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AEROSOLS AND CLIMATE (O BOUCHER AND S REMY, SECTION EDITORS)

Aerosol Absorption: Progress Towards Global and Regional Constraints

Bjørn H. Samset[1] · Camilla W. Stjern[1] · Elisabeth Andrews[2] · Ralph A. Kahn[3] · Gunnar Myhre[1] · Michael Schulz[4] · Gregory L. Schuster[5]

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Aerosol absorption: Why is it so hard to constrain?

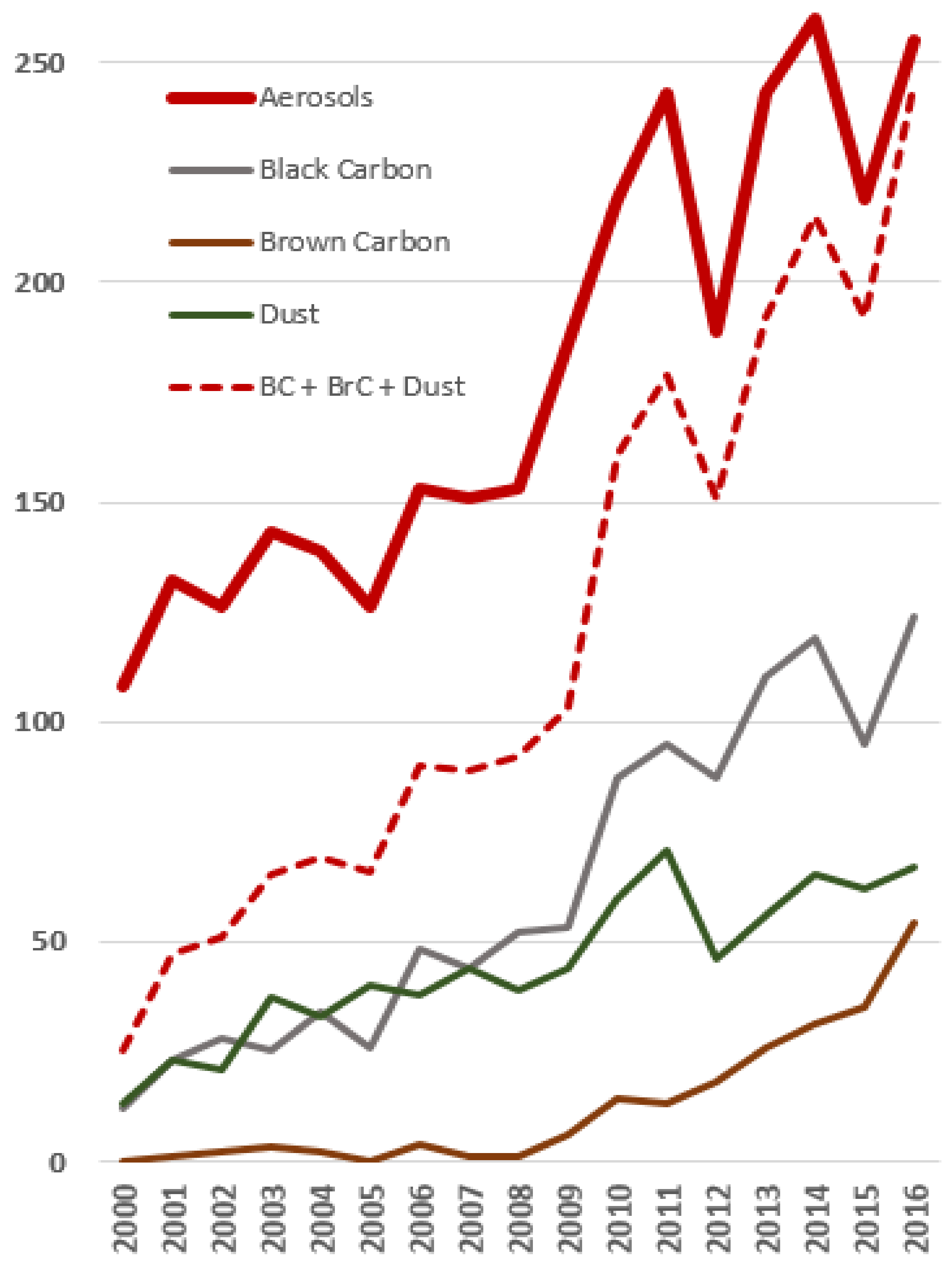
Bjørn H. Samset, Camilla W. Stjern, Elisabeth Andrews, Ralph A. Kahn,
Gunnar Myhre, Michael Schulz, Gregory L. Schuster

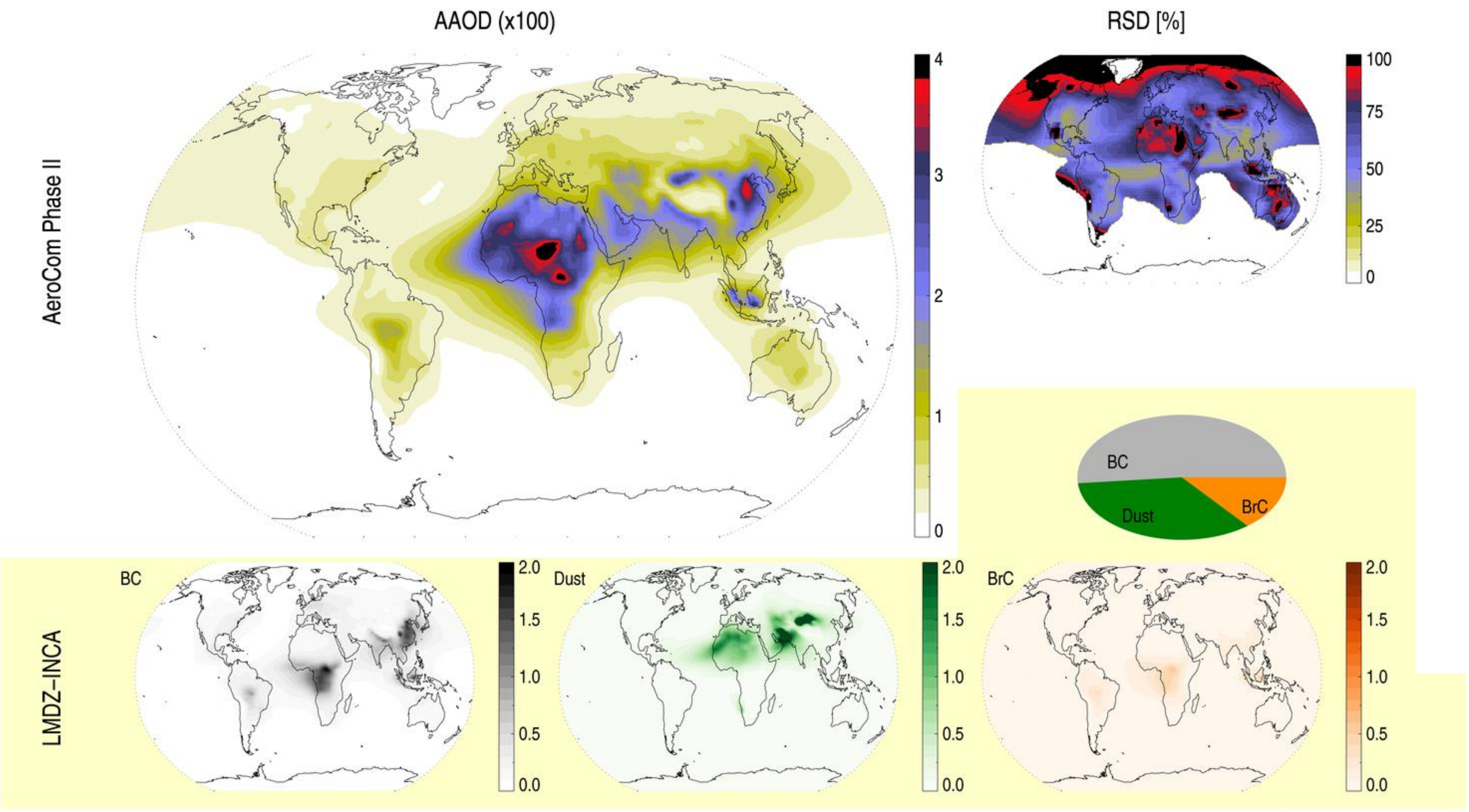
Crash course in aerosol absorption

- Aerosols affect the climate system by intercepting incoming shortwave radiation. Although all aerosols act as scatterers of radiation, reducing surface irradiance, some species also absorb, effectively adding a positive energy term to the atmospheric radiative balance.
- The main absorbing aerosol species are black carbon (BC), mineral dust, and the absorbing component of organic aerosols, usually termed brown carbon (BrC).
- Conceptually, the net shortwave aerosol absorption, usually quantified through the absorbing aerosol optical depth (AAOD), can therefore be thought of as the sum of the contributions of these three separate species, integrated over the atmospheric column.
- Observationally, however, such clear distinction into separate aerosol categories is usually not possible, because of mixing of aerosol species. This makes validation of model predictions challenging.
- Constraint: Reasonable agreement between observations and theoretical or model-based estimates, combined with a quantification of the agreement and some understanding of why the two agree.

