A SIMPLISTIC COLOR-CODED SCALE FOR DETERMINING WILDFIRE GROWTH POTENTIAL

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ABSTRACT

Fire Weather Indexes (FWI) have been utilized for nearly 40 years to assist meteorologists and wildland fire managers with improving wildfire ignition and behavioral predictions. These models, such as the Haines Index and National Fire Danger Rating System, have become standard in the United States with only minor modifications since their inception. In this article, a new, more simplistic FWI is introduced using a three-color scale to convey likelihood, or severity, of a wildfire's growth potential. Unlike the Haines Index, this new model incorporates current and forecasted weather conditions to determine wildfire growth potential. The new fire model incorporates the most important meteorological deterministic variables nearest to a fire to reduce spatial variability concerns—a large disadvantage with traditional FWIs. Because the public is typically less informed about the purpose and use of the Haines Index, that necessity was eliminated in the new model. The colors used in this new model will quickly communicate severity without a user having to actually understand how the model works. The most important advantage the new model possesses, compared to other FWIs, is its simple three-color scale consisting of green, yellow, and red; allowing a user of the model to quickly identify the wildfire's growth potential.

1. INTRODUCTION

Each year, wildfires cause billions of dollars in property damage and burn millions of acres of forests and grasslands. In 2017, 71,499 wildfires burned approximately 10.03 million acres in the United States (National Interagency Fire Center 2018a). Fire suppression costs totalled approximately $2.92 billion (National Interagency Fire Center 2018b). For decades, meteorologists and wildland fire managers have studied wildfire behavior, the variables that influence them, and how to better predict their growth and prevent them from becoming large fires (Dennison et al. 2014; Gollner et al. 2015). In the 1970s, the National Fire-Danger Rating System (NFDRS) was developed for the purposes of having one standardized system for assessing fire danger in the United States (Deeming et al. 1977; Bradshaw et al. 1984).

Currently, two predominant models are utilized by wildland fire managers and meteorologists: the Haines Index and the Fosberg Index. Both models are referred to as fire weather indexes (FWI). Haines and Fosberg's models yield credible data for decision-making purposes, including staffing of wildland firefighters, potential for "blow-up" wildfire behavior, and so forth. Despite the popularity of these FWIs, the Fire, Weather & Avalanche Center (FWAC) sought to develop, implement, and test a new fire weather index (fire model) for assessing a wildfire's growth potential. Nothing in this article is to discredit Haines' model or any other FWI, but to offer a more user-friendly tool to the public, who is typically less knowledgeable, and add another option for wildland fire managers and meteorologists producing fire weather forecasts.

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2. BACKGROUND

In the United States, 98 to 99 percent of wildfires on state- and federally-managed lands are suppressed during initial attack operations. The remaining wildfires grow quickly and to a large size by overwhelming initial attack resources, burning during poor fire weather conditions, and burning in fuel types that produce extreme fire behavior that exceeds firefighting capabilities, such as crowning and spotting (Finney 2005).

a. Wildfires & Variables

Numerous authors have concluded the same variables influence wildfire behavior in at least one way. Combinations of these variables can create extreme wildfire behavior and increase the fire's rate of spread (ROS). These variables are categorized into fuel, weather, and terrain (Gollner et al. 2015; Rothermal 1972).

Fuels and terrain are equally important variables as weather; however, this article emphasizes three meteorological variables: temperature, relative humidity, and wind speed (Werth and Ochoa 1993). These variables were first described in Deeming et al. (1977). In the development of a Canadian FWI, Beverly and Wotton (2007) discussed the need to "provide daily and hourly ratings of fire susceptibility." All else equal, meteorological conditions within the immediate proximity of a wildfire remain the most important deterministic variables for how a fire evolves (Lindley et al. 2011).

Temperature has multiple impacts on wildfire behavior and is argued to be the most important factor in determining potential wildfire behavior. Requirements for ignition and continuous combustion are dependent on temperature. High temperatures created by solar radiation will dry fuels more rapidly, and thus increase ROS. Peak temperatures are generally observed in late afternoon as part of the diurnal cycle. Convective heat produced by the fire, combined with solar radiation heat, further dries fuels in advance of the fire and will increase ROS.

