Brown Carbon Radiative Effects over High Mountain Asia: WRF-Chem model implementation and application


Credit: Gryffinpuff from Wikipedia


Credit: S. M. Skiles, NASA/JPL

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Funded by NASA High Mountain Asia grant

Background and Motivations

- **Brown carbon (BrC):** light-absorbing organic carbon; relatively strong absorption at UV wavelength (300-400 nm) and weak absorption at visible wavelengths; much weaker absorption at visible wavelengths than black carbon; Large uncertainties in BrC optical properties due to its complicated chemical constituents (POA+SOA).

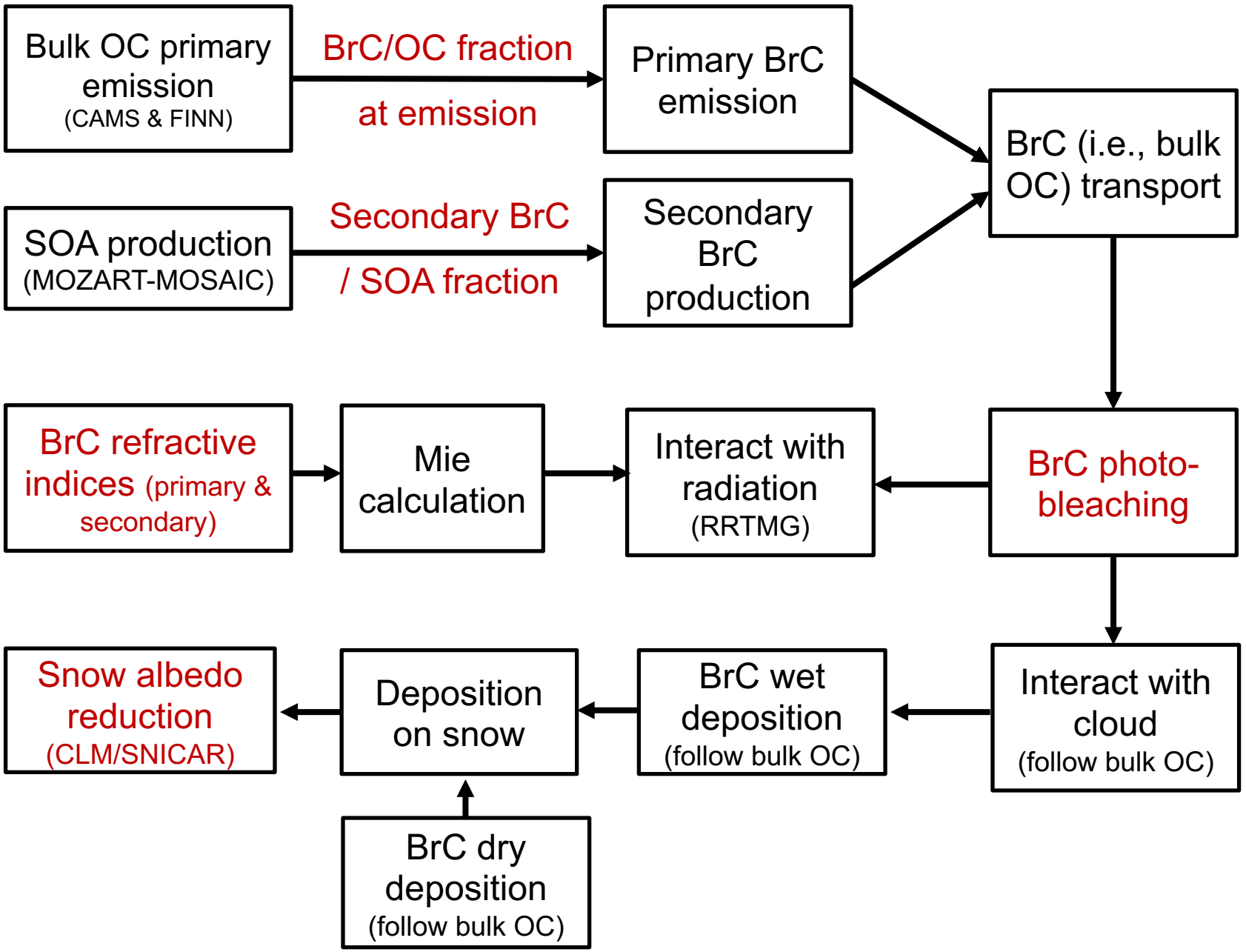
- BrC absorbs solar radiation in the atmosphere and also reduces snow albedo after deposition onto snowpack and hence accelerates snow melting and glacier retreat.

- Most previous modeling studies have focused on the climate effects of BC and dust, particularly over snow-covered areas, whereas much less is known for BrC climatic effects partially due to the lack of modeling capabilities for BrC evolution during its lifecycle.

- Recent advances in the scientific understanding of BrC atmospheric evolution allow an improved representation of BrC aerosol in chemistry-climate models. In this study, we implement a series of BrC-relevant processes into WRF-Chem to represent the BrC atmospheric evolution.

