A wildland fire emission inventory: western United States emission estimates and an evaluation of uncertainty associated with forest fuel loading

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ABSTRACT
Biomass burning (BB) emission inventories (EI) provide critical input for atmospheric chemical transport models used to understand the impact of biomass fires on air quality. Wildland fuel loadings are a significant source of uncertainty in U. S. BB EI. Fuel loading data from ~14,000 forest inventory plots has been used to quantify the bias in two commonly used wildland fuel loading models the Fuel Characteristics Classification System (FCCS) and the Fuel Loading Models (FLM) and asses the uncertainty in BB emission estimates due to uncertainty in fuel loading. In the aggregate, FLM underestimated total forest fuel loading by -3.4 kg m^{-2}, while FCCS overestimated total forest fuel loading by 0.9 kg m^{-2}. The FLM bias leads to underestimates in 2005 western U. S. forest fire emissions of 1840 Gg-CO, 263 Gg-PM2.5 and 490 Gg-NMOC. After correction of the FLM for bias, the uncertainty in ECO (at Δx = 10 km and Δt = 1 day) due to fuel loading averaged 26% for the western U. S. in 2005. This estimate of uncertainty in ECO does not consider uncertainties in A, CC, or EF.

INTRODUCTION
Biomass burning (BB) emission inventories (EI) provide critical input for atmospheric chemical transport models used to understand the impact of biomass fires on air quality. While significant progress has been achieved recently in the development of regional and global BB EI, agreement among inventories is often poor[1]. Furthermore, the uncertainties of emission estimates are typically only reported at coarse scales (e.g. the uncertainty in annual $PM_{2.5}$ emitted for the contiguous United States). Estimating uncertainties for BB EI is difficult because the appropriate data is typically not available to fully evaluate all components of emission models. Wildland fuel loadings are a significant source of uncertainty in U. S. BB EI[1,2]. In this paper we use fuel loading data from ~14,000 forest inventory plots (USDA Forest Service Forest Inventory and Analysis (FIA) program) to quantify the bias in two wildland fuel loading models the Fuel Characteristics Classification System (FCCS)[3] and the Fuel Loading Models (FLM)[4]. We applied a bias correction to the FLM and used the bias corrected fuel loadings to estimate CO emissions (ECO) from western U. S. forest fires in calendar year 2005. In addition to bias correction, the FIA plot data was used to quantify the uncertainty in ECO associated with fuel loading.

The purpose of this paper is not to present a rigorous BB EI, but rather to quantify the bias in two commonly used fuel loading models and assess the uncertainties in emission estimates resulting from to uncertainties in fuel loading after correction for mean bias. The uncertainty assessment has been conducted at scales relevant to air quality modelling (Δx = 10 km, Δt = 1 day). The analysis is limited to burned forest lands in the 11 western contiguous U. S.

BODY

Biomass Burning Emission Model

BB emission (E) of a species (i) is commonly estimated as the product of burned area (A; m^2), fuel loading (F; kg m^2), combustion completeness (CC; unit-less), and specific emission factors (EF; [kg-compound i] [kg-dry $fuel^{-1}$])[5]:

Equation (1) $E(i) = A \times F \times CC \times EF(i)$.

This study used burned area spatial data produced by the Monitoring Trends in Burn Severity project (MTBS). The burned area was distributed temporally using daily active fire detections and burn scars from the MODIS sensor on NASA's Terra and Aqua satellites[1]. CC was estimated using the First Order Fie Effects Model (FOFEM)[7]. EF for CO, PM2.5 and total non-methane organic compounds (NMOC) were taken from the literature[8].

Fuel Loading

The study examined fuel loading using the Fuel Characteristics Classification System (FCCS)[3] and the Fuel Loading Models (FLM)[4] as mapped by the LANDFIRE project (LANDFIRE). The bias of the fuel models was quantified using fuel loading data from ~14,000 forest inventory plots (USDA Forest Service Forest Inventory and Analysis (FIA) program). The FIA plot data were assigned FLM and FCCS fuel codes based on LANDFIRE maps. The analysis treated fuel loading according to 4 categories: litter, fine woody debris (fwd), coarse woody debris (cwd).

Results

The 2005 burned area included 11 FLM fuel classes and 23 FCCS fuel classes. The fuel loading bias in the FLM and FCCS was determined for the fuel categories (litter, fwd, cwd, duff) of each model's fuel classes. The effective bias of each model was calculated as the burned area weighted mean of the bias across all fuel classes in each fuel category. The mean bias of FLM and FCCS are shown in Figure 1. The FLM underestimated fuel loading for all fuel categories, while the FCCS overestimated fuel loading for fwd, cwd, and duff. In the aggregate, FLM underestimated total fuel loading by -3.4 kg m^{-2} and FCCS overestimated total fuel loading by 0.9 kg m^{-2}. The error in 2005 western U. S. forest fire emissions resulting from the FLM negative bias is shown in Figure 2 for CO, PM2.5, and NMOC. The emission calculations used temperate forest EF of 89 g kg^{-1}, 12.7 g kg^{-1}, and 23.7 g kg^{-1} for CO, PM2.5, and NMOC, respectively[8].

