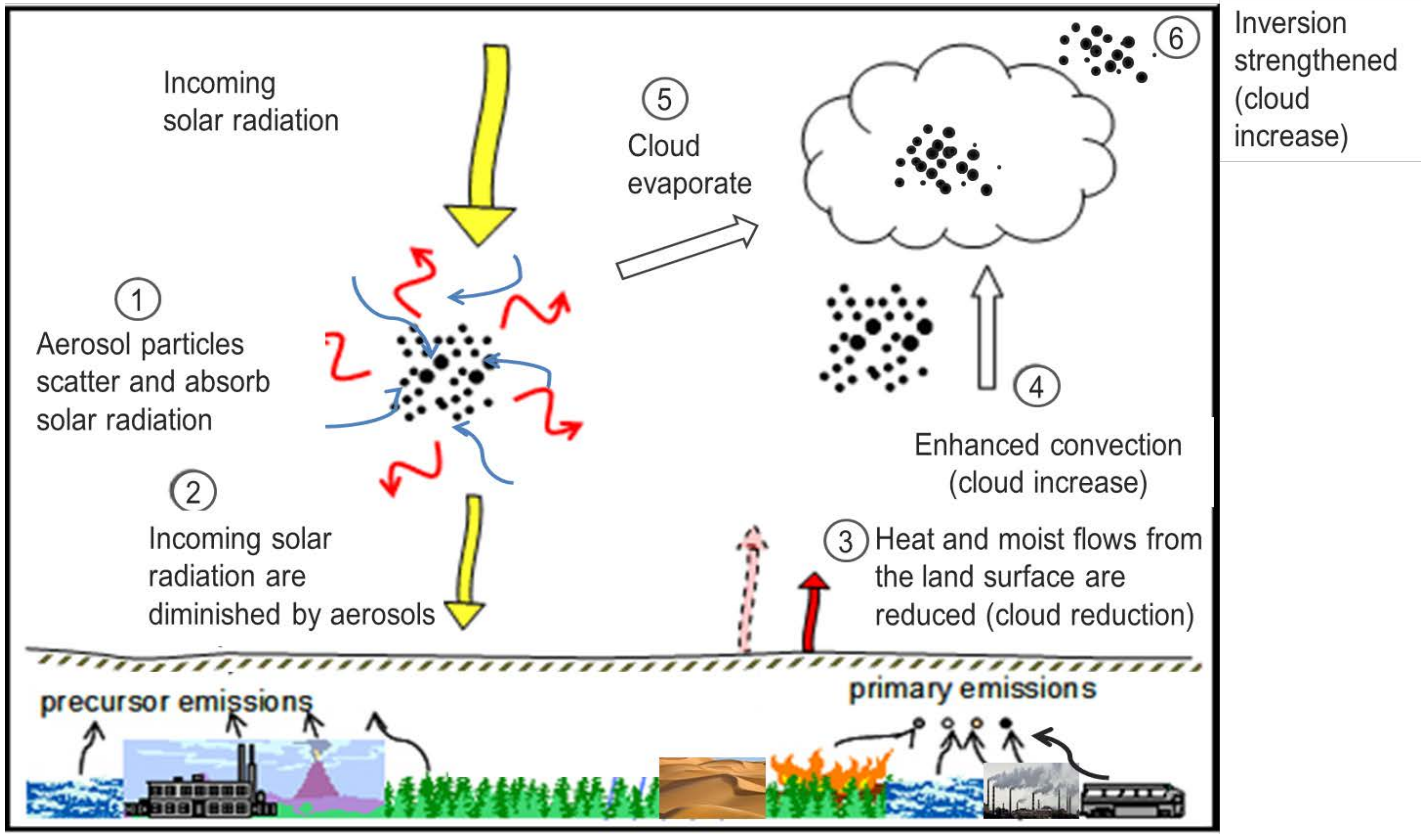
CLOUD RESPONSE TO INCREASED ABSORPTION BY BROWN CARBON IN BIOMASS BURNING

YAN FENG AND RAO KOTAMARTHI
Environmental Science Division
Argonne National Laboratory