- **High-mountain Asia (HMA)** (also known as the Third Pole) functions as a “water tower” of Asia, with its glacier and snowpack providing water resources for billions of people for drinking, irrigation, and other activities.

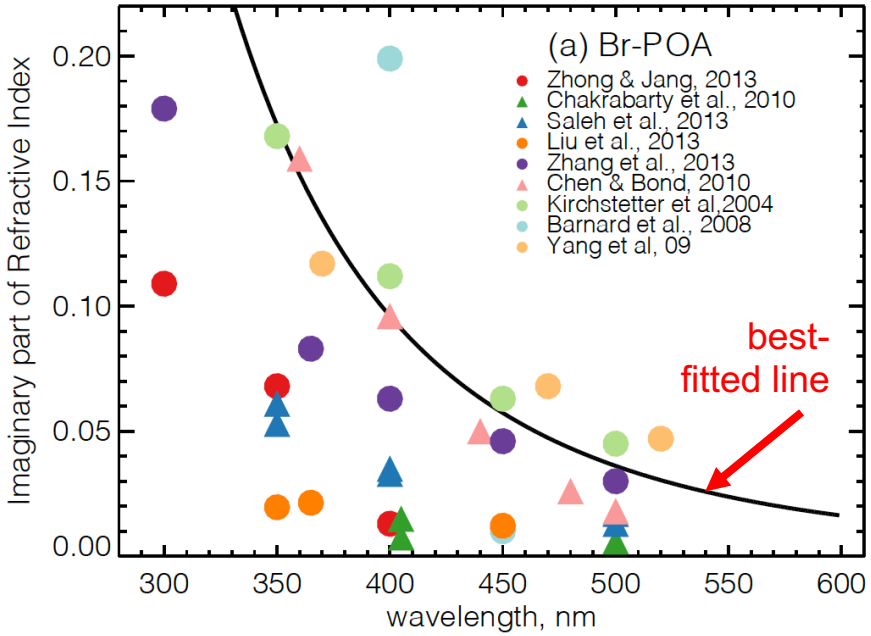
General workflow for our brown carbon (BrC) implementation