We corrected the FLM fuel loadings for bias and used this bias corrected FLM to repeat the ECO calculations daily on a grid with horizontal resolution of 10 km × 10 km. The analysis provided 3497 daily burned grids which we used to assess the uncertainty in ECO due to uncertainty in fuel loading. The uncertainty in fuel loading was estimated using the FIA plot data and propagated into the emission model (Equation 1) using a Monte Carlo style simulation[1]. The assessment considered ONLY uncertainties in fuel loading, uncertainties in burned area (A), fuel consumption (CC), and EF were not considered. Figure 3 shows the distribution of daily burned grids (each representing daily ECO from a 10 km^2 grid) by fractional uncertainty in ECO, uECO. The distribution in uECO is right skewed with a mode of ~0.20 and an average of 0.27.

Figure 1. Fuel load bias of FLM and FCCS fuel loading models.

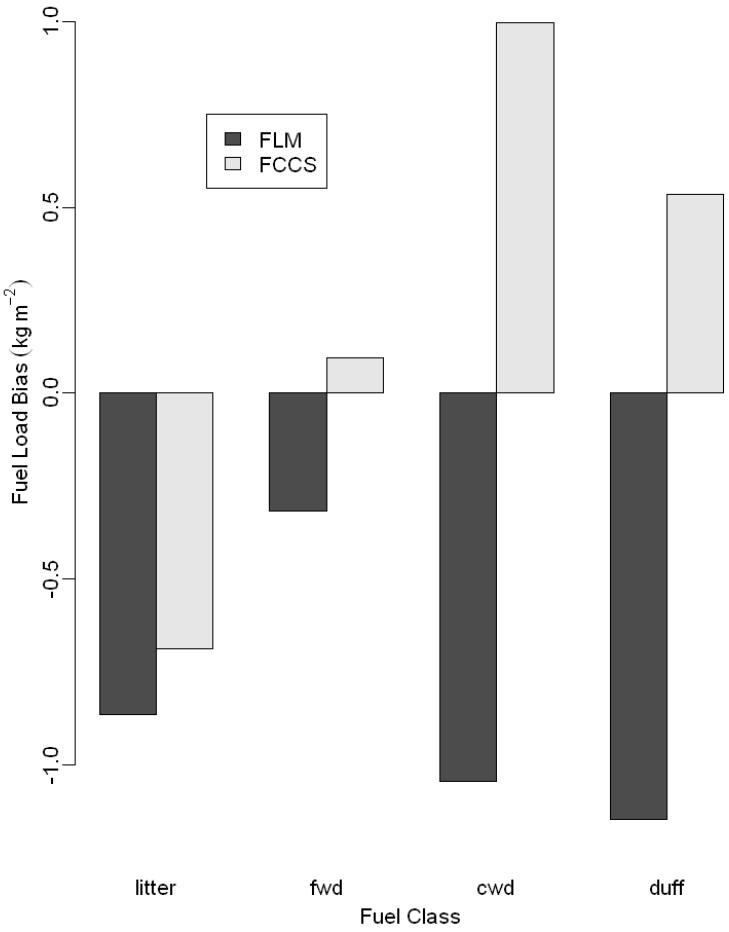


Figure 2. Error in 2005 western U.S. forest fire ECO due to bias in FLM fuel loading.

