Quantification of fuel moisture effects on biomass consumed derived from fire radiative energy retrievals

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[1] Satellite based fire radiant energy retrievals are widely applied to assess biomass consumed and emissions at regional to global scales. A known potential source of uncertainty in biomass burning estimates arises from fuel moisture but this impact has not been quantified in previous studies. Controlled fire laboratory experiments are used in this study to examine the biomass consumed and the radiant energy release (Fire Radiative Energy, FRE, (MJ)) for western white pine needle fuels burned with water content (W_C, unitless) from 0.01 to 0.14. Results indicate a significant relationship: FRE per kilogram of fuel consumed = −5.32 W_C + 3.025 (r^2 = 0.83, n = 24, P < 0.001) and imply that not taking into account fuel moisture variations in the assumed relationship between FRE and fuel consumed can lead to systematic biases. A methodological framework to derive a revised formula that enables the estimation of biomass consumed from FRE, which explicitly takes into account fuel water content, is presented. **Citation:** Smith, A. M. S., W. T. Tinkham, D. P. Roy, L. Boschetti, R. L. Kremens, S. S. Kumar, A. M. Sparks, and M. J. Falkowski (2013), Quantification of fuel moisture effects on biomass consumed derived from fire radiative energy retrievals, *Geophys. Res. Lett.*, *40*, 6298–6302, doi:10.1002/2013GL058232.

1. Introduction

[2] Biomass burning is a significant source of atmospheric trace gas and aerosol emissions, accounting globally for ~40% of annual carbon dioxide and carbon monoxide emissions [*van der Werf et al.*, 2010], although the exact quantities vary with interannual variability of climate processes [*Slegert et al.*, 2001; *Littell et al.*, 2009]. Quantifying biomass consumed and subsequent emissions is fundamental in understanding terrestrial-atmospheric Earth system processes and climate change [*Bowman et al.*, 2009]. Regional to global scale emission estimates are obtained conventionally via remotely sensed estimates of the area burned, model estimates of the quantity of fuel consumed, and the emission factors of the associated emitted greenhouse and trace gases [*Crutzen and Andreae*, 1990]. Recently, fire radiant energy remote sensing products from polar-orbiting and geostationary coarse resolution fire products have been applied to infer fire behavior and biomass consumed at regional to global scales [*Kaufman et al.*, 1998; *Wooster*, 2002; *Roberts et al.*, 2005; *Smith and Wooster*, 2005; *Wooster et al.*, 2005; *Roberts and Wooster*, 2008; *Kumar et al.*, 2011; *Kaiser et al.*, 2012; *Zhang et al.*, 2012; *Heward et al.*, 2013]. The fire radiant power (FRP; units: W) retrieved at the time of satellite overpass is related to the instantaneous rate of biomass consumed; temporal integration of sampled FRP over the fire duration provides the Fire Radiative Energy (FRE; units: J) which has been shown, with both laboratory and field measurements, to be linearly related to the amount of biomass burned [*Wooster*, 2002; *Wooster et al.*, 2005; *Freeborn et al.*, 2008; *Kremens et al.*, 2012].

[3] A known potential source of uncertainty arises from water contained within the fuel but this impact has yet to be quantified by remote sensing FRE studies [*Brown and Davis*, 1973; *Freeborn et al.*, 2008; *Kremens et al.*, 2012; *Roy et al.*, 2013; *Wooster et al.*, 2013]. The fuel may not be completely dry when it is burned, depending on the precipitation and temperature regimes, the amount of drying due to the antecedent and current incoming solar radiation, the relative humidity of the atmosphere, condensation of dew onto the fuel surface, the state of decay of the fuels, and the proportion of live vegetation in the fuel. In terms of FRP measurement, the latent energy required to change the phase of liquid water in the fuel to water vapor (i.e., the enthalpy of vaporization) is not measured when sensing the combusting fuel within an actively burning fire. Moreover, the energy required to raise the liquid water in the fuel from ambient to boiling temperature and the energy required to drive the moisture out of the fuel (i.e., the heat of desorption) will reduce the emitted energy that is remotely sensed [*Brown and Davis*, 1973]. The emitted radiant energy may also be absorbed by water vapor and smoke in the atmospheric column between the fuel and the sensor and may be reemitted in a direction away from the sensor. The combined impact of these loss mechanisms on fire radiant energy retrievals has yet to be quantified, which limits the confidence in using satellite derived radiant energy products for the assessment of regional to continental biomass consumed and emission estimates. Arguably these uncertainties, in addition to FRP sampling issues [*Boschetti and Roy*, 2009; *Kumar et al.* 2011], may have prevented a wider uptake of FRP-based emission estimations. However, recent continental and global emission estimation systems that use FRP also rely on other data, for example, using empirical coefficients based on aerosol optical thickness retrievals [*Sofiev et al.* 2009] or, as in *Kaiser et al.*, [2012] normalizing the FRP-based emission

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