Biomass burning emission analysis *based on **MODIS aerosol optical depth** and **AeroCom multi-model simulations***: Implications for model constraints and emission inventories

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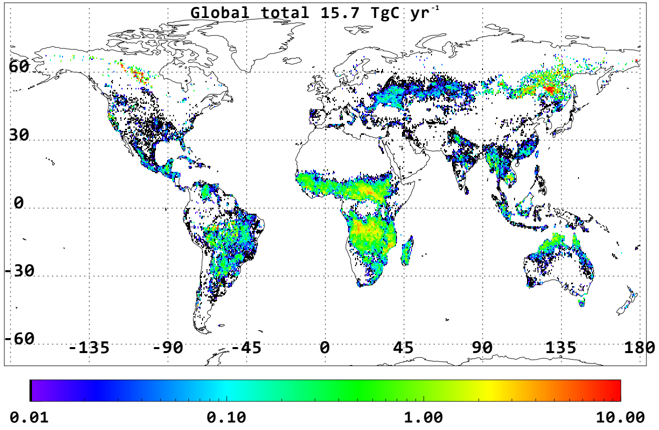
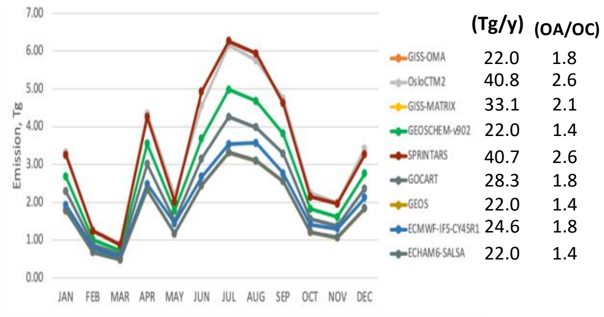
AEROCOM BB Experiment

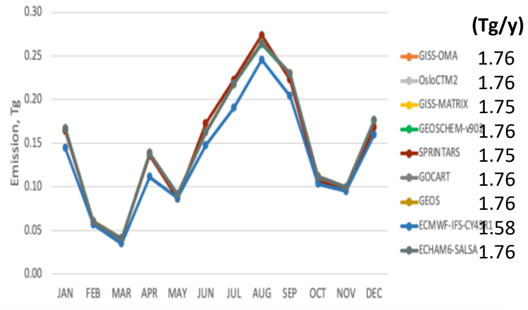
Phase 1 Emission Source Strength (M. Petrenko)



GFEDv3 2008 OC Emissions (g/m²/y)



