Strongly Absorbing Aerosol Refractive Indices in the Highly Polluted Indo-Gangetic Plains

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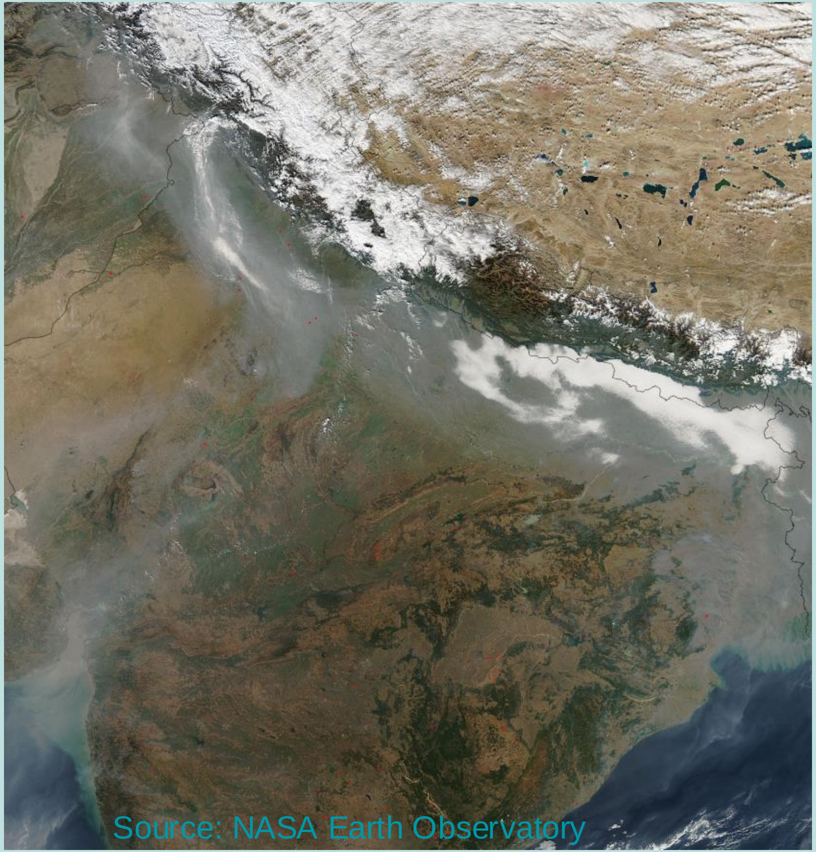
Kapoor et al., 2023; JGR: Atmospheres



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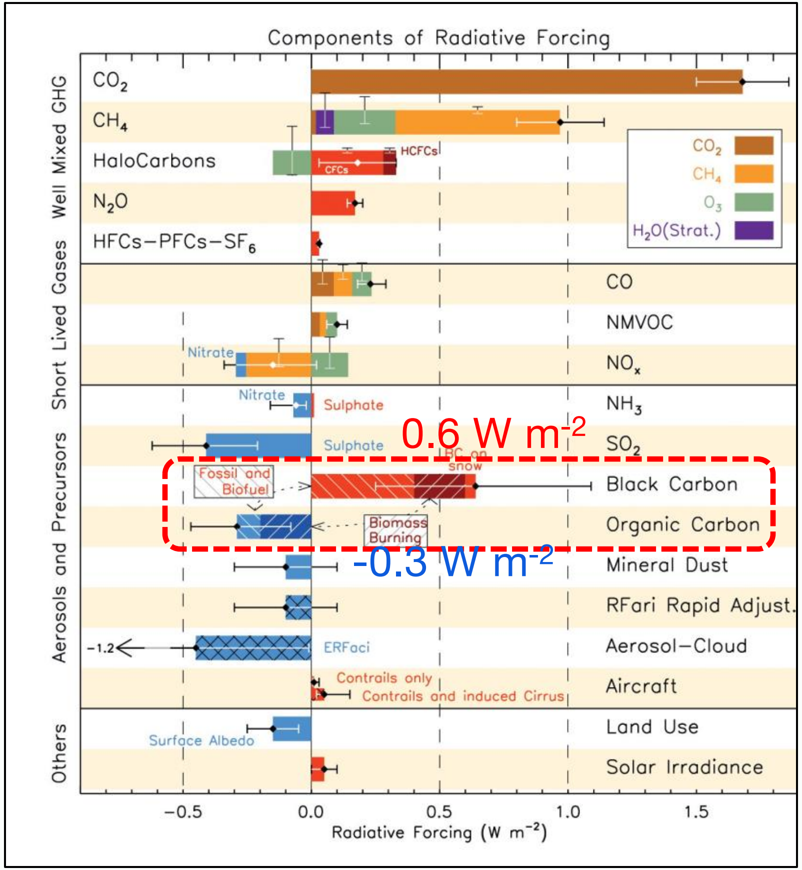
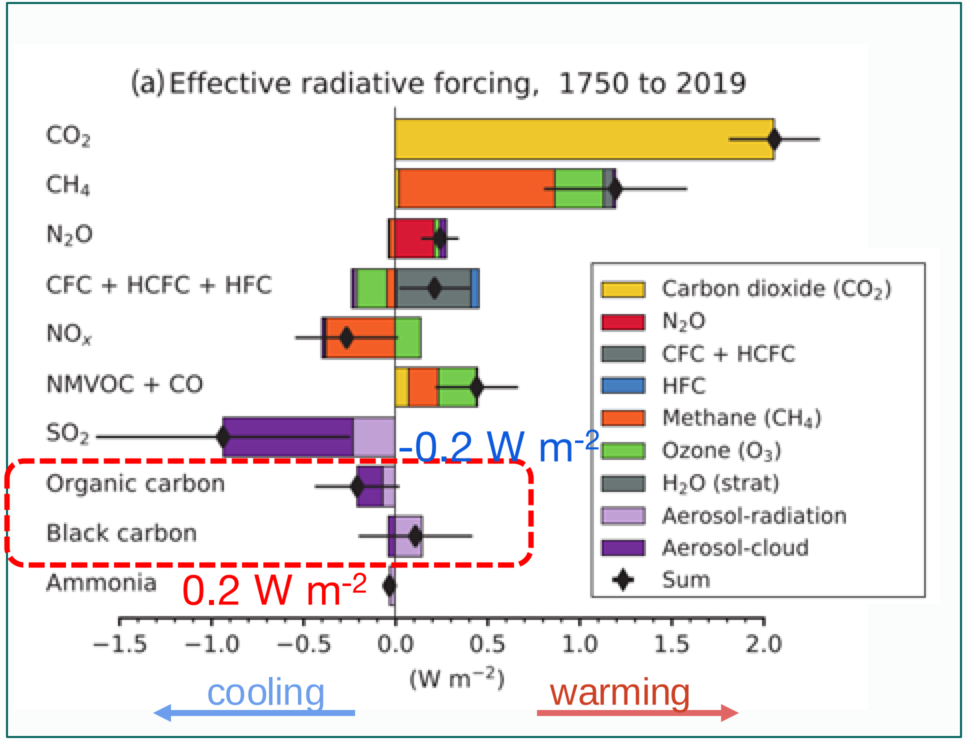
center for aerosol science and engineering

