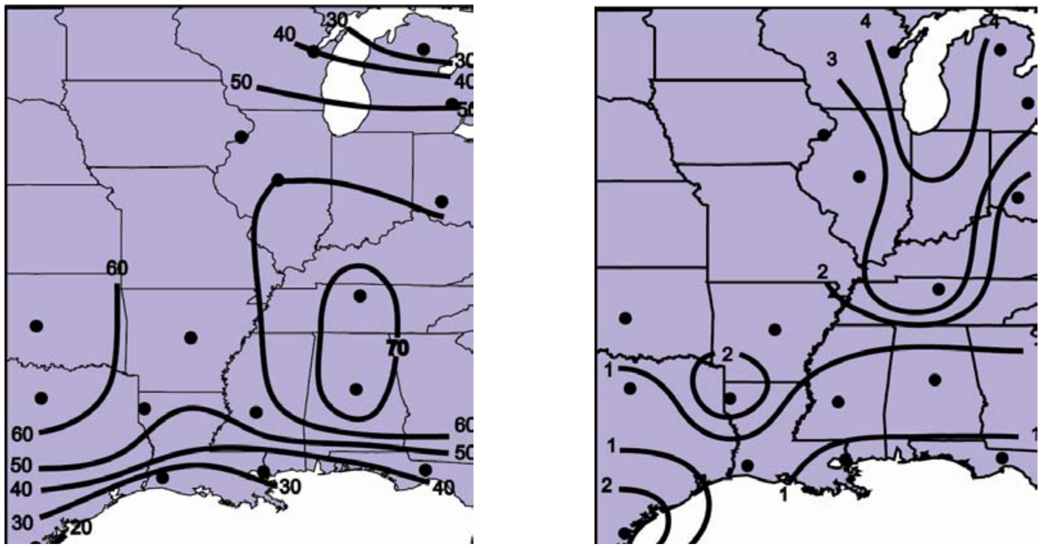
Figure 1. Example maps from the 1961-2000 climatology of the Haines Index: (a) annual frequency of low elevation Haines Index values greater than or equal to 5; (b) maximum run length of low elevation Haines Index values equal to 6, c) mean summertime value of the mid elevation variant of the Haines Index, d) average summertime value of the B (dryness) component of the mid elevation Haines Index, e) mean summertime value of the high elevation variant of the Haines Index, and f) summer frequency of high elevation Haines Index values equal to 6.

2) Calculation of the Low Elevation Variant of the Haines Index

In the process of preparing the Haines Index climatology, we discovered that the low elevation variant was not calculated uniformly at National Weather Service and Forest Service offices. Furthermore, the ability of alternative calculation methods to reproduce the original Haines Index had not been systematically evaluated. As originally formulated, the “low” variant was calculated from temperature observations at the 950-hPa 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, and following this change, measurements at 950 hPa became less frequent. An informal survey found that some sources of observed and forecasted Haines Index values continue to use 950-hPa temperature, usually interpolated from 925-hPa and surface temperatures, to calculate the low Haines Index, whereas others directly substitute the 925-hPa temperature for the originally specified 950-hPa value. 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, different approaches to calculating the low variant of the Haines Index were compared.

Comparison of alternative calculation methods required upper-air soundings with temperature observations at both the 950-hPa and 925-hPa levels. Twice-daily (00 UTC and 12 UTC) soundings for 1958-2000 at 18 radiosonde stations within the low variant region were searched for observations at both pressure levels. These stations are a subset of radiosonde stations located in the central United States that had been used for a previous research project by one of the PIs (Winkler) and that were carefully analyzed for station relocations and missing observations. A total of 80,974 soundings were included in the analysis; the majority came from the period 1992-1997, shortly after the time the 925-hPa level was introduced as a mandatory level.

Results show that direct substitution of 925-hPa temperature for the 950-hPa temperature can dramatically underestimate potential wildfire severity compared to the original formulation of the Haines Index (Figure 2a). On the other hand, a low elevation variant of the Haines Index calculated from interpolated 950-hPa temperature is usually in close agreement with the original formulation of the index (Figure 2b). 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. We communicated our results to the Missoula Fire Lab, which has now changed their calculation method for the low variant of the Haines Index.