Relative humidity is also argued to be the most important factor; however, temperature determines relative humidity (deferring temperature to the most important). Relative humidity is the ratio of the vapor pressure to the saturation vapor pressure with respect to water, typically expressed as a percentage (American Meteorological Society 2018). Higher relative humidities allow more heat to be absorbed by fuels before combustion; lower relative humidities have the opposite effect. Additionally, moisture will evaporate faster when relative humidity is low and can increase ROS.

Wind can create unpredictable wildfire behavior. The velocity and direction of wind can change throughout the day; atmospheric instability can contribute to additional unexpected wind conditions. Wind can advance the drying of fuels ahead of a fire and can physically move a fire in a specific direction due to pressure exertion. Various other wind types can create additional concerns, such as frontal winds, land/sea breezes, or gradient winds. Terrain can create additional complex wind conditions and further complicate wildfire behavior prediction. Non-convective winds, such as large-scale synoptic features and pressure gradient winds, may or may not dominate the surface layer (Schroeder and Buck 1970).

b. Purpose

In 2017, FWAC observed nearly one million website visitors on a proprietary interactive wildfire map that displays every wildfire (in designated states) reported to interagency dispatch centers. The map provides safety, strategy, and stoke for backcountry adventurers (Sather and Hurd 2016). It is well known that wildfires affect forest recreation and its users (Englin et al. 2008). With the disadvantages described in subsection c, FWAC sought to further its proprietary services by developing a new wildfire growth model that encompasses additional spatial variability concerns and displays as a color-coded scale.

Eastern Research Group (2014) found that colors and symbols should be used to convey threats. The public is typically inexperienced, or not knowledgeable of FWIs, and may lack understanding about the variables that influence the overall value. For example, the public may be unaware of the energy release component in the NFDRS. The FWAC fire model goal was to consist of green, yellow, and red colors that correspond to a certain level of wildfire growth potential. The colors allow users to easily identify the growth potential. The limitation of three colors allows users to not be overloaded with information. Mass et al. (2009) highlights the importance of having high-resolution probabilistic weather prediction in an accessible format; part of the goal being sought by FWAC.

c. Current Models

Several other models already exist to assist wildfire managers and meteorologists in making predictions relative to their positions.

The Haines Index is highly referred to in fire weather forecasts. The index is based on atmospheric stability and moisture content measuring the potential for wildfires to grow into large fires, but not actual fire starts (Winkler et al. 2007). Due to elevation variances in the United States, the Haines Index is derived for low elevations (950-850 mb), mid elevations (850-700 mb), and high elevations (700-500 mb). Additionally, the Haines Index is based on current data or forecasted data. Werth and Ochoa (1993) concluded that the Haines Index is best suited for plume-dominated fires with low winds. Fires that are substantially wind-driven, such as those influenced by the Santa Ana winds in Southern California, are not well-depicted by Haines. The Fosberg Index represents expected flame length and fuel drying based on model output of temperature, relative humidity, and wind speed and is considered biased towards the northeast portion of the United States and does not factor in fuels (Roads et al. 1991). Fosberg is not as commonly used as Haines.

The U.S. Forest Service maintains the Wildland Fire Assessment System (WFAS) website (https://www.wfas.net) where several of these models are posted publicly, including the NFDRS, Haines Index, Dry Lightning, Potential Lightning Ignition, and Lightning Efficiency. Each is useful for some purpose. The Storm Prediction Center (SPC) issues Fire Weather Outlooks on their website to highlight areas of elevated, critical, or extreme fire weather threats; isolated and scattered dry thunderstorms are also highlighted. Each model has value and can aid in making complete and informed decisions. Further disadvantages with these models include output based on larger regions, and not local geographical areas. Spatial variability creates further uncertainty with the Haines and Fosberg indexes. Skew-T data offers many benefits for analyzing various levels of the atmosphere, but the data is only gathered at 12 UTC and 00 UTC for specific RAOB sites. The information quickly becomes obsolete as local conditions change.

