10.1071/WF21134
International Journal of Wildland Fire

Supplementary Material

A note on fire weather indices

Jason J. Sharples[A,B,C,*]

[A]School of Science, UNSW Canberra, ACT, Australia

[B]Bushfire and Natural Hazards Cooperative Research Centre, East Melbourne, Vic., Australia

[C]ARC Centre of Excellence for Climate Extremes, UNSW Canberra, ACT, Australia

*Correspondence to: Email: J.Sharples@adfa.edu.au

Fire Weather Indices

This section presents technical information on the four fire weather indices considered.

Fosberg Fire Weather Index $FFWI$

The original formulation of $FFWI$ was based on imperial units of measurement. While this imperial form of the index is still employed (e.g., Kambezidis and Kalliampakos 2016), the metric version is used in this work (see Appendix A), with wind measured in km h^{-1}, temperature expressed in °C and relative humidity in %:

$$FFWI = 2.069863\ \eta\sqrt{2.589975 + U^2}.$$

The moisture damping coefficient η is defined as:

$$\eta = 1 - 2\left(\frac{m}{30}\right) + 1.5\left(\frac{m}{30}\right)^2 - 0.5\left(\frac{m}{30}\right)^3,$$

where m is the moisture content of the fuel, estimated as:

$$m = \begin{cases} 0.03229 + 0.26258\ H - 0.00104\ HT, & H < 10\% \\ 1.75440 + 0.16011\ H - 0.02661\ T, & 10\% \leq H \leq 50\% \\ 21.0606 + 0.005565\ H^2 - 0.00063\ HT - 0.49440\ H, & H > 50\%. \end{cases}$$

Hot-Dry-Windy Index $HDWI$

$HDWI$ is defined by Srock *et al.* (2018) as the product of wind speed U (m s^{-1}) and vapour pressure deficit VPD (hPa):

$$HDWI = VPD \times U,$$

where the values for U and VPD are the maximum values found within a 500-metre layer above the surface.

In the absence of direct measurements, VPD was calculated from air temperature T (°C) and relative humidity H (%) using Tetens' formula (Montieth and Unsworth 2013):

$$VPD = 6.1078 \exp\left(\frac{17.27\ T}{T + 237.3}\right)\left(1 - \frac{H}{100}\right).$$

Canadian Forest Fire Weather Index $CFWI$

Following Matthews (2009), the $CFWI$ is given by:

$$CFWI = \begin{cases} \exp\left(2.72(0.434 \ln B)^{0.647}\right., & B \geq 1; \\ B, & B < 1. \end{cases}$$

Here $B = 4 \times ISI \times A$, where $A \in [0,1]$ is the fuel availability and ISI is the initial spread index. In this study, the fuel availability is assumed to take its maximum value $A = 1$. The ISI is determined as a function of wind speed U (km h^{-1}) and fuel moisture content m (%):

$$ISI = 0.208\, e^{0.05039U}\left(91.9\, e^{-0.1386m}\right)\left(1 + \frac{m^{5.31}}{4.93 \times 10^{7}}\right).$$

The fuel moisture content is determined recursively, based on the initial fuel moisture content m_0, as follows:

$$m = \begin{cases} E_d + (m_0 - E_d) \times 10^{-k_d}, & \text{if } m_0 > E_d; \\ E_w - (E_w - m_0) \times 10^{-k_w}, & \text{if } m_0 < E_w; \\ m_0, & \text{otherwise.} \end{cases}$$

Here E_d is the equilibrium moisture content obtained by drying from above, and E_w is the equilibrium moisture content obtained by wetting from below, in percent moisture content based on dry weight (Van Wagner 1987). In this study, in the absence of an initial fuel moisture content, we initialize the calculation of m by assigning m_0 to be the mean of the initial values of E_d and E_w.