NATIONAL CARBONACEOUS AEROSOLS PROGRAMME
COALESCE

Uncertainties in Carbonceous Aerosol Radiative Forcing

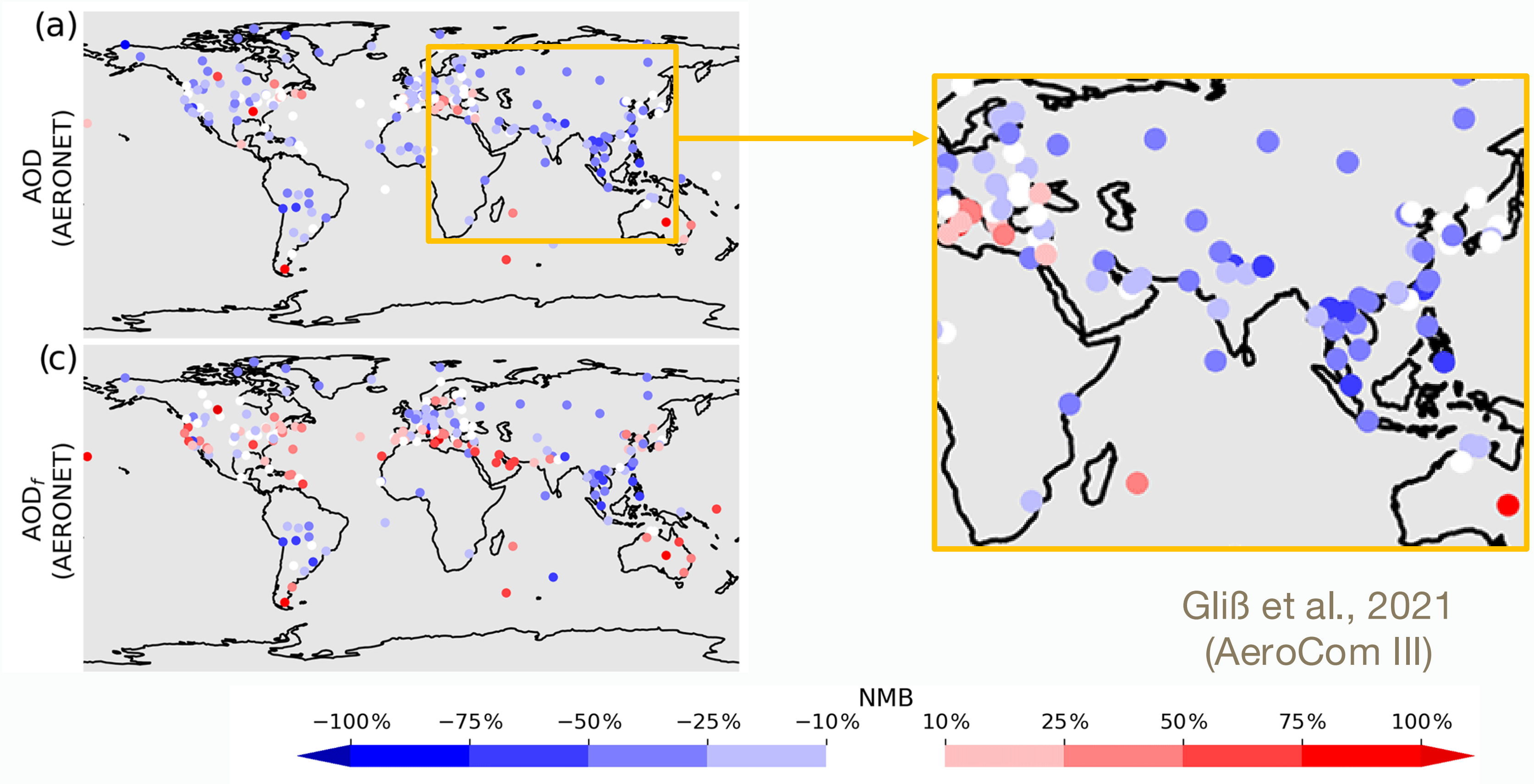


IPCC, AR5 (2014)



IPCC, AR6 (2021)

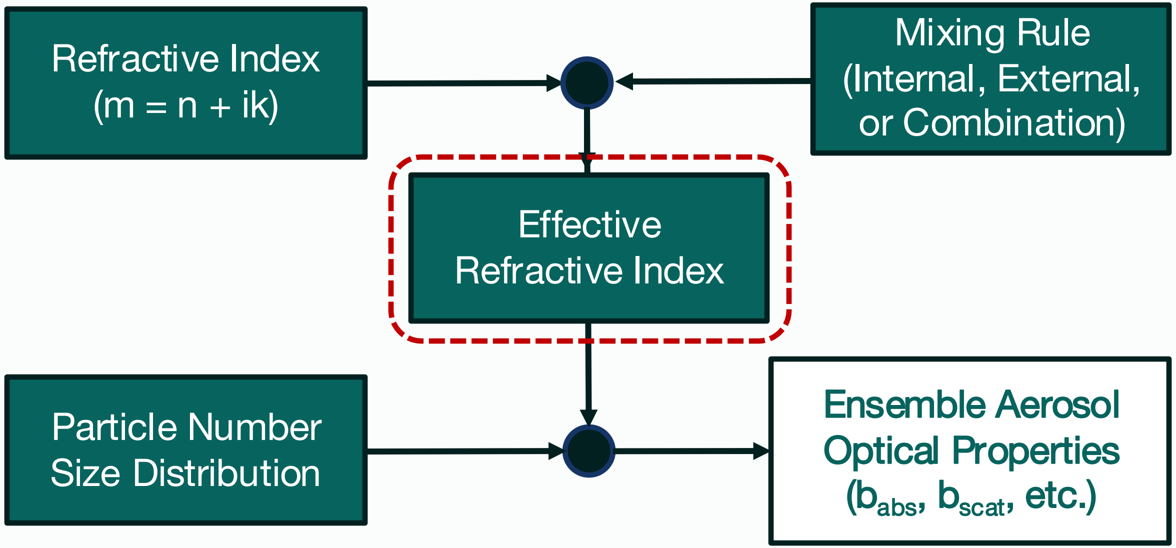
Underestimation of Aerosol Optical Depth over India



Gliß et al., 2021 (AeroCom III)

Aerosol Optical Property Calculations in Climate Models

Aerosol Type	BC	...
Refractive Index (λ=550 nm)	1.95+0.79*i*	
AAE	1	
SAE	1.5	
CMD	150	
GSD	1.5	