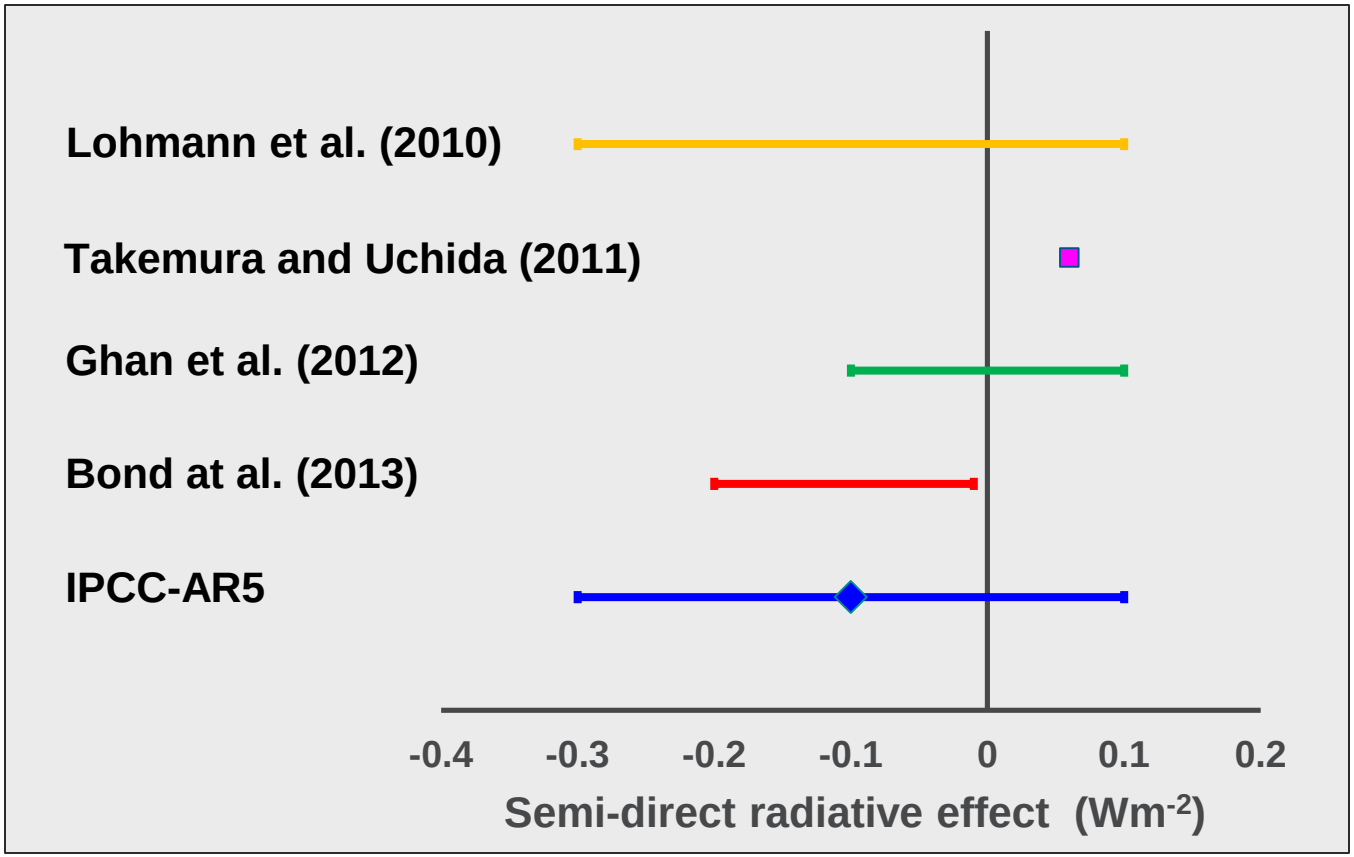
XIAOHONG LIU
University of Wyoming

Rapid adjustments of clouds and land surface to aerosols (absorbing) ⟶ "Semi-direct effect"

Direct ① ② Semi-direct ③ ④ ⑤ ⑥

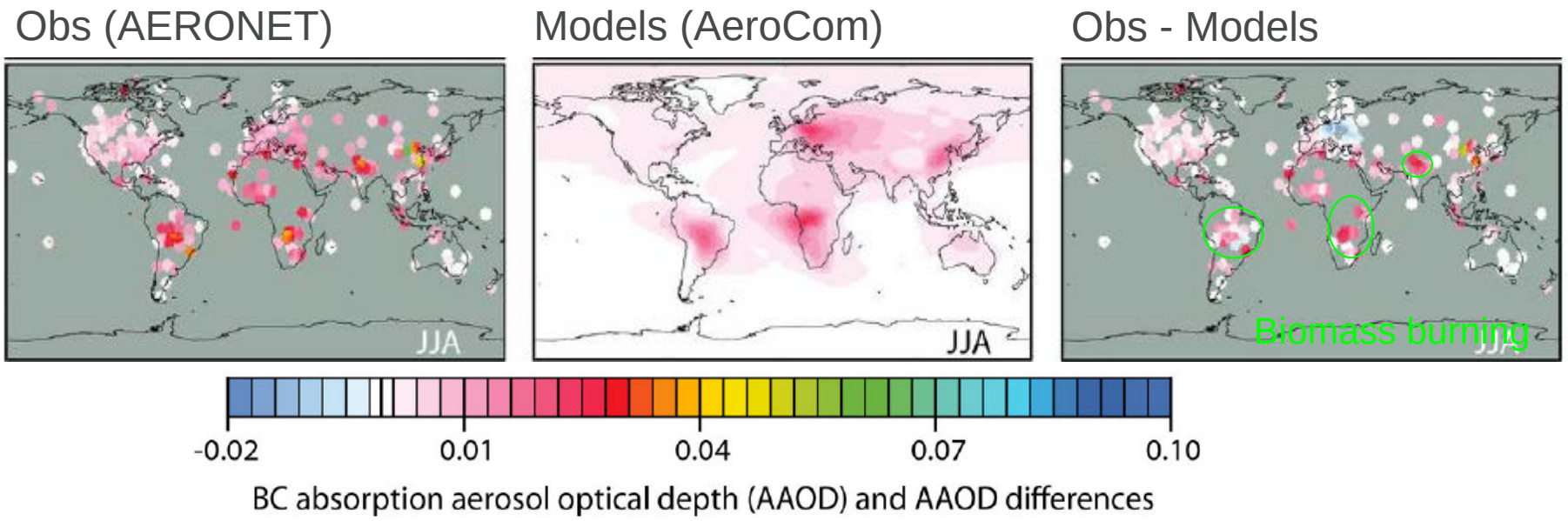


Global model estimates of semi-direct effect



"Very low confidence" **in sign and magnitude (IPCC-AR5, 2013)**

Models underestimate aerosol absorption by a factor of 2 to 3 compared with AERONET



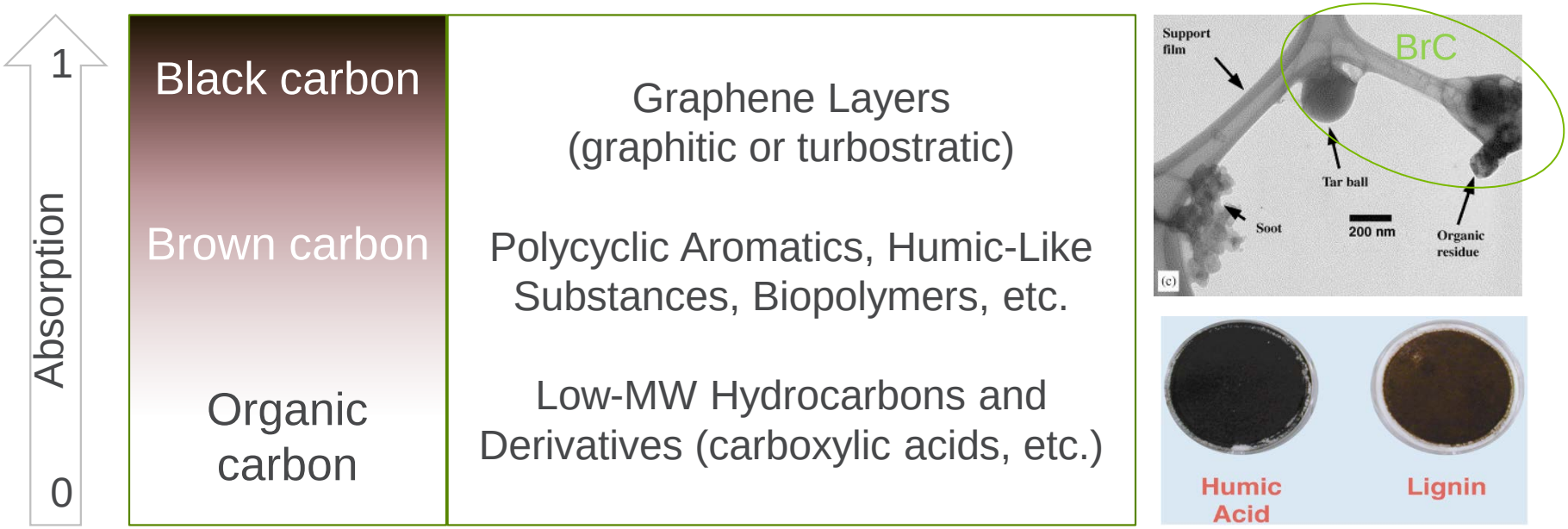
(Bond et al., 2013)

