Potential Climate Change Impacts on Fire Weather in the United States

Warren E. Heilman, Ying Tang, Lifeng Luo, Shiyuan Zhong, Julie A. Winkler, and Xindi Bian

Introduction

Occurrences of large and sometimes extreme and erratic wildfires in the United States in recent years have raised speculation about what projected future climate conditions might mean for future wildfire activity and fire weather in different regions of the United States. This speculation has led to studies by the scientific community on the possible linkages between long-term global and regional climate change and changes in the frequency of occurrence of short-term weather events that are conducive to large fires and/or erratic fire behavior. In particular, researchers at Michigan State University and the Forest Service's Northern Research Station worked on a joint study to examine the possible effects of future global and regional climate change on the occurrence of fire-weather patterns often associated with extreme and erratic wildfire behavior in the United States. The Haines Index (HI) (Haines 1988), an operational fire-weather index used by fire managers and fire-weather forecasters to characterize how conducive middle and lower atmospheric moisture and thermal stability conditions are to extreme and erratic fire behavior, was computed from multiple future climate projections.

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Published results from that study can be found in Luo et al. (2013) and Tang et al. (2015). This article provides a summary of the methodology, key results, and conclusions from those publications.

Methods

To investigate potential changes in regional fire-weather conditions as a result of climate change, we incorporated a subset of the suite of North American regional climate change projections that are currently available from the North American Regional Climate Change Assessment Program (NARCCAP). NARCCAP is an international program designed to develop high-resolution climate-change simulations covering the North American continent using a suite of regional climate models (RCMs). The RCMs are driven by a number of different coupled global-scale atmosphere-ocean general circulation models (AOGCMs) (Mearns et al. 2009, 2012). For our study, we used NARCCAP regional climate simulation data for the "current" climate (1971–2000) and obtained the future climate (2041–2070) from six AOGCM-RCM combinations involving three RCMs and three AOGCMs. The RCMs included the Regional Climate Model, version 3 (RCM3; Pal et al. 2007), the Canadian Regional Climate Model (CRCM; Caya and Laprise 1999), and the Weather Research and Forecasting model (WRF; Skamarock et al. 2005), all with a horizontal grid spacing of 31 miles (50 km). The driving AOGCMs included the Geophysical Fluid Dynamics Laboratory (GFDL) general circulation model (Delworth et al. 2006), the Canadian Global Climate Model, version 3 (CGCM3; Flato 2005), and the National Center for Atmospheric Research (NCAR) Community Climate System Model, version 3 (CCSM3; Collins et al. 2006). For the future climate (2041–2070) simulations, we forced the driving AOGCMs with the "A2" greenhouse gas emissions scenario that is consistent with a continuously increasing global population and regionally oriented economic growth (Nakicenovic et al. 2000).

Using the 0000 Coordinated Universal Time (UTC) (corresponding to a time of 5:00 p.m. Pacific Daylight Time (PDT) during the summer months) temperature and atmospheric moisture data obtained from the six AOGCM-RCM simulations of the current and future climates, we computed daily HI values at each RCM grid point. As described in Haines (1988), the HI takes on integer values ranging from 2 to 6 depending on the instability and moisture content in the atmospheric layers used to compute the index. HI values of 5 or 6 indicate unstable and dry conditions in the lower to middle troposphere, a feature often associated with extreme fire behavior if fires are present. We focused our HI analyses on the months of March, August, and October, given that wildfires in the Eastern United States are more likely to occur in the late-winter, early spring, and autumn months, and August is usually the most active month for wildfire occurrence and area burned in the Western United States (Haines et al. 1975, Westerling et al. 2003).

Summary of Key Results

In Luo et al. (2013), we examined changes in the percentage of August days with HI ≥ 5 at 0000 UTC between current and projected future climate conditions over the Western United States. The scenarios obtained from the six NARCCAP AOGCM-RCM model simulations all suggest that large areas of the western U.S. region may see an increase in the frequency of HI ≥ 5 occurrences during the month of August under future climate conditions compared to current climate conditions (figure 1). Note that under current climate conditions, it's typical for about 40 percent of summer (June–August) days in portions of the Western United States to have 0000 UTC HI values equal to 5 or 6 (Winkler et al. 2007, Lu et al. 2011). The CRCM-CCSM3 and CRCM-CGCM3 simulations used in this study project future atmospheric stability and moisture conditions over Wyoming, Colorado, and New Mexico that

