11.6 USING VARIABLE COLUMN PRECIPITABLE WATER AS A PREDICTOR FOR LARGE FIRE POTENTIAL

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Abstract

Drought and extended periods of low values of relative humidity have long been known to be precursors to large wildland fires. However, little focus has been given to the entire tropospheric moisture column, or subsets of this column, as related to wildland fires. This study utilizes a precipitable water database from the upper-air observing site at Rapid City, South Dakota—in conjunction with the wildland fire database for western South Dakota—to examine large wildland fires. Comparisons were made between large fire occurrence/growth and deviation from average values of precipitable water over various atmospheric layers. Preliminary results indicate that using layer precipitable water deviation is, at times, more relevant to wildland fire potential than the dewpoint depression at a single level.

1. INTRODUCTION

Atmospheric moisture plays a large role in wildland fire growth and evolution. Low values of relative humidity (RH) at the surface have long been known to lead to large wildland fire growth (Lansing 1939). Depressed values of RH promote the drying of fuels, leading to easier ignition/fire spread. The role of above-ground tropospheric moisture is less understood in terms of its role on wildfire evolution. If enough moisture exists where condensation would occur in a rising parcel, then latent heat would be released. In the case of a wildfire, this release of latent heat would likely enhance the vertical convection column, resulting in further parcel instability. The overarching hypothesis of this paper is that the type of atmosphere most conducive for large wildland fire growth would be one with a dry surface and lower troposphere to promote desiccation of fuels with enhanced moisture near the mid troposphere to promote instability through condensation and latent heat release.

Currently, instability is often diagnosed within fire weather forecasts by the Lower Atmosphere Stability Index (Haines Index, Haines 1988). This index takes into account the temperature difference between each layer and the dewpoint/temperature spread at the top of this layer. The resulting output is a numeric digit ranging from 2 to 6 (low potential for large wildland fire growth to high potential for large wildland fire growth). One major drawback of the Haines Index is that it is limited to only one of three differing atmospheric layers depending on surface elevation. This may result in instability being over- or under-diagnosed if the true surface elevation lies between two idealized levels. For example, Rapid City, SD is at an elevation of approximately 3200 ft MSL on the eastern fringe of the Black Hills, falling right on the dividing line between using the mid-elevation and high-elevation Haines Index. (Bailey (2001a, 2001b) elaborates further on evaluation of and improvements to the Haines Index for the Black Hills National Forest.)

The impetus for this paper is to develop a more robust methodology for diagnosing atmospheric conditions that lead to enhanced instability and large fire growth. Instead of using a pre-defined, elevation-dependent layer (such as Haines does), a variable column method employing temperature and precipitable water is described. Precipitable water (PW) is defined as the depth of the total amount of atmospheric water vapor contained between two vertical layers of a specified cross-sectional area if condensed and let to stand in that same cross-sectional area. This allows PW to be used as a direct indicator of the atmospheric moisture content between two levels.

2. METHODOLOGY

This study was completed using the fire start database collected from the Great Plains Dispatch Center (GPDC) in Rapid City, SD. All fires larger than 1000 acres, regardless of fuel type, and within 160 km (~100

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mi) of Rapid City were included. Radiosonde data from 1960-2011 from the Rapid City upper-air site (KRAP prior to fall 1995 and KUNR thereafter) were collected to diagnose the atmospheric profile. Fire start days were found and matched to corresponding sounding times with both the 12Z and 00Z soundings included.

A total of 45 wildland fire days (hereinafter "fire days") were included in the study. Due to missing or poor quality radiosonde data, only 41 and 38 cases were included in the 12Z and 00Z datasets, respectively.

To mitigate the static level issues that the Haines Index has, this study used pressure levels above the surface to diagnose the atmospheric column. The layer encompassing 100-200 hPa above the surface was used to characterize the lower troposphere, while the mid-troposphere was diagnosed by using a layer from 300-500 hPa above this surface. Because Rapid City's average surface pressure is roughly 900 hPa, these layers included the 800-700 hPa (lower troposphere) and 600-400 hPa (mid-troposphere) layers. The lower layer was chosen to be above the surface to avoid many of the impacts of the ground surface itself. Precipitable water and lapse rates were then calculated for each of the layers. For comparison purposes, a mid-elevation and high-elevation Haines Index were calculated for each of the cases as well.

3. RESULTS

For climatological comparisons, averages of 850/700/500 hPa temperature and dewpoint and 800-700/600-400 hPa lapse rate and PW were computed foreach calendar day for all years included in the aforementioned radiosonde dataset (hereinafter "mean day"). For example, if a fire occurred on 29 August 2009, the average weather variable for each layer/level was computed for 29 August for all years. To determine a departure from normal, the "mean day" values were subtracted from the "fire day" values. Finally, these departures, for both 12Z and 00Z, were then averaged to produce the data in Table 1. The values in Table 1 can be interpreted as follows: if the value is positive, then the fire day was hotter, drier, had steeper lapse rates, more PW, or a higher Haines Index (the opposite holds true). Table 1 shows that for fire days, the three representative levels were warmer on fire days and that the lower troposphere was drier on fire days and the mid troposphere was more moist on fire days as compared to the mean day. In addition, the lapse rate within both defined layers was steeper and there was less PW in the lower troposphere and more PW in the mid troposphere on fire days as compared to the mean days. The Haines Index was also higher, which is to be expected on days with large fires.