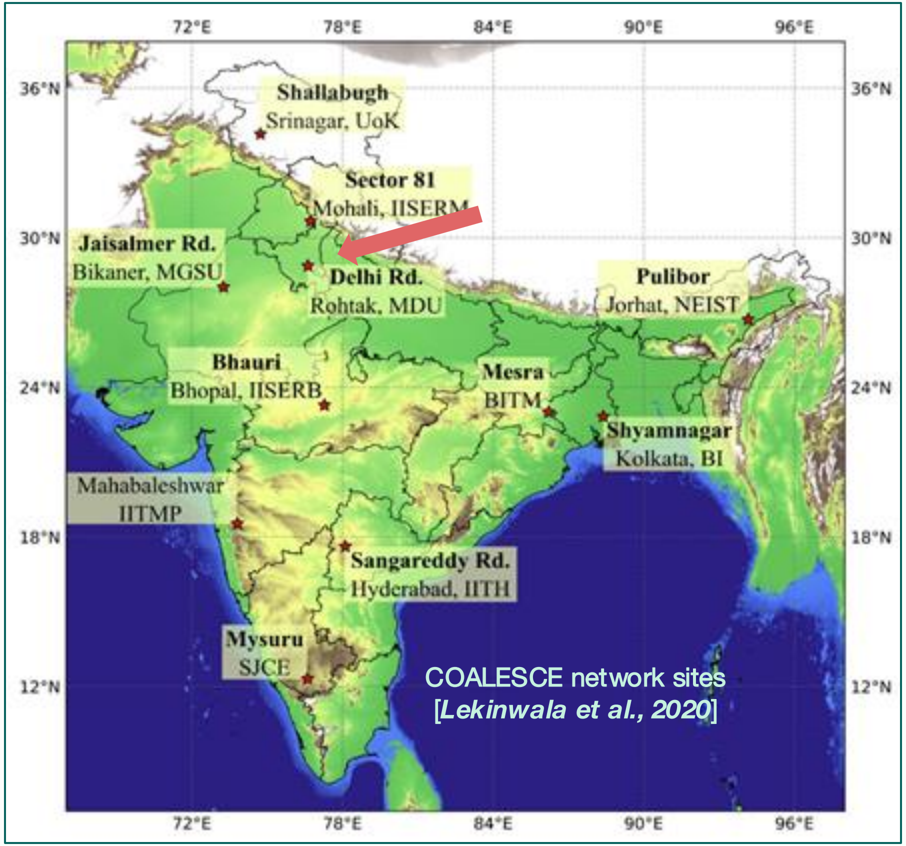


Refractive Index, m = n + k *i*

n: Scattering; k: Absorption

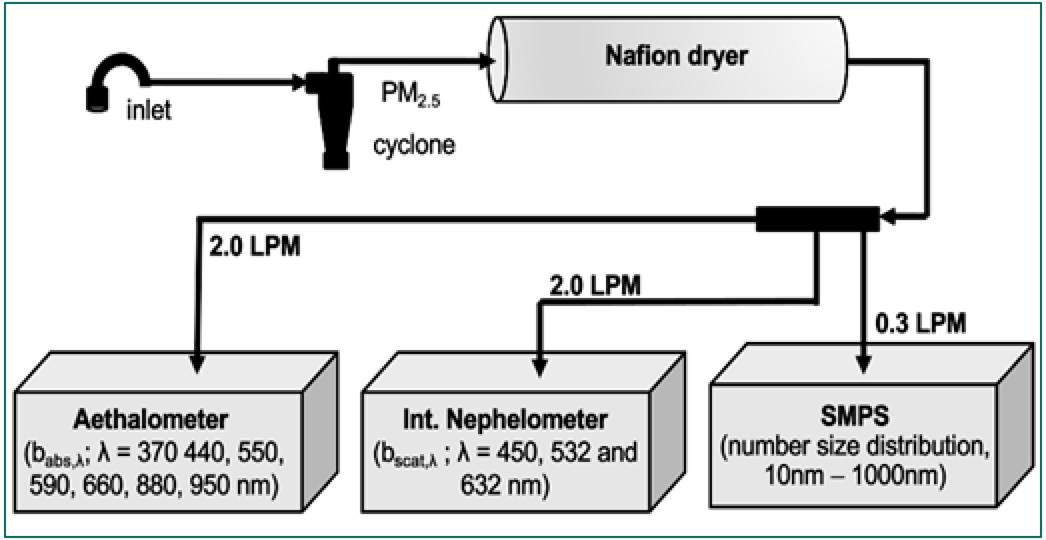
Effective refractive index - optically representative - not associated with any mixing scheme.

Indian COALESCE Network Sites



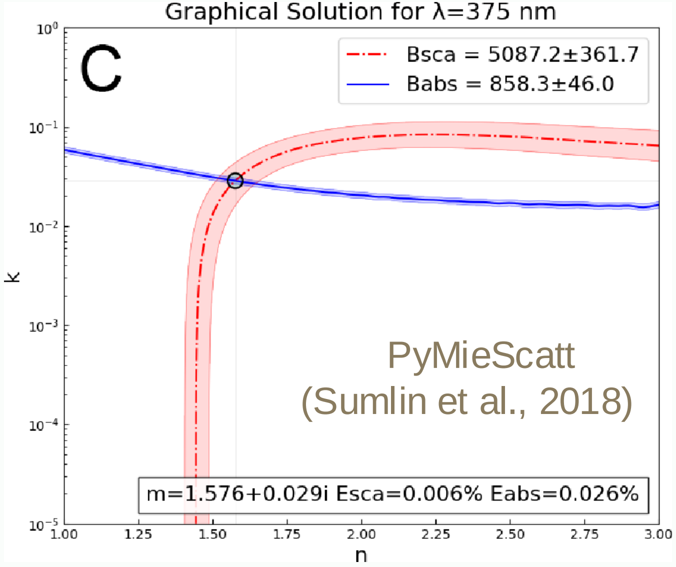
- Indian National Carbonaceous Program – CarbOnaceous AerosoL Emissions, Source apportionment and ClimatE Impacts, **NCAP-COALESCE – improve understanding of carbonaceous aerosols over Indian region**
- **Indo-Gangetic plains experiences haze events during post-monsoon and winter months**
- Limited understanding of **optical properties in the region and relationships with aerosol chemical properties** in the region
- Especially **intrinsic aerosol optical properties** (SSA, AAE, refractive index, etc.)

Measurements – site and instrumentation



Inverted Refractive Index using:

- Absorption and scattering coefficients
- Particle number size distribution

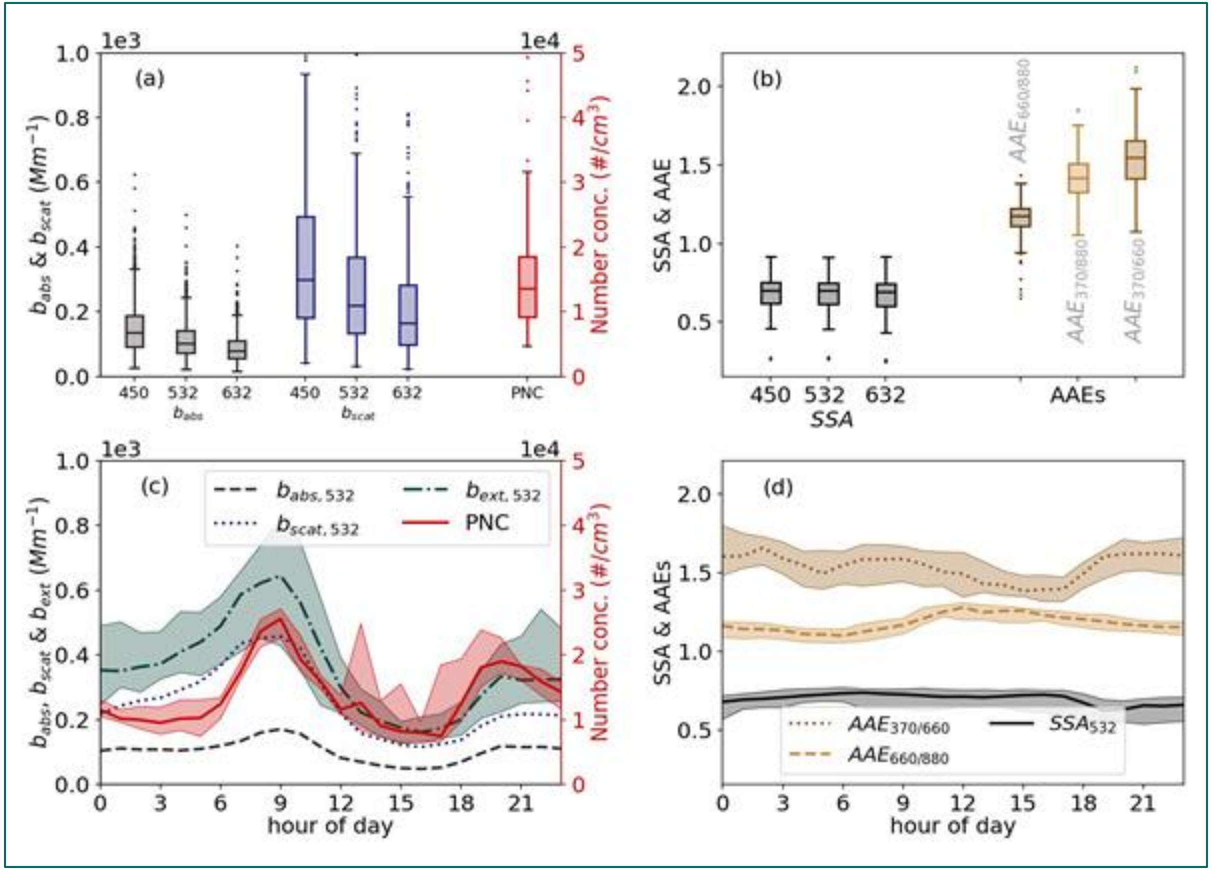


Time-integrated measurements (daily)