Explicitly, E_d and E_w are given in terms of relative humidity H (%) and temperature T (°C) as:

$$E_d = 0.942\, H^{0.679} + 11e^{(H-100)/10} + 0.81(21.1 - T)(1 - e^{-0.115H}),$$

$$E_w = 0.618\, H^{0.753} + 11e^{(H-100)/10} + 0.81(21.1 - T)(1 - e^{-0.115H}).$$

The exponents k_d and k_w are the drying and wetting rates, respectively, and are defined in terms of T, H and U as:

$$k_d = 0.581e^{0.0365T}\left\{0.424\left[1 - \left(\frac{H}{100}\right)^{1.7}\right] + 0.069U^{0.5}\left[1 - \left(\frac{H}{100}\right)^{8}\right]\right\},$$

$$k_w = 0.581e^{0.0365T}\left\{0.424\left[1 - \left(\frac{100-H}{100}\right)^{1.7}\right] + 0.069U^{0.5}\left[1 - \left(\frac{100-H}{100}\right)^{8}\right]\right\}.$$

Spread index $S(\mu)$

The spread index is defined here as a one-parameter family of functions of wind speed U (km h^{-1}) and the fuel moisture index FMI:

$$S(\mu) = \frac{\max(1, U)}{FMI + \mu}.$$

Sharples *et al.* (2009) defined the FMI as a simple affine transformation of the difference between air temperature T (°C) and relative humidity H (%):

$$FMI = 10 - 0.25(T - H).$$

The FMI is considered as a dimensionless index, and while it doesn't directly produce fuel moisture content values, it has been shown to provide an equivalent scale, or measure, for fine dead fuel moisture content (Sharples and McRae 2011).

Note that the spread index has also been implemented as a two-parameter family of functions, e.g., by Sharples (2019), but in the present work one parameter was found to be adequate.

Appendix A: Derivation of the metric version of the Fosberg Fire Weather Index

The Fosberg Fire Weather Index as presented by Fosberg (1978) can be easily converted into metric form by converting wind speed in miles per hour into kilometres per hour and converting temperature in Fahrenheit into Celsius. Note that:

$$T_F = 1.8\,T_C + 32,$$

where T_F is temperature expressed in °F and T_C is temperature in °C.

Starting with Eq. (5a) of Fosberg (1978), which applies when $H < 10\%$, we have:

$$\begin{aligned} m &= 0.03229 + 0.281073\,H - 0.000578\,H\,T_F, \\ &= 0.03229 + 0.281073\,H - 0.000578\,H(1.8\,T_C + 32), \\ &= 0.03229 + (0.281073 - 32 \times 0.000578)\,H - 1.8 \times 0.000578\,H\,T_C, \\ &= 0.03229 + 0.26258\,H - 0.00104\,H\,T_C. \end{aligned}$$

Similarly, Eq. (5b) of Fosberg (1978), which applies when $11\% \leq H \leq 50\%$, can be rewritten as:

$$
\begin{aligned}
m &= 2.22749 + 0.160107\ H - 0.014784\ T_F, \\
&= 2.22749 + 0.160107\ H - 0.014784\ (1.8\,T_C + 32), \\
&= (2.22749 - 32 \times 0.014784) + 0.160107\ H - 1.8 \times 0.014784\ T_C, \\
&= 1.75440 + 0.16011\ H - 0.02661\ H\,T_C.
\end{aligned}
$$

Finally, Eq. (5c) of Fosberg (1978), which applies when $H > 51\%$, can be rewritten as:

$$
\begin{aligned}
m &= 21.0606 + 0.005565\ H^2 - \ 0.00035\ H\ T_F - 0.483199\ H, \\
&= 21.0606 + 0.005565\ H^2 - \ 0.00035\ H\ (1.8\ T_C + 32) - 0.483199\ H, \\
&= 21.0606 + 0.005565\ H^2 - 1.8 \times 0.00035\ H\,T_C - (0.483199 + 32 \times 0.00035)\ H, \\
&= 21.0606 + 0.005565\ H^2 - 0.00063\ H\ T_C - 0.49440\ H.
\end{aligned}
$$

To calculate the $FFWI$, these converted expressions for m are substituted into (the unmodified) Eq. (4) of Fosberg (1978):

$$
\eta = 1 - 2\left(\frac{m}{30}\right) + 1.5\left(\frac{m}{30}\right)^2 - 0.5\left(\frac{m}{30}\right)^3.
$$

This is then substituted into Eq. (3) of Fosberg (1978), which has been rewritten for wind expressed in kilometres per hour as:

$$
FFWI = 2.069863\ \eta\sqrt{2.589975 + U^2}.
$$

Goodrick (2002) modified the $FFWI$ to include the effects of drought on fuel availability. While the effects of fuel availability were not considered in this study, the modified $FFWI$ is given here in metric units for the sake of completeness. It is

$$
mFFWI = (0.000031\,K^2 + 0.72) \times FFWI,
$$

where K is the Keetch-Byram Drought Index expressed in units of mm.