(a) (b)

Figure 2. Error frequency (%) for spring for alternative methods of calculating the low elevation Haines Index. (a) Error using 925 hPa temperature directly, (b) error when 950 hPa temperature is interpolated from surface and 925 hPa temperature. Both cases are compared against the original method of calculation using measured 950 hPa temperature.

3) Future Changes in Wildfire Potential

In our original proposal, we indicated that we would use the Canadian Climate Centre CGCM1 simulation with a one percent per annum increase in carbon dioxide as the primary GCM simulation to estimate potential future changes in wildfire risk. This decision was based solely on availability, as at the time the proposal was written the CGCM1 model was the only one for which we could obtain output for the multiple levels in the atmosphere (i.e., 950, 850, 700, and 500 hPa) needed to calculate the Haines Index. We also proposed to supplement the CGCM1 simulation with simulations from at least one additional GCM, although we would need to empirically-derive the temperature and dewpoint temperature for some of the levels used in the Haines Index calculation.

After the proposal was submitted, simulations from the NCAR CCSM3.0 model became available to climate change impact analysts, and we made the decision to use these simulations instead of the originally proposed CGCM1 simulations. The primary reason behind this choice is that the CCSM3.0 is a much newer model compared to CGCM1. The CCSM3.0 simulations were run as part of the recently released Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment, whereas the CGCM1 simulations date back to the IPCC Second Assessment. Also, the CCSM3.0 simulations were driven using the more recent SRES greenhouse gas emission scenarios (specifically the A1B scenario), whereas the CGCM1 simulations were driven with the older IS92a scenario. A third reason for the change was that as part of another research project one of the PIs (Winkler) found that the CGCM2 model, which is a more recent version of CGCM1, considerably overestimated lower tropospheric humidity during summer over the Great Lakes region (and probably other regions as well, although this was not investigated). Finally, the CCSM3.0 model has a much finer spatial resolution compared to the CGCM1 model, which eliminated the necessity to downscale simulations to rawinsonde locations or to the grid point locations of the NCAR/NCEP reanalysis fields, as originally proposed.

One “casualty” of this change was that we were unable to supplement the CCSM3.0 simulations with runs from other GCMs in order to estimate uncertainty. Downloading the CCSM3.0 files from the NCAR data archive for a 120-year period (1980-2100), over 100 gbytes of data, was a much more time consuming process than we had anticipated, and we encountered substantial problems with data transmittal speeds and data storage. Also, the daily, multi-level data needed to calculate the Haines Index were not yet available for other model runs that were prepared for the IPCC Fourth Assessment, meaning that any supplemental simulations would have to be older, Third Assessment era simulations. Given these constraints, we made the decision to focus only on the CCSM3.0 simulations. This, of course, precludes any uncertainty estimates of future Haines Index values, but we strongly feel that the switch to the more recent, finer resolution primary simulation was the appropriate choice. Hopefully, future resources will be available to extend the analysis to simulations from several GCMs.

The daily gridpoint values from the CCSM3.0 simulation for 2000-2099 were interpolated to the pressure levels used to calculate the low, mid, and high elevation variants of the Haines Index. The A and B components and Haines Index values then were summarized for 10-year overlapping periods (2000-2009, 2001-2010, … 2090-2099). In addition, index values were calculated for a 1990-1999 control period. The same statistical measures used for the Haines Index climatological atlas (described above) were calculated for each overlapping period. Because of the number of possible maps is in the tens of thousands, we have focused on a few statistical measures for two future time slices, the 2045-2054 and 2090-2099 periods. The measures selected are those that we used in our publication in the *International Journal of Wildland Fire* on the Haines Index climatology. Please see Figure 3 for an example plot for the 2045-2054 period. These maps are supplemented by time series plots for selected grid points (Figure 4). If resources become available later, maps and time series plots of other variables and for more time periods can be prepared.