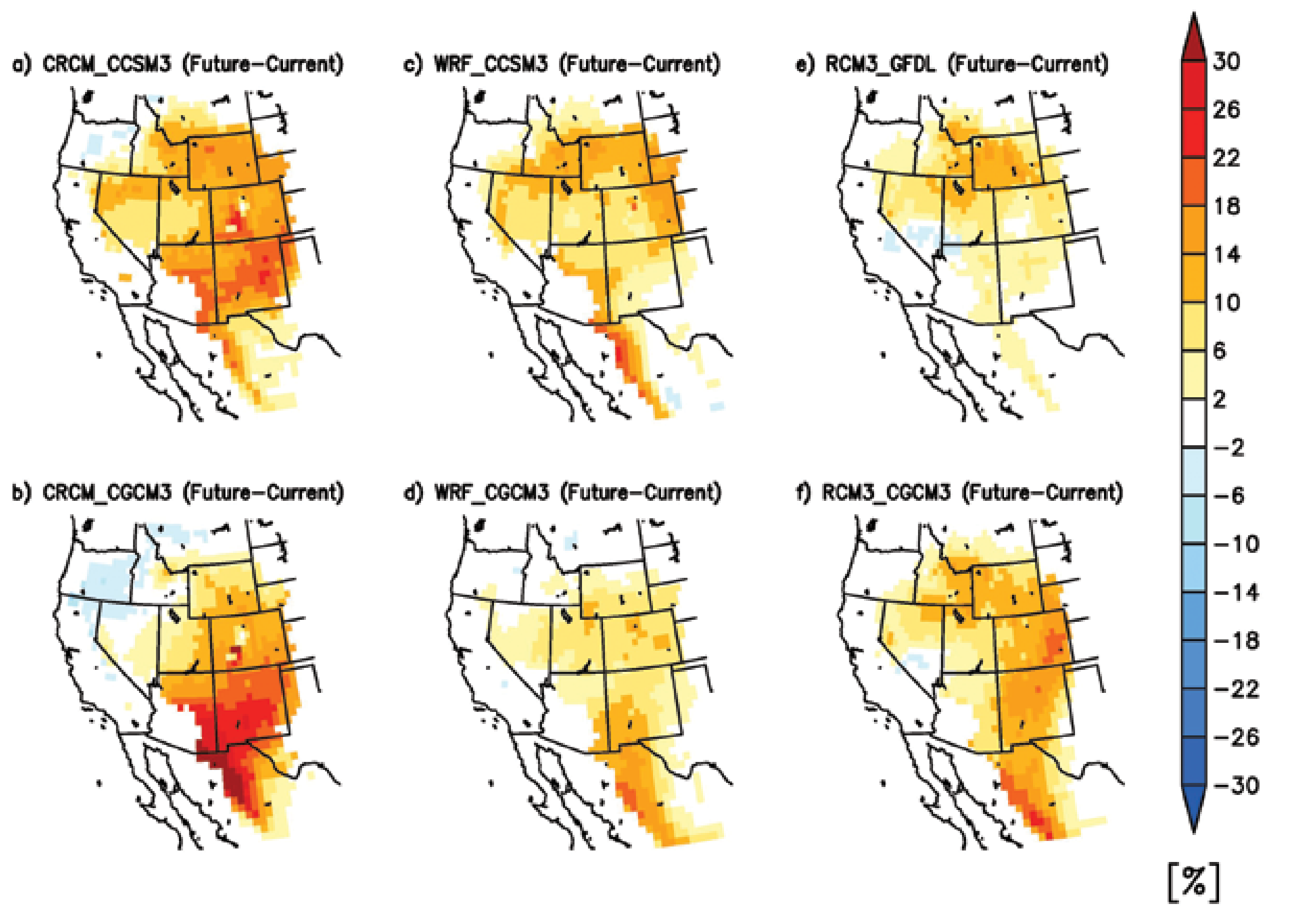

Figure 1. *Changes in the percentage of days for which HI ≥ 5 at 0000 Coordinated Universal Time during August between the current (1971–2000) and the future (2041–2070) climate as simulated by the CRCM (left), WRF (center), and RCM3 (right) regional climate models driven by the CCSM3 (top) and CGCM3 (bottom) global-scale atmosphere-ocean general circulation models. For RCM3, CCSM3 is replaced by the GFDL model. (From Luo et al. 2013; © American Meteorological Society; used with permission.)*

would lead to a substantial 10- to 26-percent increase in the percentage of August days having HI values equal to 5 or 6 (figures 1.a-b). More moderate increases over much of the Western United States are projected by the four remaining NARCCAP simulations that we used in this study (figures 1.c-f).