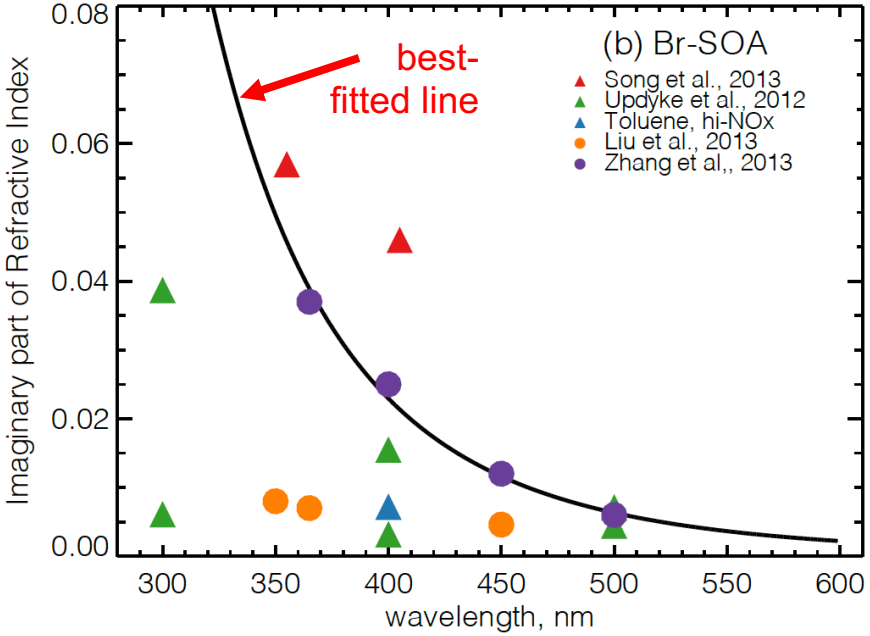
Brown carbon imaginary refractive index

Following Wang et al., 2014 best-fitted lines

Primary BrC

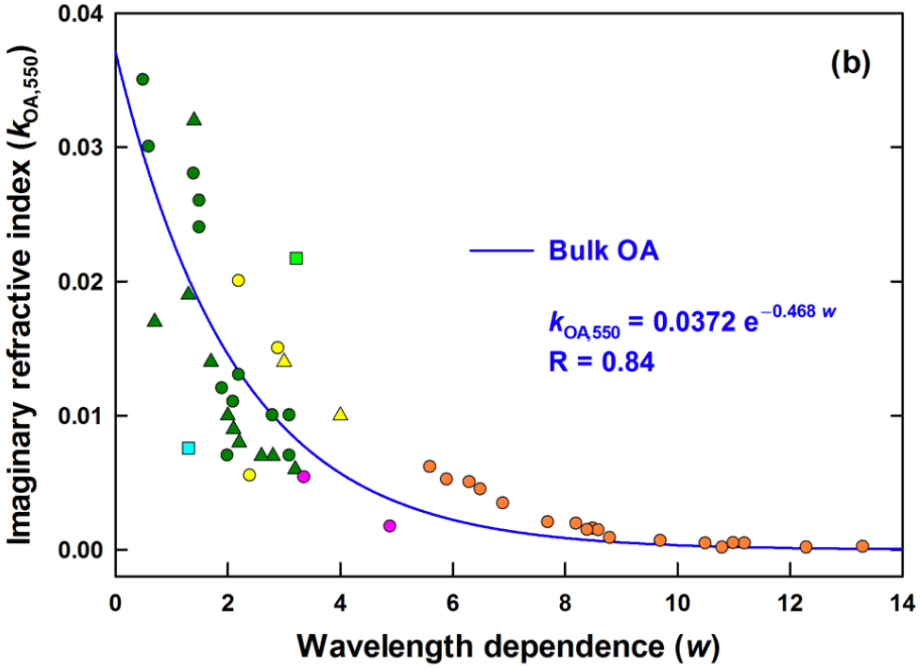


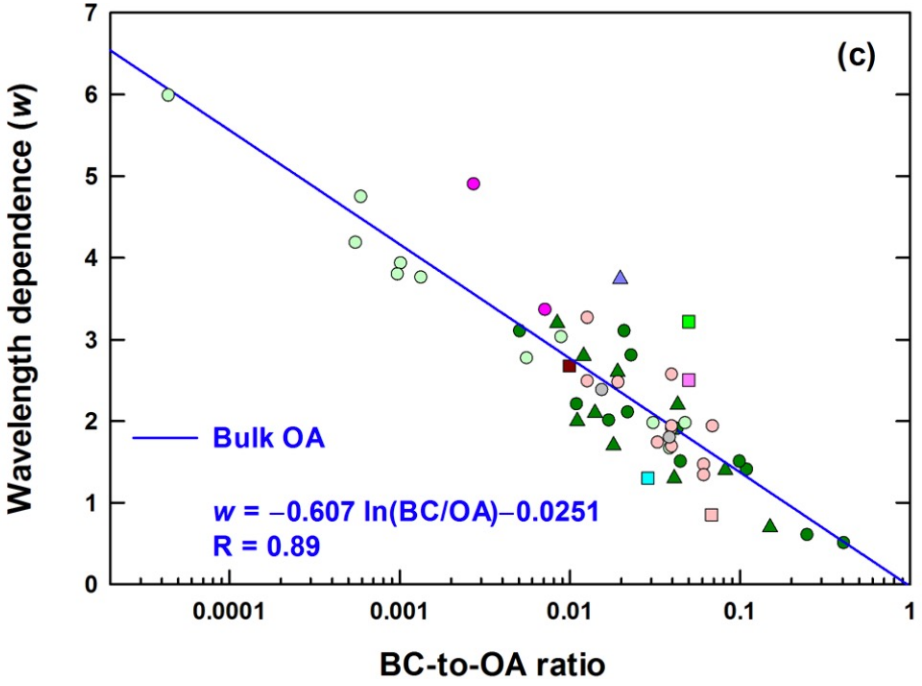
Secondary BrC



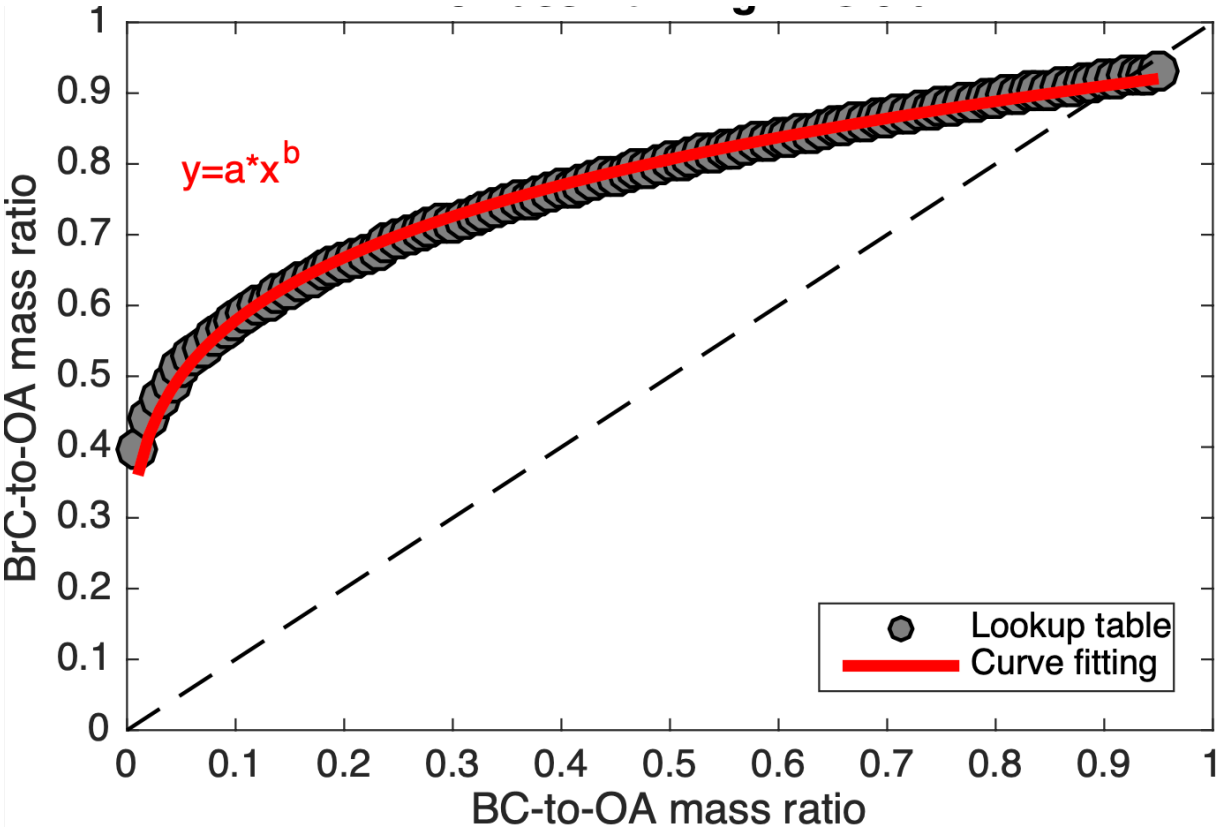
Bulk OA imaginary RI as a function of BC/OA at emission

