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Supplementary material

Inferring energy incident on sensors in low-intensity surface fires from remotely sensed radiation and using it to predict tree stem injury

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Fireline intensity

To help place our measurements of fire radiated energy density (FRED, kJ m^{-2}) in a fire behavior context that will be more familiar to fire managers and scientists we estimate fireline intensity (Byram 1959) from peak fire radiated flux density FRFD (kW m^{-2}, see Equation 1 in main manuscript). Fireline intensity is reported in Table 1 in the main manuscript. FRFD measurements from sensors with different areas of regard (because of different sensor heights or fields of view, or both) are not strictly comparable because fractional fire area (A_f) will differ. FRFD is an average value over a pixel and, all else being equal, will increase with increasing A_f

(e.g., with decreases in sensor height or field of view). In order to estimate fireline intensity from our nadir-radiometer peak FRFD measurements using the relationship from Figure 6 in Kremens *et al*. (2012), we had to re-scale peak FRFD to a common area of regard. We assume that flame fronts are roughly linear for the purpose of estimating fractional fire area having no overhead imagery with which to evaluate that assumption. The scaling factor is the fractional change in A_f between the radiometers as deployed in the RxCADRE experiments and the the "small plot" experiments described in Kremens *et al.* (2012) for which we have independent measurements of rate of spread and fuel consumption from which fireline intensity is calculated directly. Assuming a linear flame front and flame depth < diameter of the area of regard (Figure 1S), fire fractional area near peak FRFD (when the flame front is near the center of the field of view) is approximately:

$$A_f = \frac{2rd_F}{\pi r^2} \tag{1S}$$

where r is the radius of the field of view and d_F is the flame-front depth.

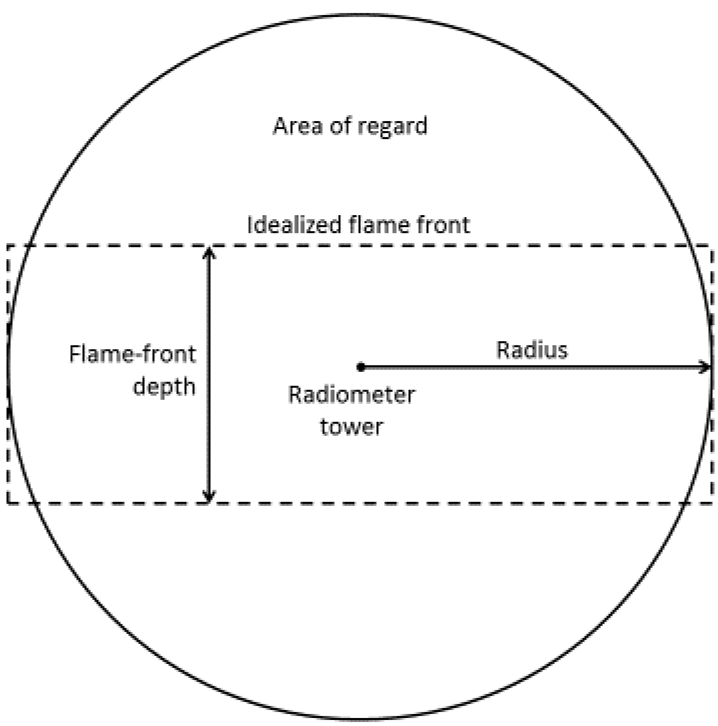

Fig. 1S. Circular area of regard of a nadir radiometer and an idealized flame front. We assume that the flame front (dotted area) near peak FRFD is centered on the area of regard and approximates a rectangle with length twice the radius and depth equal to flame depth.

The product of diameter (2*r*) and *d* is the area of the rectangular strip and approximates fire area. The scaling factor after substituting and simplifying reduces to a ratio of radii:

$$S = \frac{A_{fSP}}{A_f} = \frac{r}{r_{SP}} \qquad (2S)$$

where the subscript *SP* refers to the small plot experiment. Assuming an area of regard that increases in radius as nadir radiometer height increases, the radius of view is calculated from:

$$r = hTan(\theta) \qquad (3S)$$

where *h* is nadir radiometer height (m) and θ is half the field-of-view in degrees. The small plot radiometers had a 60 degree field of view and were positioned at 3.9 m for a radius of view of approximately 2.25 m which contrasts to a 2.68 m radius for the nadir radiometers used in this study. Thus, we estimate fireline intensity (*I*, kW m^{-2}) by inverting the linear equation from Figure 6 in Kremens et al. (2012) and applying the scaling factor (Equation 3):

$$I = \frac{S\ FRFDp}{0.0311} \qquad (3S)$$

where *S* is the scaling factor (S = 0.84), $FRFD_P$ is peak FRFD from the nadir radiometer, and 0.0311 (m^{-1}) is the proportionality constant from Kremens *et al.* (2012).

We acknowledge the idealization of the flame front and our assumption about its position in the area of regard at peak FRFD. Other uncertainties include the fall-off in signal from the center to the periphery of a pixel (the point-spread function) and the differences in fuels between Kremens et al. (2012) and the current study. The fuels in Kremens et al. (2012) were mixed oak litter. On the positive side, the range in intensities of fires in this study are within the range of those in Kremens et al. (2012) and flame depths were about 1 m (Table 1 in main manuscript), validating the assumption that flame fronts were contained within the nadir radiometer area of regard (Figure 1S). As well, our estimates of fireline intensities of 564 and 739 kW m^{-1} from nadir radiometers and Equation 3S for blocks S5 and L2G, respectively, are similar, to the 890 and 1730 kW m^{-1} calculated directly from rate of spread and fuel consumption from Butler *et al*. 2016 (Table 5). The measurements are not strictly comparable because our estimates are local while those from Butler *et al*. (2016) use burn block-averaged consumption and rate of spread estimated over 10's of meters. Despite uncertainties, we feel that there is value in having approximate estimates of fireline intensity and must leave examination of the consequences of the simplifying assumptions to later studies. A more rigorous means of estimating fireline intensities would involve direct calculation from rates of spread determined from overhead imagery and fuel consumption estimated from fire radiated energy density (FRED, kJ m^{-2}) from nadir radiometers (Johnston et al. 2017).

References

Johnston JM, Wooster MJ, Paugam R, Wang X, Lynham TJ, Johnston LM (2017) Direct estimation of Byram's fire intensity from infrared remote sensing imagery. *International Journal of Wildland Fire* **26**, 668–684.

Kremens R, Dickinson M, Bova A (2012) Radiant flux density, energy density and fuel consumption in mixed-oak forest surface fires. *International Journal of Wildland Fire* **21**, 722–730.