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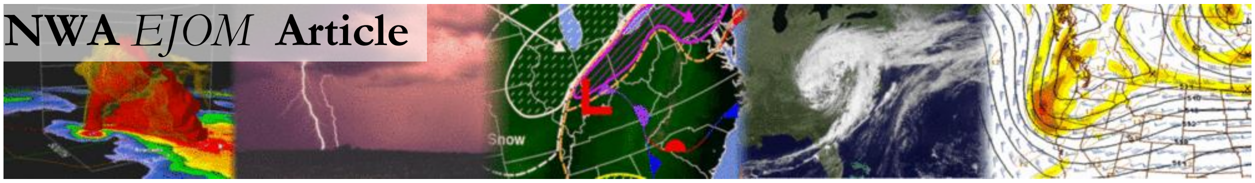

Assessing Critical Fire Weather Conditions Using a Red Flag Threat Index

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ABSTRACT

The National Weather Service issues Red Flag Warnings in agreement with land management agencies when relative humidity, wind speed, and fuels meet or exceed critical thresholds supportive of extreme burning conditions within a local vegetative and climatic regime. The degree to which relative humidity and wind speed exceed these local thresholds, however, is not quantified routinely via current warning products. This study will introduce a Red Flag Threat Index (RFTI) to express the severity of observed or forecast fire weather conditions. This Index, patterned after the widely-used Haines Index, incorporates forecast and/or observed 2-m relative humidity and 6-m wind speed and is derived by a summation of numerical terms for these commonly used variables in fire weather prediction. The value of these terms is determined from quartile rankings of nearly 2,300 critical fire weather observations across west Texas. With scores that range from 0 (“Non-Critical”) to 10 (“Historically Critical”), the RFTI is intended to increase situational awareness for fire weather forecasters and to convey risk levels to fire managers and decision makers while providing an important tool in assessing the severity of critical fire weather relative to climatology. Utility of the RFTI is demonstrated through an analysis of its correlation to a pre-existing database of meteorological proximity observations for significant wildfire starts. This index is well suited for use in operational forecast environments and adaptable to any location or climate regime, especially those vulnerable to wind-driven fires in fine fuels.

1. Introduction

Red Flag Warnings (RFWs) are issued by the National Weather Service (NWS) for conditions that favor extreme burning conditions and problematic containment of wildland fire. Local weather conditions and their impact upon vegetative fuels are the most dynamic variables

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to influence wildland fire behavior (Pyne 1984). Thus, the criteria that govern the issuance of RFWs are a combination of weather and fuel information typically based on local thresholds of relative humidity, wind speed, and an adjective fire danger rating. These criteria are formally agreed upon by local NWS Weather Forecast Offices (WFOs) and fire agencies within the WFO's respective forecast areas. RFWs are then issued when these locally determined critical fire weather and fuel conditions are met or forecast to occur. The degree to which weather influences fire behavior can vary substantially from day to day and is dependent upon the particular state of the atmosphere and available fuels.

This study will introduce an index methodology to quantify the severity of critical fire weather conditions through the operational utility of the Red Flag Threat Index (RFTI). As a meteorological indicator of wind-driven wildfire risks, the RFTI will be compared to a previously documented dataset of meteorological proximity observations for significant wind-driven grassland wildfire starts in eastern New Mexico and west Texas.

2. The Red Flag Threat Index (RFTI)

a. Background and methodology

In meteorology, indices and categories are commonly used to describe the magnitude of weather phenomenon and their impacts (i.e. hurricanes, tornadoes, and drought). Within the sub-specialty of fire meteorology, there are multiple indices that describe threats or the potential for specific fire weather conditions. Such indices include: the Haines Index (Haines, 1988), the Fosberg Fire Weather Index (Fosberg 1978), and the Grassland Fire Danger Index (McArthur 1966). The Haines Index is probably the most commonly used of these fire weather indices, and is a unitless value derived from the addition of terms representing dewpoint depression and lapse rate. This index, however, is most often used as an indicator of the potential for rapid fire growth in plume-dominated fires, which typically occur in large fuel or forested regimes.

Patterned after the Haines Index, the RFTI is also a unitless numerical value that is independent of fuel. Instead of using characteristics of the low-level thermal profile and a single moisture level as the Haines Index, the RFTI utilizes 2-m relative humidity and 6-m wind speed and is thus an appropriate indicator for wind-driven fires in fine fuels. The index, represented by the following equation:

$$RFTI = RFTI(A) + RFTI(B) \qquad (1)$$

is derived by the summation of two terms based on statistical analyses of observed basic fire weather variables. RFTI(A) and RFTI(B) are assigned a value of 0 through 5 as correlated to quartile rankings for a 10-year observational dataset of 2-m relative humidity and 6-m wind speed respectively when each parameter meets or exceeds locally defined RFW thresholds.