Table 1. Averaged values for differing weather variables for 12Z and 00Z on the day of the fire start. See text for explanation.

Weather Variable/Time	12Z	00Z
850 mb T (°C)	6.020	4.513
850 mb Td (°C)	-0.784	-0.064
700 mb T (°C)	4.515	3.473
700 mb Td (°C)	0.800	1.052
500 mb T (°C)	2.103	1.337
500 mb Td (°C)	2.155	3.322
800-700 mb LR (°C/km)	0.960	0.589
600-400 mb LR (°C/km)	0.421	0.435
800-700 mb PW (in.)	-0.021	-0.004
600-400 mb PW (in.)	0.038	0.054
Haines (M)	0.725	0.365
Haines (H)	0.783	0.556

To contextualize how the PW data fits into monthly climatology, monthly statistics utilizing the entire radiosonde dataset were compiled. The mean, minimum, and maximum values for each month were found, as well as the 10th and 90th percentiles. Figures 1a-d show these data with the monthly average for the fire days overlaid. The dataset contains no fires in the months of February/March/April (months 2, 3, and 4). These data do not show much of a trend of above/below average PW for the fire days as compared to the monthly statistics for the 800-700 hPa layer (Figs. 1a and 1c). However, a trend of above average PW is seen in the 600-400 hPa data (Figs. 1b and 1d). Considering that this study includes both human and lightning caused fires, it is possible that the values in Fig. 1 may be skewed towards the days that are conducive for producing thunderstorms and thus lightning starts, namely in the summer months. Thus this study may not be so much one that diagnoses conditions present for large fire days; rather it may point to days that are conducive to fire starts.

Figure 2 is similar to Fig. 1 except that human and lightning caused fire days are separated. The data show that human-caused fires occur year-round but only the summer/early fall months produce lightning-caused fires, which is to be expected. Interestingly, the largest human-caused fires occur when the 800-700 hPa layer is largely near or below average in terms of PW content. There is no such discernible pattern for PW in the 400-600 hPa layer. What is more, lightning-caused large fires tended to start when the PW was near or above the average monthly value. This is likely due to the environment where thunderstorms occur—one with an above-average moisture content.

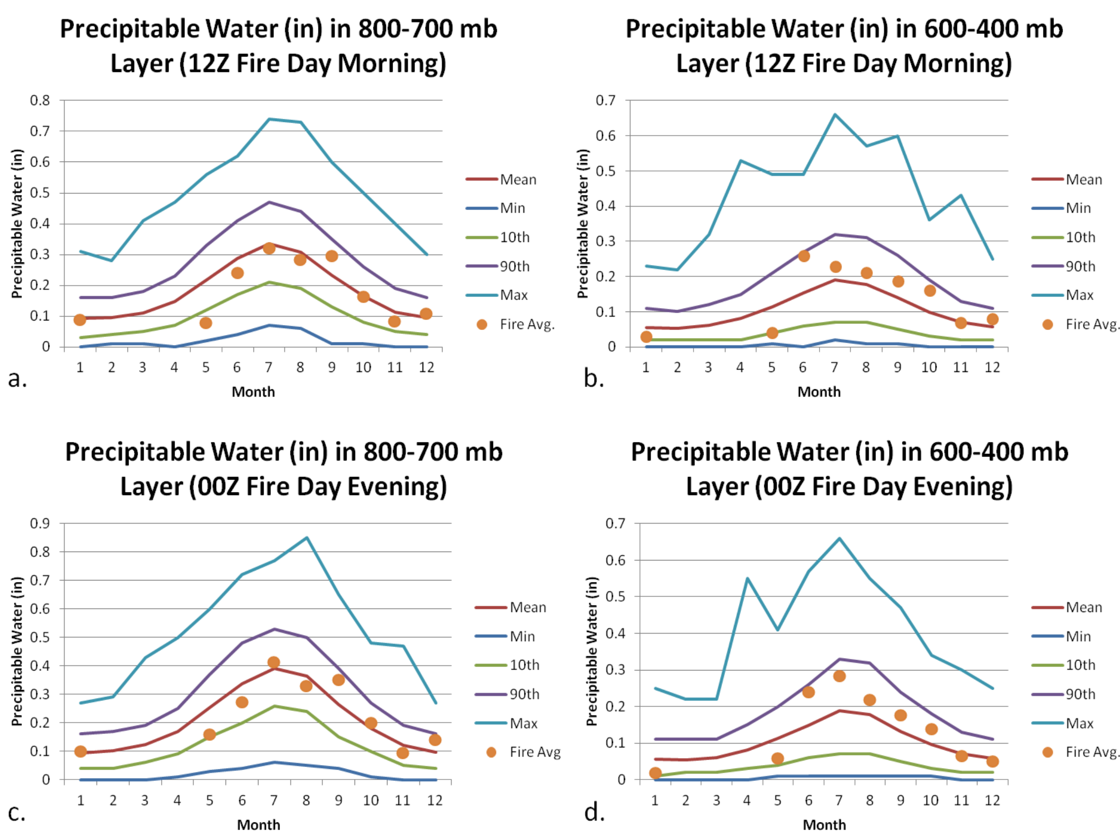

Fig. 2. Values of precipitable water for the 800-700 hPa and the 600-400 hPa layers for 12Z and 00Z, respectively. The minimum, maximum, 10th, and 90th percentiles are given along with the mean for the month.