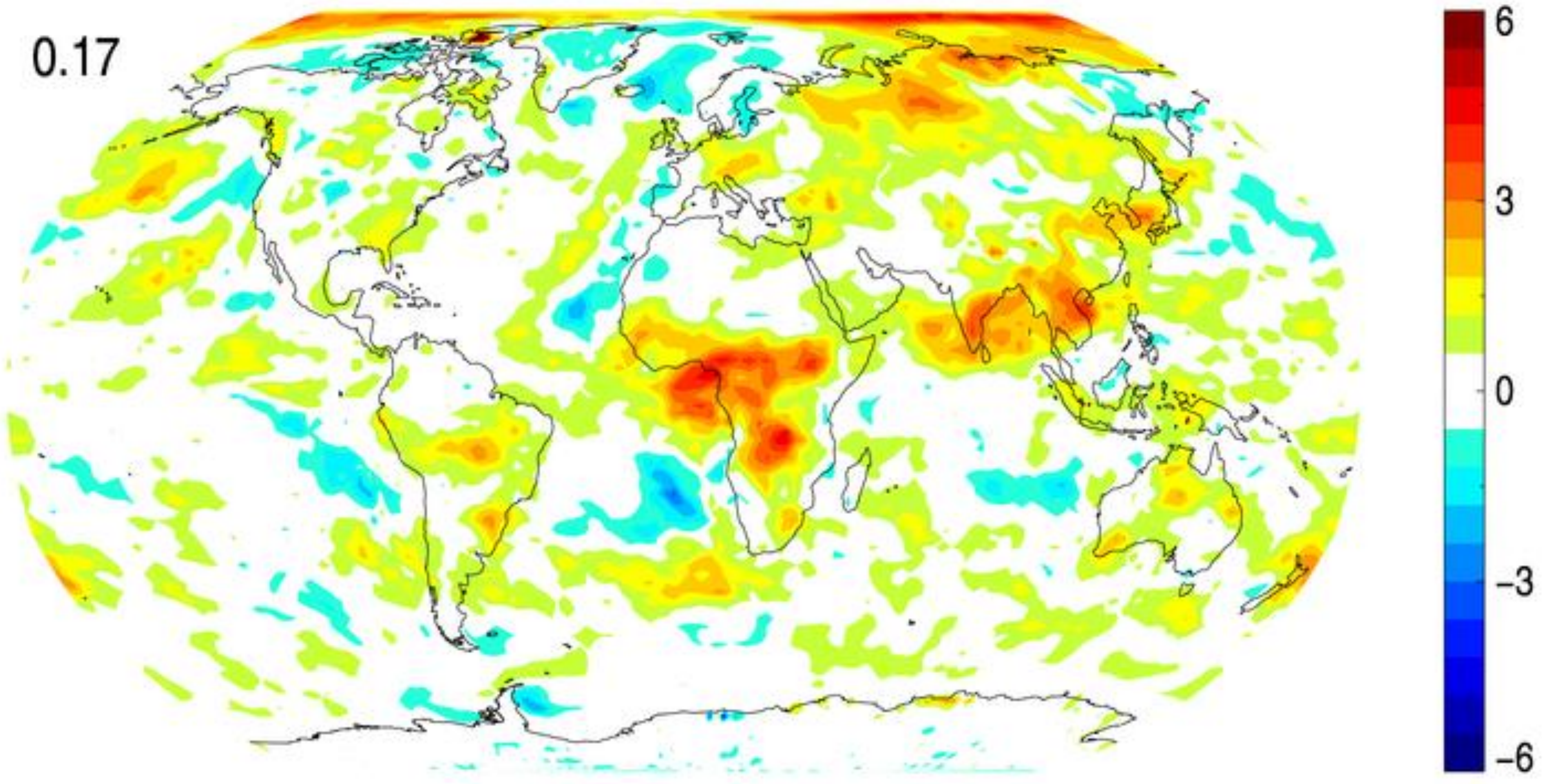
Outline
(of the paper…)

- Motivation
- Species-based advances
  - BC
  - BrC
  - Dust
  - Multi-species model-based constraints
- Observational advances
  - Remote sensing by ground stations
  - Remote sensing by satellites
  - In situ surface stations
  - In situ aircraft measurements
- A roadmap towards improved constraints on aerosol absorption

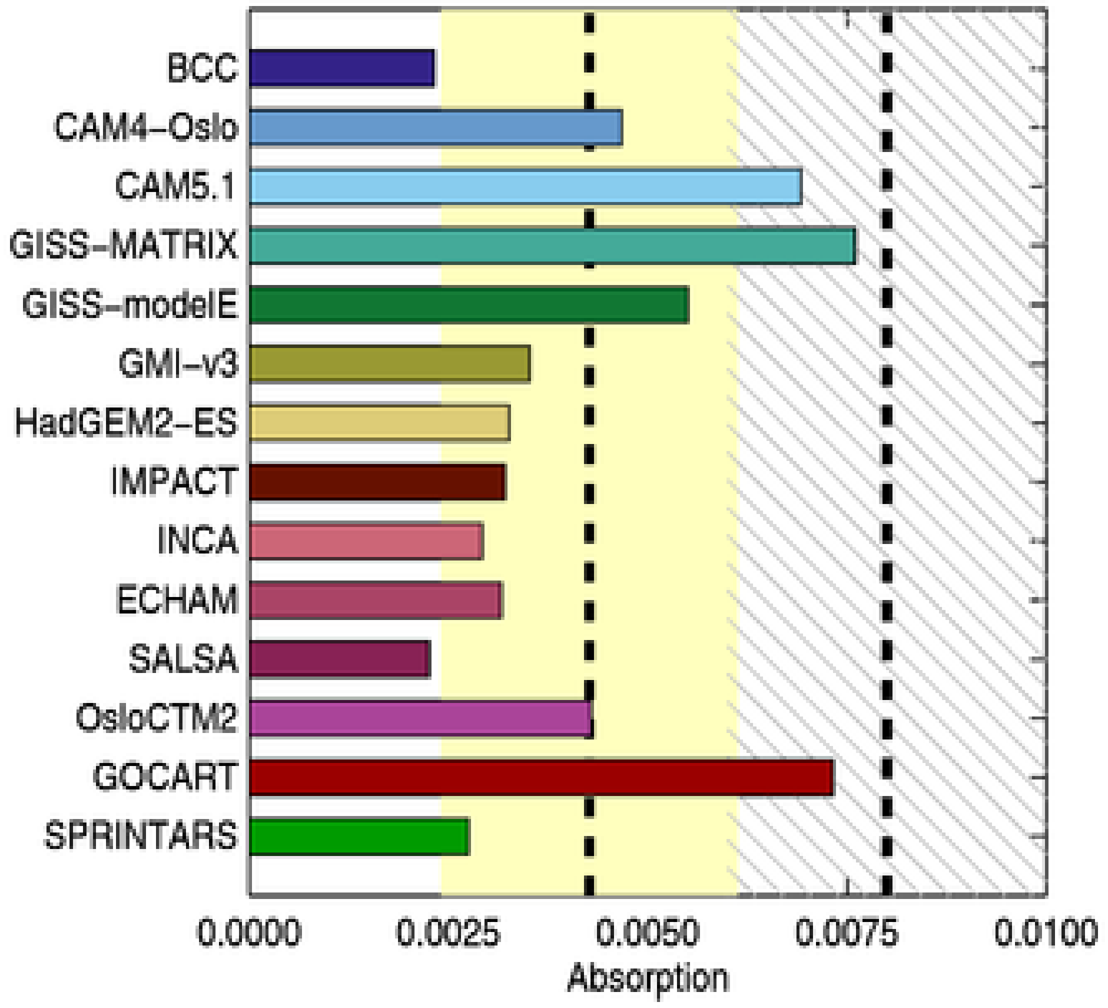




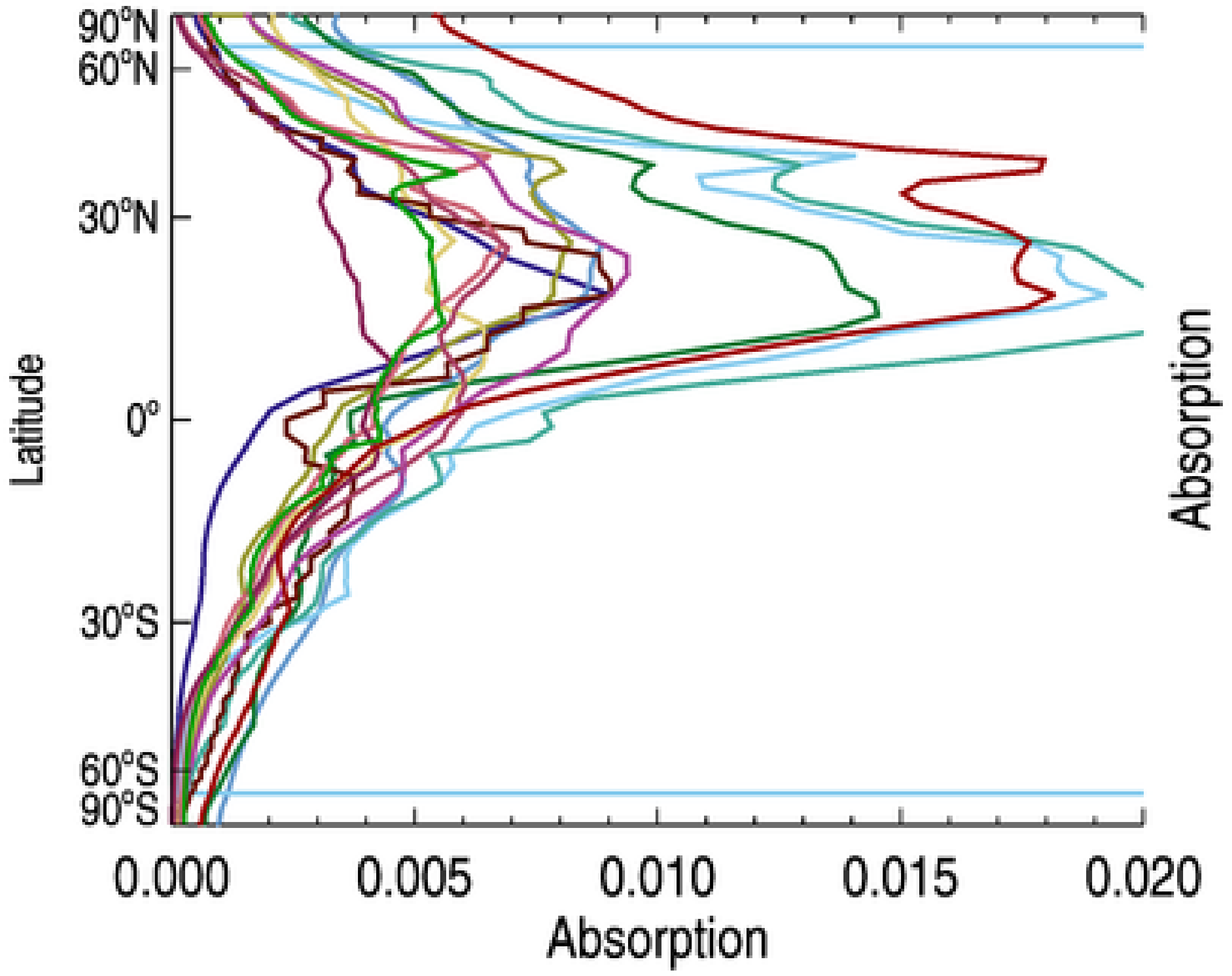
ERF (CAM4)