Light absorption of brown carbon (BrC), a class of absorbing organics, is underrepresented in most models

Optical Classification

Molecular Structure

Transmission Electron Microscope

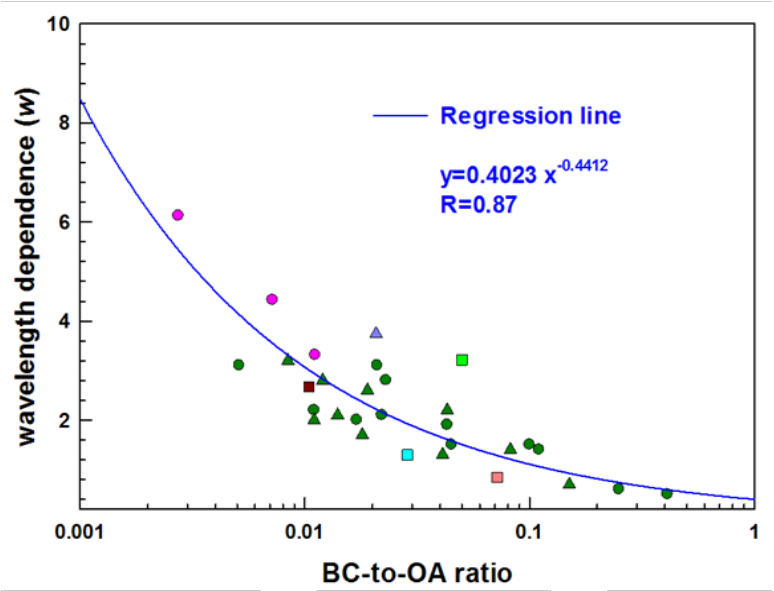


(Pöschl, 2003; Kis et al., 2006; Andreae and Gelenscér, 2006)

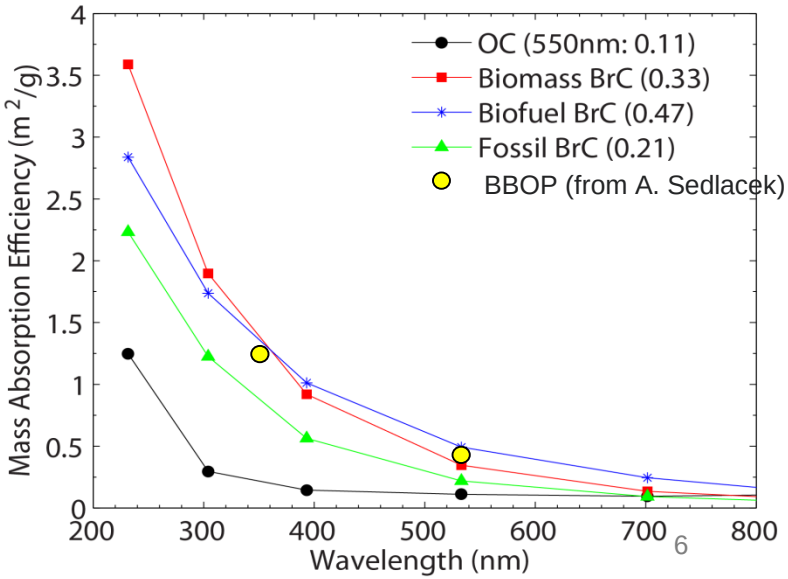
Primary emissions	biomass burning, biofuel combustion, and biogenic
Secondary	oxidation (e.g., O_3, nitrate radicals), polymerization, aqueous reactions with amines, …