Because occurrences of multiday episodes of atmospheric stability and moisture conditions conducive to extreme and erratic fire behavior are also of concern for fire management activities, we examined potential changes in the persistence of high HI values during the month of August across the Western United States. Figure 2 shows projected changes in the average number of consecutive days in August with HI ≥ 5 at 0000 UTC under future climate conditions compared to current climate conditions as derived from the six NARCCAP modeling systems used in this study. Five of the six simulations suggest future climate conditions may lead to large areas in the Western United States that experience increases in the duration of HI ≥ 5 events. The largest increases in the length of HI ≥ 5 events in August are projected by the CRCM-CCSM3 simulations, with events projected to last on average up to 7 to 9 days longer than the present over much of the Intermountain West. Smaller increases are suggested by the other NARCCAP modeling systems.

The intent of the analyses is to inform fire and forest managers and policymakers of the possible impacts that regional climate change may have on future extreme fire behavior occurrence in the United States.

Building upon the analyses of the Western United States conducted in Luo et al. (2013), we extended the analyses to the entire United States, as presented in Tang et al. (2015). In addition to August, we included the months of March and October in our analyses because wildfires in the Eastern United States are more frequent during the spring and autumn seasons.

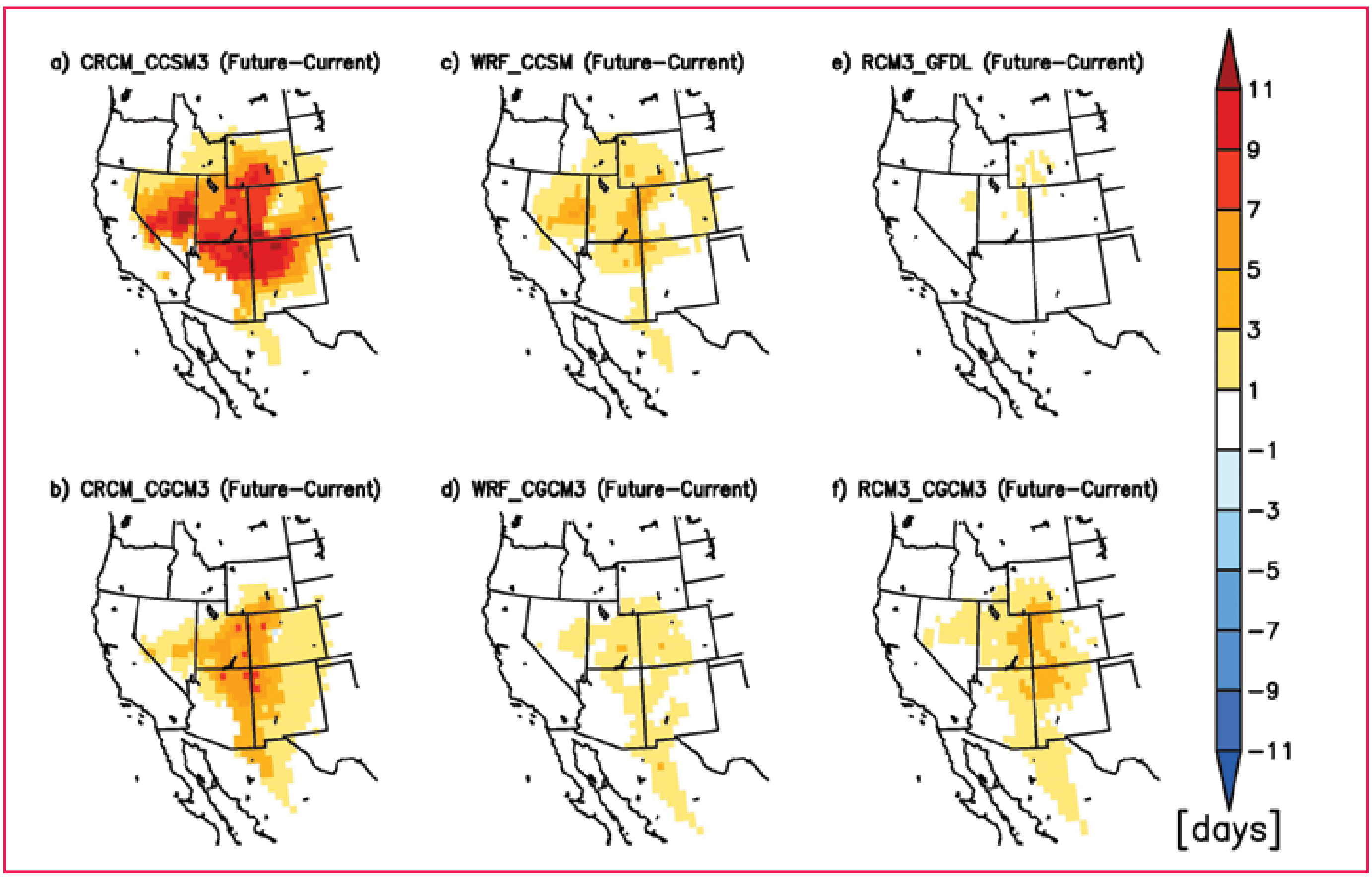