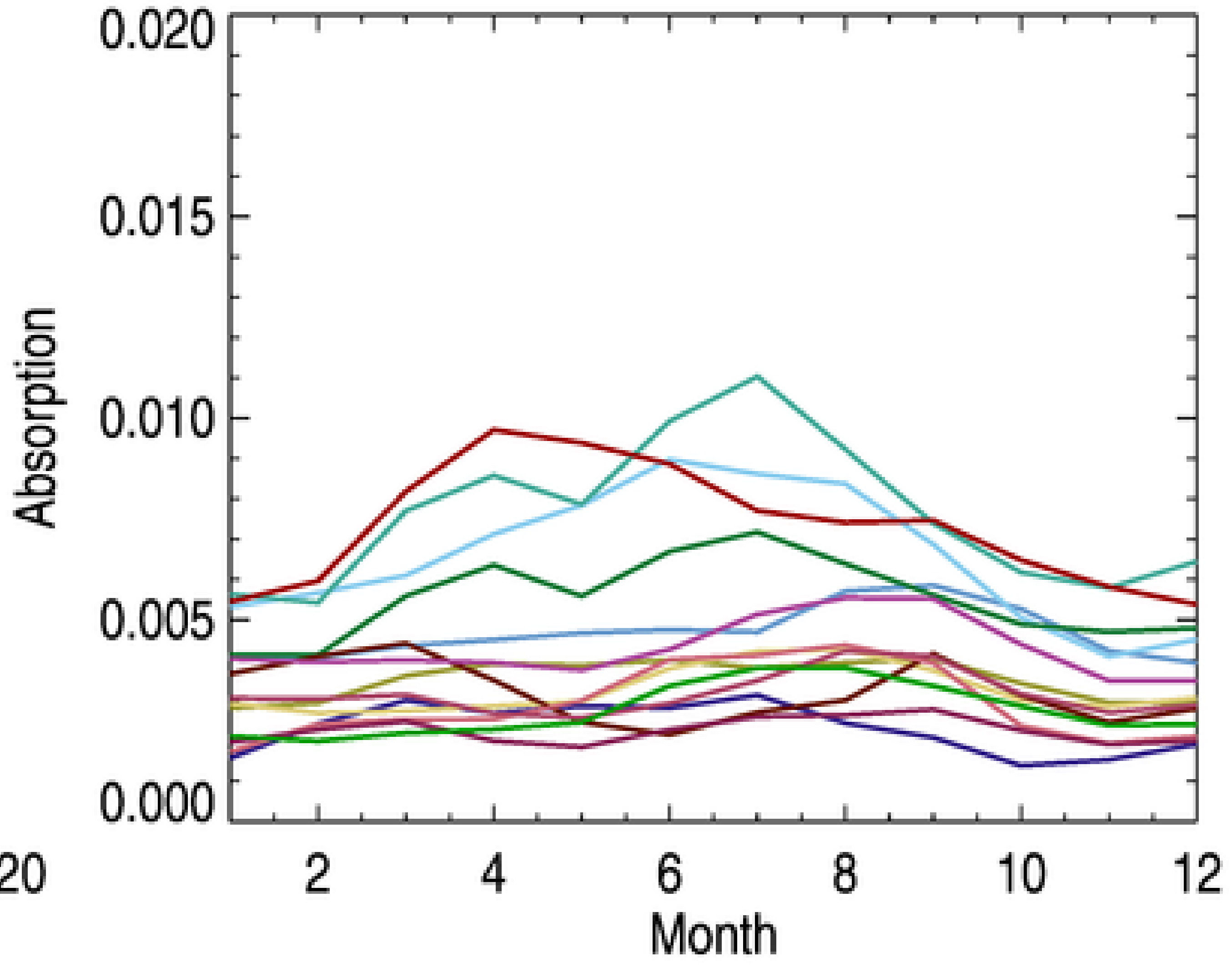


AAOD
Base: 0.003
Signal: 0.004



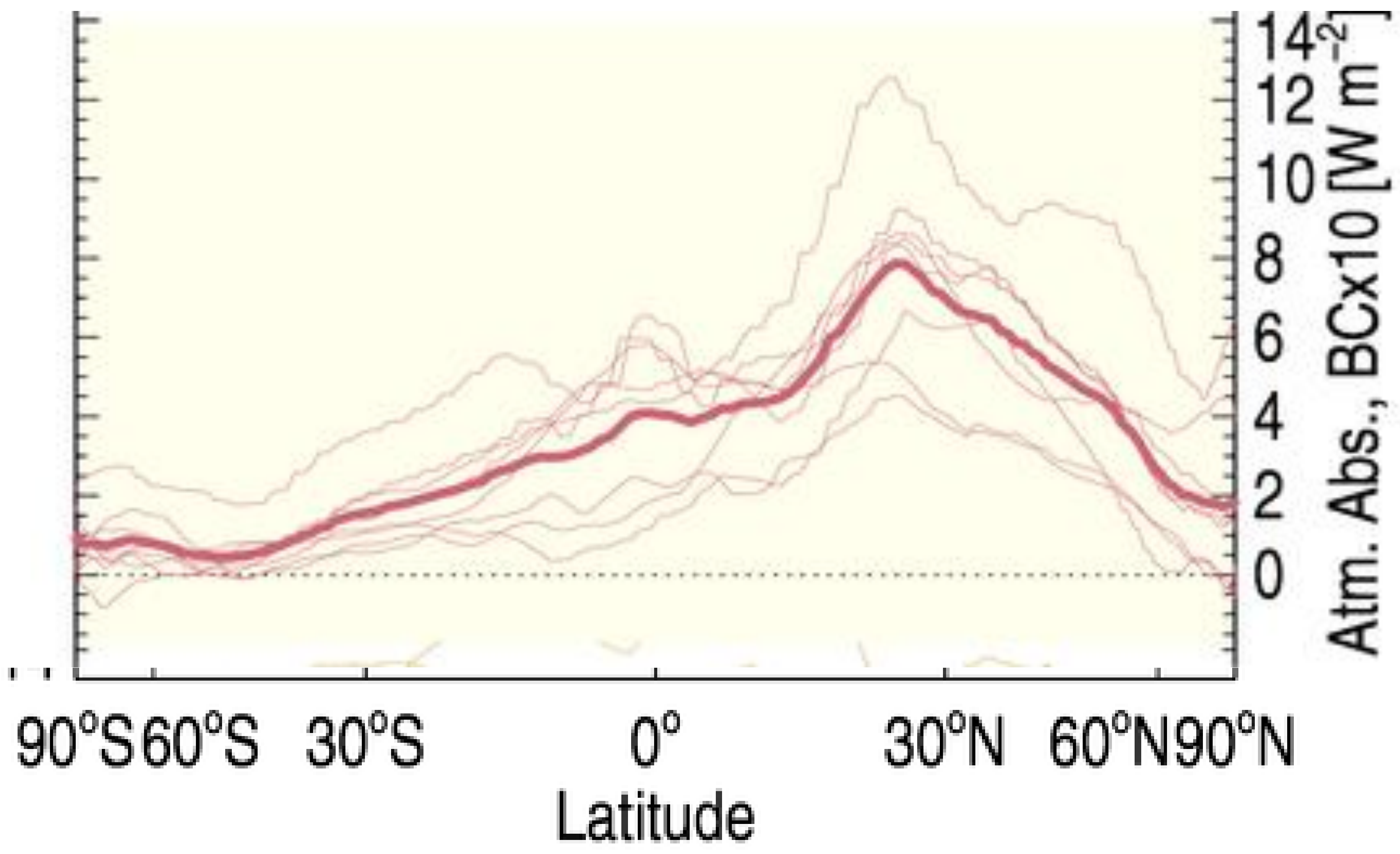
MACC



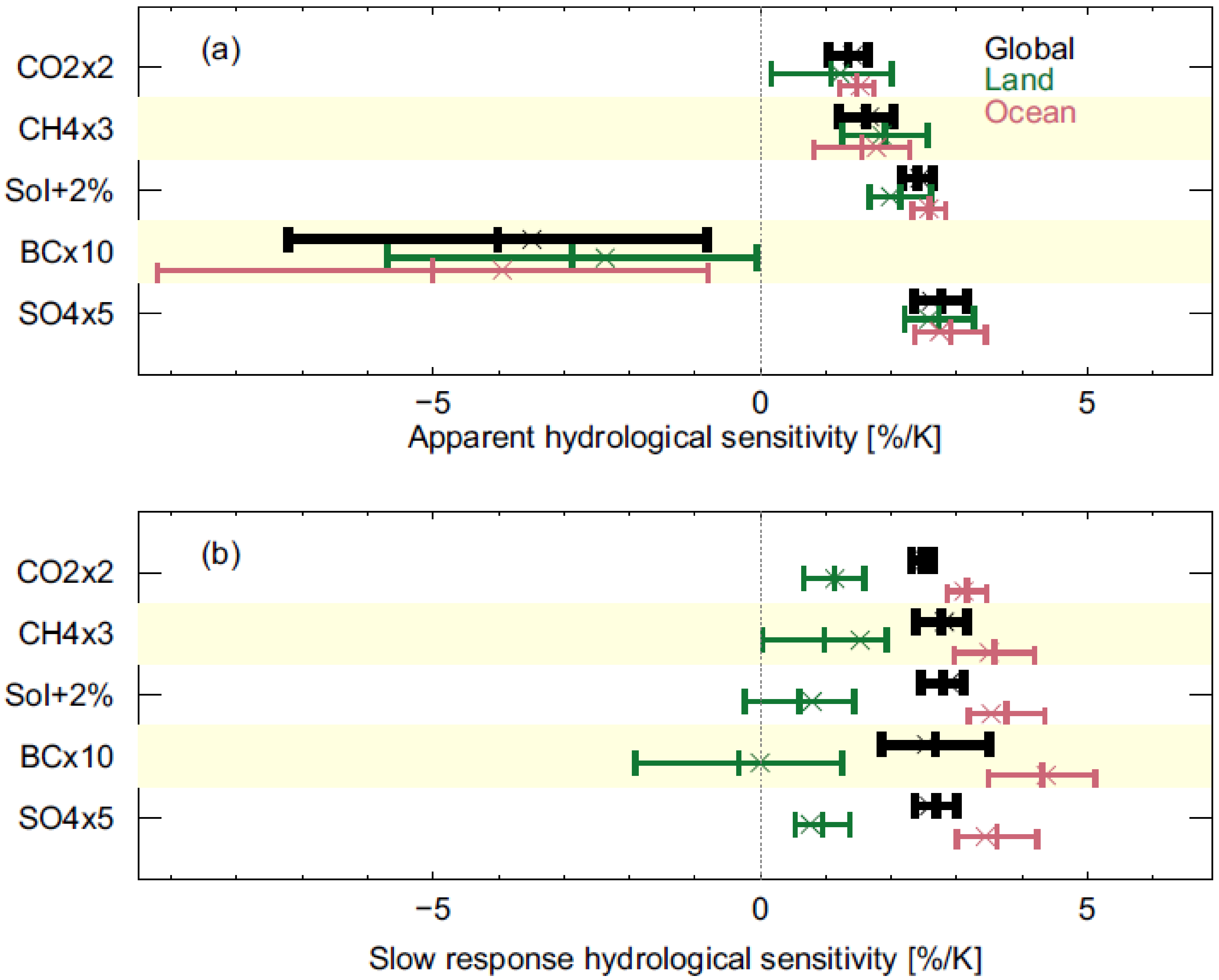