Enhanced aerosol absorption by OC⟶ BrC

Lab/Field data of biomass burning aerosols

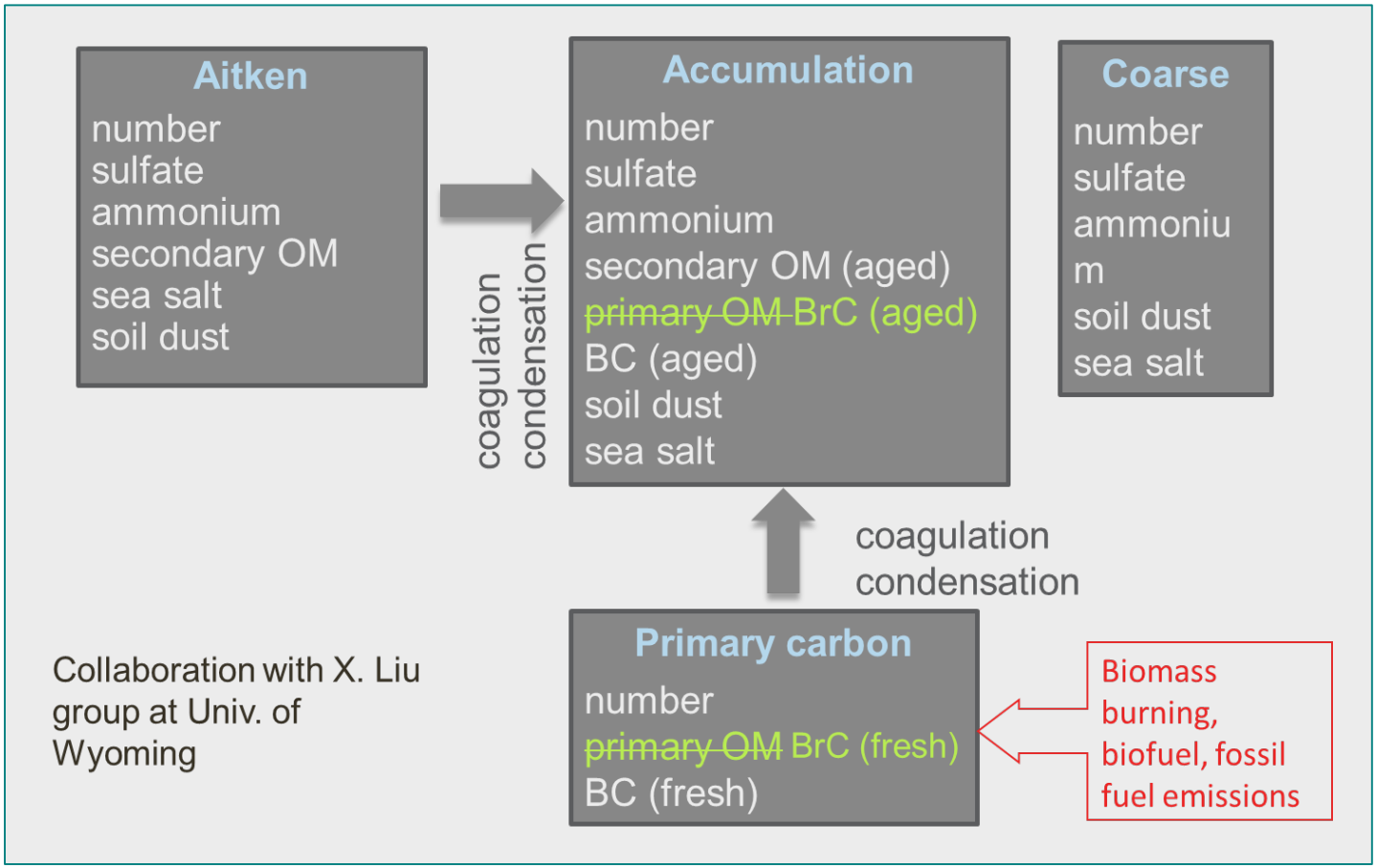


Model parameterization of BrC absorption by emissions



- Absorption properties of BrC are highly variable by origins
- A parameterization is developed by linking BrC absorption to BC/OC ratio at emission (Lu et al., 2015)
- BrC enhances aerosol light absorption in the short wave (< ~800nm)

Modal Aerosol Module (MAM4) in CAM5.3



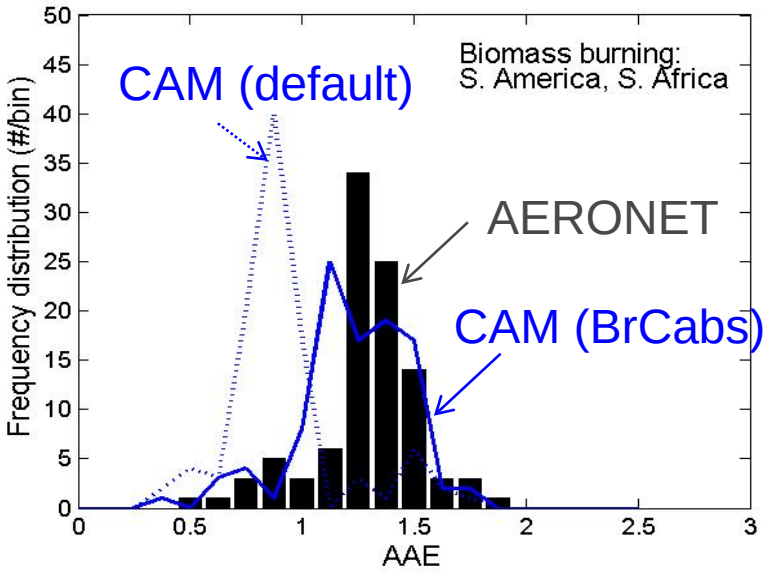
BrC : OC + more absorptive refractive indices

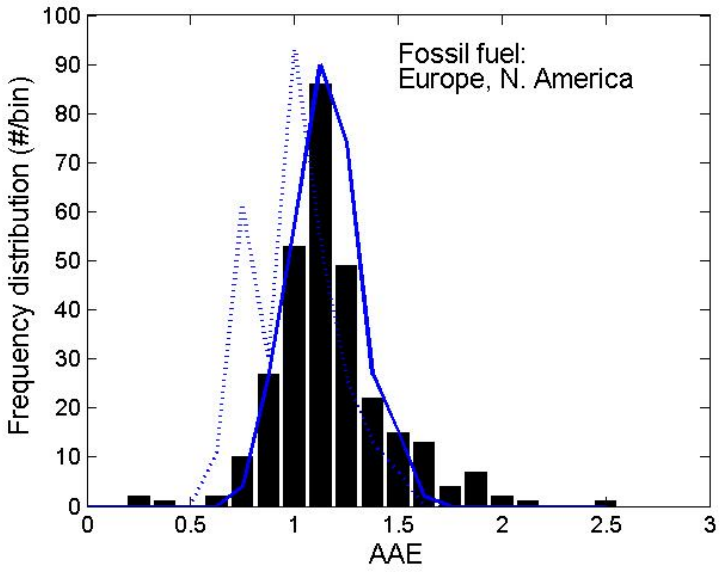
BrCabs = BrC - OC: enhanced absorption by converting OC to BrC

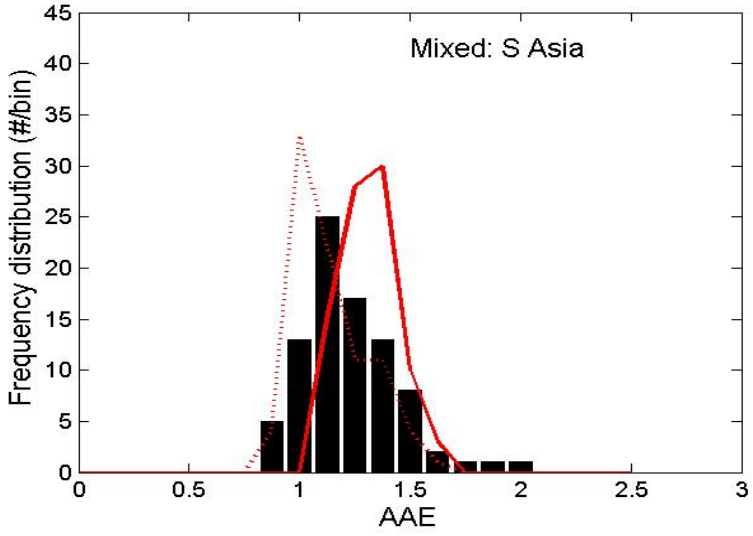
Only primary BrC is considered

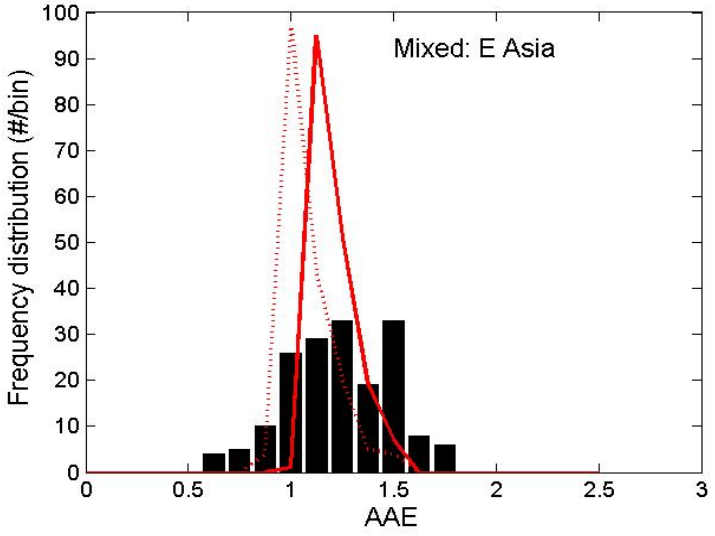
Argonne NATIONAL LABORATORY

Improved representation of aerosol absorption spectral dependence (AAE) by OC ⟶ BrC