3. METHODOLOGY

Due to the proprietary nature of the FWAC fire model, the algorithm used to create the index can not be disclosed. However, the inputs used in the algorithm will be discussed further.

FWAC combined the three weather variables (temperature, relative humidity, and wind speed) based on current observations and forecasted meteorological data. There is an emphasis on the importance of local meteorological conditions in proximity to a fire (Lindley et al. 2011; Erickson et al. 2016); therefore, current observations are derived from a group of 30,000+ publicly-available weather observation sites. The 12 hours subsequent to a fire start is considered the first operational period for wildfire suppression activities. The FWAC fire model analyzes observed and forecasted meteorological variables during that period. Various data from the National Weather Service (NWS) will be integrated with the current weather station observations to compute the index value. Due to operational costs, FWAC determined the use of the NWS' data was more feasible. While the FWAC fire model could be extended to a longer range of time, the accuracy and reliability would decrease. The original purpose of the FWAC fire model was to be relevant at the current time a fire was burning and most likely to change growth potential. Because 98 to 99 percent of wildfires are suppressed quickly, the FWAC fire model would have no purpose past a fire's duration. The FWAC fire model must be able to be calculated almost instantaneously upon request on the website. For every new fire displayed on the FWAC Wildfire Map, the fire model is calculated automatically for the first time upon the user's request on the website. The model is cached for displaying to other users until every subsequent hour afterwards. The model is then recalculated using the most recent meteorological data to ensure its accuracy.

For the purposes of this article, fire season is considered June-September with most wildfires starting between 08:00 and 18:00. This was determined by analyzing wildfire starts from previous years. Using these time parameters, sounding climatology across the Western U.S. from the SPC website was analyzed to determine minimum, average, and maximum temperatures, relative humidities, and wind speeds.

4. RESULTS

FWAC weighted each of the variables in the model based on importance to wildfire ROS (temperature = 0.25, relative humidity = 0.125, wind speed = 0.625). Using FWAC's proprietary algorithm, the fire model scale was developed based on 10,000 sample cases run during the development phase of this project. Minimal-low yields a 33 percent chance of a fire growing larger, moderate yields a 34-66 percent chance of a fire growing larger, and high-extreme yields a 67-100 percent chance of a fire growing larger.

FWAC Fire Model Scale

Index Value	Likelihood	Scale/Color
0 - 3.9	0-33%	Minimal-Low
4 - 6.9	34-66%	Moderate
7+	67-100%	High-Extreme

Users of the FWAC fire model should remember that it does not factor in drought conditions, fuels, or topography. In fact, lower moisture content in fuels, ongoing drought conditions, and steep terrain should imply that fire conditions are equally, if not worse, than the model yields.

5. CONCLUSION

The FWAC fire model will be more beneficial to the public compared to other FWIs such as the Haines Index. The simplistic three-color scale easily conveys severity to a user (see Figure 1).

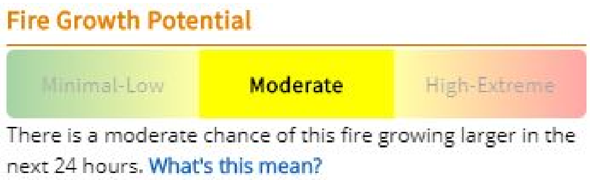

Figure 1: Example display of the fire model color scale on the FWAC website.

The green, yellow, and red colors are easy to visualize and are typically well understood by most (Tjan 2013). Other color-coded scales, such as the North American Avalanche Danger Scale and the Storm Prediction Center severe weather risk scale convolute the public's interpretation of the scales. The colors used in the FWAC fire model quickly communicates severity without a user having to actually understand how the model works whereas the Haines Index requires understanding. Additionally, the public is less likely to be confused by the FWAC fire model's three colors compared to Haines' five colors.