2008 Global Monthly BB OA Emission (Tg)

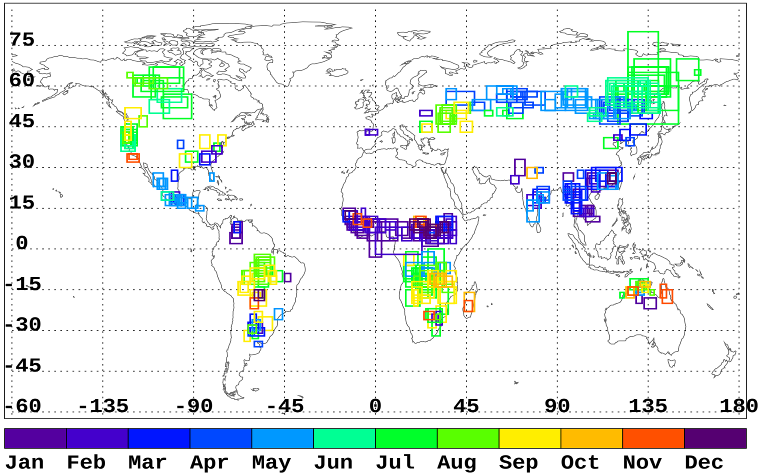


2008 Global Monthly BB BC Emission (Tg)

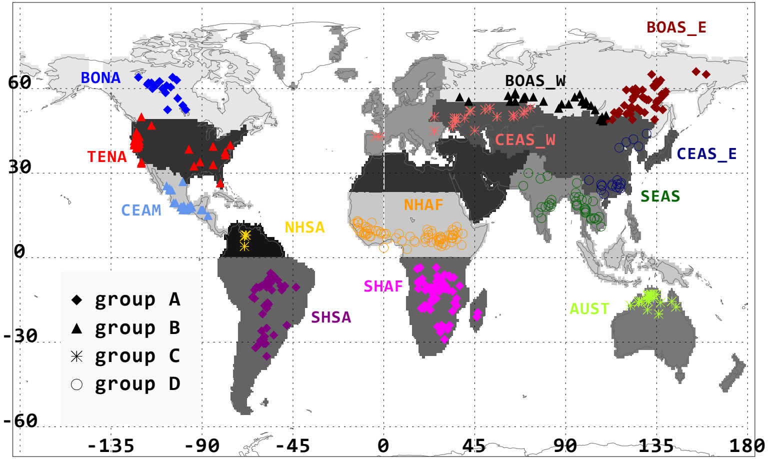
- **11 global aerosol models** with different resolutions and other characteristics
- **Same BB Emissions** for all models: Global Fire Emissions Dataset (GFEDv3)
- **GFEDv3 BB Species**: CO, SO_2, NO_x, NH_3, VOCs, BC, & OC (volatile, black, & organic carbon)
- **Benchmark year 2008**: 12-month run with 3-month “spin-up”
- **5 Model Runs**: (a) **no BB**; (b) **GFEDv3 x 1**; (c) GFEDv3 x 0.5; (d) GFEDv3 x 2; (e) GFEDv3 x 5