Figure 2. *Same as figure 1, except for changes in the average duration of consecutive days with HI ≥ 5. (From Luo et al. 2013; © American Meteorological Society; used with permission.)*

Averaging the six NARCCAP simulations, we found mean projected changes in the percentage of days with HI ≥ 5 at 0000 UTC over the entire United States to be much more substantial during August than during March or October. The largest projected increases during August are found over regions of the Intermountain West, as previously mentioned in the Luo et al. (2013) summary, and over portions of the Midwest, including Ohio, western Pennsylvania, West Virginia, and eastern Kentucky and Tennessee (figure 3). Average projected increases in these areas reach as high as 10 to 14 percent, corresponding to an additional 3 to 4 days each August, under future climate conditions, that could have high HI values. Based on the analysis of Winkler et al. (2007) of current HI patterns over the United States, this increase would result in some areas of the Western and Eastern United States experiencing, on average, about 15 and 10 high HI days, respectively, in August under future climate conditions.

For March and October, we found the spatial patterns of projected changes in the percentage of days having high HI values across the United States to be highly variable (-10 to +10 percent) and inconsistent among the six AOGCM-RCM simulations. Because of this inconsistency, the averages of the projected changes in high HI occurrence during March and October as computed from the six AOGCM-RCM simulations are relatively small (<5 percent). This inconsistency limits our confidence in concluding from this study that regional climate change in the United States will lead to specific changes in the occurrence of atmospheric conditions conducive to