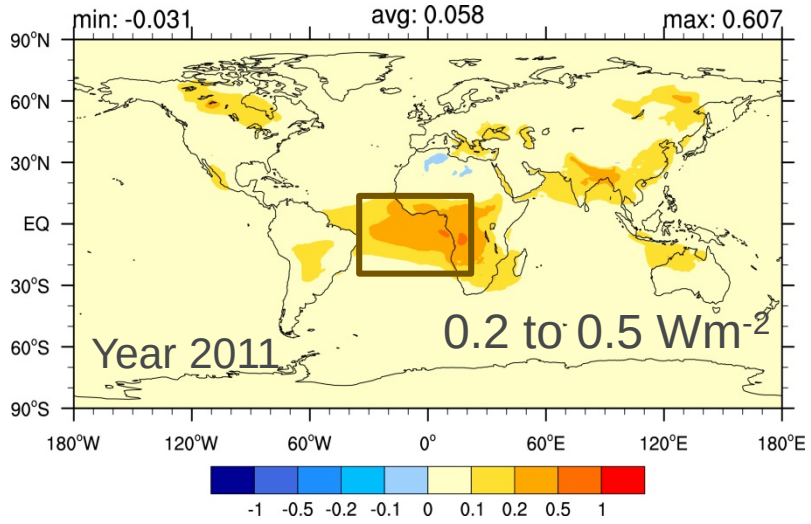




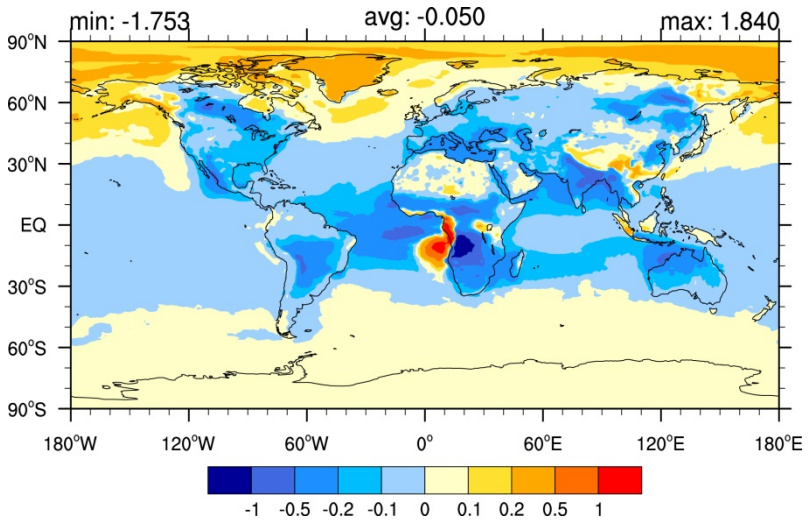


Direct radiative effect (DRE) due to BrCabs

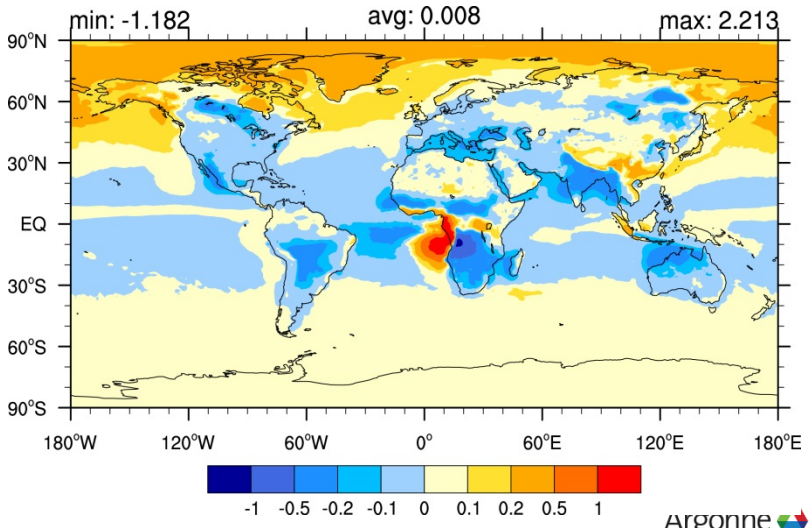
BrCabs = BrC - OC



OC



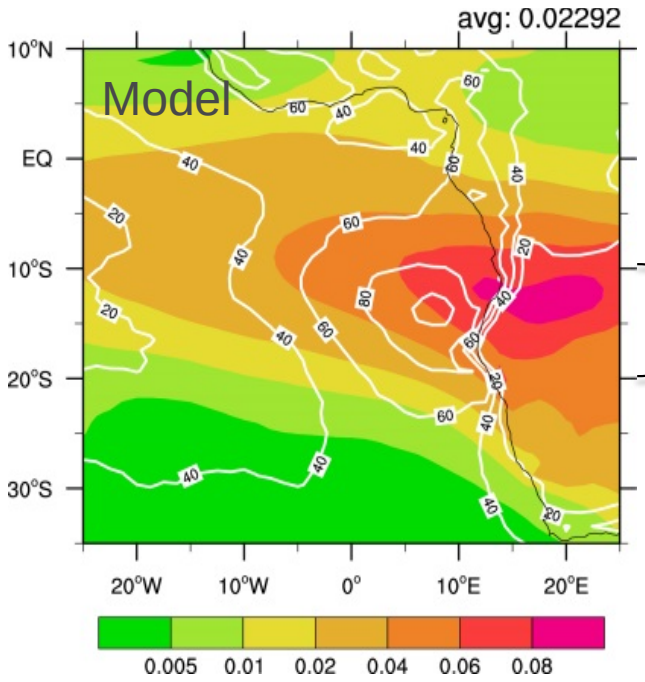
BrC



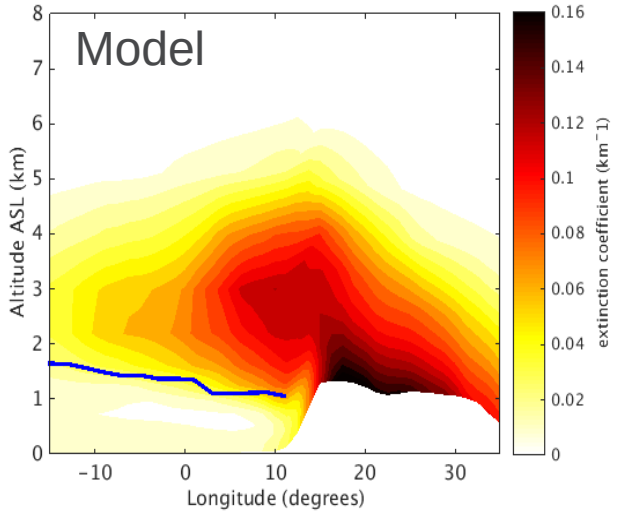
- Inclusion of BrCabs inserts a positive forcing of +0.06 Wm^{-2} at TOA, about 11% of BC DRE (0.55)
- It changes the OC DRE from a cooling effect to slightly warming