MODIS Observational Dataset

Instantaneous constraint on source strength:
447 satellite **snapshots**



GFED-based Biomass Burning regions

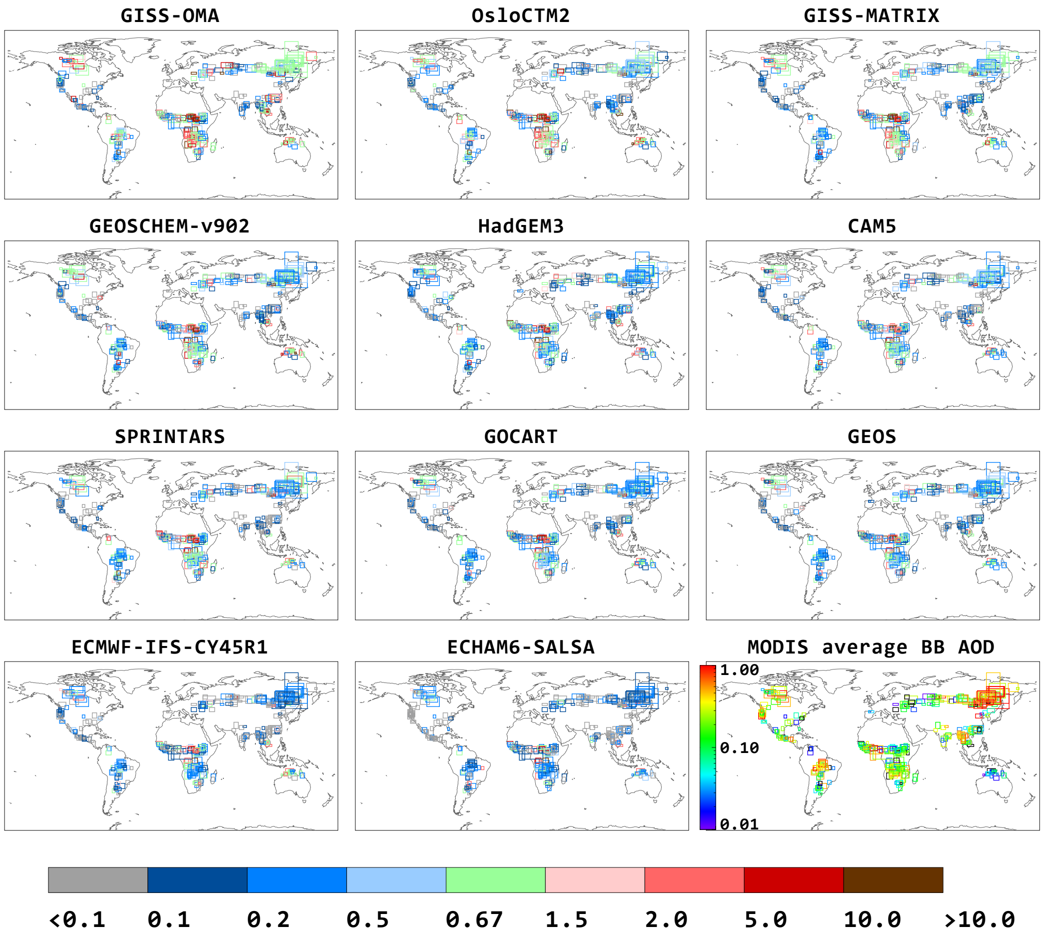


Fire case selection for our source-strength studies:

(1) plumes with at least one linear dimension of **100 km**, to be useful for modeling studies
(2) a coordinated pattern of **elevated AOD**,
(3) a **visible smoke plume** in the satellite imagery
(4) a MODIS **thermal anomaly fire signal**

Unique approach to comparison:

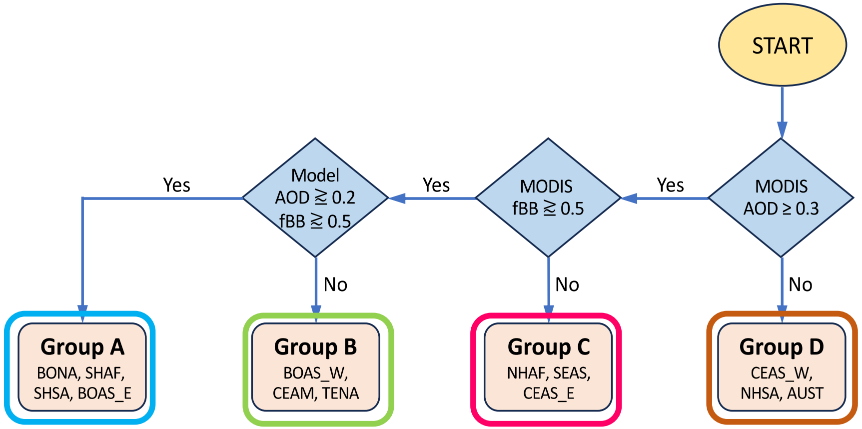
- **Case box average** as a unit of comparison
- Instantaneous **snapshots** (satellite and model)

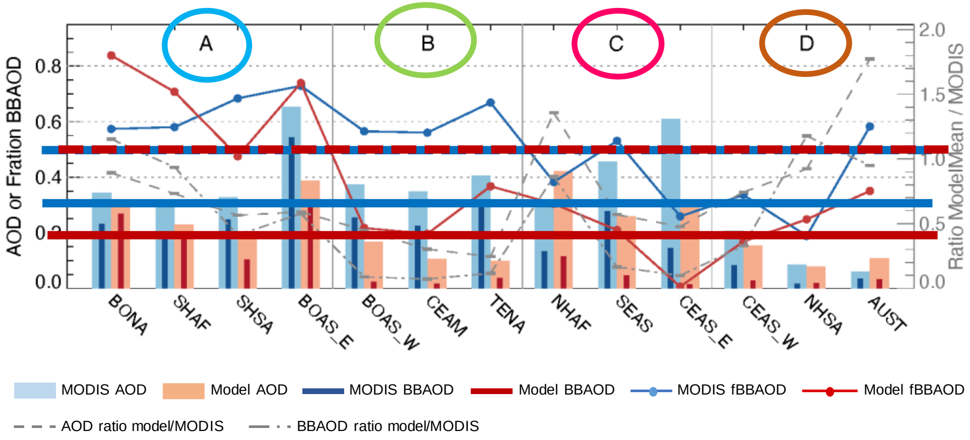


Ratio of **Model-simulated / MODIS BB AOD** for all individual fire cases.