The RFTI was developed for west Texas by employing an analysis of 2,279 red flag weather observations from a 10-yr. climatology. The hourly observations were measured by Automated Surface Observing System (ASOS) sites at Amarillo, Texas (KAMA), Lubbock, Texas (KLBB), and Midland, Texas (KMAF) between 2000 and 2009. Selected observations exceeded red flag warning criteria (NWS cited 2012), frequently referred to as "critical fire weather conditions" locally defined within the study domain as 6-m relative humidity of 15 percent or less with the simultaneously occurrence of 10-m wind speeds of 20 mph or greater or gusts of 35 mph. The database of observations is independent of fire occurrence, temperature, and fuel state. Measured 10-m wind speeds were reduced to approximated 6-m values and expressed in mph (metric units parenthesized in text), the accepted height and unit for fire weather wind observations and forecasts, per a 0.886 correction factor. This factor was observed to be an appropriate 10-m/6-m relationship for burn periods at Reese Center, Texas (REES, Fig. 5, 25 km west of KLBB), a centrally located West Texas Mesonet (WTM) site within the study domain (Lindley et al. 2011). This correction factor will be different for observations that are subject to sheltering. Critical fire weather observations from each ASOS site were evaluated through the method of quartile rankings relative to the local RFW criterion of 2-m relative humidity ≤ 15% and 6-m wind speed ≥ 20 mph (9 m s^{-1}) (SWCC cited 2011). RFTI(A) and RFTI(B) were each assigned: 0 for non-critical relative humidity or wind speeds, 1 for values between the minimum and lower quartile (25th percentile), 2 from the lower quartile to median (50th percentile), 3 from the median to upper quartile (75th percentile), 4 from the upper quartile to maximum, and 5 for values in excess of the maximum observed value in the 10-yr climatology (Fig. 1a-b - 3a-b). These quartile rankings insure that values of 9 and 10 are only achieved during the rarest critical fire weather conditions when RFTI(A) and/or RFTI(B) exceeded the 10-yr observational database. Additionally, RFTI=0 when neither RFTI(A) nor RFTI(B) meet critical RFW thresholds. Thus, summed RFTI(A) and RFTI(B) values of RFTI are categorized as 0 “Non-Critical”, 1-2 “Elevated”, 3-4 “Critical-Low”, 5-6 “Critical-High”, 7-8 “Extremely Critical”, and 9-10 “Historically Critical” (Fig. 4) in accordance with their relationship to locally defined RFW criteria and climatological significance.

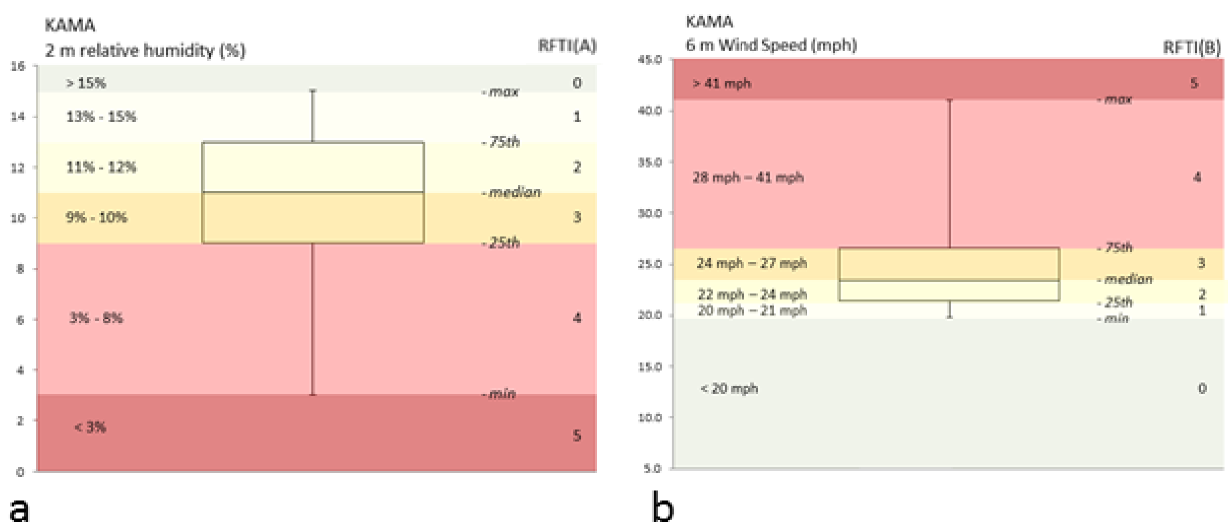

Figure 1: Climatological quartile rankings and RFTI(A) and RFTI(B) at Amarillo, Texas (KAMA).