Lu et al. 2015 parameterization from compilation of previous measurements





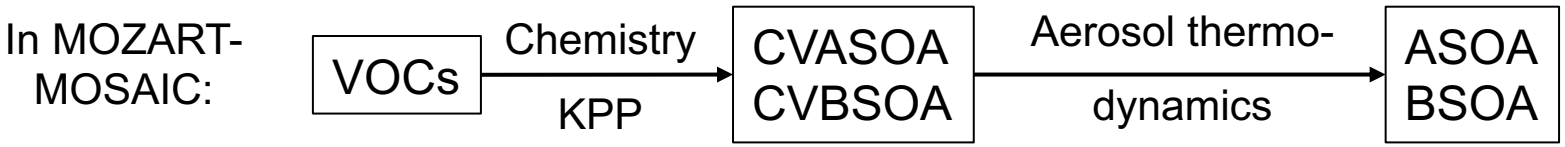
Our derived parameterization:
BrC/OA fraction as a function of BC/OA at emissions



Brown carbon secondary formation:

assume only aromatic SOA to be secondary BrC

Following previous BrC lab & modeling studies, e.g., Zhang et al. 2020; Nakayama et al., 2010



Precursors for CVASOA in MOZART-MOSAIC: BIGENE, BIGALK, BENZENE, TOLUENE, XYLENES

Brown carbon photobleaching due to OH oxidation

Following Wang X. et al. 2018 parameterization:

$$\mathrm{Abs}_{\mathrm{BrC},t+\Delta t} = \mathrm{Abs}_{\mathrm{BrC},t} \cdot \exp\left(-\frac{[\mathrm{OH}] \cdot \Delta t}{5 \times 10^5}\right)$$

Important Notes:

- Attribute the change of BrC absorption due to photobleaching to the change of BrC mass (i.e., photobleached BrC is converted to pure scattering OC)
- Same photobleaching for both primary & secondary BrC
- Set a minimum allowed remaining absorption threshold: 25% (Wang et al. 2018)

Brown carbon from boundary inflow

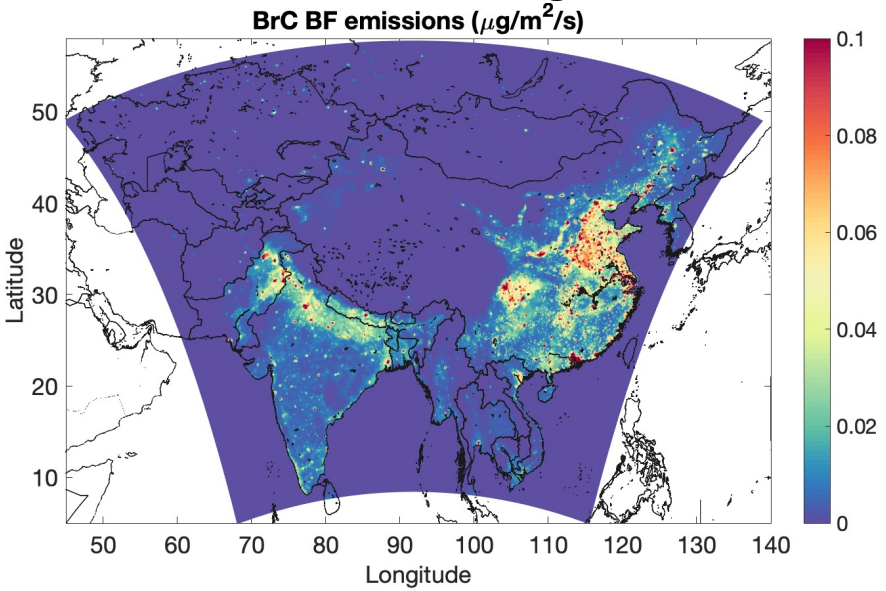
- Assume total 20% OC from boundary inflow to be BrC (primary 10%, secondary 10%) based on previous global studies (see Table below)