- EC/OC concentrations – IMPROVE-A – quartz
- $PM_{2.5}$ – gravimetric – teflon

Measurements from 25 Jan – 24 Feb, 2020

Measured Aerosol Optical Properties



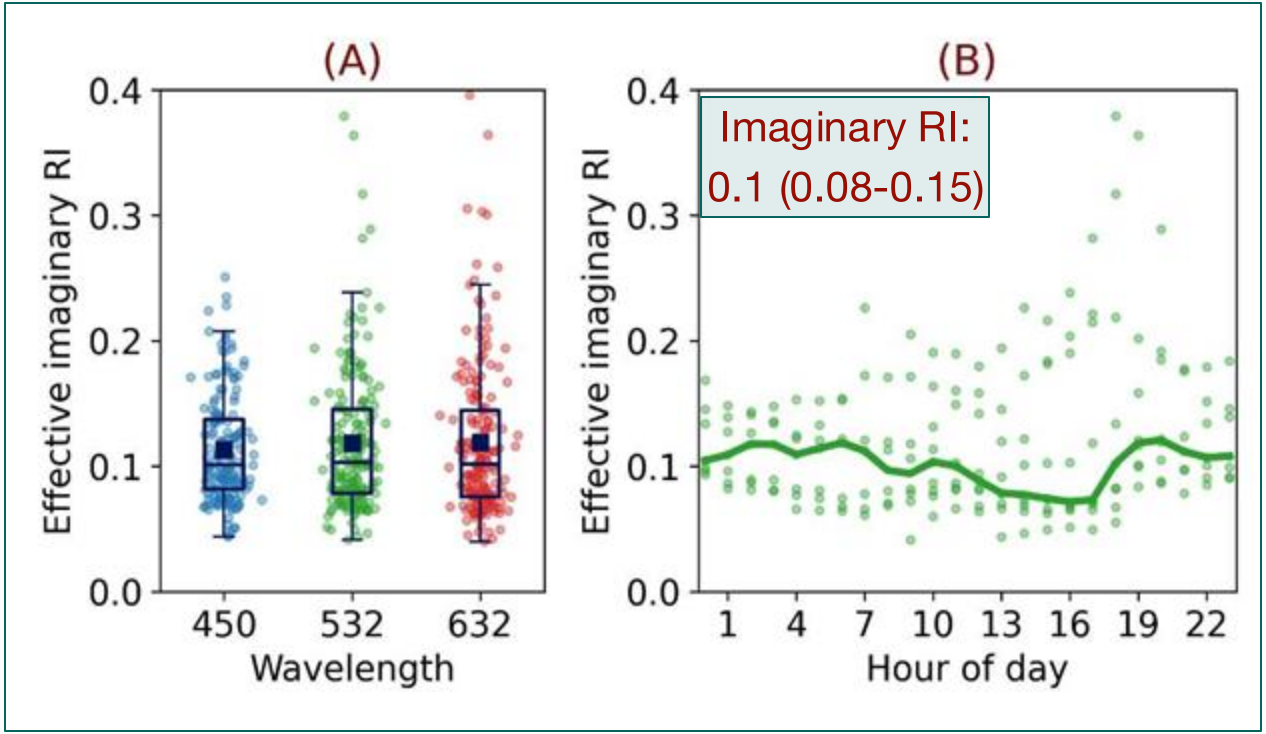
- Diurnal variations
  - Extrinsic properties – strong variation
  - Intrinsic properties – little variation
- $AAE_{370/660}$~1.5 – some BrC

$$AAE = -\frac{\log\left(\frac{b_{abs,\lambda 1}}{b_{abs,\lambda 2}}\right)}{\log\left(\frac{\lambda 1}{\lambda 2}\right)}$$

- SSA~0.7 - warming aerosols - found spectrally invariant

$$SSA_\lambda = -\frac{b_{abs,\lambda}}{b_{scat,\lambda}}$$

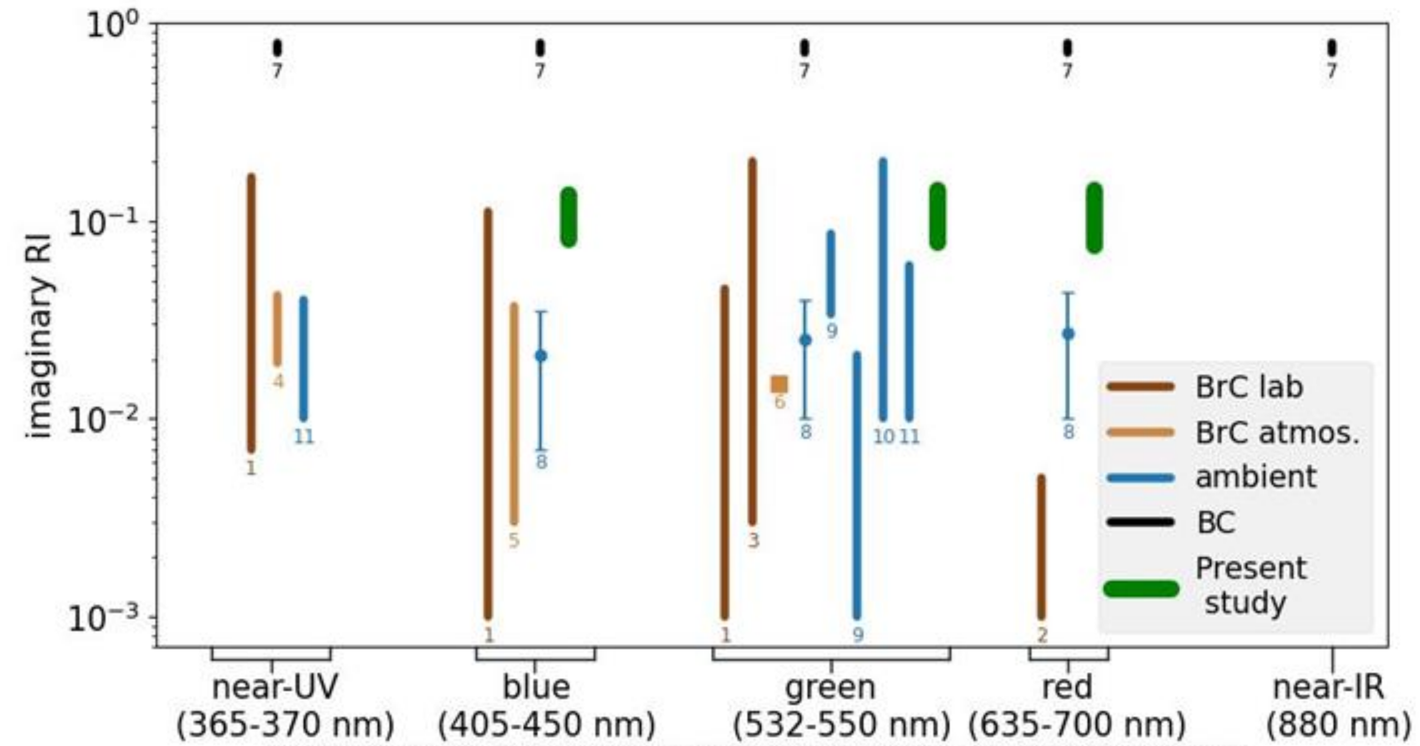
Aerosol Absorption Refractive Index



Refractive Index calculated by optical closure, PyMieScatt (Sumlin et al., 2018)