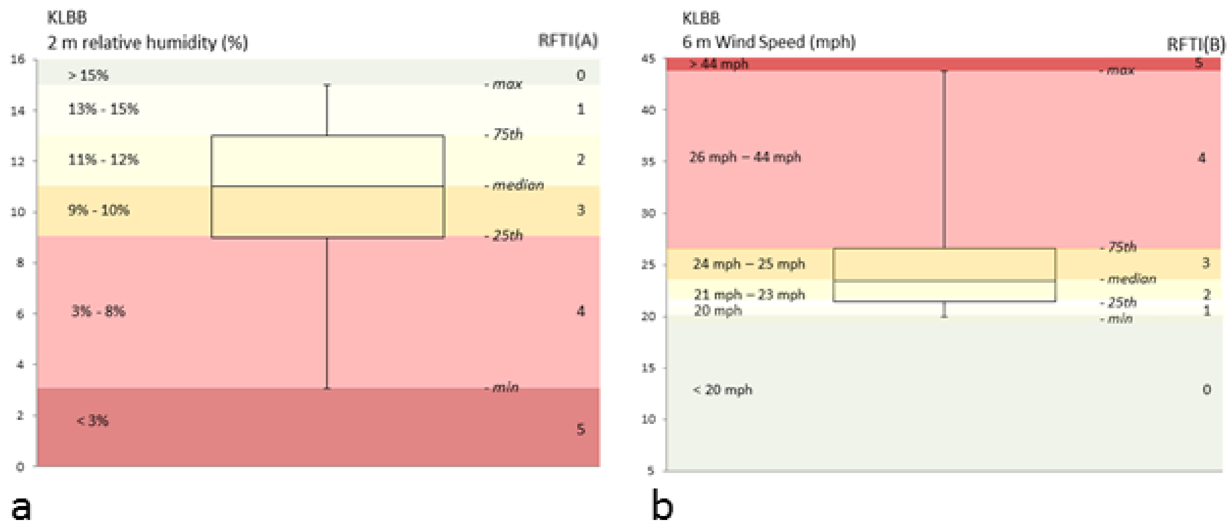

Figure 2: Climatological quartile rankings and RFTI(A) and RFTI(B) at Lubbock, Texas (KLBB).

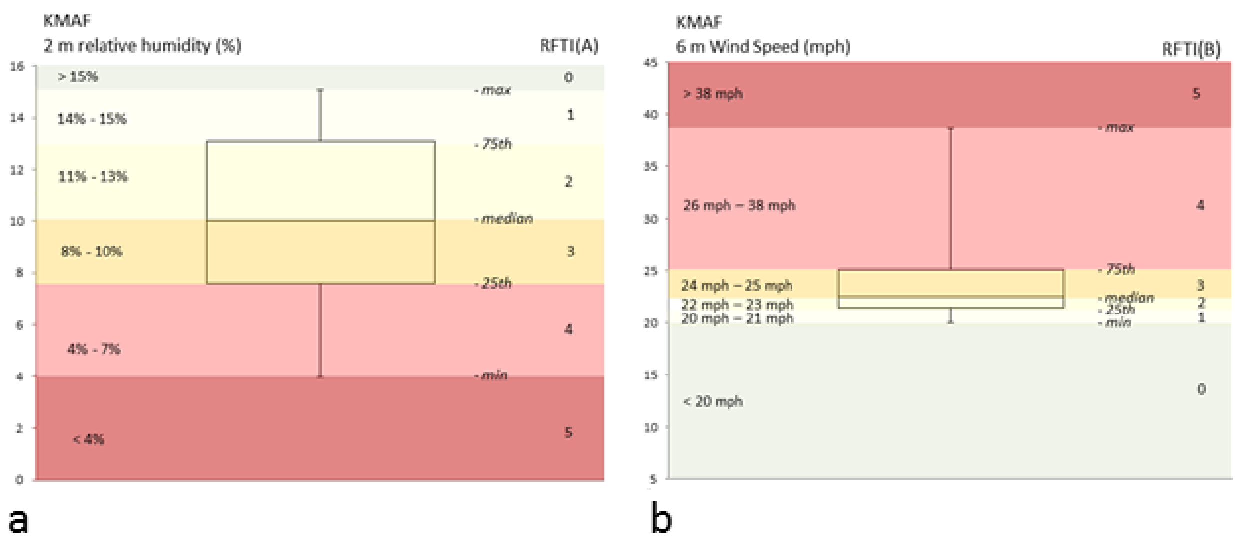

Figure 3: Climatological quartile rankings and RFTI(A) and RFTI(B) at Midland, Texas (KMAF).