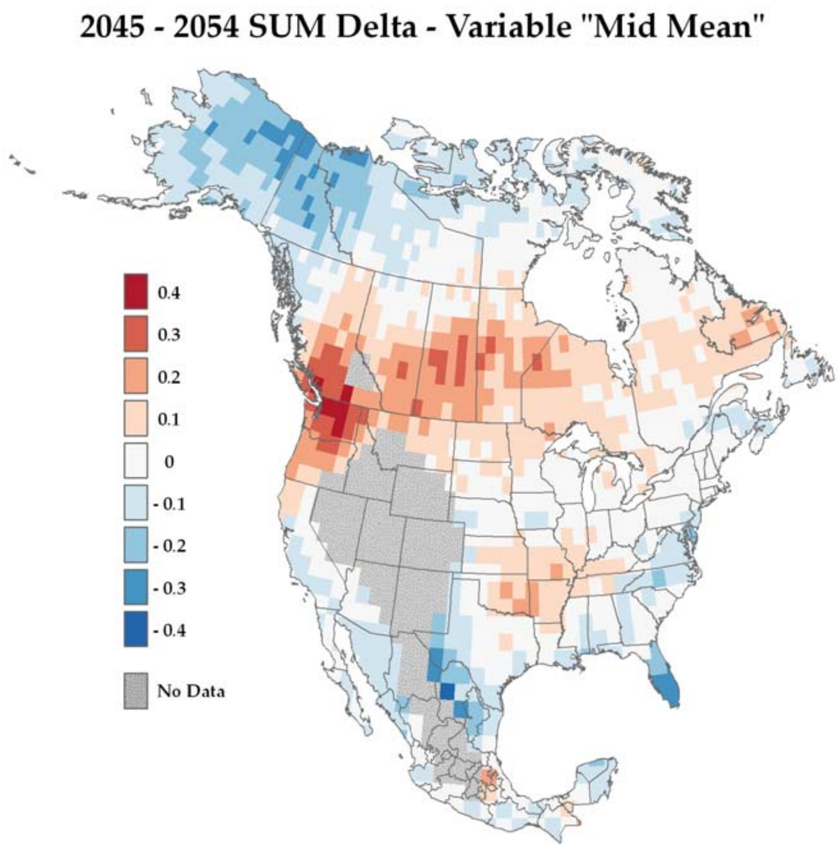


Figure 3. Projected change for 2045-2054 in the summertime average value of the mid elevation variant of the Haines Index. Grey stippling indicates those grid points where the pressure was less than 850 hPa.

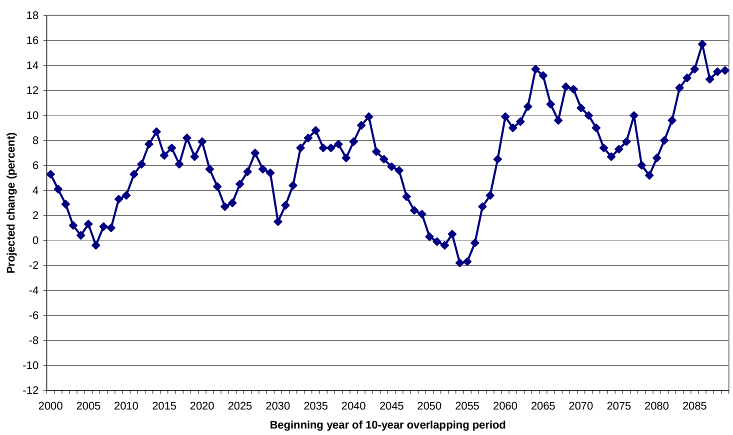


Figure 4. Projected change in the frequency of high elevation Haines Index values equal to 6 in northeastern Arizona (gridpoint #1604) for 10-year overlapping periods beginning in the 2000-2009 and continuing to 2090-2099. All changes, or deltas, are calculated with respect to the 1990-1999 control period.

The plots suggest considerable spatial variation in the projected changes in the characteristics of the Haines Index. However, as with all climate change analyses, the results must be interpreted cautiously, particularly as simulations from only one GCM were used in the analysis. Also, the bounded nature of the Haines Index makes correcting for bias in the GCM simulations more difficult. For this reason, a better strategy for evaluating potential future wildland fire potential is to directly analyze the environmental lapse rate and dewpoint depression used to calculate the Haines Index.

Summary

Funds from the Joint Fire Science Program were used to investigate climatological patterns of the atmospheric component of wildland fire risk as measured by the Haines Index and potential future changes in the Haines Index. The analyses represent the first attempt to develop a long-term, spatially extensive climatology of the Haines Index, and the first attempt to assess possible future changes in the atmospheric component of wildland fire potential. The results have utility for both short term and long range planning.