Modelled absorption strongly affects modelled precipitation…

Myhre 2017, BAMS



Samset 2018, npj Clim. Atm. Sci.



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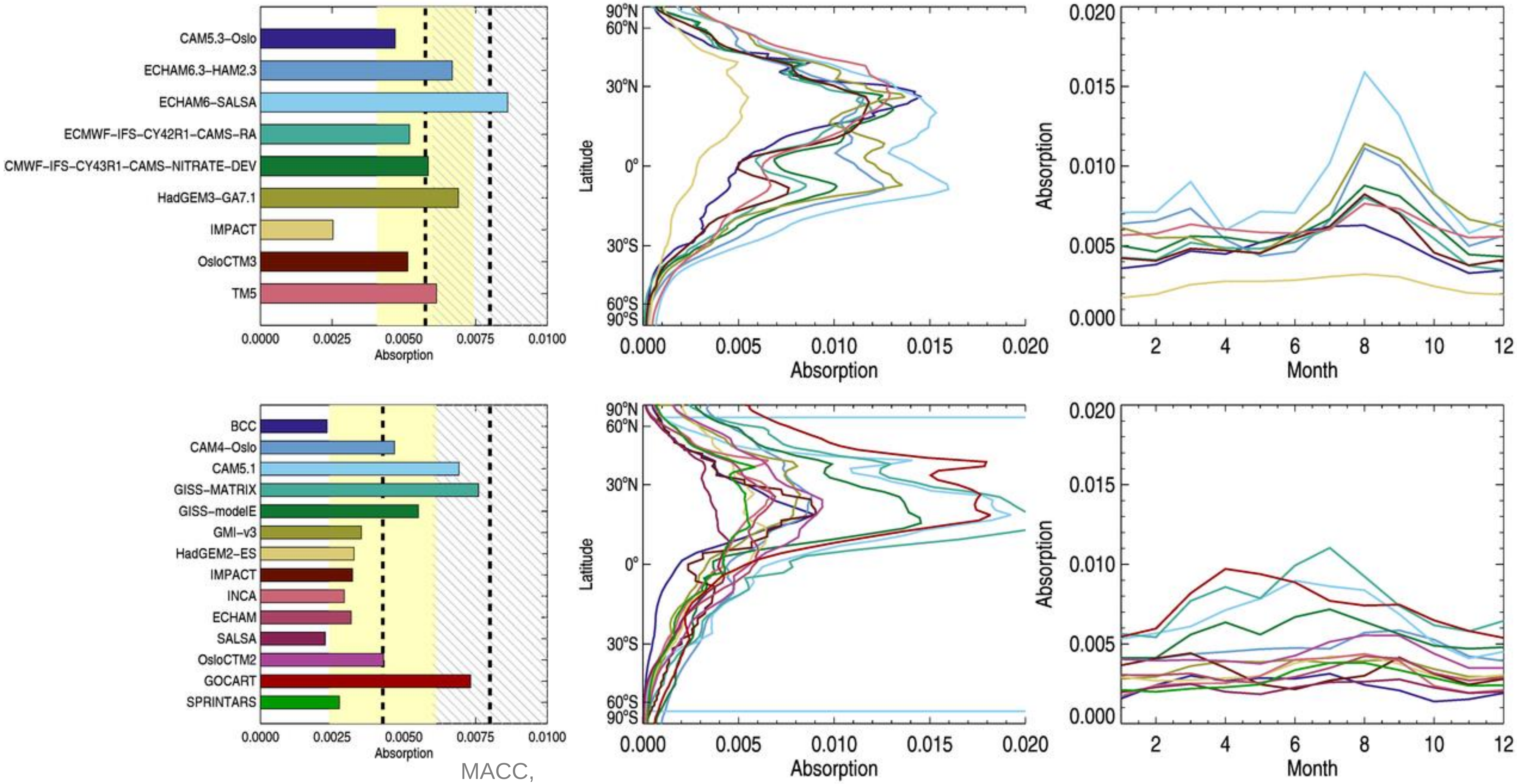