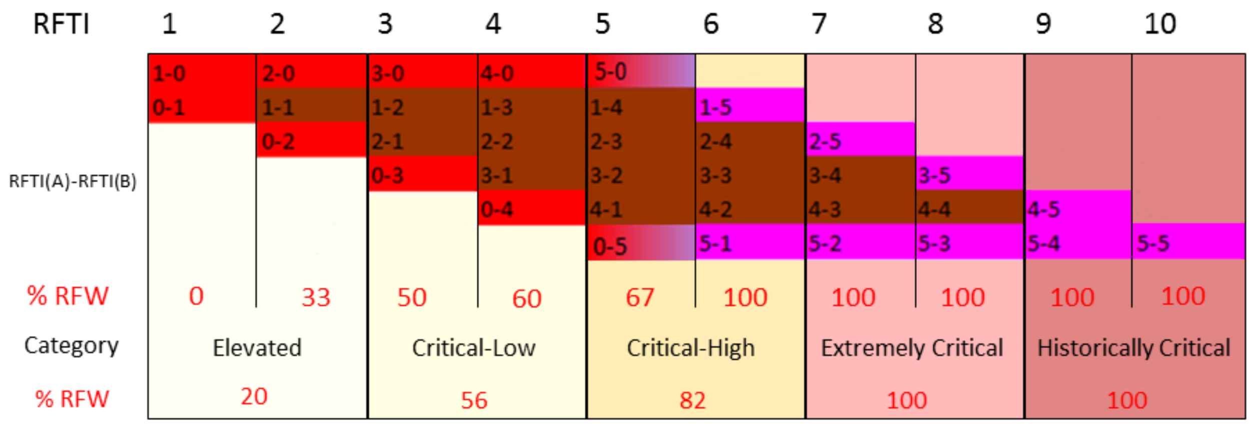

Figure 4: Matrix showing combinations of RFTI (A) and RFTI (B) for each RFTI value, category, and relationship to RFW criteria. Red cells=non-RFW, maroon cells=typical RFW conditions, purple cells=very rare term values outside a 10-yr climatological database.

b. Application to fire weather severity

Three interdependent variables influence wildland fire behavior: weather, fuels, and topography (Deming et al. 1978). Topography, as well as the type and amount of available fuels, remains constant over short distances and burning periods. Other fuel characteristics such as moisture and temperature, however, are variable and highly dependent on local weather conditions, which can change substantially on the order of only a few hours. Tanskanen et al. (2008) described the state of fine dead fuels, such as dormant grasses, as being primarily controlled by ambient weather. The potential fire danger associated of with a 30 mph (13 m s^{-1}) wind speed in a 5% relative humidity environment is greater than a 20 mph (9 m s^{-1}) wind coincident with a 15% relative humidity. Despite the fact that both combinations of relative humidity and wind speed technically qualify as RFW conditions in west Texas, their effects on wildland fire behavior differs.

Meteorological proximity observations for significant fire starts reveal that combinations of 2-m relative humidity and 6-m wind speed that support wildfire development exist along a linear spectrum and is not contained to environments that explicitly meet defined RFW or "critical" conditions (Lindley et al. 2011), but the severity assessment along the spectrum remains largely subjective. The RFTI can be utilized as an objective tool that eliminates some of this subjectivity. Thus, when applied to fire weather forecasts and warnings, the RFTI is a means to express the threat posed in a specific fire weather environment.

3. Application of wildfire database

The RFTI was applied to a previously documented dataset of 99 significant wildfires ≥300 acres (121 ha) that occurred within the WTM domain in far eastern New Mexico and west Texas between 2006 and 2010 (Fig. 5) (Lindley et al. 2011). This dataset, composed of meteorological proximity observations for significant wind-driven grassland wildfire starts, was used to investigate the utility of RFTI relative to observed wildland fire activity. RFTI values were calculated based upon proximity observations of 2-m relative humidity and approximated

6-m wind speed for each wildfire start using the climatological quartiles from the nearest ASOS site (KAMA, KLBB, or KMAF).

