Supplemental Information for

Constraining the particle-scale diversity of black carbon light absorption using a unified framework

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Data from field and laboratory experiments

Cappa, et al. 2012.

The mixing state of internally mixed BC aggregates measured by Cappa *et al.* 2012 (1) was found by first fitting a power-law function to mean R_{BC} as function of photochemical age (-log([NO_x]/[NO_y])), which is shown in figure 1(a). The fitted equation is given by:

$$R_{BC} = (12.215 \pm 0.396)\left(-\log\left(\frac{[NO_x]}{[NO_y]}\right)\right)^{0.554 \pm 0.067}. \quad \text{(S1)}$$

Mass absorption cross-section of BC (MAC_{BC}) at wavelength (λ) of 532 nm is then calculated from figure S-17 of Cappa *et al.* 2012, which shows MAC_{BC} enhancement (E_{abs}) as a function of photochemical age. Photochemical age was converted to R_{BC} using equation S1, and E_{abs} was converted to MAC_{BC} using the reported value for MAC_{BC} of pure BC (7.75 m^2/g). The morphology of particles from this study was inferred using lognormal fits of the size distributions given in figure S-13 of Cappa *et al.* 2012. The single particle BC mass was then calculated assuming BC density of 1.8 g/cm^3 (2).

Saliba, et al. 2016.

Measured MAC_{BC} as a function of BC mixing state was taken from Figure 4 of Saliba *et al.* 2016 (3). The mixing state was then converted from organic to black carbon mass ratio (OA:BC) to R_{BC} using:

$$R_{BC} = \text{OA:BC}. \quad \text{(S2)}$$

The morphology of particles from this study was inferred using lognormal fits of the size distributions given in figure S9 of Saliba *et al.* 2019. The single particle BC mass was then calculated assuming BC density of 1.8 g/cm^3 (2).

Xie, et al. 2019.

Measured E_{abs} as a function of R_{BC} was taken from Figure 1a of Xie *et al.* 2019 (4). enhancement was converted to MAC_{BC} using a reference MAC_{BC} value of 6.55 m^2/g at λ = 630 nm, given that the authors state that the thermodenuder-derived E_{abs} was well correlated with E_{abs} calculated using reference MAC_{BC} (4).

Cui, et al. 2016.

Measured E_{abs} as a function of BC mixing state was taken from Figure 5c of Cui *et al.* 2016 (5). The mixing state was converted from organic to elemental carbon ratio (OC/EC) to R_{BC} using:

$$R_{BC} = \text{OC/EC}. \quad \text{(S3)}$$

Absorption enhancement was converted to MAC_{BC} using MAC_{BC} of pure BC = 4.02 m^2/g at λ = 678 nm, given in figure 2 of Cui *et al.* 2016 (5).

Denjean, et al. 2020.

Measured E_{abs} as a function of BC mixing state was taken from Figure 2 of Denjean *et al.* 2020 (6). Absorption enhancement was converted to MAC_{BC} using MAC_{BC} of pure BC = 7.7 m^2/g at λ = 550 nm. The morphology of particles from this study was inferred using lognormal fits of the size distributions given in figure 1 of Denjean *et al.* 2020. The average mass was then calculated assuming BC density of 1.8 g/cm^3 (2).

Zanatta, et al. 2018.

Average MAC_{BC} and R_{BC} were found using reported values for average coating thickness, coating density, and MAC_{BC} in Zanatta et al. 2018 (7). The morphology of particles from this study was inferred using reported size distributions given in Table 2 of Zanatta *et al.* 2018. The single particle BC mass was then calculated assuming BC density of 1.8 g/cm^3 (2).

Liu, et al. 2015.

Measured MAC_{BC} as a function of BC mixing state was taken from Figure S2 of Liu *et al.* 2015 (8). We utilize MAC_{BC} derived using standardized major axis at λ = 781 nm in order to avoid potential influence of absorbing coatings on MAC_{BC}. The morphology of particles from this study was inferred using the limits of BC diameter given in Figure 1d of Liu *et al.* 2015. The single particle BC mass was then calculated assuming BC density of 1.8 g/cm^3 (2).

Cappa, et al. 2019.

Measured MAC_{BC} as a function of BC mixing state was taken from Figure S4 and S6 of Cappa *et al.* 2019 (9). We analyze measurements of MAC_{BC} at λ = 532 nm only.

Shiraiwa, et al. 2010.

Measured E_{abs} as a function of BC mixing state was taken from Figure 2 of Shiraiwa *et al.* 2010 (10). The mixing state was converted from the ratio of total particle diameter to black carbon diameter using BC density of 1.8 g/cm^3 and coating density of 1.2 g/cm^3 (2). The morphology of particles from this study was inferred using reported BC core diameter.

Zhang, et al. 2018.

Measured E_{abs} as a function of BC mixing state was taken from Figure S3 of Zhang *et al.* 2018 (11). The mixing state was converted from organic to elemental carbon mass ratio to R_{BC} using equation S3. Absorption enhancement was converted to MAC_{BC} using MAC_{BC} of pure BC = 4.7 m^2/g at λ = 880 nm. The morphology of particles from this study was inferred using the reported range of BC core diameters (100-150 nm).