- RI not varying with wavelength – also reported by Zhang et al. (2013) at China
- No appreciable diurnal variation – also reported by Nandan et al. (2021) at India

Comparison of refractive index with literature



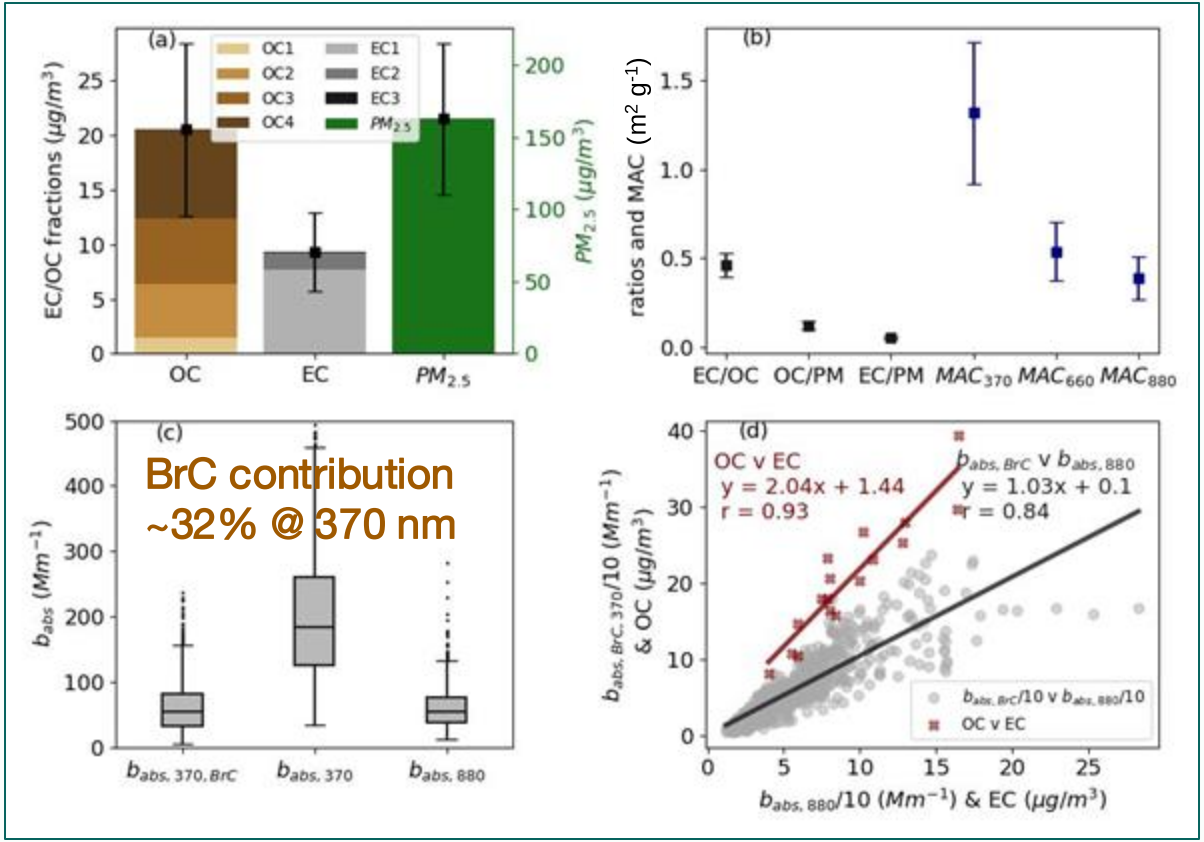
References:
1: Sumlin et al., 2018 & Kirchstetter et al., 2004
2: Kirchstetter et al., 2004
3: Saleh et al., 2018
4: Shamjad et al., 2016 and Flores et al., 2014
5: Cappa et al., 2012, Shamjad et al., 2016 & Flores et al., 2014
6: Shamjad et al., 2016
7: Bond and Bergstrom, 2006
8: Zhang et al., 2013 - China
9: Ebert et al., 2004 - Germany
10: Nandan et al., 2021 - India
11: Raut and Chazette, 2007 - France

- Ambient imag-RI b/w BC and BrC
- Other locations: France, Germany, China, and India

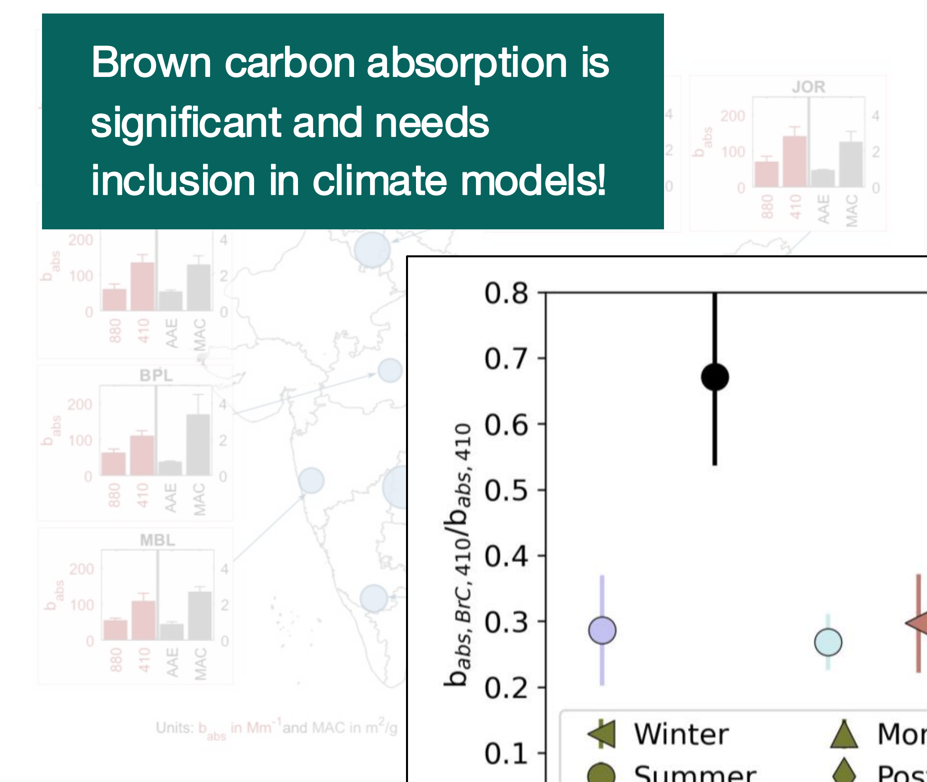
NOTE: y-axis in log-scale

Carbonaceous aerosol absorption and concentrations

- EC/OC of 0.5 – little variation
- OC – dominated by OC3 & OC4 – low-volatility – strongly absorbing [Saleh et al., 2016; Chakrabarty et al., 2023]
- $MAC_{OC,550}$ ~ 1.9 $m^2 g^{-1}$ – strongly absorbing BrC [Saleh, 2020]
- Good correlation b/w OC & EC, and $b_{abs,BrC}$ and $b_{abs,BC}$ – BrC likely from combustion sources