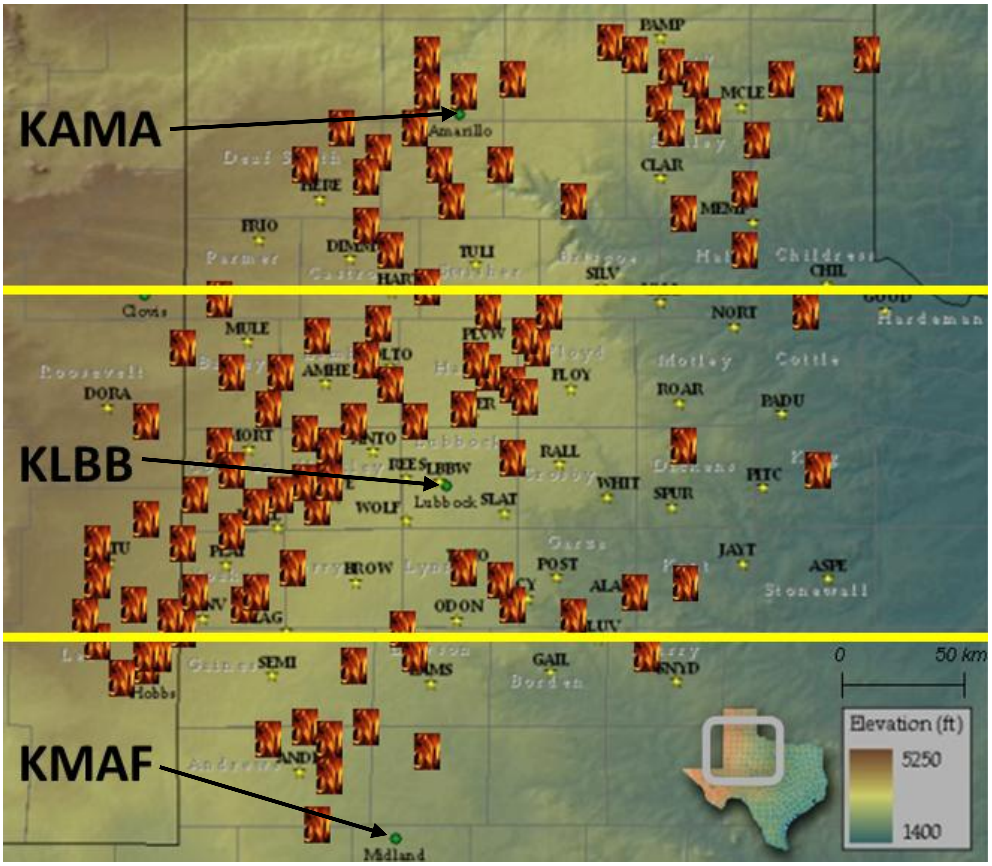

Figure 5: Lindley et al. 2011 wildfire start dataset shown as applied to the appropriate climatological quartiles for critical fire weather at KAMA, KLBB, and KMAF.

The occurrence of significant fire starts within the dataset approximated a normal distribution relative to RFTI centered on "Critical" values of 3 to 6 (Fig. 6). With respect to particular ranges of RFTI, minimal fire starts (1%) were associated with "Non-Critical" RFTI values of 0, while 7% of the observed fire starts occurred when the index ranged from 1 to 2 "Elevated". "Critical-Low" scores of 3 and 4 had the highest total of observed wildfire starts and accounted for 39% of the cases. This result is expected given that these values have a slight tendency (53% likelihood) to be associated with the onset of RFW criteria. Combinations of 2-m relative humidity and 6-m wind speed that meet or exceed RFW criteria have been found to be associated with a majority (64%) of significant wildland fires in the study domain (Fig. 7), and low-end RFW conditions are climatologically more frequent than more severe combinations of relative humidity and wind. As the severity of RFW conditions increases, the individual fire occurrences within the "Critical-High" ranges of RFTI 5 and 6, and "Extremely Critical" RFTI values of 7 and 8 decrease at 28% and 24% respectively; however, the total number of fires in these categories increase by 13% over the "Critical-Low" RFTI scores of 3 to 4. This general increase in the number of significant fire starts is seen in spite of a decreased climatological frequency of occurrence for such conditions. RFTI values of 9 and 10 represent environments with either 2-m relative humidity and/or 6-m wind speeds in excess of the 10-yr climatological outliers; thus, no observed fire starts occurred in such rare conditions.

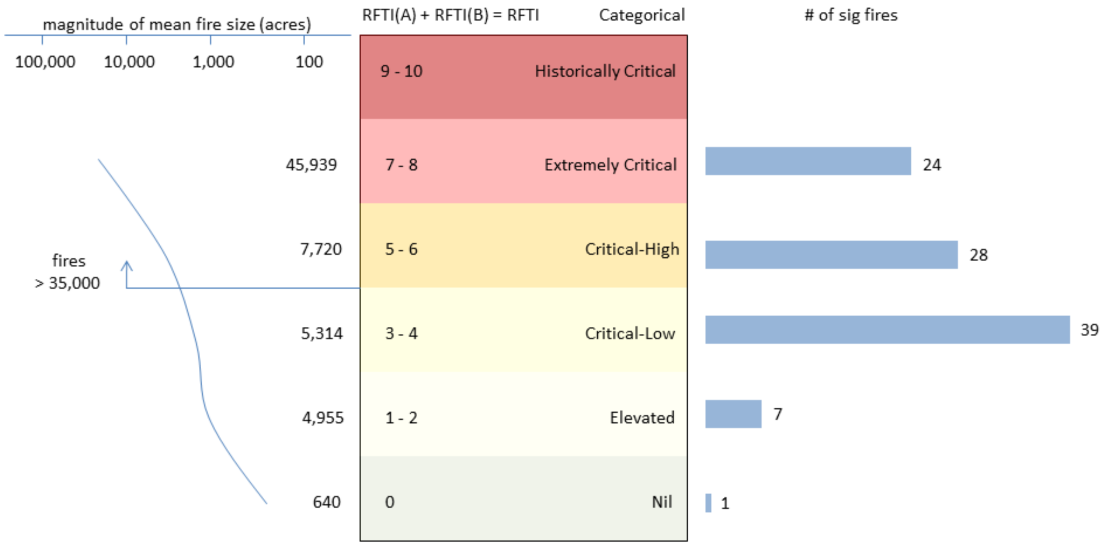

Figure 6: Categorical break down of RFTI relative to the Lindley et al. 2011 WTM proximity observations database for significant wildfire starts, as well as mean fire size for each categorical ranking, using appropriate climatic quartile rankings from KAMA, KLBB, and KMAF.