Biomass burning aerosols overlaid with subtropical marine stratus or stratocumulus

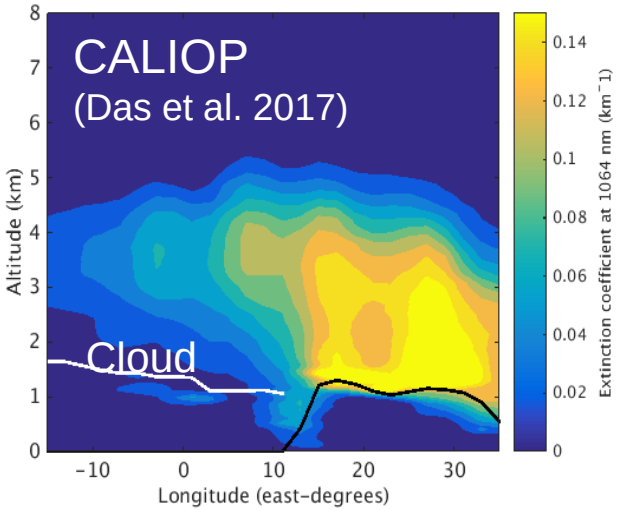
Southeast Atlantic (Sept. 2011)



Longitude vs Height cross section



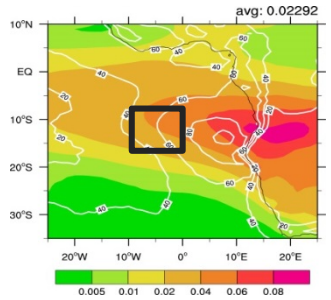
Extinctionx2



Extinction

Filled contours: AAOD

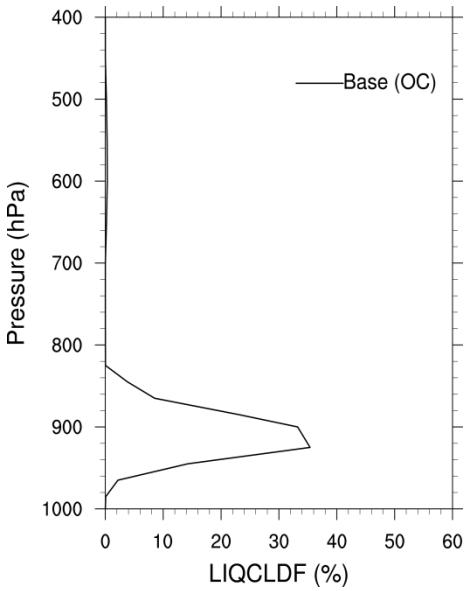
White contours: liquid stratus cloud fraction



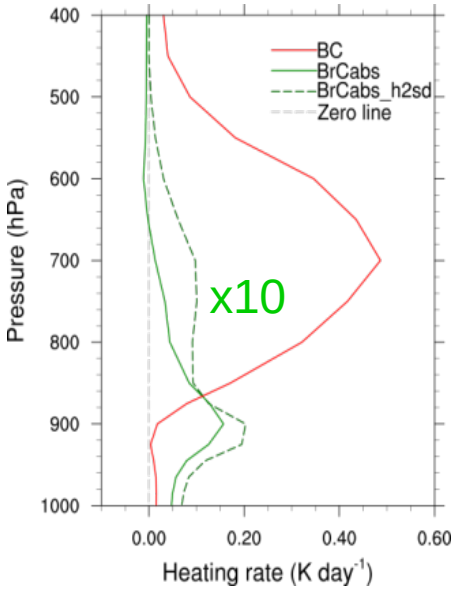
BrCabs-induced changes in heating rates, temperature and cloud fraction

10-year simulations: All aerosols (OC->BrC) – All aerosols (OC)

Cloud fraction

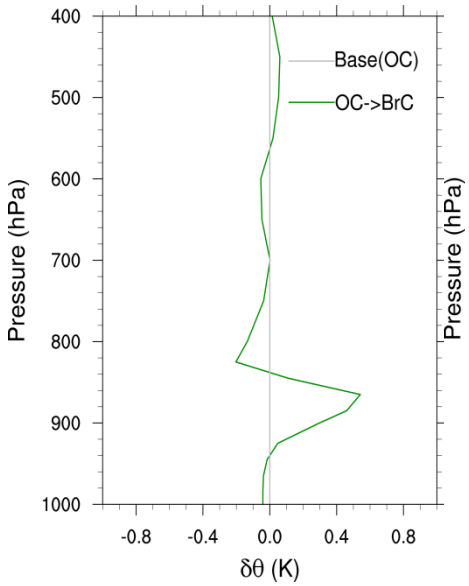


Heating Rate



BrCabs results in a heating profile different from BC – larger effect when background aerosols less absorbing

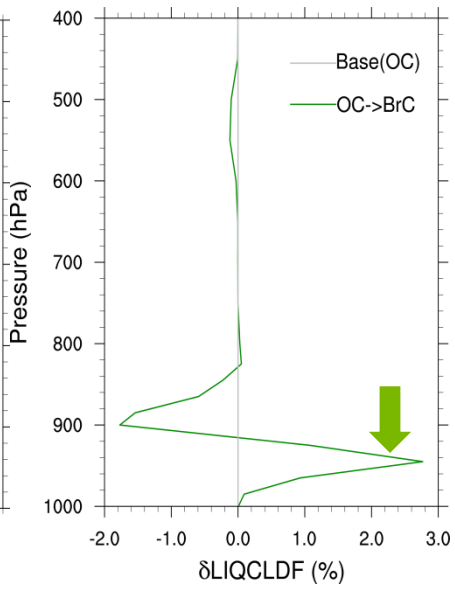
Potential Temp.