Phase III
CTRL2016
Year 2010

Phase II

MACC,
Bellouin 2013

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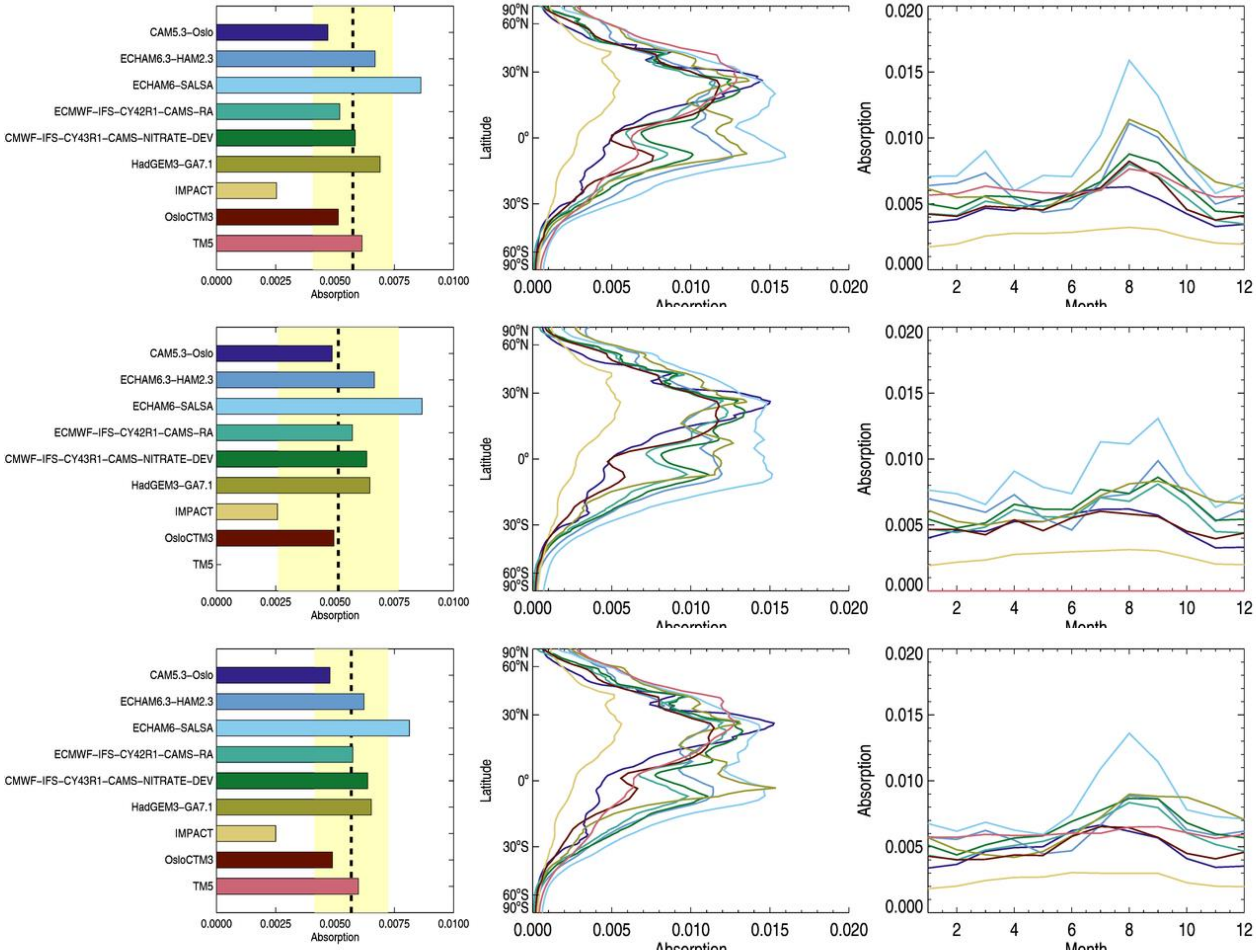
AeroCom Phase III
CTRL2016



2010

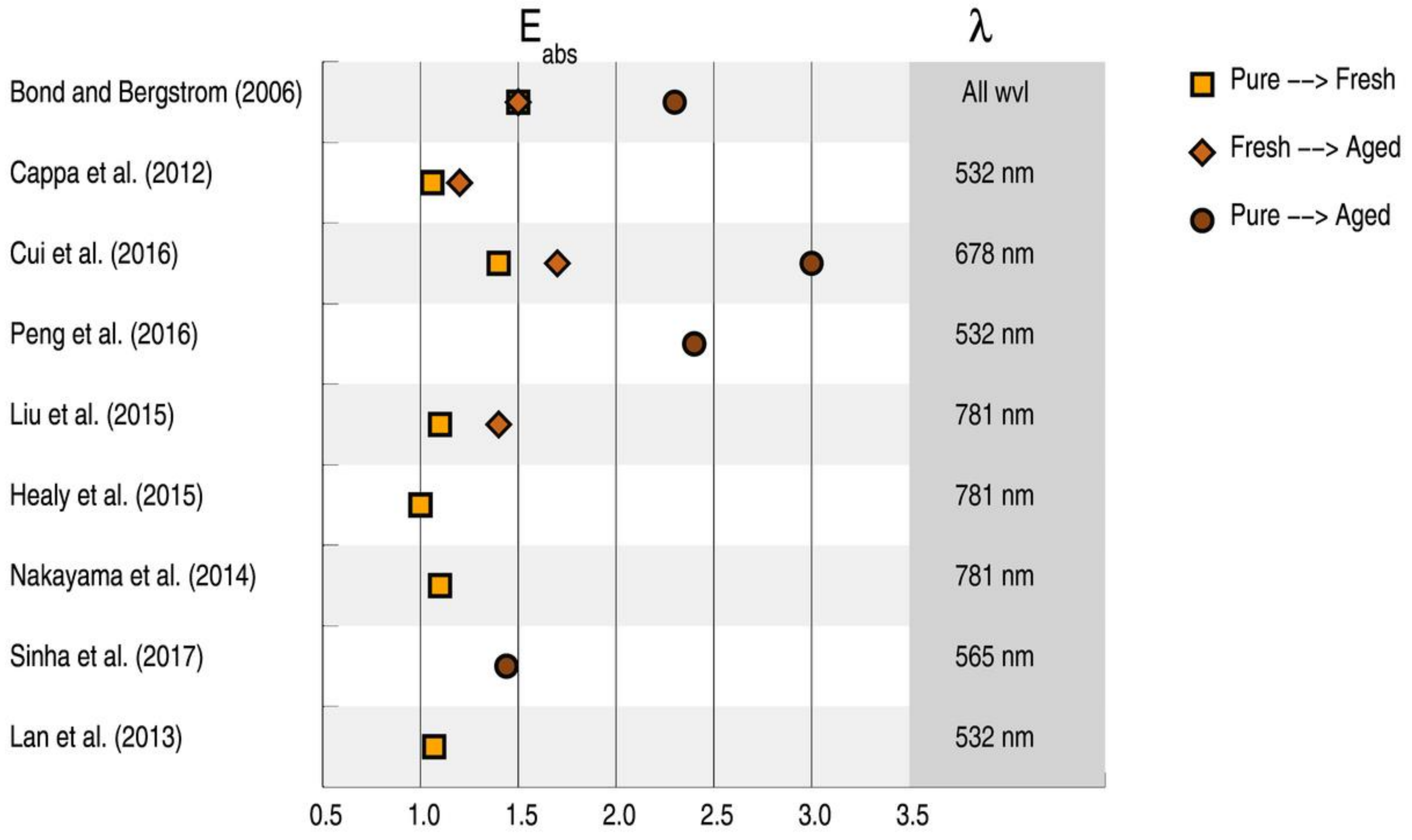
2008

2006

Issues and current topics:
Physical properties and modelling

BC	**Consistency of definition**, absorption enhancement during ageing, emission inventories, residence time, vertical concentration profiles
BrC	**Consistency of definition,** composition (e.g. tarballs), wavelength dependence, lensing, absorption decay over time, vertical concentration profiles
Dust	Modeled source terms, size distributions, composition and assumptions on shape.
Model-based constraints	Optical properties, model process differences, assimilation

BC absorption enhancement



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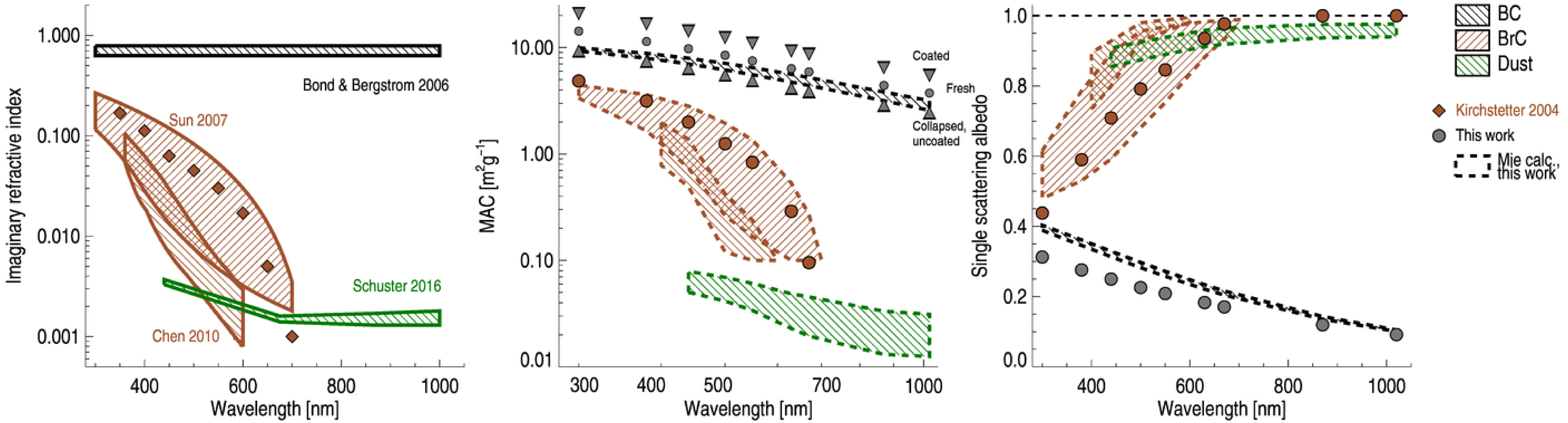
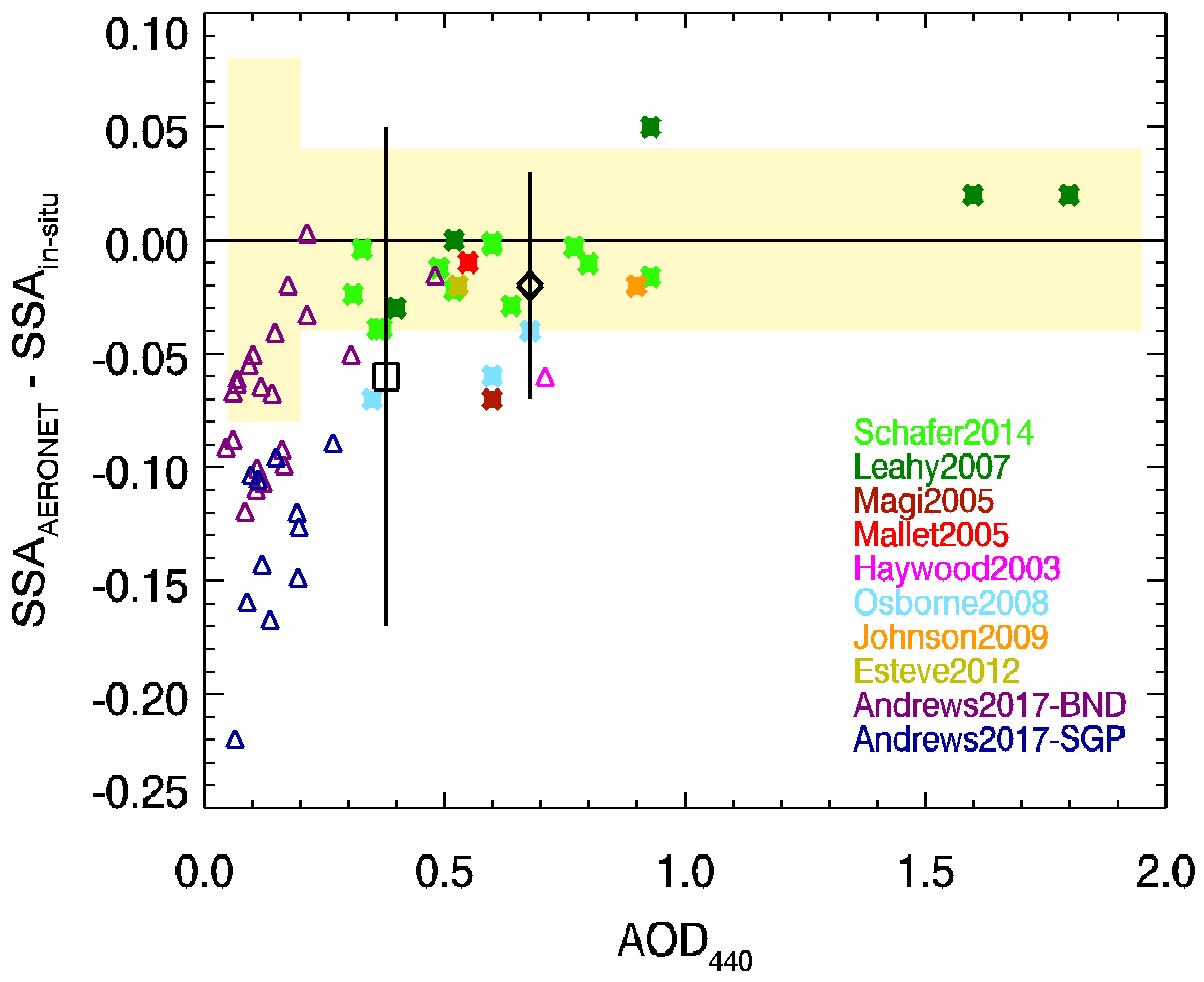
Consistent set of optical properties for absorbing aerosol species