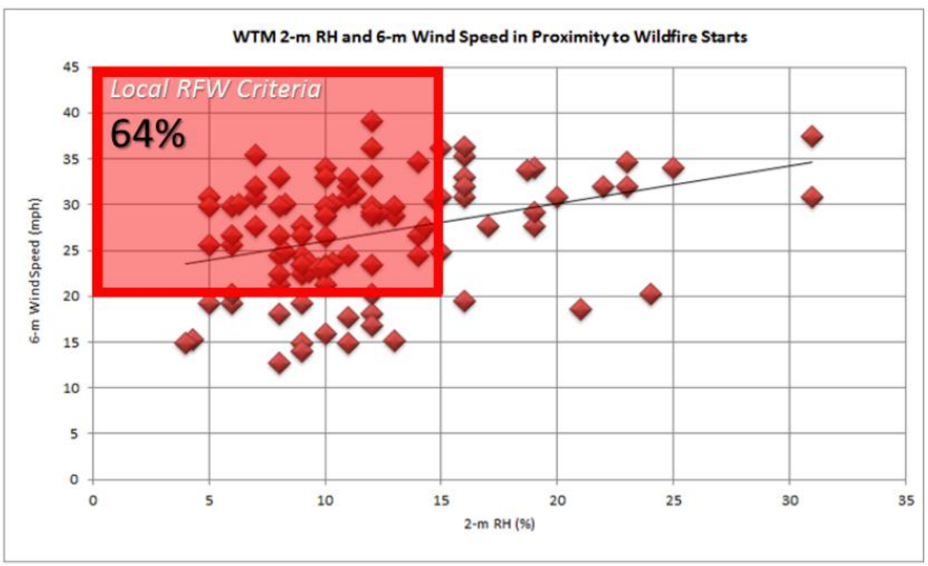

Figure 7: Results from Lindley et al. (2011) showing 64% of 2-m relative humidity and 6-m wind speed environments with significant wildfire starts occurred within defined local RFW conditions, along with associated best-fit trend line.

The eventual burn size for each of the dataset wildfire starts also was considered relative to RFTI. It is noted that there are inherent difficulties in making definitive conclusions in relating fire size and severity due to the availability of firefighting resources, firefighting response time, topography, fuel characteristics, and fire management. It is apparent, however, that the mean size of dataset fires within each RFTI category increased with escalating category. The fire size slope is steepest from “Critical-High” values of 5 and 6 to “Extremely Critical” values of 7 and 8, when mean fire size increased from 7,720 acres (3,124 ha) to 45,939 acres (18,590 ha). All fires that grew to consume ≥ 35,000 acres (14,164 ha) occurred when RFTI≥5. Part of this can be explained by duration (as fire weather conditions become more extreme the duration of burns increases). This trend is also substantiated from an operational aspect in fire management in that increasingly severe fire weather conditions lead to worsening fine dead fuel conditions, and thus the likelihood of problematic fire behavior and control problems increase (Cheney, 2008).

4. Operational use

It is emphasized here that the RFTI is not a direct predictor of fire starts. The RFTI is, however, a decision tool that provides support for the mitigation of fires by providing fire weather forecasters and land managers information useful in appropriate weather-based threat resource allocation and situational awareness.

Unlike strict RFW criteria based solely upon defined thresholds for relative humidity and wind speed, the RFTI does not inappropriately minimize sub-RFW or low-end RFW weather conditions. Lindley et al. (2011) found that 36% of significant wildfire starts on the southern Great Plains occurred in environments outside of the currently defined RFW criteria. The linear spectrum of relative humidities and wind speeds associated with observed fire activity supports the concept that certain combinations of weather and fuel can lead to conditions favorable for wildland fire, even when traditionally accepted fire weather predictors indicate limited potential. For instance, the ignition of the 98,200 acre (39,740 ha) Huckabee Fire (Pecos County, Texas, 126 km south-southwest of KMAF) on 30 April 2008 corresponded to a 2-m relative humidity of 3% and 6-m wind speed of 16 mph (7 m s^{-1}) per a proximity observation at Fort Stockton, Texas (KFST, Fig 8b.) *(this wildfire was outside the WTM domain and not observed by Lindley et al. 2011).* When compared to the KMAF climatological analysis for RFTI, terms of RFTI(A)=5 and RFTI(B)=0 yield a RFTI of 5 “Critical-High”. These conditions did not meet the rigid local RFW criteria, however, with a “Historically Critical” relative humidity, the RFTI(A) term was maximized. In such instances, the RFTI shows improved skill over traditional fire weather predictors. Extreme states of relative humidity or wind, as well as antecedent fuels, can compensate for weaker parameters and result in a high ambient fire danger when strict RFW criteria may suggest a perceived absence of critical weather. As is the case with most atmospheric indices, however, other relevant data such as fuel conditions should additionally be used to support threat levels indicated by the RFTI.