Evaporates cloud top;

Inversion strengthened

Cloud Fraction



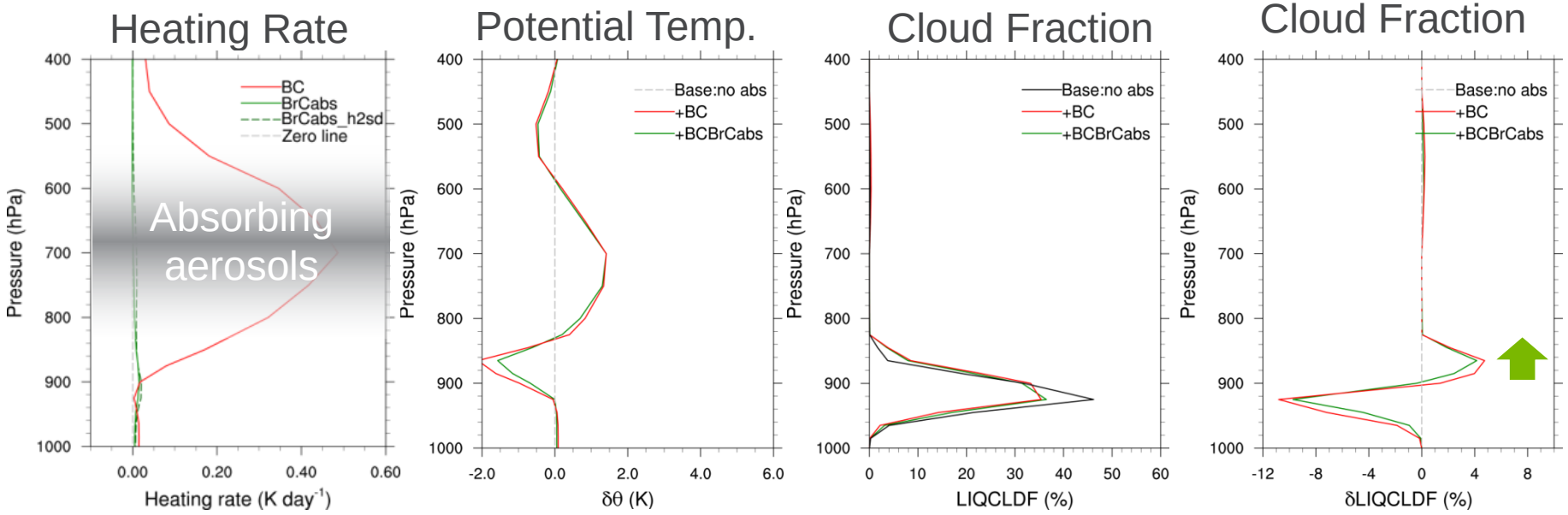
Clouds thinning;

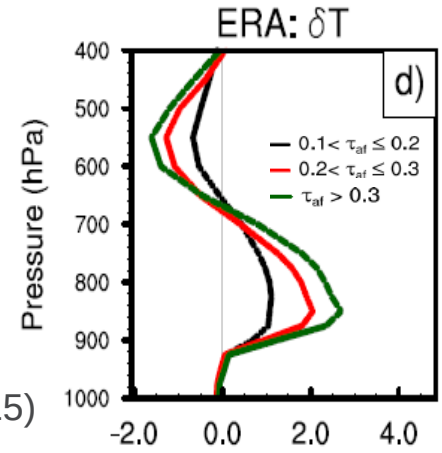
Cloudiness increases by 3%;

Argonne NATIONAL LABORATORY

BC- induced changes in thermodynamic structure and cloud fraction

All aerosols (OC) – All aerosols (OC, no BC)





(Adebiyi et al., 2015)

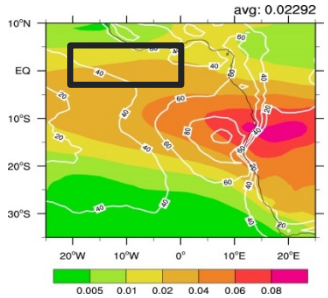
Compared with ERA reanalysis, the model predicts weaker inversion enhancement due to aerosols, especially near the cloud top;

Reduced subsidence dominates

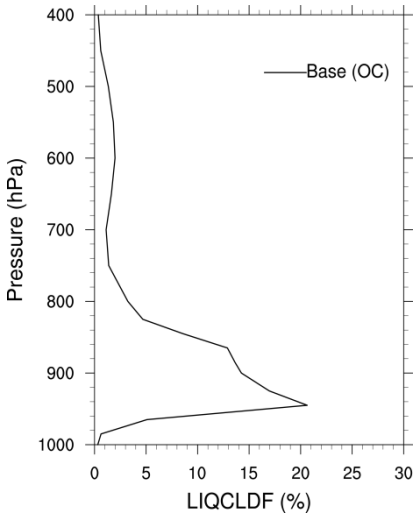
Clouds deepened with smaller cloud fractions

Argonne NATIONAL LABORATORY

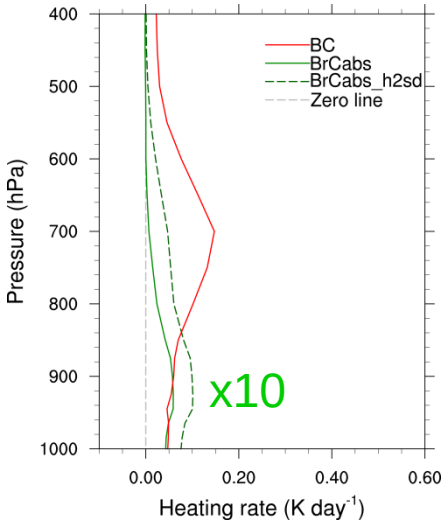
BrCabs- (Top) vs BC- (Bottom) induced changes



