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Supplementary material

Monthly adaptations of the Drought Code reveal nuanced fire-drought associations in montane forests with a mixed-severity fire regime

Raphaël D. Chavardès[A,C], *Lori D. Daniels*[A], *Bianca N. I. Eskelson*[B] *and Paul D. Pickell*[A]

[A]Forest and Conservation Sciences Department, University of British Columbia, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada.

[B]Forest Resources Management Department, University of British Columbia, 2424 Main Mall, Vancouver, BC V6T 1Z4, Canada.

[C]Corresponding author. Email: raphael3@alumni.ubc.ca

Supplementary Material 1

Daily Drought Code

The daily Drought Code (DC) is a dimensionless index which tracks, on a daily basis over the fire season, changes in moisture within the deep layer (~18 cm) of compact (~25 kg m^{-2} dry weight) organics in the soil (Van Wagner 1987) and large diameter woody fuels (Wotton 2009). The DC has a slow drying rate with a lagtime of 53 days (Lawson and Armitage 2008) where the lag represents the time required to lose roughly two-thirds of the free moisture content over 24 hours at 21.1 °C and relative humidity of 45% (Van Wagner 1987). By default, the DC is given a value of 15 at the start of the fire season which is either the third day after snow has melted in regions normally covered by snow during the winter, or the third day that noon temperatures of 12 °C or higher have been recorded in regions where snow cover is not a significant feature (Lawson and Armitage 2008). The DC on any subsequent day of the fire season is calculated as:

$\mathrm{DC} = 400 \times \ln(800/\mathrm{Q})$, if Q >800 then Q = 800

where Q is the daily moisture equivalent (dimensionless) with maximum value 800 corresponding to saturation, and minimum value 0 corresponding to the driest condition (Van Wagner 1987). On each successive day of the fire season, DC is calculated by adding the effects of total daily precipitation (mm, as water equivalent) (Lawson and Armitage 2008) followed by daily potential evapotranspiration. The effect of total daily precipitation ppt is added to the previous day's value of the DC (DC_{d-1}) and the moisture equivalent after precipitation Q_{ppt} is calculated as:

$$Q_{ppt} = 800 \times e^{[-DC_{d-1}/400]} + 3.937 \times PPT_{EFF}, \text{ if ppt} > 2.8 \text{ mm}$$

or

$$Q_{ppt} = 800 \times e^{[-DC_{d-1}/400]}, \text{ if ppt} \leq 2.8 \text{ mm}$$

where $PPT_{EFF} = 0.83 \times ppt - 1.27$ is the effective precipitation (mm) after canopy and surface fuel interception (Girardin and Wotton 2009). The effect of potential evapotranspiration E (dimensionless) over a given day d of the fire season (E_d) is calculated as:

$$E_d = 0.36(TMX_d) + L_f, \text{ if } E_d < 0 \text{ then } E_d = 0, \text{ if } TMX_d < 0\ °C \text{ then } TMX_d = 0\ °C$$

where TMX_d is the daily maximum temperature (°C), and L_f is a standard day length adjustment factor which varies by month (April = 0.9, May = 3.8, June = 5.8, July = 6.4, August = 5.0, September = 2.4, October = 0.4, and November–March = -1.6) (Girardin and Wotton 2009). The present day's value of the DC (DC_d) is calculated as:

$$DC_d = 400 \times \ln(800/Q_{ppt}) + 0.5 \times E_d$$

By default, DC calculations are continued until snow covers the ground or noon temperatures drop below 12 °C for three consecutive days (Lawson and Armitage 2008).

Overwintered Drought Code

In areas with moisture depletion in between fire seasons, the starting moisture equivalent value in the spring (Q_s; i.e., Q on the first day of the fire season) is calculated as:

$$Q_s = a \times Q_f + b(3.94 \times ppt_w)$$

where Q_f is the final moisture equivalent value in the fall (i.e., Q on the last day of the fire season), *a* is the carry-over fraction of prior fall moisture estimated as 0.5, 0.75 or 1.0, and *b* is the effectiveness of winter precipitation in recharging moisture reserves in spring estimated as 0.5, 0.75 or 0.9, and ppt_w is total winter precipitation (mm, as water equivalent) (Van Wagner 1987).