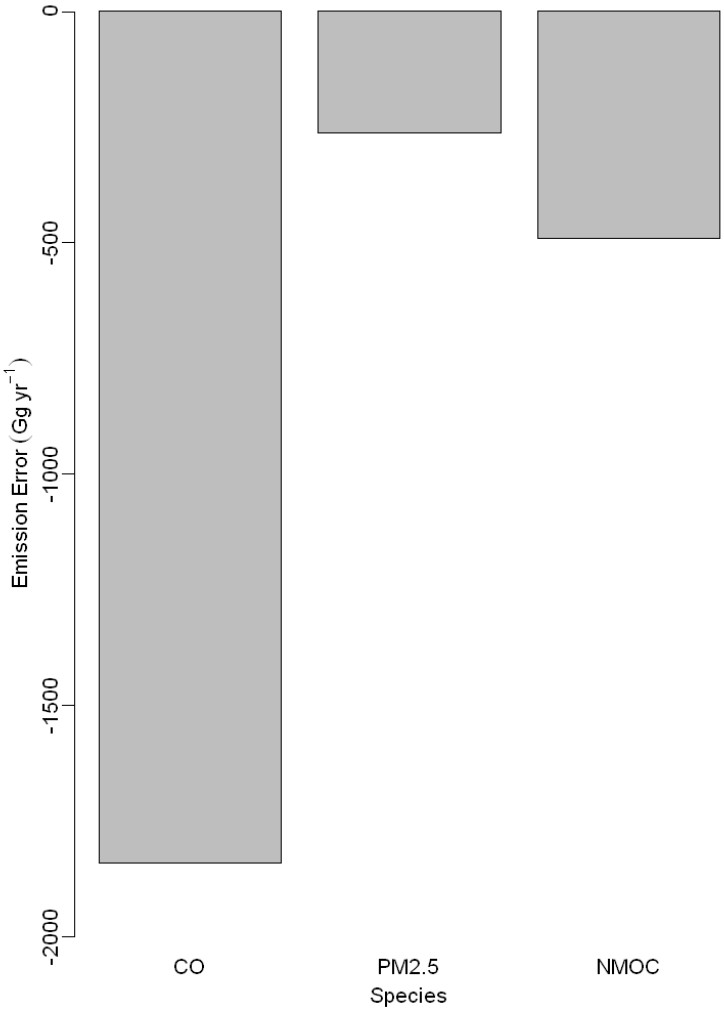
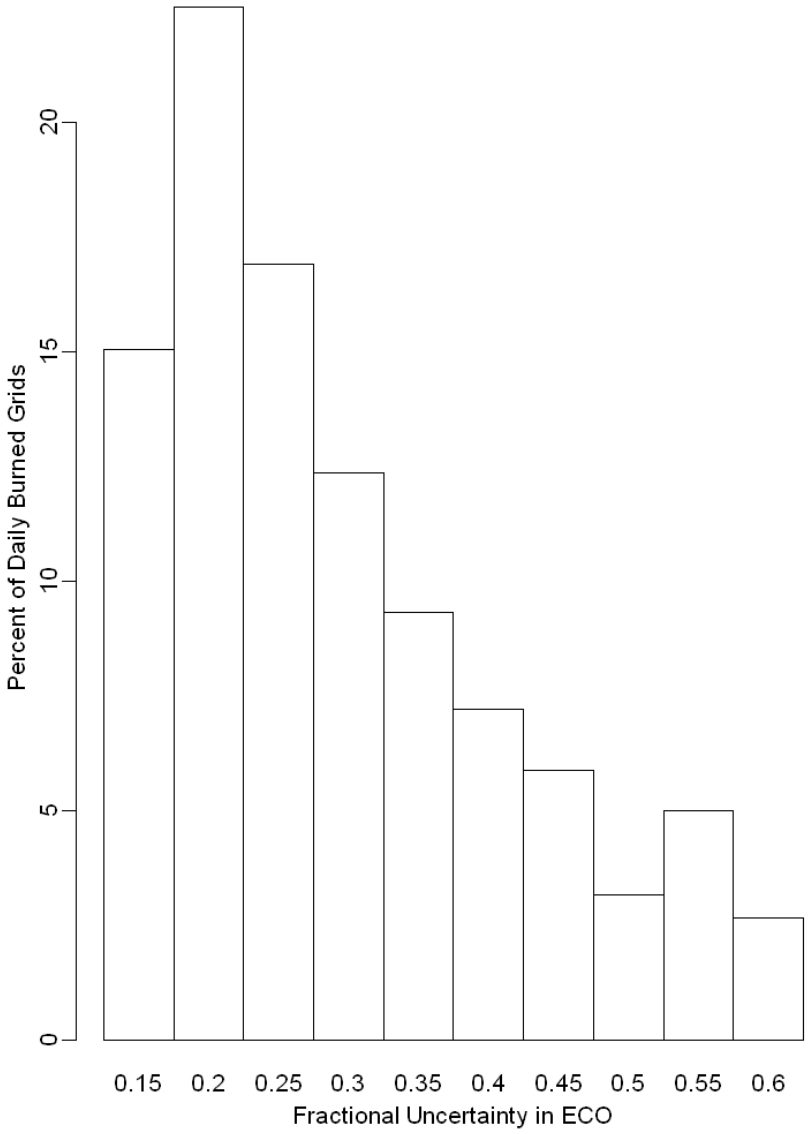


Figure 3. Distribution of fractional uncertainty in ECO for daily, 10 km^2 burned grids.



CONCLUSIONS

Two fuel loading models, FLM and FCCS, which have been mapped by the LANDFIRE project are commonly used for estimating wildland fire emissions in the U. S. were determined to have significant bias. The FLM bias leads to underestimates in 2005 western U. S. forest fire emissions of 1840 Gg-CO, 263 Gg-PM2.5 and 490 Gg-NMOC. Bias corrected FLM fuel loadings were derived and used with the FIA plot data to assess the uncertainty in fuel loading propagated into estimates of CO emissions from forest fires. At a resolution relevant to air quality modelling, Δx = 10 km and Δt = 1 – day, the uncertainty in ECO due to fuel loading averaged 26%. This estimate of uncertainty n ECO does not consider uncertainties in A, CC, or EF.

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KEYWORDS
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