retrievals against the Global Fire Emissions Database which is produced using a conventional bottom-up emission estimation approach [*van der Werf et al.*, 2010]. For the first time, we present results from a laboratory experiment to quantify how increasing moisture content impacts remotely sensed fire radiant energy retrievals.

2. Methodology

2.1. Experimental Setup

[4] Fire experiments were conducted at the Idaho Fire Institute of Research and Education located in an indoor climatically controlled environment that is shielded from weather effects. Multiple approaches exist to estimate FRP, including single-band midwave-infrared thermal imagers, dual-band thermometry, and Planck function curve fitting of 0.3–2.5 μm spectroradiometer data; the relative merits and the variation of FRP retrieved from these different methods are discussed in past studies [*Dozier*, 1981; *Wooster et al.*, 2005; *Kremens et al.*, 2010]. In this study, we used a dual-band infrared radiometer (0.15–11 μm and 6.5–20 μm) developed by the Rochester Institute of Technology to estimate FRP per unit area ($\mathrm{W\,m^{-2}}$) at 0.5 s intervals using dual-band thermometry, where in contrast to single wavelength devices, measurements are acquired independently of emissivity [*Kremens et al.*, 2010, 2012]. As detailed in the literature [*Dozier*, 1981; *Daniels*, 2007; *Kremens et al.*, 2010, 2012], dual-band thermometry uses the principal that for a black- or grey-body radiation source the ratio of two infrared bands enables the kinetic temperature of the source to be estimated via a two point fit to the Planck function. The radiometer employs a ST60 dual-detector infrared thermopile (Dexter Research Center, Michigan) as an active element with custom noise filtering and amplifying electronics mounted on a printed circuit board in a ventilated fire resistant housing [*Kremens et al.*, 2012]. The system was radiometrically calibrated using standard blackbody radiation sources (Omega Engineering part # BB-4A and #BB-704) between 373 K and 1250 K [*Wolfe and Zissis*, 1993]. During operation, dry air was streamed across the dual-band infrared radiometer to reduce fouling due to soot and other smoke particulates. The ambient temperature of the dual-detector infrared thermopile was measured using a digital thermometer. The dual-band infrared radiometer has a 52° instrument field of view and was positioned at a fixed height of 1.16 m directly above the center of a 1 $\mathrm{m^2}$ circular fuel bed, so that the extent of the fuel bed was equal to the sensor field of view. To minimize the effects of conductive heat transfer, the fuel bed was placed on a low conductivity fiberglass mesh reinforced ceramic board. The board was placed on a Sartorius EB Series scale (65 kg capacity, accurate to 1 g), synchronized with the dual-band radiometer to record fuel mass loss throughout the burn period. Fuels were collected from a single species western white pine (*Pinus monticola*) stand located adjacent to the University of Idaho, USA and were manually sorted to remove impurities such as bark flakes, lichens, etc.

[5] For each ignition, a small amount of lighter fluid was added to the edge of the fuel bed and ignited to provide a uniformly spreading flaming front. Each burn trial was considered complete once no mass loss was observed for at least 20 s. The radiometer recorded zero FRP values after the fire had extinguished, indicating the radiant energy emitted from the heated board was below the radiometer's detection limit. Prior to each ignition, all fuel beds were compressed to a constant bulk density of 85.7 $\mathrm{kg\,m^{-3}}$ to minimize variation in fire behavior and combustion completeness across the burn trials.

[6] The FRE was derived as the discrete integral of the FRP over the duration of each burn:

$$\mathrm{FRE} = \sum_{t1}^{t2} \mathrm{FRP}_t \Delta \mathrm{t}, \tag{1}$$

where t_1 (s) and t_2 (s) denote, respectively, the start and end of combustion, as defined above; FRP_t (W) is the power measured by the radiometer at time t; and $\Delta t = 0.5$ s is the measurement sampling interval.

2.2. Fuel Water Content

[7] Fuel moisture was quantified in terms of water content, defined as the percentage of water over the total mass of the (wet) sample:

$$W_C = \frac{W_M}{S_M} = \frac{W_M}{D_M + W_M}, \tag{2}$$

where W_C (dimensionless) is the fuel water content, S_M (kg) is the total mass of the wet fuel sample, W_M (kg) is the water mass, and D_M (kg) is the dry mass of the fuel sample. The water content W_C is univocally related to the fuel moisture content (FMC), commonly used in the fire ecology community, which is defined as the water content (W_C) divided by the dry mass (D_M). The fuel moisture was controlled by reducing all materials to $W_C < 0.01$ in an oven, weighing the fuel beds to derive the dry mass, and then allowing the fuel to equilibrate outside the oven to the mass associated with the desired water content.

2.3. Theoretical Heat Budget

[8] The radiant energy release fraction (f_r), defined as the fraction of total energy released during combustion in the form of radiation [*Freeborn et al.*, 2008], was calculated as

$$f_r = \frac{\mathrm{FRE}}{H_C * \mathrm{BC}}, \tag{3}$$

where H_C ($\mathrm{MJ\,kg^{-1}}$) is the heat of combustion, FRE (MJ) is defined via (1), and BC (kg) is the total biomass consumed as measured by the scale.

[9] A theoretical radiant heat budget per unit mass consumed was derived to independently quantify the deficit of retrieved fire radiant energy due to fuel moisture. The theoretical FRE released by a burnt sample is defined [*Brown and Davis*, 1973; *Kremens et al.*, 2012] as

$$\mathrm{FRE} = f_r * \left[H_C D_M - W_M\left(H_{\mathrm{vap}} + C_W(373 - T_a) + H_{\mathrm{Des}}\right)\right] \tag{4}$$

where f_r is defined as (3), H_C is the heat of combustion of pine needles (20.138 $\mathrm{MJ\,kg^{-1}}$) [*Font et al.*, 2009], D_M is the dry mass of the sample, W_M is the water content of the sample, H_{vap} is the enthalpy of water vaporization at atmospheric pressure (2.257 $\mathrm{MJ\,kg^{-1}}$), C_W is the heat capacity of water (0.0042 $\mathrm{MJ\,kg^{-1}}$), T_a = ambient temperature (300 K), and H_{Des} is the heat of desorption = 0.1 $\mathrm{MJ\,kg^{-1}}$ [*Brown and Davis*, 1973; *Shottafer and Shuller*, 1974].