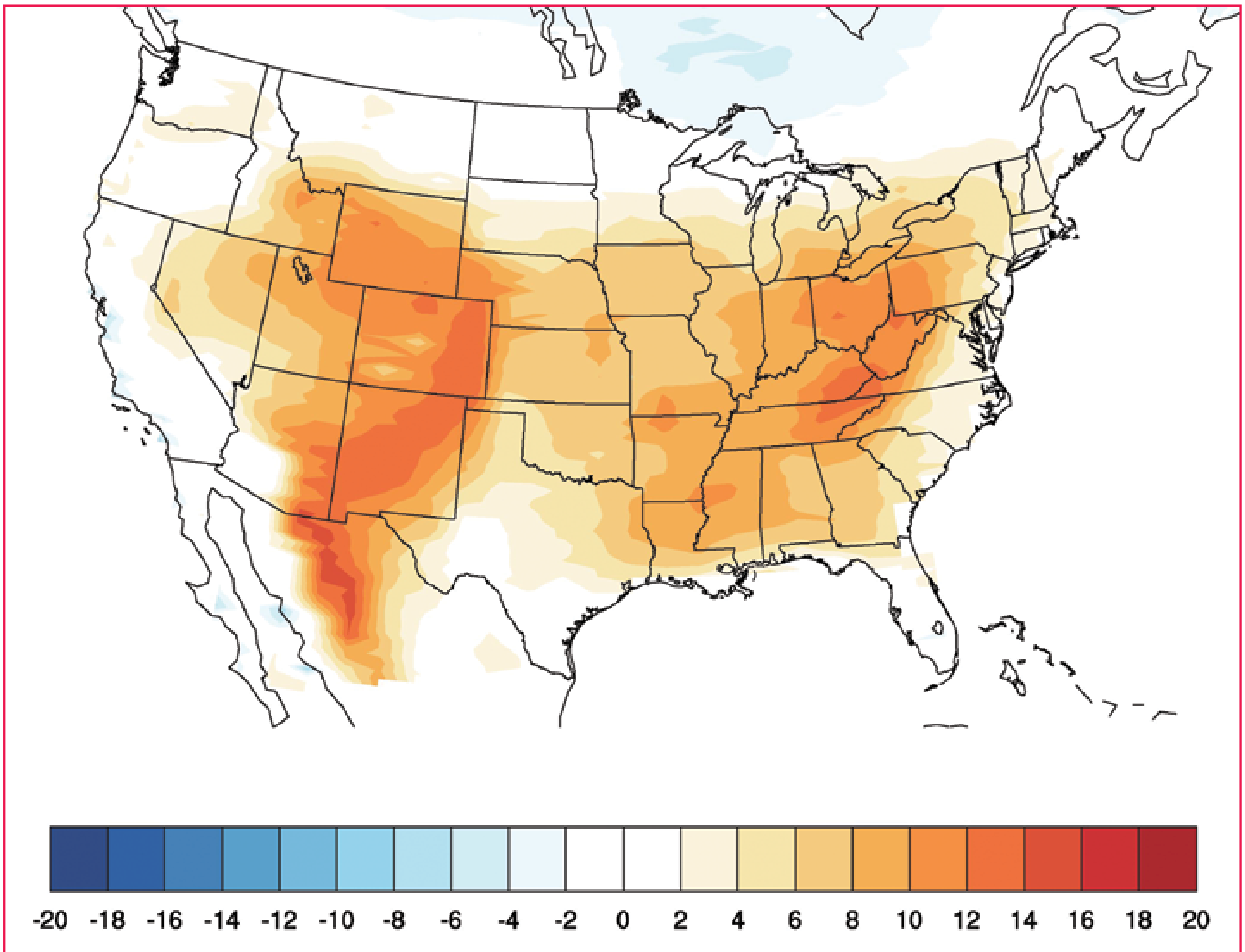

Figure 3. *Changes in the percentage of days for which HI ≥ 5 at 0000 Coordinated Universal Time during August between the current (1971–2000) and the future (2041–2070) climate based on an average of the North American Regional Climate Change Assessment Program climate simulation results from six different coupled AOGCM-RCM modeling systems reported in Tang et al. (2015).*

extreme fire behavior during the spring and autumn seasons.

The ensemble of AOGCM-RCM projections in Tang et al. (2015) also suggest that future climate conditions could lead to longer duration summertime high HI events, not only in the Intermountain West region as noted in Luo et al. (2013), but also over the southern Great Plains (figure 4). Averaging over the six AOCGM-RCM modeling systems used in our study, we found projected mean increases in the average length of HI ≥ 5 events during August to be as high as 4 to 5 days over portions of Texas, Oklahoma, Colorado, Utah, Arizona, and New Mexico. No areas of the United States are projected to have decreases in the mean length of HI ≥ 5 events during August. For March and October, the average of the six AOCGM-RCM projections yielded changes in the duration of high HI events that are minimal (0 to 2 days) across the entire United States. Again, this result is a reflection of the substantial variability and inconsistency in the computed spring and autumn HI patterns across the United States between the different AOGCM-RCM simulations.

Conclusions

The analyses of Luo et al. (2013) and Tang et al. (2015) provide new insight into how changing climate conditions could affect future fire weather in the United States, particularly during the summer season when wildfires are common in the Western United States. Potential summertime increases in the number of days having high HI values and the number of consecutive days with high HI values over portions of the Western United States, as highlighted in these analyses, suggest more frequent extreme wildfires are a possibility there.