While Haines may convey a lower or higher severity, the public typically lacks understanding about what Haines is portraying. The public will also find the FWAC fire model highly beneficial because it is based on data nearest to a fire, unlike Haines. Weather, according to Lindley et al. (2011), is the data that is most important to wildfire behavior. Also unlike Haines, the FWAC fire model uses current and forecasted weather conditions to determine its scale value. When a FWAC wildfire map website user seeks more information about individual fires, they will see the fire model color unique to each fire.

During fire season 2020, FWAC will continue to test the fire model for wildfires across states in the western United States. Results will be stored in a database to review and analyze at a later time. The goal will be determining if the FWAC fire model accurately assessed and/or predicted fire growth conditions. It is expected that there will be occasional anomalies and outliers. Significant weather phenomenon, such as Santa Ana winds, tornadoes, or microbursts, are likely to substantially increase the FWAC fire model value and inaccurately measure fire growth potential. FWAC recognizes the scale will be less efficient for larger fires due to spatial variability and weather differences at various locations near or within the fire perimeter.

In future revisions of the FWAC fire model, other variables could be included to determine a fire's growth potential, such as the Haines Index or lightning potential. If the FWAC fire model is determined to be successful, a peer-reviewed version of this article may be published.

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REFERENCES

American Meteorological Society, cited 2018a: Relative humidity. Glossary of Meteorology. [Available online at http://glossary.ametsoc.org/wiki/Relative_humidity].

__, cited 2018b: Lapse rate. Glossary of Meteorology. [Available online at http://glossary.ametsoc.org/wiki/Lapse_rate].

Beverly, J. L., and B. M. Wotton, 2007: Modelling the probability of sustained flaming: predictive value of fire weather index components compared with observations of site weather and fuel moisture conditions. *International Journal of Wildland Fire*, **16**, 161-173.

Bradshaw, L. S., J. E. Deeming, R. E. Burgan, and J. D. Cohen, 1984: The 1978 National Fire Danger Rating System: Technical documentation. U.S. Dept. of Agriculture Forest Service General Tech. Rep. INT-169, 44 pp. [Available online at http://www.fs.fed.us/rm/pubs_int/int_gtr169.pdf].

Brotak, E. A., and W. E. Reifsynder, 2003: Predicting major wildland fire occurrence. *Fire Management,* **63**, 20-24. [Available online at https://www.fs.fed.us/fire/fmt/fmt_pdfs/fmt63-4.pdf#page=20].

Deeming, J. E., R. E. Burgan, J. D. Cohen, 1977: The National Fire-Danger Rating System-1978. U.S. Department of Agriculture

Forest Service, Gen. Tech. Rep. INT-39, 63 pp.

Dennison, P. E., S. C. Brewer, J. D. Arnold, and M. A. Moritz, 2014: Large wildfire trends in the western United States, 1984–2011. *Geophysical Research Letters*, **41**, 2928-2933.

Doswell III, C. A., and D. M. Schultz, 2006: On the use of indices and parameters in forecasting severe storms. *Electronic J. of Severe Storms Meteor.*, **1**.

Eastern Research Group, 2014: National Weather Service hazard simplification project social science research for Phase I: Focus groups, Contract #EAJ33C-09-CQ-0034, Task Order #40. [Available online at https://www.weather.gov/media/hazardsimplification/Haz-Simp-Final%20-Focus-Group%20Report-Phase%20I-TO%20NOAA.pdf].

Englin J., T. P. Holmes, and J. Lutz, 2008: Wildfire and the economic value of wilderness recreation. *The Economics of Forest Disturbances*, T. P. Holmes, J. P. Prestmon, K. L. Abt, Eds., Springer, 191–208.

Erickson, M. J., J. J. Charney, and B. A Colle, 2016: Development of a fire weather index using meteorological observations within the northeast United States. *J. Appl. Meteor. Climatol.*, **55**, 389-402.

Finney, M. A, 2005. The challenge of quantitative risk analysis for wildland fire. *Forest Ecology and Management*, **211**, 97-108.