Global mean BrC/OA concentration/emission ratio	
Zhang et al., 2020	23% of OC emissions for BB, 38% of OA for BF
Jo et al., 2016	BrC/OC=0.2 (global mean burden ratio)
Feng et al., 2013	BrC/OC=0.43 (global mean burden ratio)
Park et al., 2010	BrC/BC=1 (global mean burden ratio), if OC/BC=3~6, then BrC/OC=0.16~0.3

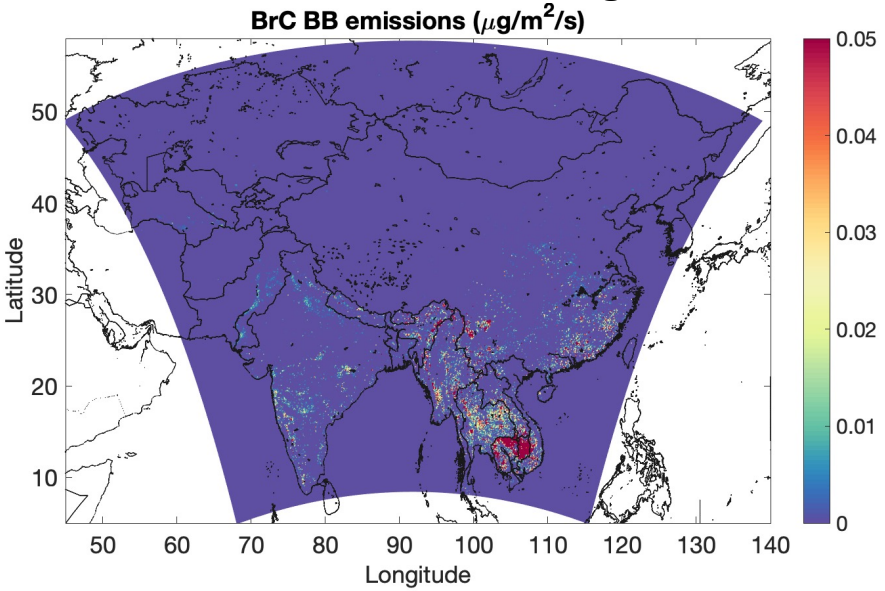
Brown carbon primary emissions & surface conc.

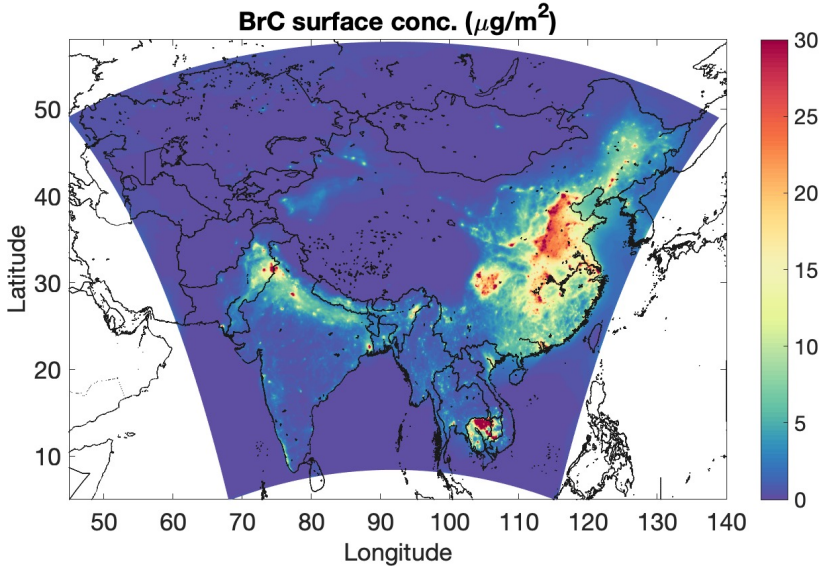
Jan 2013

Biofuel burning



Biomass burning





Brown carbon absorption optical depth (AAOD)