Issues and current topics:
Remote sensing and in-situ measurements

Remote sensing, ground stations	AERONET AAOD at AOD<0.4, representativeness of sites, retrieval assumptions, separation of species
Remote sensing, satellites	Separation of species, retrieval assumptions, aerosol above clouds
In-situ, surface stations	Limited spatial coverage, correspondence of measurements to model assumptions
In-situ, aircraft measurements	Limited spatial and temporal coverage

AERONET SSA values at high/low AOD conditions



A recurring question in recent literature has been what requirement should be set on total AOD for AERONET to give a good AAOD retrieval. As input to this, AERONET has been extensively compared with various types of airborne in situ measurements. These were recently summarized in Andrews et al. [118]. See Supplementary Fig. 2, left panel, adapted from data used in that study. The authors compare results from two US continental AERONET sites with in situ profiles from aircraft observations, with emphasis on low aerosol loading conditions. They confirm a previously reported tendency for AERONET inversions to overestimate absorption at low AOD values, suggesting a bias in either the retrievals or the in situ techniques. Previously, Kahn et al. [119], in a similar analysis comparing AERONET with MISR satellite data, attributed underestimates in AERONET SSA at least partly to methodological differences in measurements of AERONET direct-sun extinction and sky scan scattering quantities. These points further suggest caution in using AERONET to scale global model results, and brings into question the assumption that AERONET SSA values retrieved at high and low AOD conditions can be used to obtain AAOD at low AOD conditions (e.g., [98, 120]). Thus AERONET SSA may not be representative of all loading conditions and/or seasons.