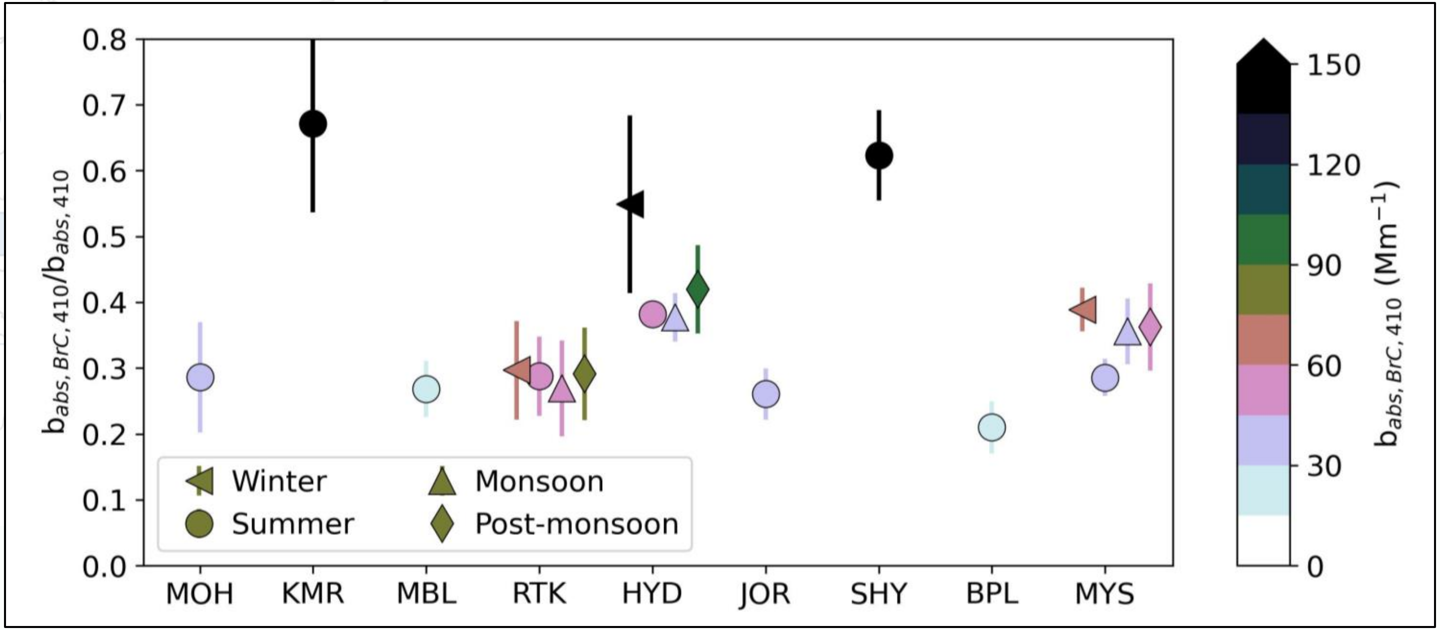
Brown carbon absorption across India



Brown carbon absorption is significant and needs inclusion in climate models!

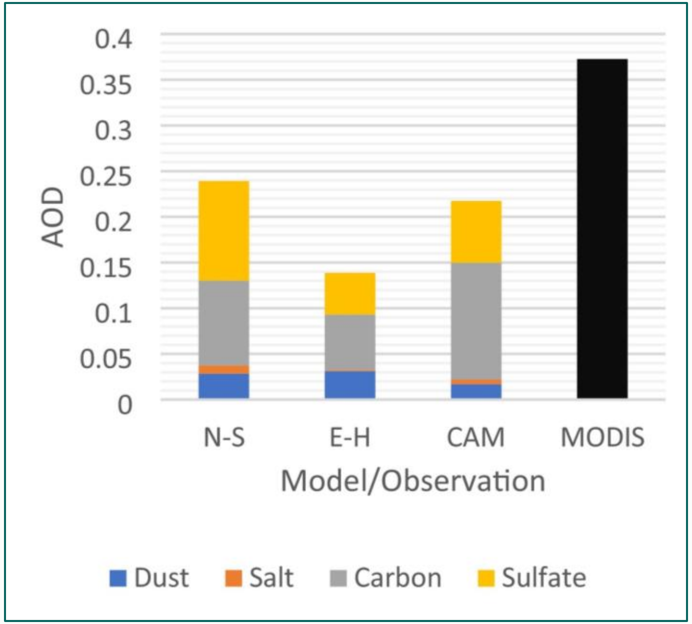
Measured Spectral Aerosol Absorption across 9 COALESCE sites.

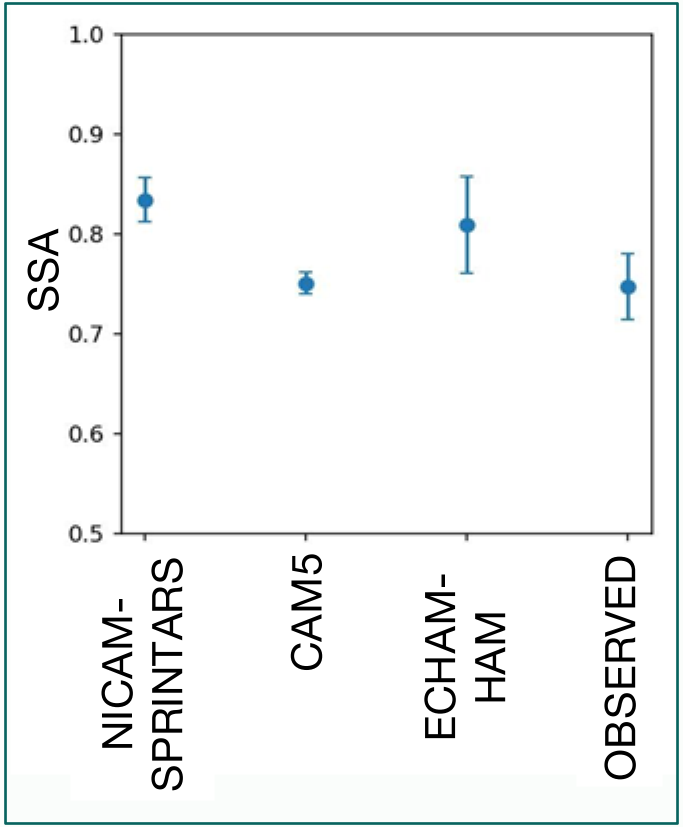
BrC absorption calculated using a Mie-theory based optimization method [Kapoor et al., 2022]



Kapoor et al., 2024 (GRL)

Climate Models Underestimate Intrinsic and Extrinsic Absorption





Sarkar et al., 2022. Evaluation of the simulated aerosol optical properties over India: COALESCE model inter-comparison of three GCMs with ground and satellite observations. *Science of the Total Environment*

Summary and conclusion

- Measured **aerosol optical and micro-physcial properties** in the Indo-Gangetic region
- Measured aerosol has **SSA of 0.7**, indicative of **very warming aerosol**
- Measured imaginary-RI
  - **0.1 (0.08-0.15**, 25^{th}–75^{th} percentile)
  - **Invariant in the visible region**
  - **No diurnal variation**
  - **Upper range of previous measurements**
- **Low volatility OC** dominate – **BrC absorption with BC like behaviour** [Saleh et al., 2016] – need to be included in climate models
- BrC and OC likely from combustion sources
- Measured Intrinsic properties useful to further **constrain and validate climate model simulations**

Published in JGR: Atmospheres

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Thank You!
Questions?