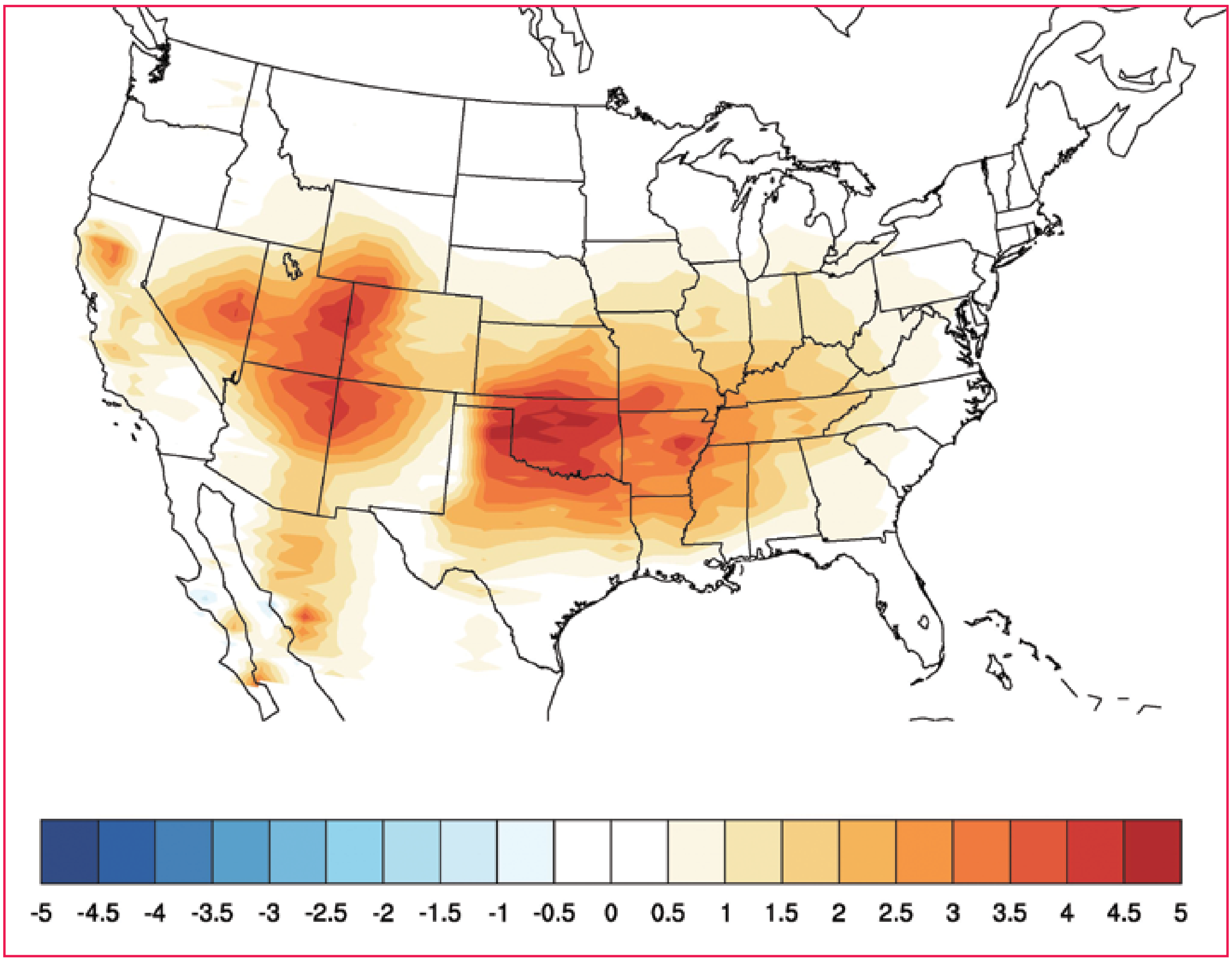

Figure 4. *Same as figure 3, except for changes in the average duration of consecutive days with HI ≥ 5.*

However, substantial variability and inconsistency in the patterns of high HI occurrence during the months of March and October, as derived from six regional climate projections, make it more difficult to offer definitive statements on the likelihood of future atmospheric conditions being more conducive to extreme wildfires in the United States during the spring and autumn seasons.

We recognize that other factors such as fuel conditions and fire-suppression activities also affect the risk of large and extreme wildfires. We also recognize the limitations in using only one fire weather index in our analyses instead of a suite of indices to characterize current and future fire weather. The use of regional climate simulation data at 31-mile (50-km) resolution for analyses of fire-weather patterns, particularly over areas of complex terrain and significant land-cover variations, adds further uncertainty to the fire-weather projections. Nevertheless, the analyses of Luo et al. (2013) and Tang et al. (2015) do suggest potential linkages between climate change and fire weather. The intent of the analyses is to inform fire and forest managers and policymakers of the possible impacts that regional climate change may have on future extreme fire behavior occurrence in the United States via atmospheric factors alone and to provide additional climate-science information for developing long-term fire and fuels management strategies in the United States.

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