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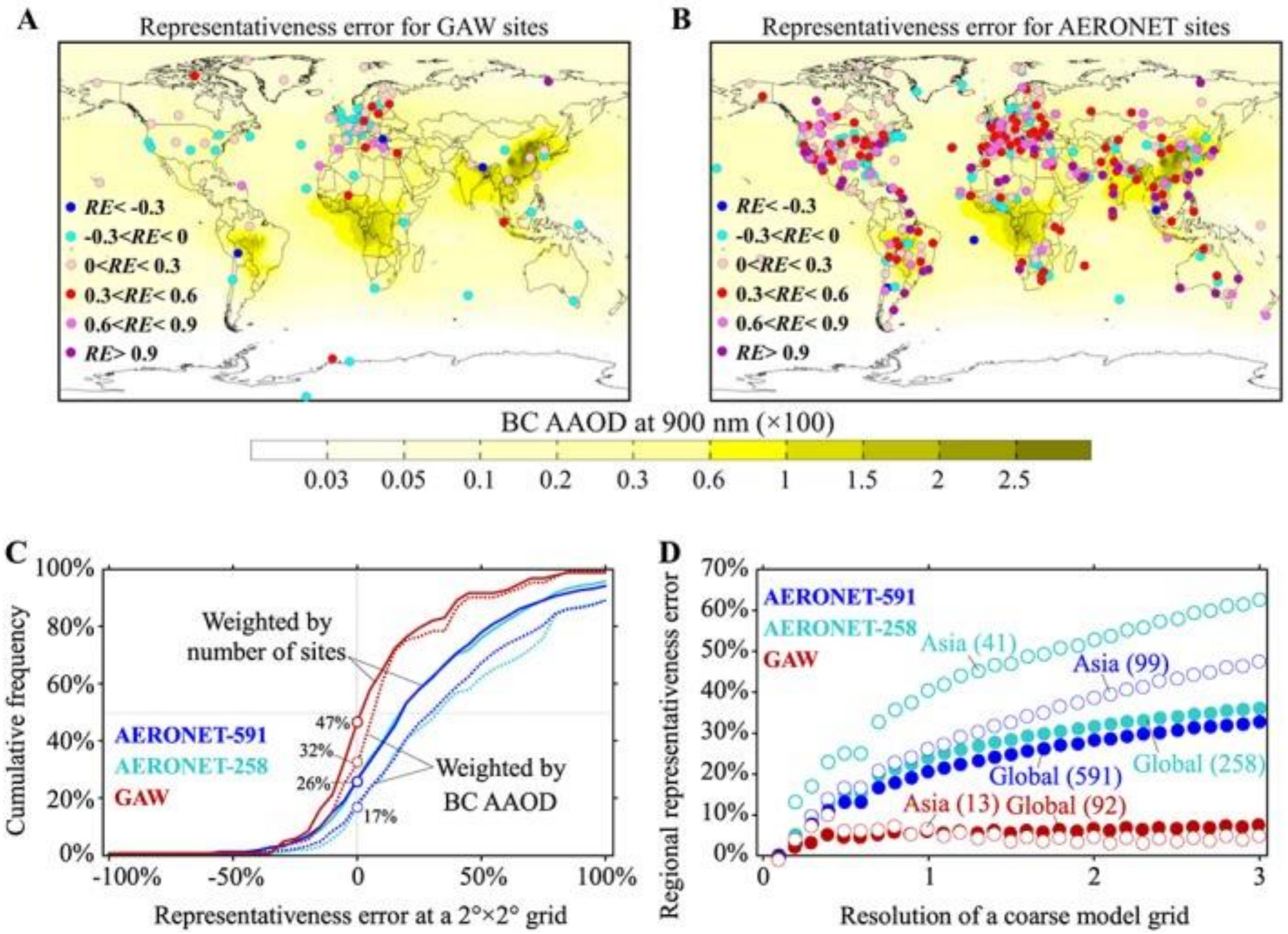
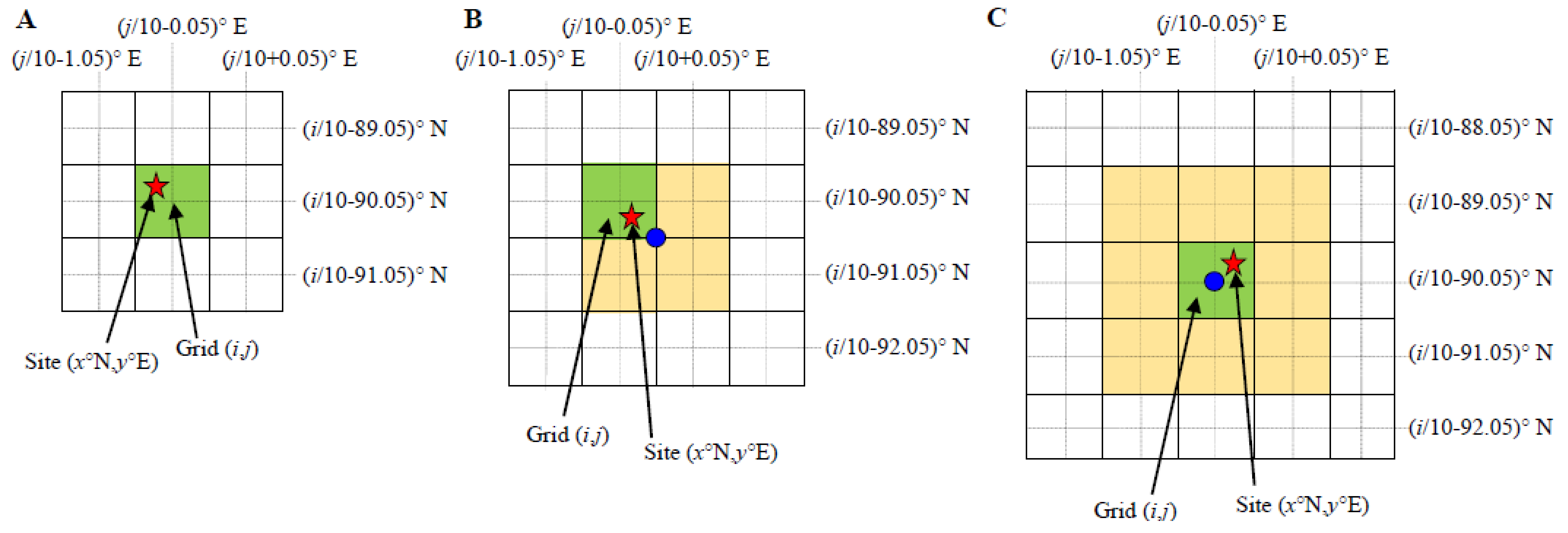
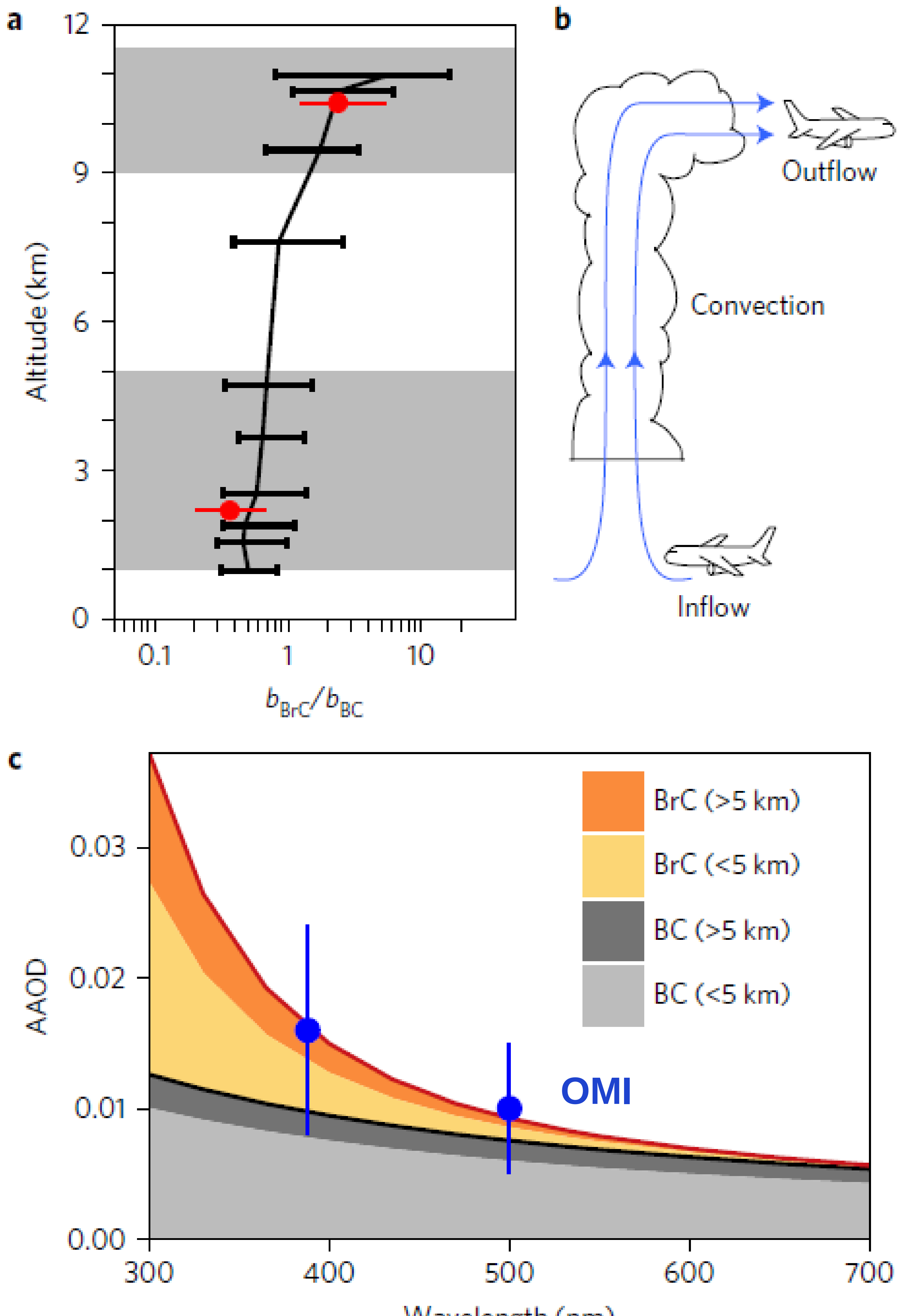
Ground station representativeness

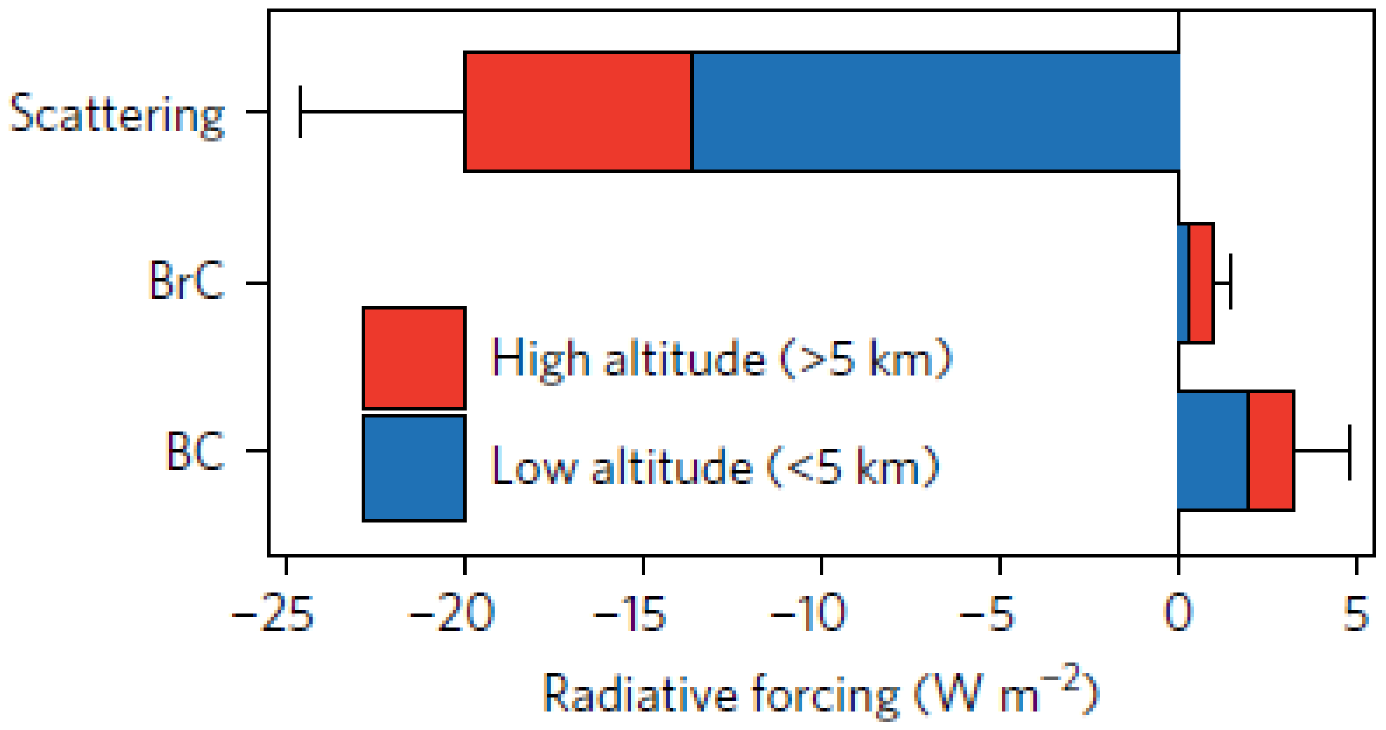




Wang et al. GRL 2018

BrC at high altitudes?





Zhang et al., NGeo 2017

A roadmap towards improved constraints on aerosol absorption

	Basic/immediate recommendations
What	**Improved dialogue between aerosol observational and modelling communities**
How	Continued focus on dedicated meetings, such as the annual AeroCom/AeroSAT workshops
What	**Use consistent terminology for BC, in both observational and model studies**
How	Adher to recommendations in Petzold et al. 2013, clearly define fresh/collapsed and young/old in optical parameter studies, avoid confusion with brown carbon
What	**Rigorous treatment of BrC, in observations and models**
How	Extend definition, discuss as part of spectrum of carbonaceous combustion products. Include in broader set of climate models. Develop emission estimates.
What	**Consistent usage of AERONET observations**
How	Adherence to quality flags, improved understanding of the impact of retrieval assumptions and treatment of the representativeness of site locations, closure studies using air borne in-situ measurements and sun photometers, bias correction for cloudy and low AOD days.