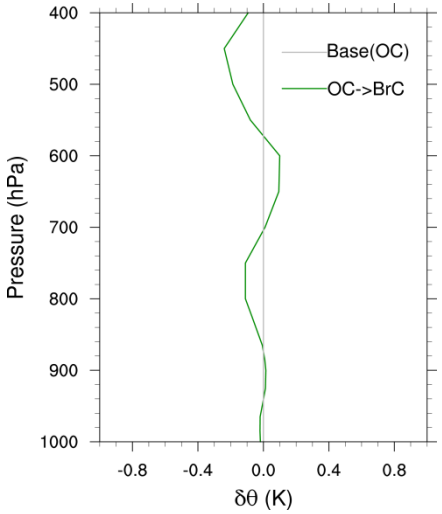
Cloud fraction



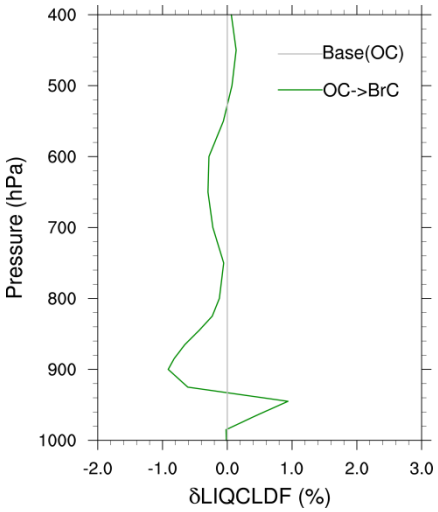
Heating Rate

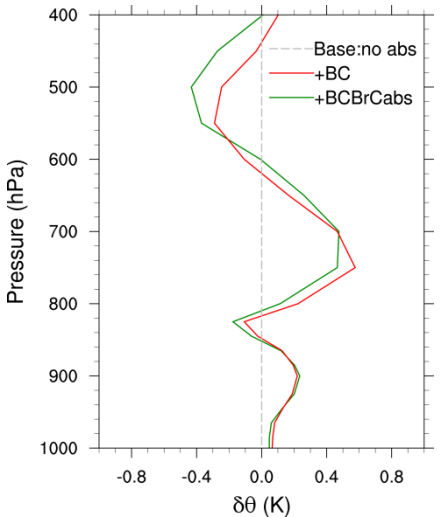


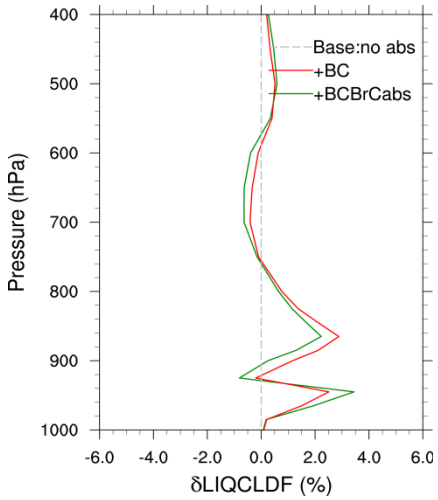
Potential Temp.



Cloud Fraction







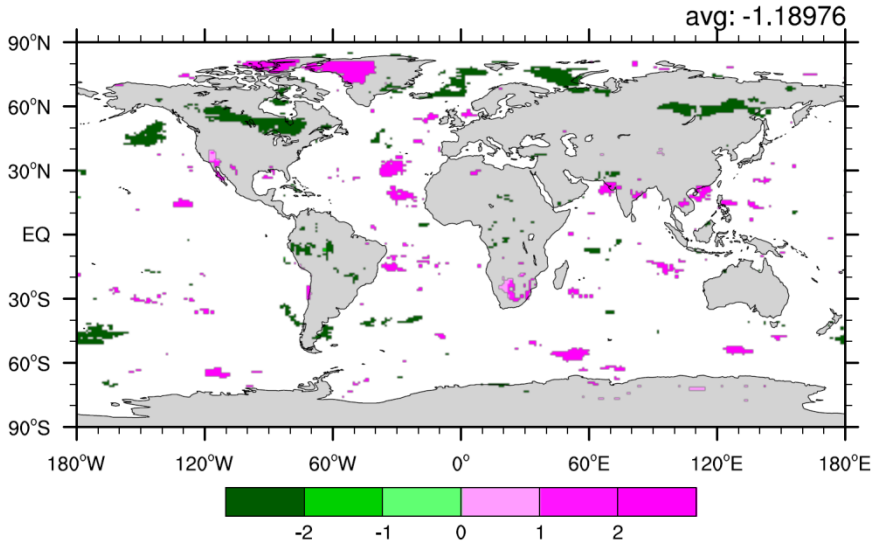
In this cumulus-like cloud region, aerosols are in the cloud, as well as above the cloud;

Similarly, BrCabs has a larger heating when background aerosols less absorbing;

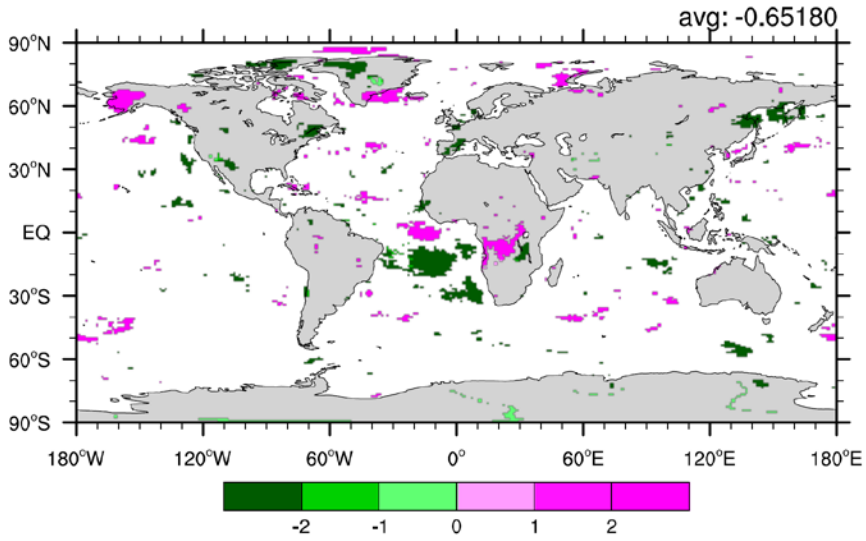
Compare to increased cloudiness by BC, BrCabs leads to slightly decreased cloud fraction

10-year mean responses of low clouds in Sept.

Cloud Fraction Changes due to BrCabs



Changes due to BC



Cloud fraction responses to absorbing BC and BrCabs are regarded as "detectable" (>standard deviation) regionally, compared to the All aerosols (OC) case

Global and annual mean responses

	BC+BrCabs			
	mean	**std**	**Max-min**	**median**
Δ Cloud cover(%)	0.034	0.111	0.377	0.044
	BC			
Δ Cloud cover (%)	-0.024	0.137	0.475	0.006
	BrCabs			
Δ Cloud cover (%)	0.058	0.123	0.404	0.056

Argonne NATIONAL LABORATORY

Conclusions

- BrCabs (OC->BrC) inserts a direct positive radiative effect that is about 11% of the BC direct effect. It is more significant regionally – and by including SOA contribution?
- The BrCabs-induced heating rate changes are different from the BC heating profiles, more significant when background is less absorbing, as a result of internal mixtures of aerosols;
- This leads to different cloud responses to BrCabs vs BC in the sign and magnitude, depending on the cloud regime and aerosol heating profiles;
- It also indicates the scaling method of BC AAOD to account for additional absorption from BrC may not be applicable;
- The simulated low-cloud responses to biomass burning BC and BrCabs are more “detectable” on the regional and monthly scale – larger impact on the cloud seasonal cycle than annual mean?