Since RFTI is only dependent upon 2-m relative humidity and 6-m wind speed, it can be incorporated into the NWS’s Graphical Forecast Editor (Glahn and Ruth, 2003) suite of forecast “grids” and included in fire weather forecast products. Since wind speed and relative humidity are a part of the core “grids”, the RFTI falls out of the baseline grid dataset of a particular NWS WFO. The WFO Midland, Texas, forecast RFTI grid for 1800 UTC 2 November 2011 showed a small area of RFTI 5 to 6 “Critical-High” values centered in southwest Texas (Fig. 8a-b). At 1900 UTC 2 November 2011 GOES-12 infrared satellite imagery depicted a wildfire hotspot in the immediate vicinity of these maximum forecast RFTI values (Fig. 9). A proximity observation using the WTM site at Coyanosa, Texas, (KCO1, Fig 8a.) indicated a 2-m relative humidity of 14% (RFTI(A)=1) and 6-m wind speed of 28 mph (13 m s $^{-1}$) (RFTI(B)=4) for a RFTI of 5 “Critically-High”.

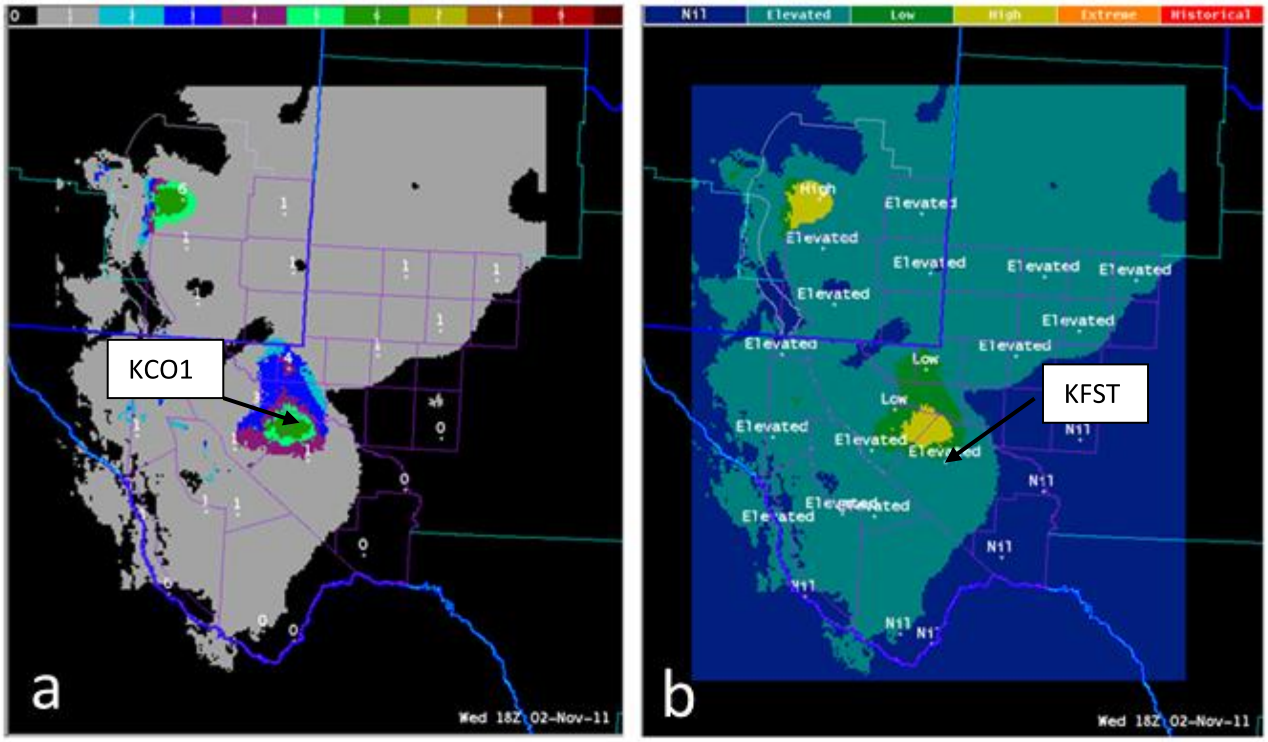

Figure 8: WFO Midland, Texas, numerical (a) and categorical (b) forecast RFTI grids for 1800 UTC 2 November 2011.