	Developments/longer term recommendations
What	**Improve microphysical treatment of aerosols in climate models**
How	Include microphysics packages, multiple size modes, constrained physical properties based on observations. Rapid adoption of observational constraints, e.g of optical properties.
What	**Improve satellite remote sensing sensitivity to absorbing-aerosol amount and type**
How	Develop global, broad-swath, UV to NIR multi-spectral , multi-angle, and polarization imaging capabilities
What	**Develop climatology of average aerosol optical properties, geographically, vertically, and seasonally resolved**
How	Systematic aircraft measurements, coordinated as appropriate with ground based and satellite observations, and used as further constraint for climate models
What	**Constrain absorption from aerosols above clouds**
How	Develop/improve satellite retrievals, aircraft observation programs, and dedicated model studies
What	**Constrain BC emissions, transport, ageing, geographical and vertical distributions**
How	Targeted in situ aircraft and ground sampling programs, in collaboration with modelling groups, explore constraints from measured long term absorption trends in different regions, document all relevant aspects of modeled life cycles of BC, BrC and dust.
What	**Heighten focus on the role of dust**
How	Measure and model optical properties of broader set of dust types, especially coarse-mode dust. Implement in retrieval algorithms and transport models

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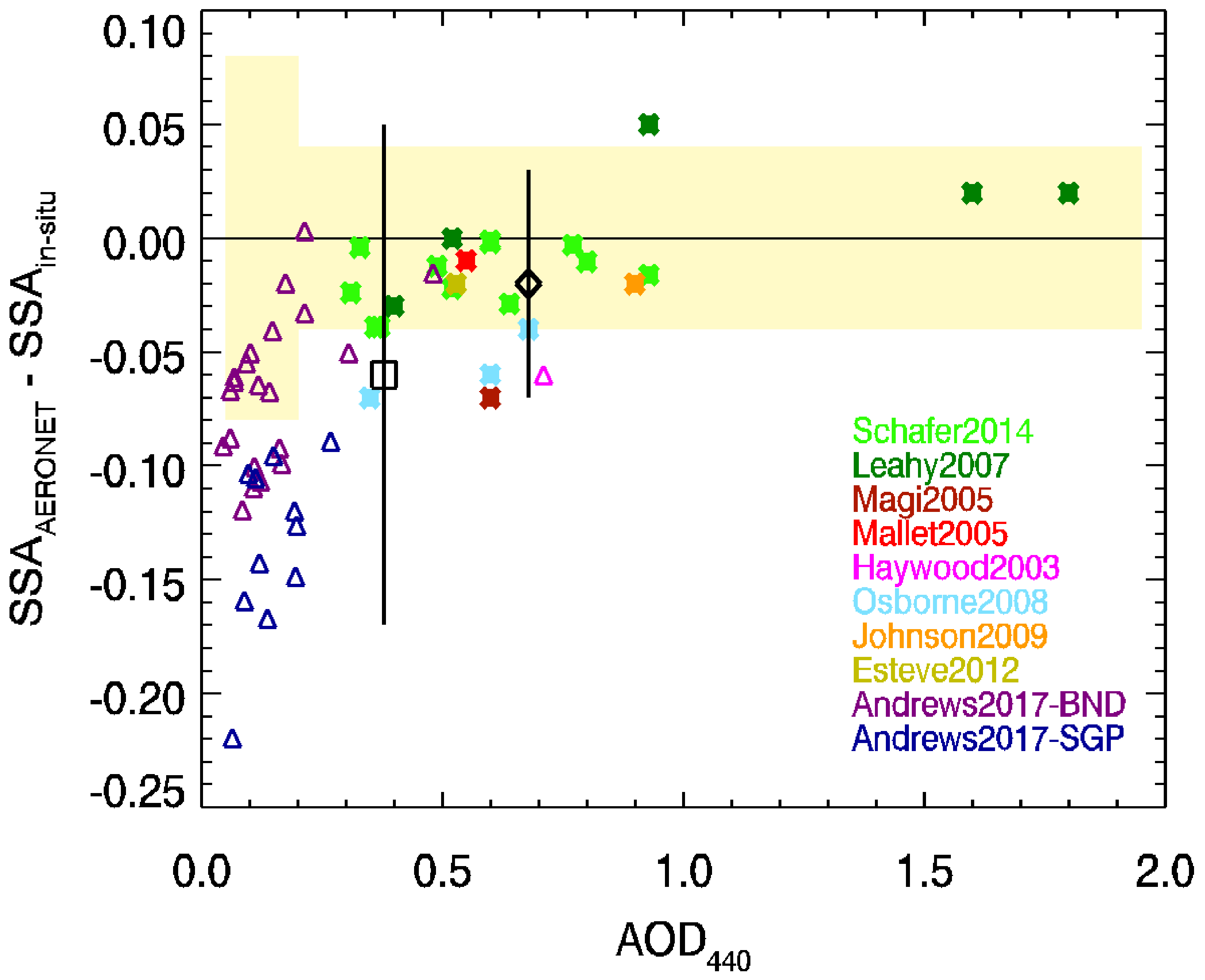
Thanks for your attention!

Backups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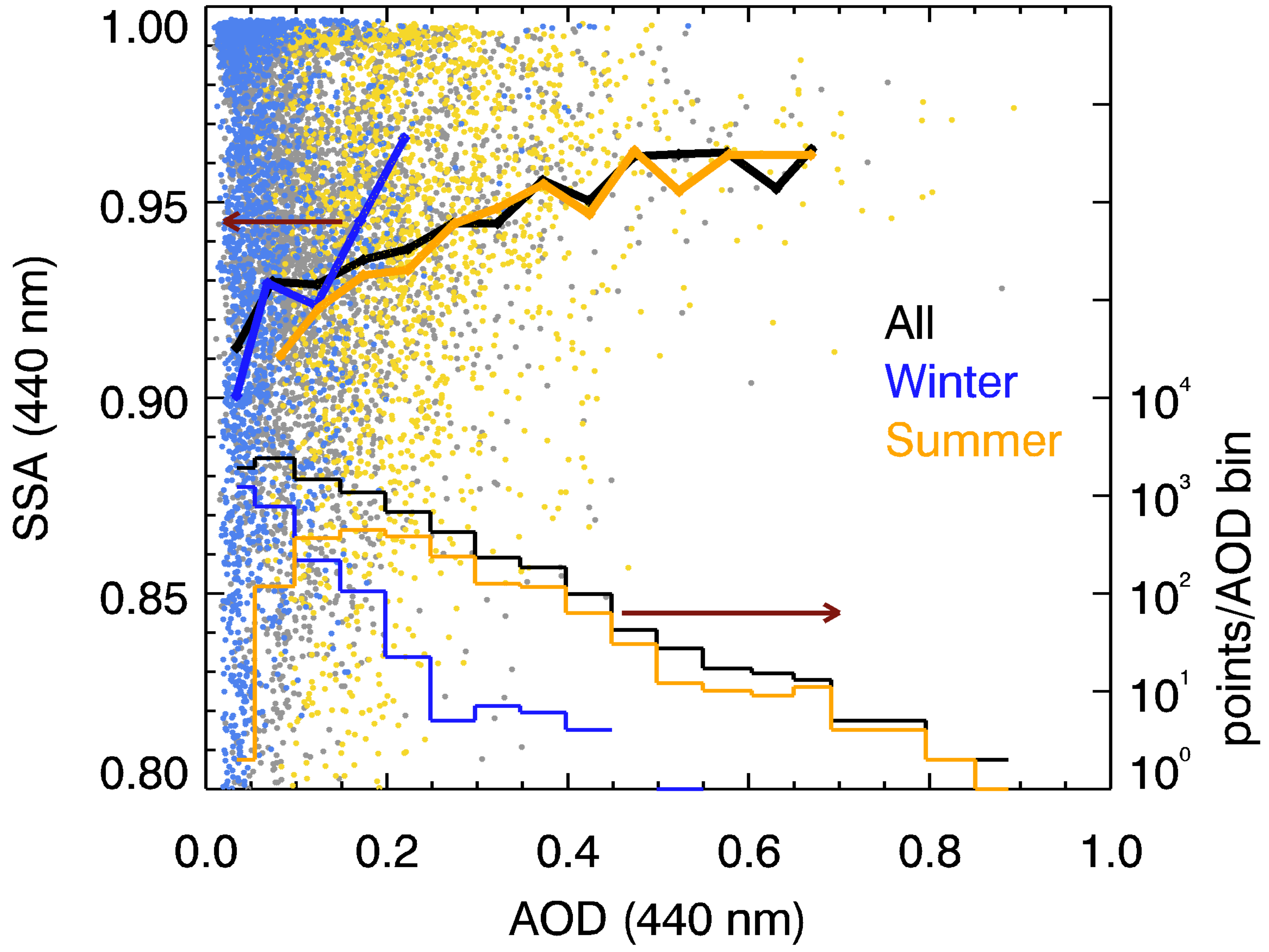
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
SSA_AERONET - SSA_in-situ
0.0
0.5
1.0
1.5
2.0
AOD440
Schafer2014
Leahy2007
Magi2005
Mallet2005
Haywood2003
Osborne2008
Johnson2009
Esteve2012
Andrews2017-BND
Andrews2017-SGP


1.00
0.95
0.90
0.85
0.80
SSA (440 nm)
0.0
0.2
0.4
0.6
0.8
1.0
AOD (440 nm)
All
Winter
Summer
10^4
10^3
10^2
10^1
10^0
points/AOD bin

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