Monthly Drought Code

The Monthly Drought Code (MDC) is a dimensionless index which tracks monthly changes in moisture in deep compact organics in the soil and large-diameter woody fuels (Girardin and Wotton 2009). Typically, the MDC is assigned a value of 15 on 30 April (Girardin and Wotton 2009) or 31 March (Bergeron et al. 2010), the day preceding the start of the fire season. The MDC in any given month of the fire season is calculated as:

$\mathrm{MDC} = 400 \times \ln(800/\mathrm{Q_m})$, if $Q_m > 800$ then $Q_m = 800$

where Q_m is the moisture equivalent (dimensionless) during month m (Girardin and Wotton 2009). In their MDC calculations, Girardin and Wotton (2009) assumed that drying occurs in the first half of the month, total precipitation occurs in the middle of the month, and drying occurs again in the second half of the month. In a first step, potential evapotranspiration over a given month (E_m) of the fire season is calculated as:

$\mathrm{E_m} = \mathrm{N}[0.36(\mathrm{TMX_m}) + \mathrm{L_f}]$, if $E_m < 0$ then $E_m = 0$, if $TMX_m < 0$ °C then $TMX_m = 0$ °C

where TMX_m is the monthly mean of daily maximum temperatures (°C), L_f is the standard day length adjustment factor applied to each month as in the daily DC, and N is the number of days in the given month (Girardin and Wotton 2009). Following drying in the first half of the month, MDC is calculated as:

$\mathrm{MDC_{1st\ half}} = \mathrm{MDC_e} + 0.25 \times \mathrm{E_m}$

where MDC_e is the MDC value at the end of the previous month. The effect of total monthly precipitation (PPT_m; mm, as water equivalent) occurring mid-month affects the corresponding moisture equivalent (Q_{mr}) as follows:

$$\mathrm{Q_{mr}} = 800 \times \mathrm{e}^{[-(\mathrm{MDC_{1st\,half}})/400]} + 3.937 \times \mathrm{PPT_{EFF}}$$

where $\mathrm{PPT_{EFF}} = 0.83 \times \mathrm{PPT_m}$ is the monthly effective precipitation (Girardin and Wotton 2009). Following drying over the second half of the month, the MDC value of at the end of the month, MDC is calculated as:

$$\mathrm{MDC_{2nd\,half}} = 400 \times \ln(800/\mathrm{Q_{mr}}) + 0.25 \times \mathrm{E_m}$$

Averaging the MDC values at the end of the previous month and at the end of the given month yields the MDC value for the given month:

$$\mathrm{MDC_m} = (\mathrm{MDC_e} + \mathrm{MDC_{2nd\,half}})/2$$

By default, MDC calculations are discontinued at the end of each year on 31 October and do not account for potential overwinter drying of fuels (Girardin and Wotton 2009).

Adjusted Monthly Drought Code

The adjusted Monthly Drought Code (adjMDC) accounts for overwinter drying of fuels and starts on 1 April. With adjMDC, moisture equivalents at the end of the fire season on 31 October (Q_{Oct}) and at the start of the fire season (Q_{Mar}) are calculated as:

$$\mathrm{Q_{Oct}} = 800 \times \mathrm{e}^{[-\mathrm{adjMDC_{Oct}}/400]}$$

And,

$$\mathrm{Q_{Mar}} = a \times \mathrm{Q_{Oct}} + b(3.94 \times \mathrm{PPT_w}), \text{ if } \mathrm{Q_{Mar}} > 800 \text{ then } \mathrm{Q_{Mar}} = 800$$