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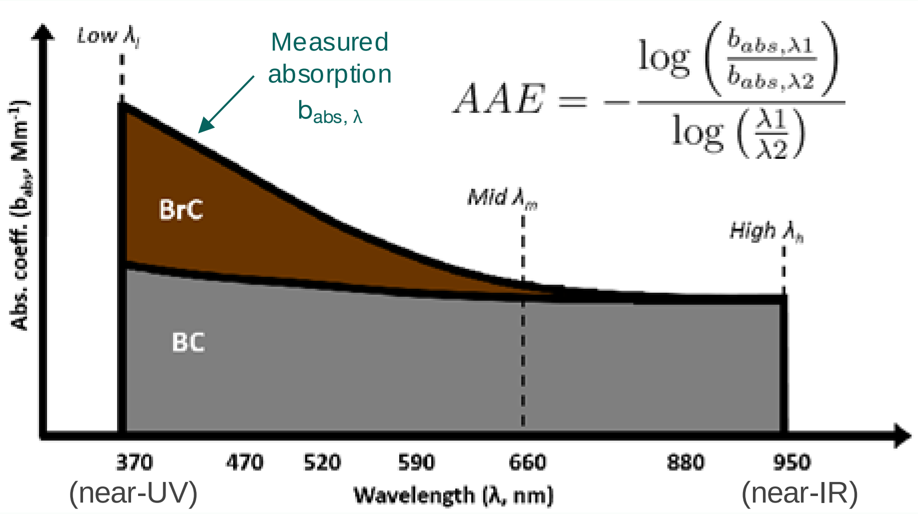
Literature review – methods to estimate BrC absorption

- **Organic carbon species that absorb radiation –** brown carbon
- OC was treated as purely scattering – properties still uncertain
- BrC **absorbs preferentially in near-UV**
- Extrapolating BC absorption:
  - Assumptions, AAE = 1 [Olson et al., 2015; Tian et al., 2019; Zhang et al., 2018; Zhu et al, 2017, Chen et al., 2015]
  - Sophisticated instrumentation and Mie theory [Wang et al., 2016; Wang et al., 2018]
- Study reported constant AAE_{ratio} (AAE_{UV}/AAE_{IR}) [Wang et al, 2018]



$b_{abs,\lambda} = b_{abs,BC,\lambda} + b_{abs,BrC,\lambda}$

$b_{abs,880} = b_{abs,BC,880}$

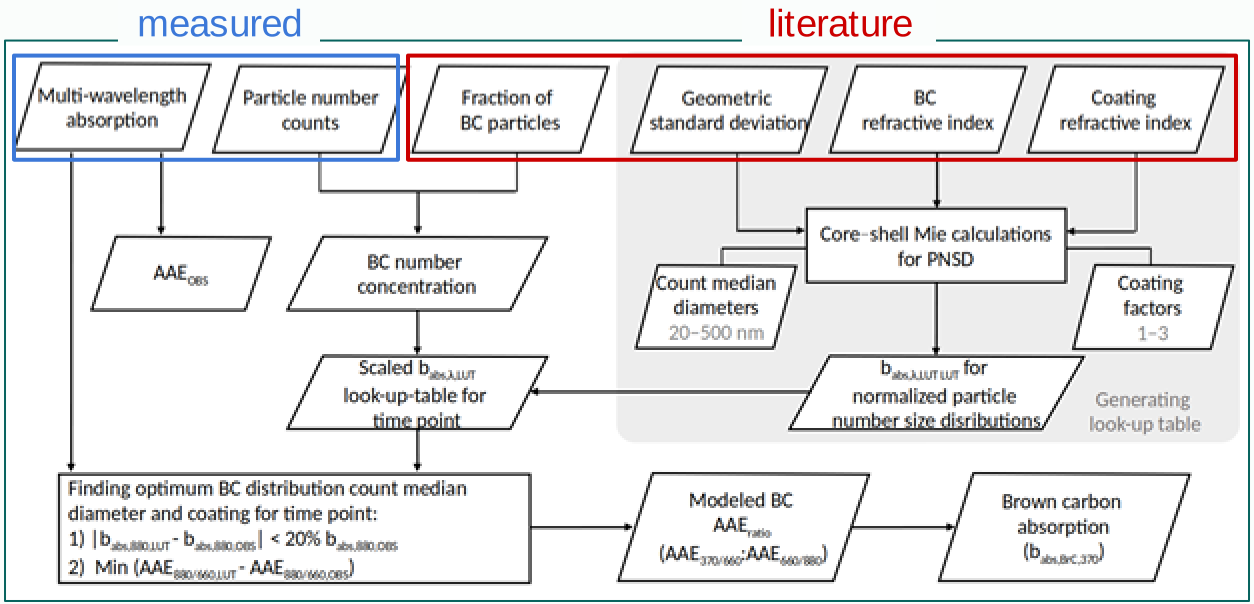
$b_{abs,660} = b_{abs,BC,660}$

$b_{abs,370} = b_{abs,BC,370} + b_{abs,BrC,370}$

Developed method to calculate BrC absorption

- Mie theory – core shell
- LUT with BC absorption properties
- Literature derived inputs
  - Fraction-BC particles
  - BC size distributions
  - BC RI
  - Coating RI
- Optically representative BC distribution
  - BC CMD
  - Coating factor

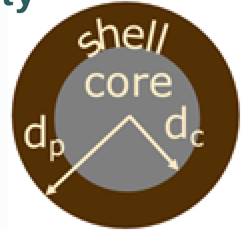
} AAE_{ratio}



Overall ~32% uncertainty

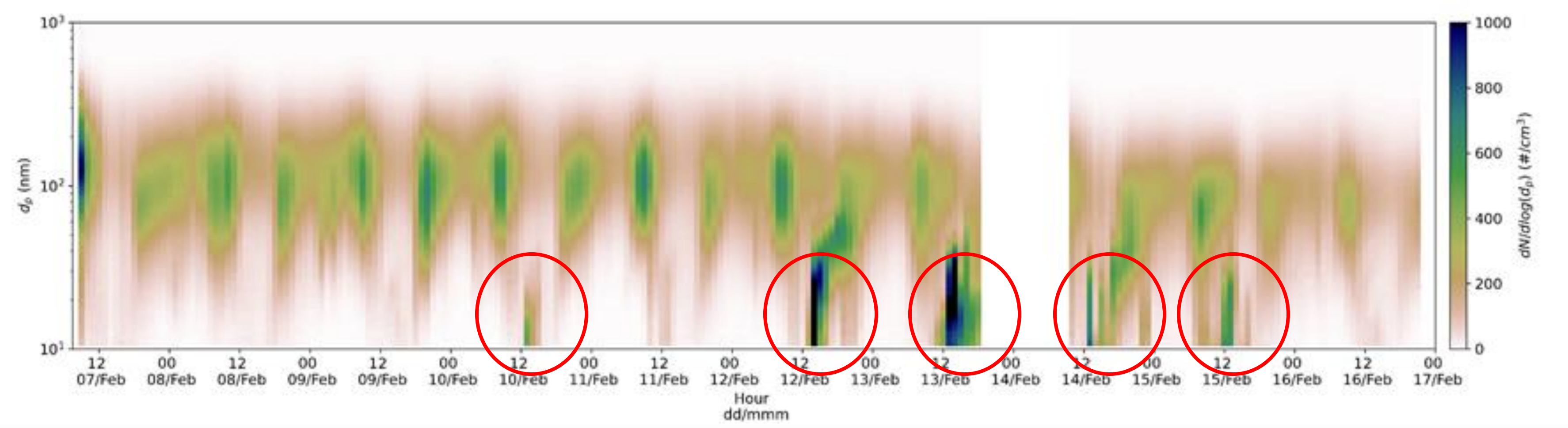
Measurements:

- Multi-wavelength absorption (here Aethalometer)
- Particle number counts (here SMPS, CPC)

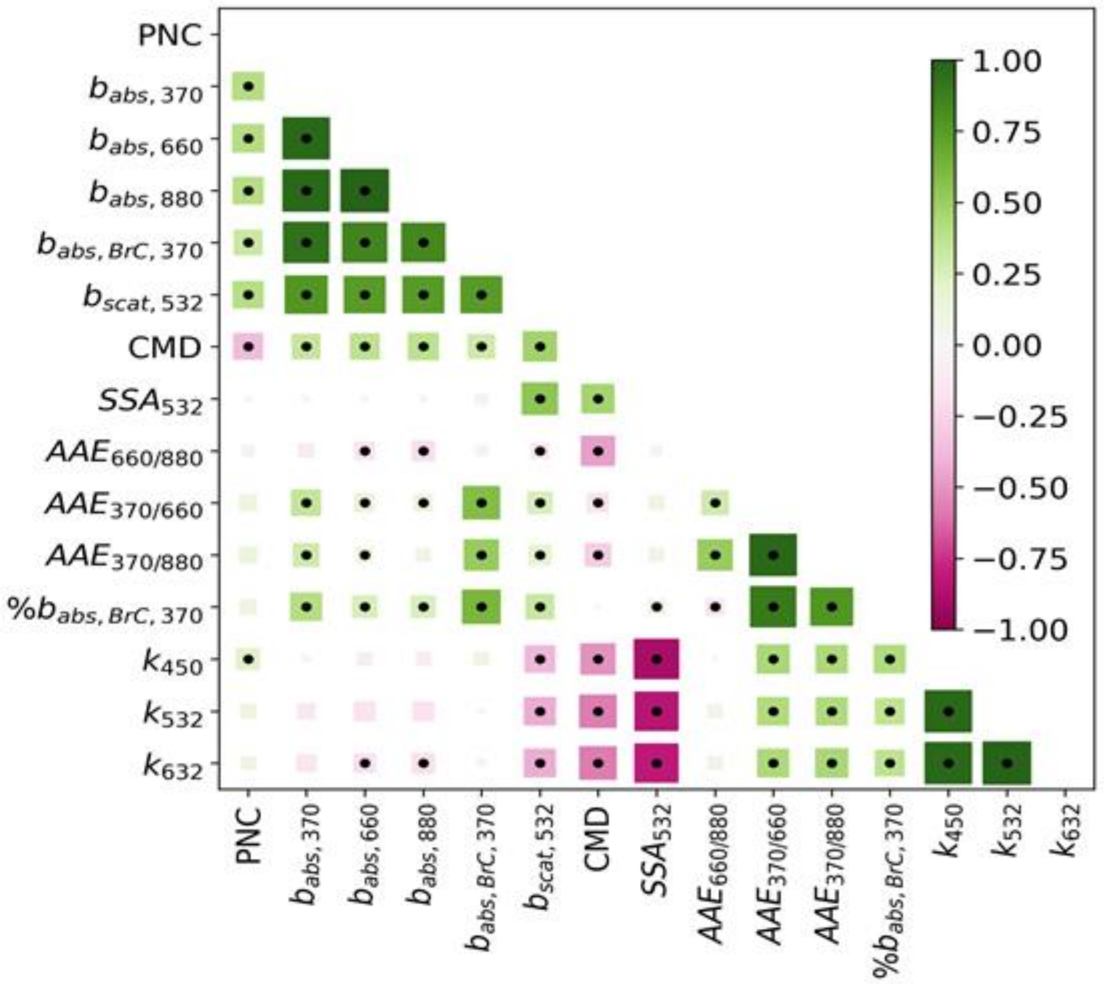


[Kapoor et al, 2022]

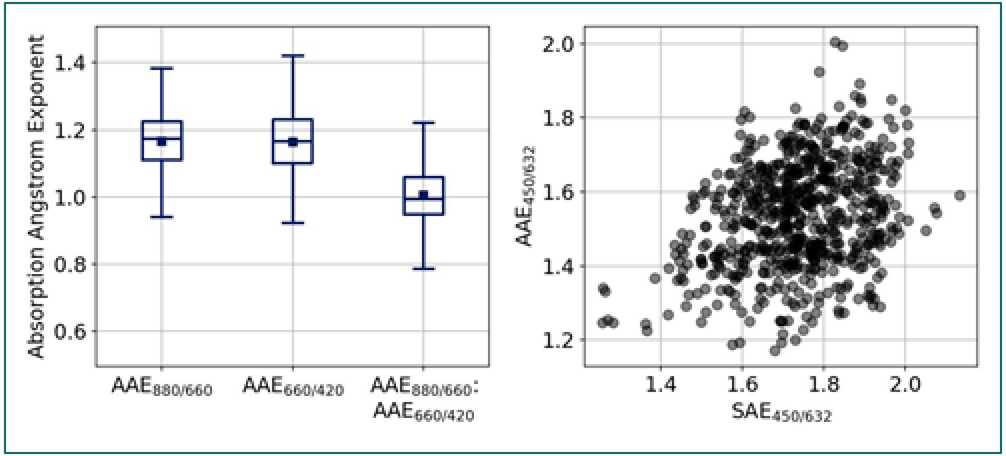
New particle formation



Correlation coefficient plot



Possible dust contributions?



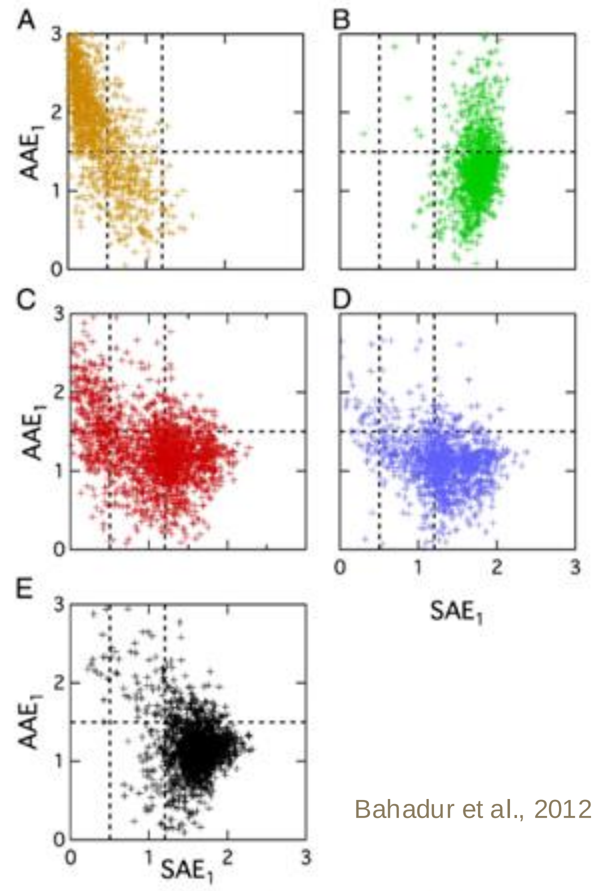


Fig. 1. (A–E) Scatter plots of AAE1 and SAE1 calculated from AERONET measurements at (A) dust (DU), (B) BB, (C) UF, (D) NF, and (E) CA sites. Dashed lines illustrate the threshold values of SAE1 = 0.5, SAE1 = 1.2, and AAE1 = 1.5 used to separate dust-dominated and dust-free regimes.

Bahadur et al., 2012

Diurnal Variation of Particle Number Size Distribution