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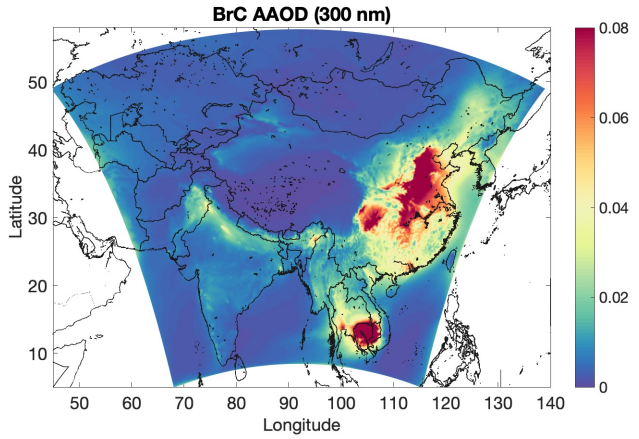
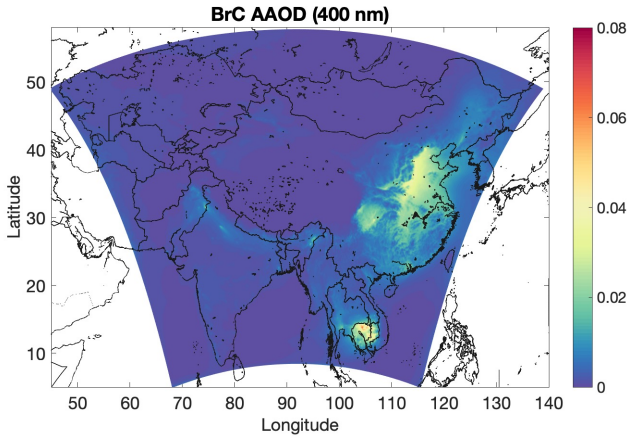
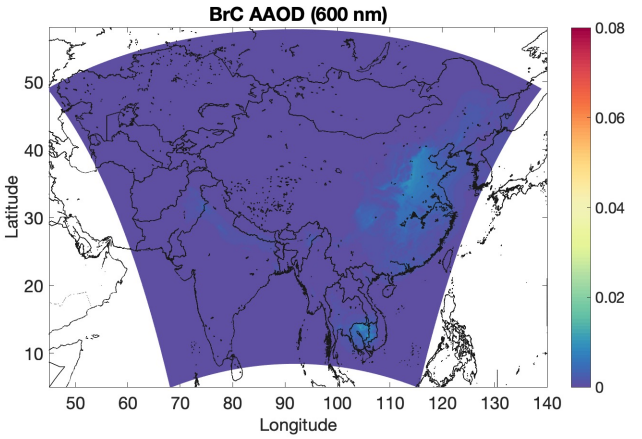
300 nm