Fire, Weather & Avalanche Center, 2017: Foundations of the the Slope or Nope (SløNø) Model at the Fire, Weather & Avalanche Center. [Available online at https://www.fireweatheravalanche.org/avalanche/foundations-slope-nope-model-at-fire-weather-avalanche-center].

Fosberg, M. A., 1978: Weather in wildland fire management: The fire weather index. *Proc. Conf. on Sierra Nevada Meteorology,* South Lake Tahoe, CA, Amer. Meteor. Soc., 1–4.

Gollner, M., A. Trouve, I. Altintas, J. Block, D. Callafon, C. Clements, A. Cortes, E. Ellicott, J. B. Filippi, M. Finney, K. Ide, M. A. Jenkins, D. Jimenez, C. Lautenberger, J. Mandel, M. Rochoux, and A. Simeoni, 2015: Towards data-driven operational wildfire spread modelling. *The Report of NSF-Funded WIFIRE Workshop,* San Diego, CA. [Available online at http://cone.gollnerfire.com/wp-content/uploads/2015/09/WIFIRE_Wks_Report_FINAL.pdf].

Haby, J., 2003. SKEW-T: A look at LI. *The Weather Prediction*. [Available online at http://www.theweatherprediction.com/habyhints/300/].

Haines, D. A., 1988: A lower atmospheric severity index for wildland fire. *Natl. Weather Dig.*, **13**, 23-27.

Lindley, T. T., J. D. Vitale, W. S. Burgett, and M-J. Beierle, 2011: Proximity meteorological observations for wind-driven grassland wildfire starts on the southern High Plains. *Electronic J. Severe Storms Meteor.*, **6**, 1–27.

Mass, C., S. Joslyn, J. Pyle, P. Tewson, T. Gneiting, A. Raftery, J. Baars, J. M. Sloughter, D. Jones, and C. Fraley, 2009: PROBCAST: A web-based portal to mesoscale probabilistic forecasts. *Bull. Am. Meteorol. Soc.*, **90**, 1009-1014.

National Interagency Fire Center, 2018a: National report of wildland fires and acres burned by state. [Available online at https://www.predictiveservices.nifc.gov/intelligence/2017_statssumm/fires_acres17.pdf].

__, 2018b: Federal Firefighting Costs (Suppression Only). [Available online at https://www.nifc.gov/fireInfo/fireInfo_documents/SuppCosts.pdf].

Roads, J. O., K. Ueyoshi, S. C. Chen, J. Alpert, and F. Fujioka, 1991: Medium-range fire weather forecasts. *International Journal of Wildland Fire*, **1**, 159-176.

Rothermel, R. C., 1972: A mathematical model for predicting fire spread in wildland fuels 1972. U.S. Dept. of Agriculture Forest Service Res. Pap. INT-169, 40 pp. [Available online at https://www.fs.fed.us/rm/pubs_int/int_rp115.pdf].

Sather, B. A., and T. D. Hurd, 2016: Online systems for integrating the safety, strategy, and stoke of backcountry adventure. *International Snow Science Workshop*, Breckenridge, CO. [Available online at https://arc.lib.montana.edu/snow-science/objects/ISSW16_P2.19.pdf].

Schroeder, M. J., and C. C. Buck, 1970: Fire weather: A guide for application of meteorological information to forest fire control operations. U.S. Dept. of Agriculture Forest Service, Agriculture Handbook 360.

Tjan, A. K., 2013: Make priorities clear with green, yellow, and red. *Harvard Business Review*. [Available online at https://hbr.org/2013/04/winning-with-green-yellow-and.html].

Werth, P., and R. Ochoa, 1993: The evaluation of Idaho wildfire growth using the Haines Index. *Wea. Forecasting*, **8**, 223-234.

Winkler, J. A., B. Potter, D. Wilhelm, R. Shadbolt, X. Bian, and K. Piromsopa, 2007: A climatology of the Haines Index for North America derived from NCEP/NCAR reanalysis fields. *International Journal of Wildland Fire*, **16**, 139-152.