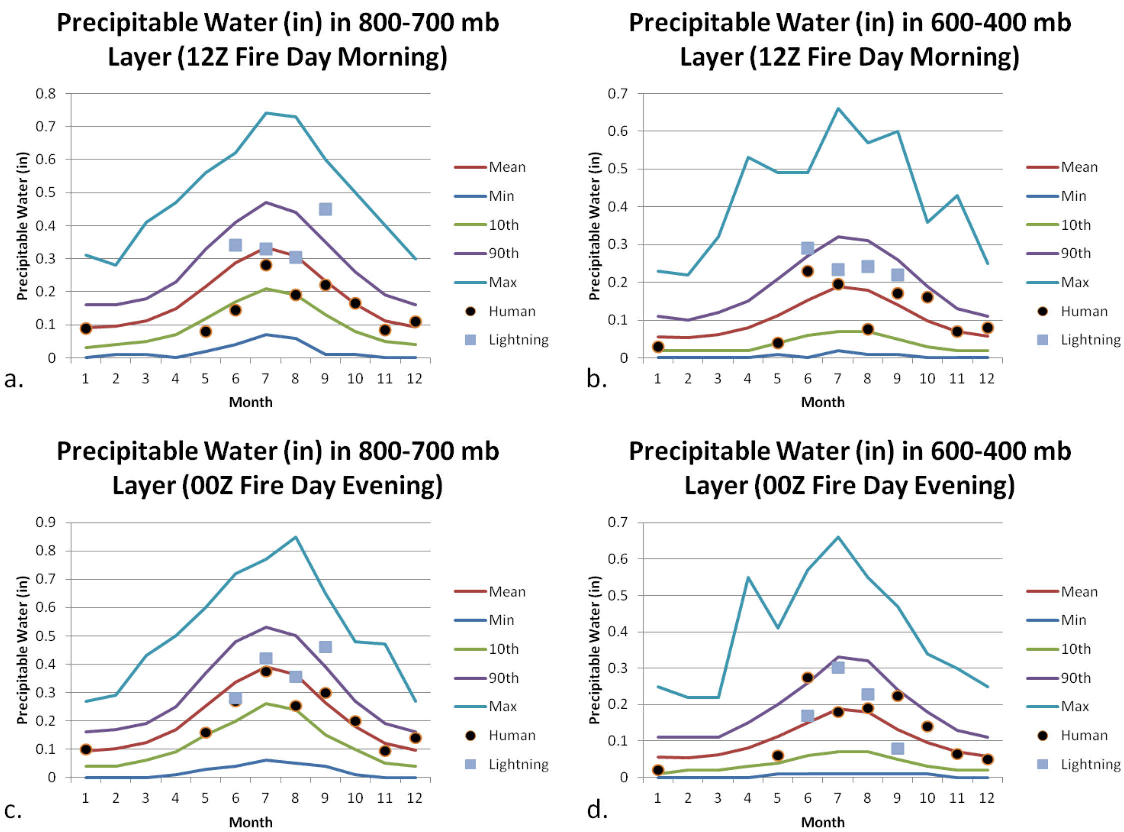

Fig. 3. As in Fig. 1 but with human and lightning caused fires separated.

4. DISCUSSION

The above results show some interesting trends in the average atmospheric profile when considering fire starts. But this study most clearly illustrates the issues when attempting to parse through a fire dataset. Unless further research is done into the individual fires themselves, it is not known if the fires burned aggressively on the day of the fire start as only total acreage was used in determining which fires to include in the study. The total burned acreage used in this study also includes land that was burned due to suppression efforts, not just due to fire growth. Fires are often fought with techniques that use controlled fire as a means to construct a fuel break around an existing uncontrolled fire. This implies that even though a particular atmosphere may not have been conducive for fire growth, large fire 'growth' did occur because of additional fire being put on the ground during suppression efforts. Furthermore, if the uncontrolled fire reached a natural fuel break even at a time when the atmosphere was conducive for a blow-up, the fire would not have gained much in terms of additional acreage.

This study shows that there is promise in looking at other meteorological variables besides the traditional dewpoint depression and temperature lapse rate as is used in the Haines Index to diagnose a fire-conducive atmosphere. It also demonstrates that it is now possible to move away from using pre-defined atmospheric levels, as Haines (1988) does, and move towards a more dynamic method which would utilize a station's native surface pressure to choose the incorporated atmospheric levels.

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