Measured Parameterization of Fire Aerosol Single Scattering Albedo Using Combustion Efficiency

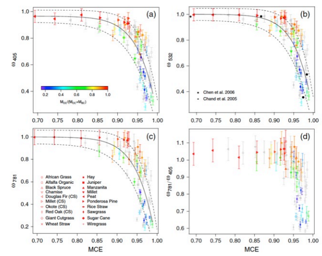
Research Highlight

Biomass burning (BB) is one of the largest sources of carbonaceous aerosols that are known to affect the radiative balance of the Earth (Bond et al. 2013). The net BB radiative forcing is small (0.0 ± 0.20Wm 2) (IPCC 2013), but very uncertain, due to the need to resolve the balance between the positive forcing by black and brown carbon (BC, BrC) and the negative forcing by organic carbon (OC). Furthermore, since BB could increase as future warming accentuates favorable conditions for wildfires, it is important to quantify the magnitude and sign of this feedback. Single scattering albedo (#) is the key optical parameter that describes the magnitude and sign of aerosol's direct radiative forcing. Consequently, the uncertainty in # is the dominant source of uncertainty in the modeled direct aerosol radiative forcing, especially for the all-sky scenario simulation when clouds are present. In radiative-transfer modeling, the # values are usually based on data from limited field measurements, retrieved from inversion of radiometric measurements or modeled using the Mie theory with assumed refractive indices. It has been shown that the estimated # values using these methods are inconsistent with each other, which can cause a large bias in the model predictions, given the high sensitivity of the modeled forcing to #. Moreover, one wavelength independent # value is often assumed across the spectrum as model inputs, which can result in errors induced by the wavelength dependence of # largely due to BrC and OC that has not been measured extensively. Therefore, more systematic optical measurements of BB aerosols that cover the range of atmospheric conditions and process-based parameterizations of fire emissions are urgently needed to constrain the model inputs and to reduce the uncertainties in prediction.

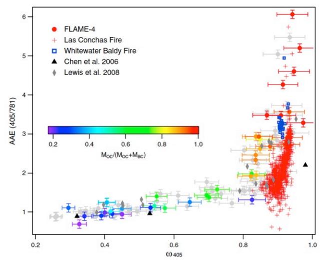
In this study, we conduct controlled laboratory combustion experiments using a range of globally significant fuels to explore the factors that control the variability of #. We use our laboratory results to derive parameterizations to predict # for fresh emissions that are then evaluated using field measurements. We assess the uncertainties and possible future refinements of the parameterization for its potential applications. The spectral dependence of # and absorption for BB aerosols are also discussed.

Single scattering albedo (#) of fresh biomass burning (BB) aerosols produced from 92 controlled laboratory combustion experiments of 20 different woods and grasses were analyzed to determine the factors that control the variability in #. Results show that # varies strongly with fire-integrated modified combustion efficiency (MCEFI)—higher MCEFI results in lower # values and greater spectral dependence of #. A parameterization of # as a function of MCEFI for fresh BB aerosols is derived from the laboratory data and is evaluated by field observations from two wildfires. The parameterization suggests that MCEFI explains 60 percent of the variability in #, while the 40 percent unexplained variability could be accounted for by other parameters such as fuel type. Our parameterization provides a promising framework that requires further validation and is amenable for refinements to predict # with greater confidence, which is critical for estimating the radiative forcing of BB aerosols.

We demonstrated that although # of BB aerosols spans a large range (~0.2–1) and shows strong spectral dependence, 60 percent of its variation can be explained and captured by MCEFI, while the remaining unexplained variability could be due to fuel type or other parameters. A framework to predict # as a function of MCEFI has been established from laboratory fires and confirmed with two wildfire measurements. Since MCEFI has been measured extensively for most major vegetation classes and types of biomass burning, our reported parameterization could be used to predict the # of fresh smoke for most fire types to estimate their radiative forcing in climate models with additional verification and refinement being desirable. Our model predicted the ~9 h old aged WB fire plume well. However, we note that further wildfire measurements, particularly at lower # values, are needed to verify and refine the parameterization. In addition, our results show that both # and absorption Ångström



Fire-integrated # as a function of fire-integrated MCE at (a) 405 nm, (b) 532 nm, and (c) 781nm measured during FLAME-4. (d) The ratio of #781 to #405 versus MCE.



Fire-integrated AAE405nm/781nm versus #405 during FLAME-4 overlaid with Los Conchas and Whitewater Baldy wildfires and earlier laboratory data.

exponent (AAE) increase with aging, so if aging effects on # are also modeled, this could further improve the radiative forcing estimates for BB and allow enhanced modeling of coupled climate-fire feedback. This work reinforces the importance of evaluating aerosol # under different combustion conditions as well as at multiple wavelengths, both of which could potentially enhance the accuracy in the predicted radiative forcing of BB aerosols.

Reference(s)

Liu S, AC Aiken, C Arata, M Dubey, CE Stockwell, RJ Yokelson, EA Stone, T Jayarathne, AL Robinson, and PJ DeMott. 2014. "Aerosol single scattering albedo dependence on biomass combustion efficiency: Laboratory and field studies." Geophysical Research Letters, , 10.1002/2013GL058392. ACCEPTED.

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Working Group(s)

Aerosol Life Cycle