where $adjMDC_{Oct}$ is the adjMDC value on 31 October, *a* is the carry-over fraction of prior fall moisture estimated as 0.5, 0.75 or 1.0, *b* is the effectiveness of winter precipitation in recharging moisture reserves in spring estimated as 0.5, 0.75 or 0.9, and PPT_w is total winter precipitation (mm, as water equivalent) from November–March inclusive. We conducted a sensitivity analysis to select the most suitable combination *a* and *b* for our study area. We compared adjMDC, calculated with all possible combinations of *a* and *b*, against the overwintered DC_m values for April or May (depending on the start date for daily DC each year) from 1989 to 2013. Based on boxplots, Mann-Whitney rank sum tests, and Pearson product moment correlations adjMDC values were most suitable in April and May when *a* and *b* were both 0.75, corresponding to areas exposed to winter moisture depletion and sites that are moderately drained, respectively (Lawson and Armitage 2008). To begin each fire season, the adjMDC value on 31 March is calculated as:

$$\mathrm{adjMDC}_{\mathrm{Mar}} = 400 \times \ln(800/\mathrm{Q}_{\mathrm{Mar}})$$

Fig. S1. Monthly mean Drought Code (DC_m) versus adjusted Monthly Drought Code (adjMDC) including overwintering and an 1 April start of the fire season at the Palliser fire-weather station during 25 fire seasons including 1989–2013.

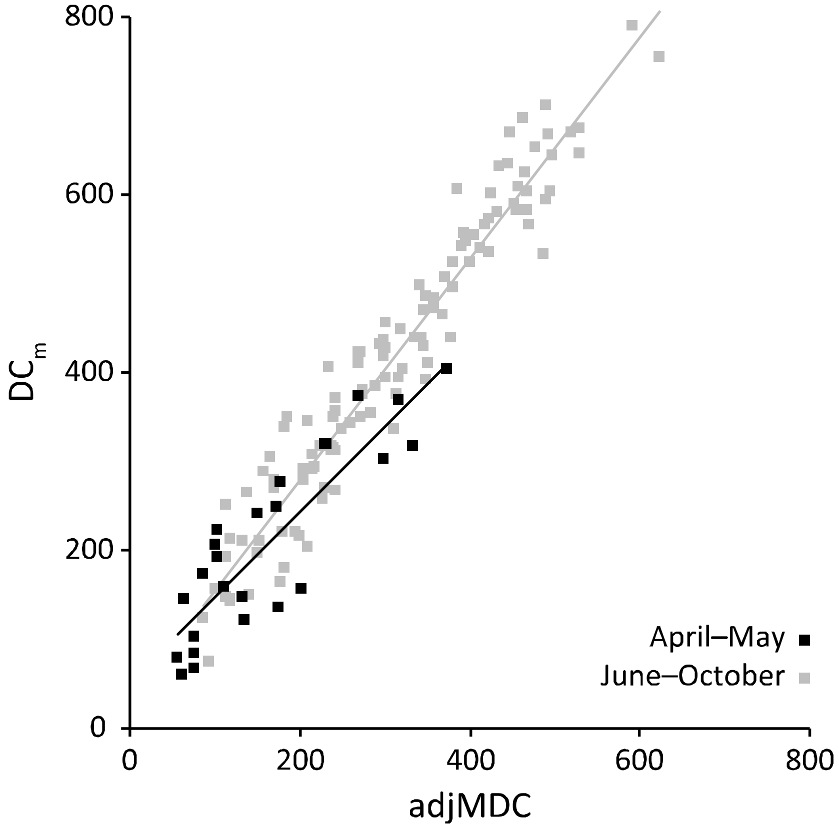

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Fig. S2. Fire-drought associations for the Monthly Drought Code (MDC), adjusted MDC (adjMDC), and predicted monthly mean Drought Code ($predDC_m$) for the Palliser fire-weather station. Black (white) bars represent mean values during fire (non-fire) years. Stars depict significant associations with fire years (1, 2, and 3 stars indicate the 95, 99, and 99.9 % confidence levels, respectively).