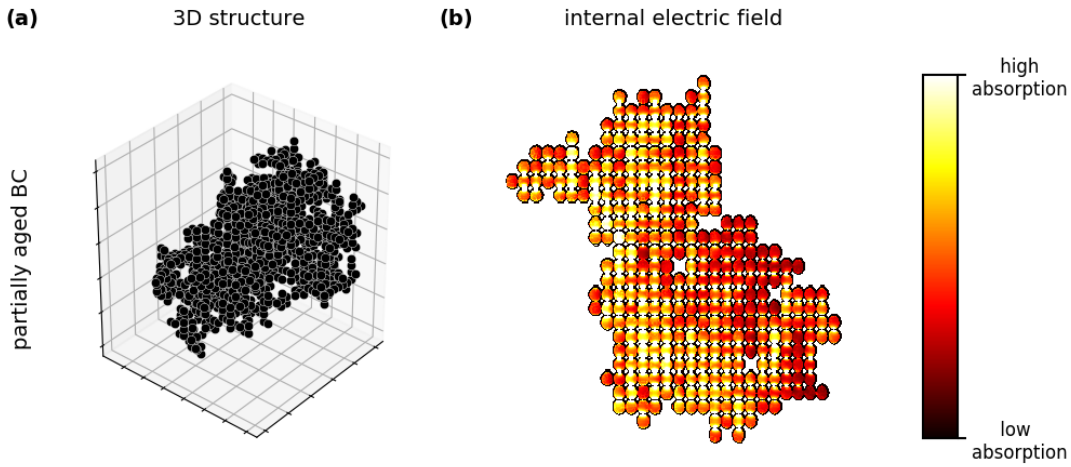

Figure S1: (a) 3D structure of a partially collapsed aggregate. (b) Internal light absorption of the partially collapsed aggregate with light incident from the left.

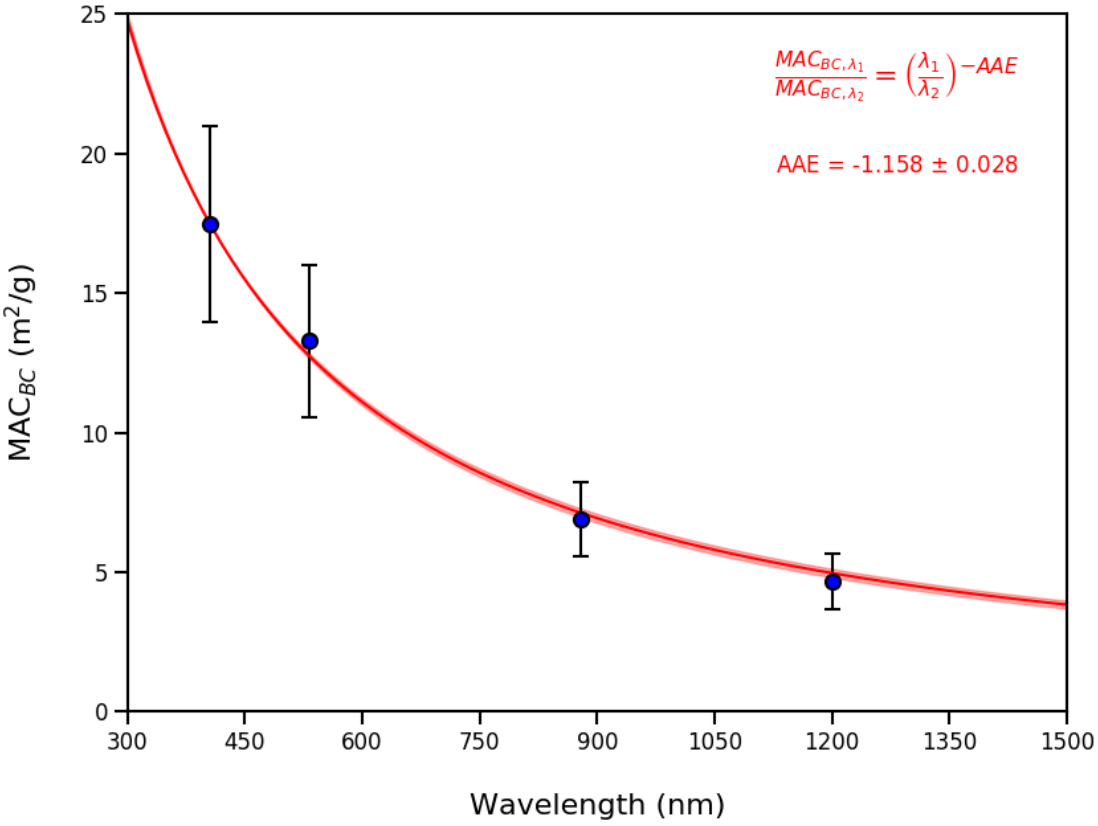

Figure S2: Data used to calculate AAE for fractal BC aggregates with $\rho_{BC} \leq 1$, error bars show one standard deviation. Solid line shows fitted equation given in figure, error of AAE is reflective of 95% confidence interval.