Further, wildland fire occurrence is often closely related to human activity and infrastructure (Guyette and Dey, 2000). Thus the risk of fire starts is, at least to some degree, related to the public’s perception of the threat of fires. The RFTI also may have utility in conveying risks to the public in efforts to encourage mitigation and the appropriate use of caution for a given weather scenario.

5. Summary

The RFTI is a tool that allows forecasters, fire managers, and emergency decision makers to quantify the severity of forecast and/or observed fire weather conditions. RFTI is derived by a summation of two terms related to the local critical fire weather climatology through quartile rankings for 2-m relative humidity and 6-m wind speed observations in excess of local RFW criteria. Thus, the RFTI is a unitless number between 0 (“Non-Critical”) and 10 (“Historically Critical”). Since the index scoring system is based upon quartile rankings, there are definitive statistical reference points in which to base strategic and tactical decisions, and the index can easily be utilized anywhere a 10-yr climatological record exists.

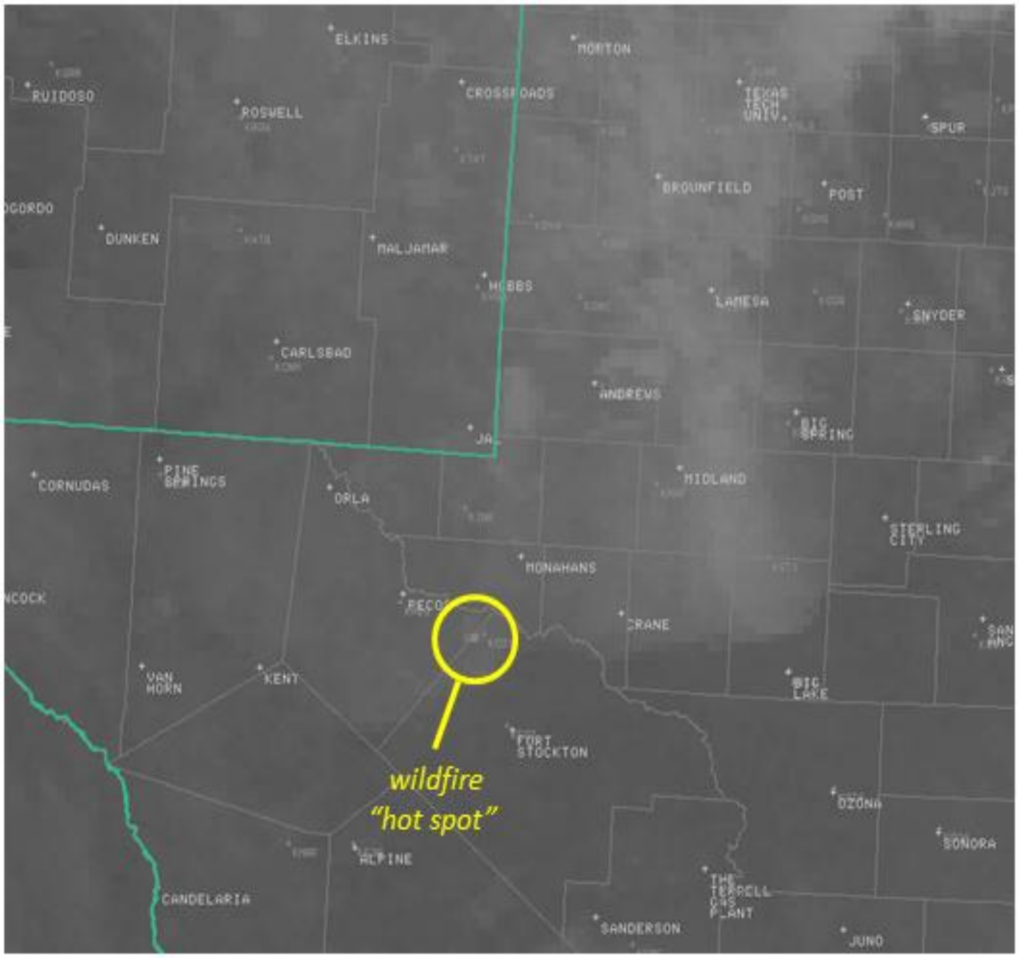

Figure 9: GOES-12 infrared satellite imagery showing a wildfire hotspot in southwest Texas at 1900 UTC 2 November 2011.

The RFTI provides a means to assess daily and hourly fire weather severity, and is a gauge of low-end meteorological environments that are sufficient for fire growth when compared to strict RFW criteria. In addition one of the benefits of the index is the ability to highlight upper-quartile fire weather conditions. When used in conjunction with the identification of synoptic or mesoscale patterns associated with critical fire weather events, the RFTI can give forecasters a discriminate means to add threat appropriate information to fire weather forecasts, watches, and warnings. Use of the RFTI, when combined with local knowledge of the vegetative fuel state, may additionally enhance conceptual models for wildland fire danger and increase confidence in tactical and strategic decisions for fire management.

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