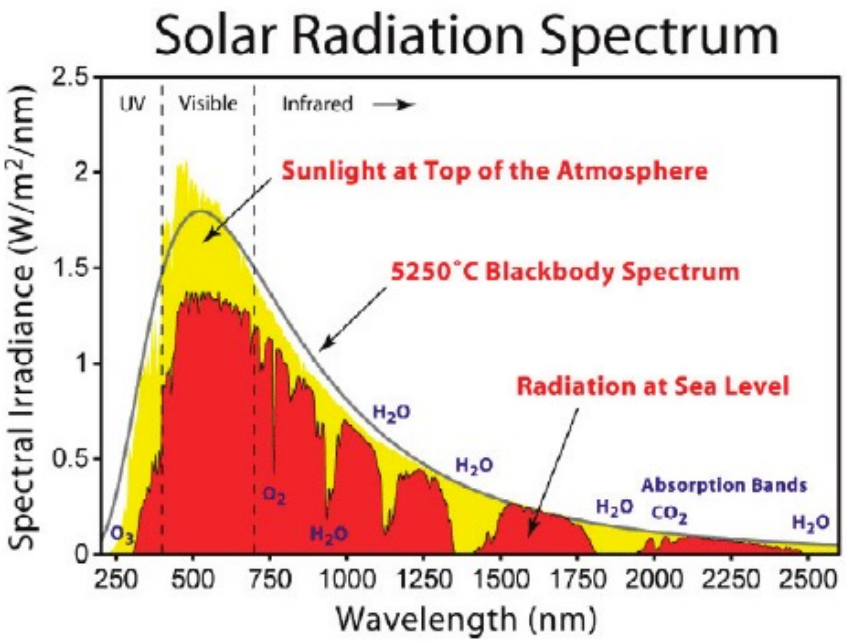
400 nm



600 nm



UV lights only accounts for ~8% of total solar spectrum energy



Brown carbon direct radiative effects

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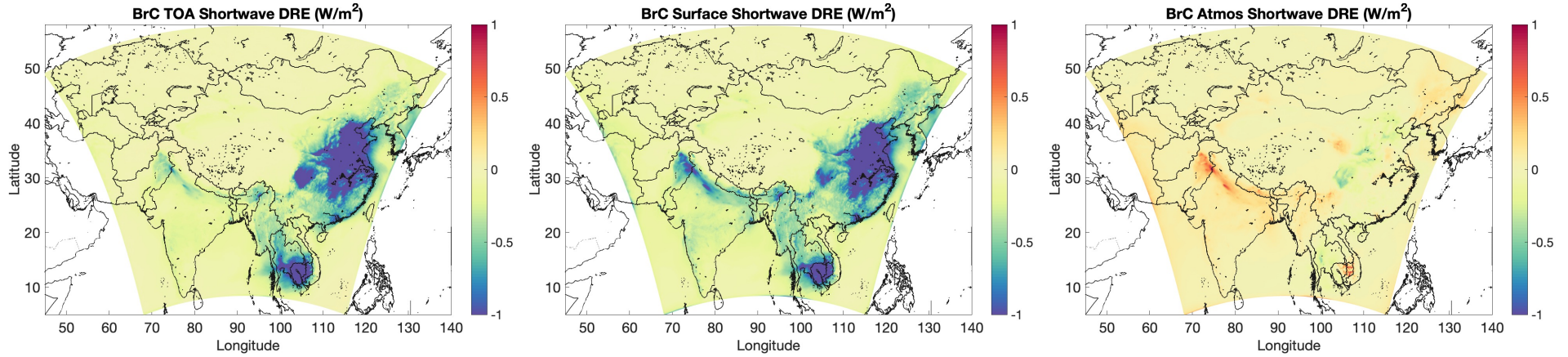
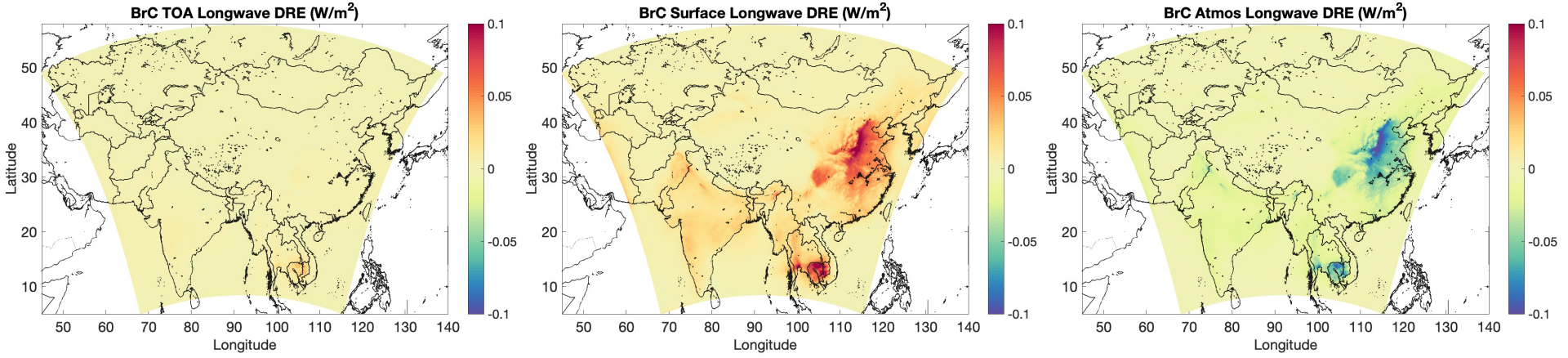
Shortwave

TOA = **Surface** + **Atmosphere**



Longwave

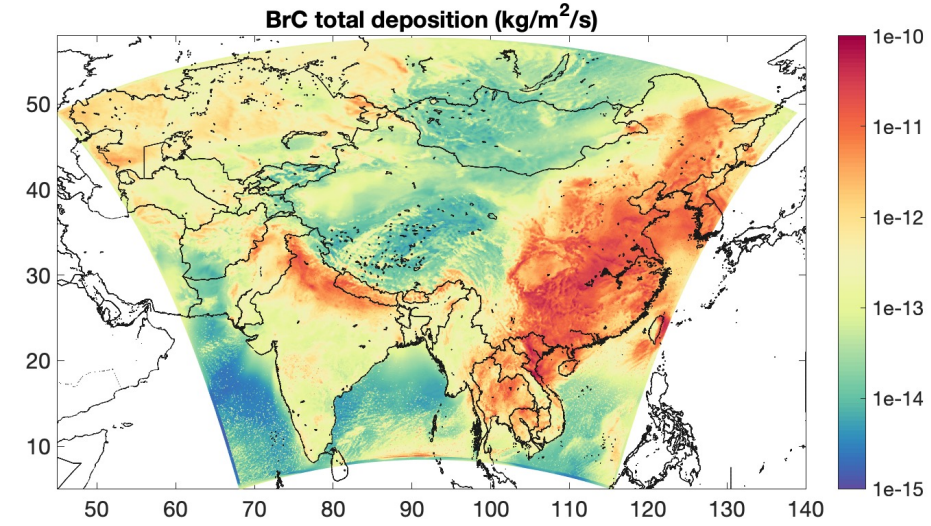
TOA = **Surface** + **Atmosphere**

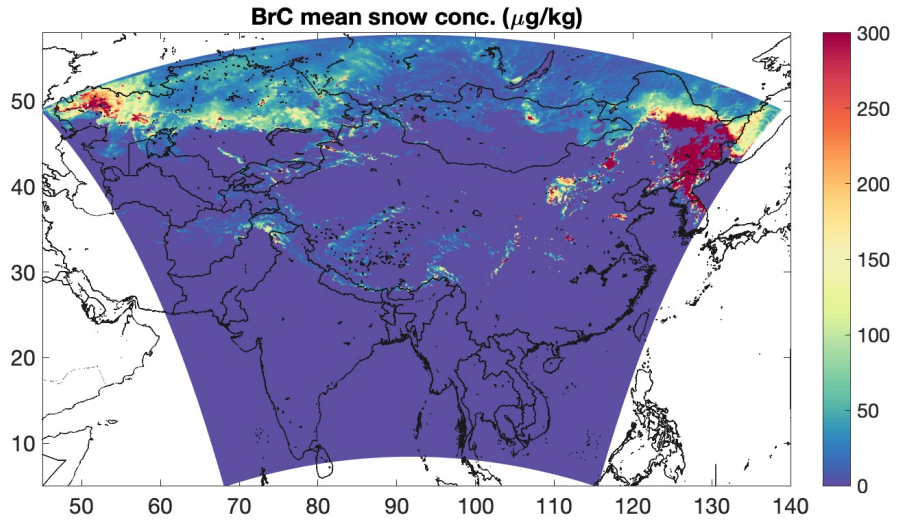


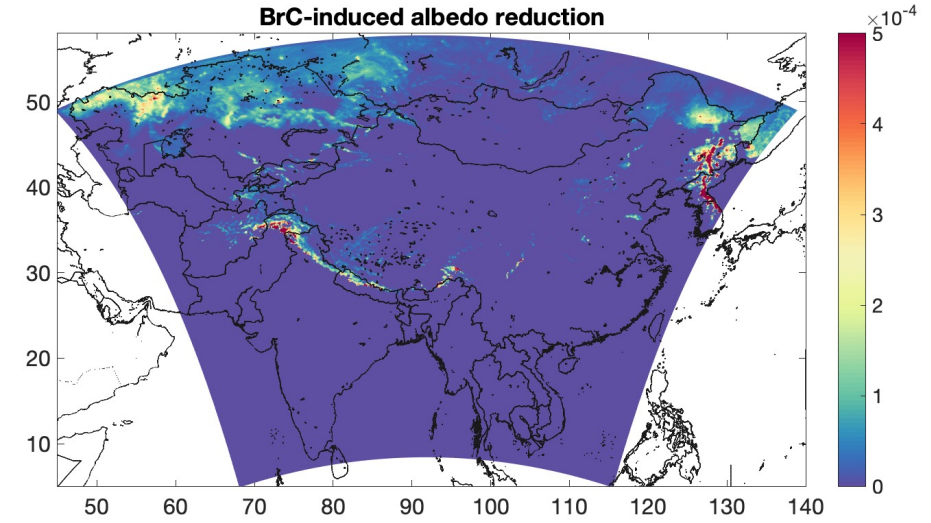
LW effect is one order of magnitude lower than SW effect!

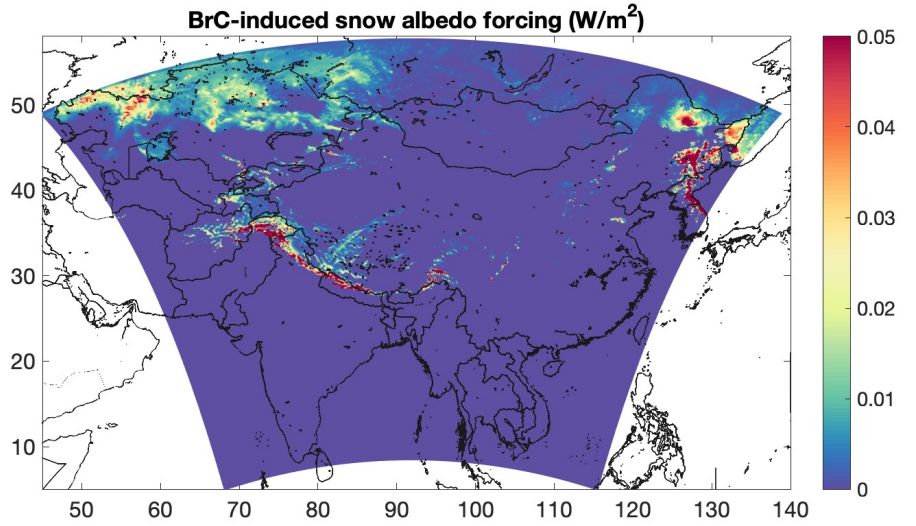
Brown carbon deposition & snow albedo effect

Jan 2013









On-going work

- Evaluate simulated aerosol and BrC by comparing with observations, including surface OC measurements, MODIS AOD, OMI AAOD, AERONET AAOD, SSA, OC in surface snow (ground), surface albedo, snow cover, surface temp., precipitation

- Production run: our 17-year (2003-2019) production run with assimilation of MODIS AOD and MOPITT CO

Thank you !

Other key WRF-Chem configurations

- 12-km resolution over Asia
- FINN fire emission, CAMS anthropogenic emissions
- CAMS global chemistry boundary condition
- ERA-Interim met boundary condition with 6-hourly nudging
- MOZART-MOSAIC chemistry
- RRTMG radiation,
- Morrison double moment microphysics
- CLM-SNICAR land model with aerosol deposition coupling