- Models ranked from highest to lowest overall model BB AOD
- Generally consistent model performance within individual BB regions
- Some regions are under- (USA, SEAsia) or overestimated (NCAfrica) by all models
- But there are also significant inter-model differences

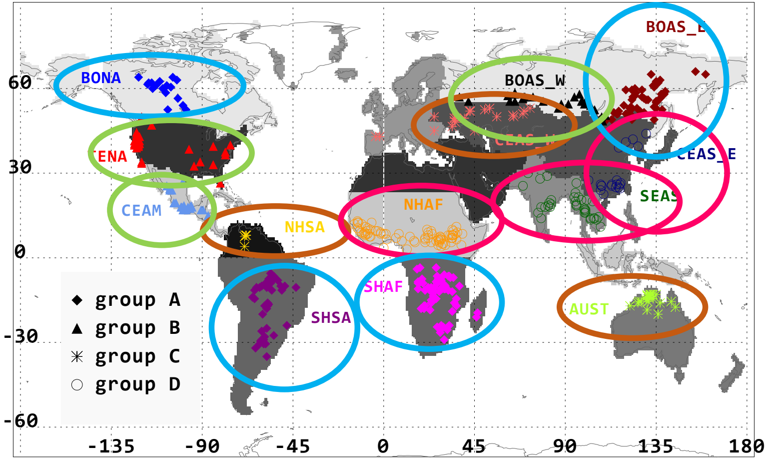
Grouping BB regions for source-strength estimation



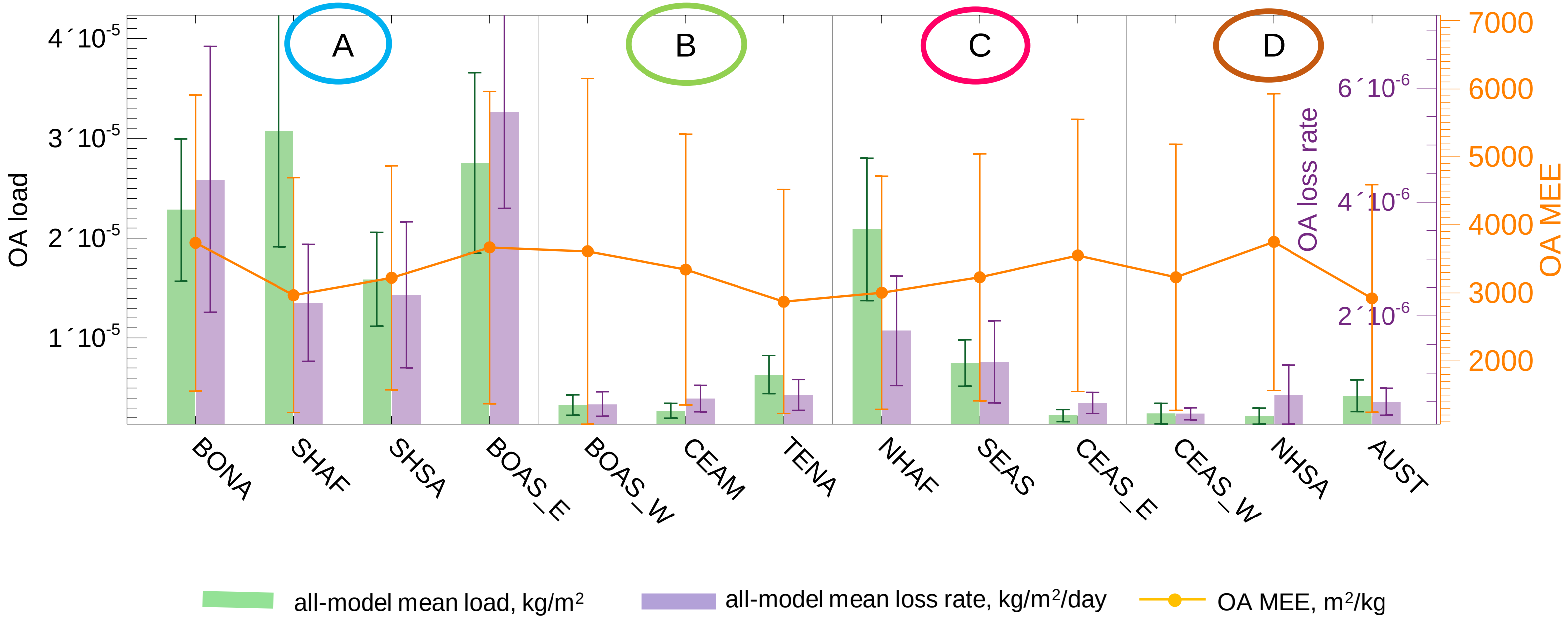


Using satellite observations to constrain BB aerosol **simulations work best** in regions:

- With relatively **high total (and BB)** MODIS AOD
- **Low/uncomplicated background** aerosol – so BB aerosol dominates



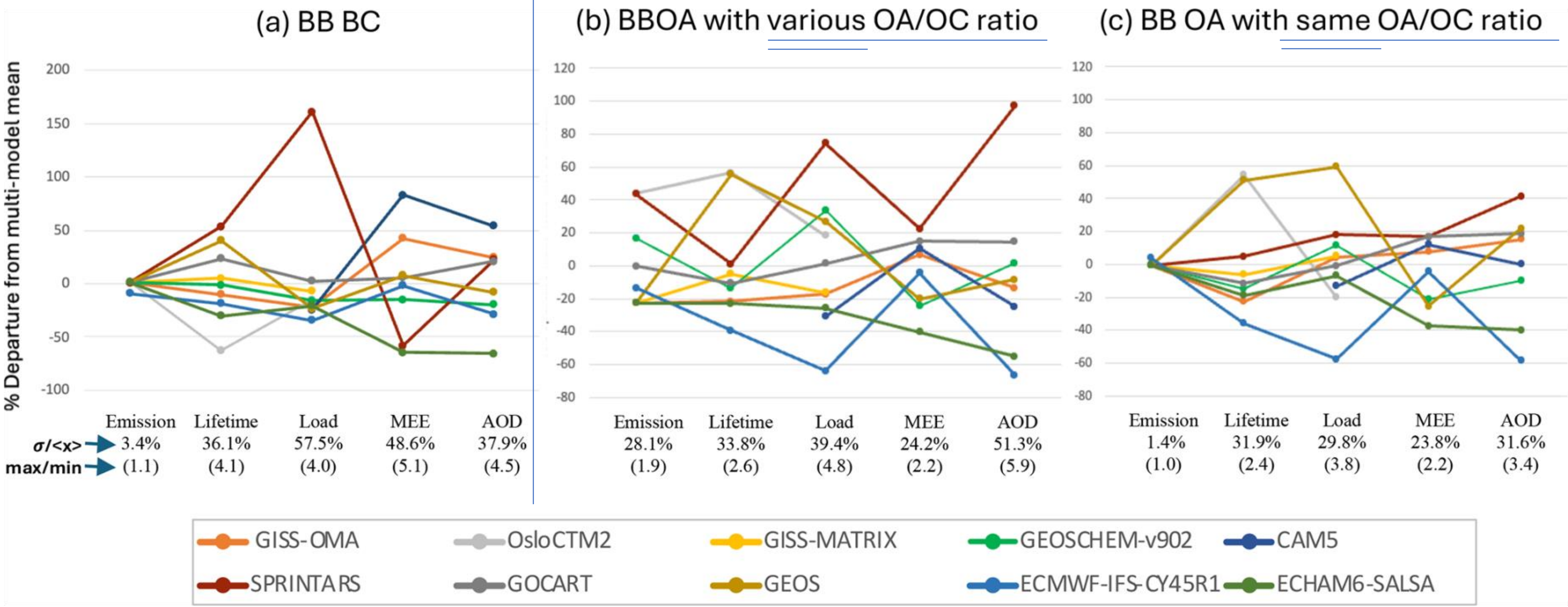
Grouping BB regions for source-strength estimation



BB aerosol simulation Inter-model diversity

Biomass burning **Black Carbon**

Biomass burning **Organic Aerosol**



Conclusions:
Implication for characterizing fires and emission inventories

- **Aerosol optical depth** (AOD) is currently the satellite-reported aerosol property, most frequently and reliably used to constrain aerosol models

- BB regions: **four groups** w.r.t. source-strength estimation method applicability:

  - **A**: **high total (and BB) AOD**, **low background**, high BB AOD fraction, high confidence: boreal NH, woodlands of SH

  - **B**: **med AOD**, **low BG**, medium confidence, **possibly missing emissions: cultivated lands**

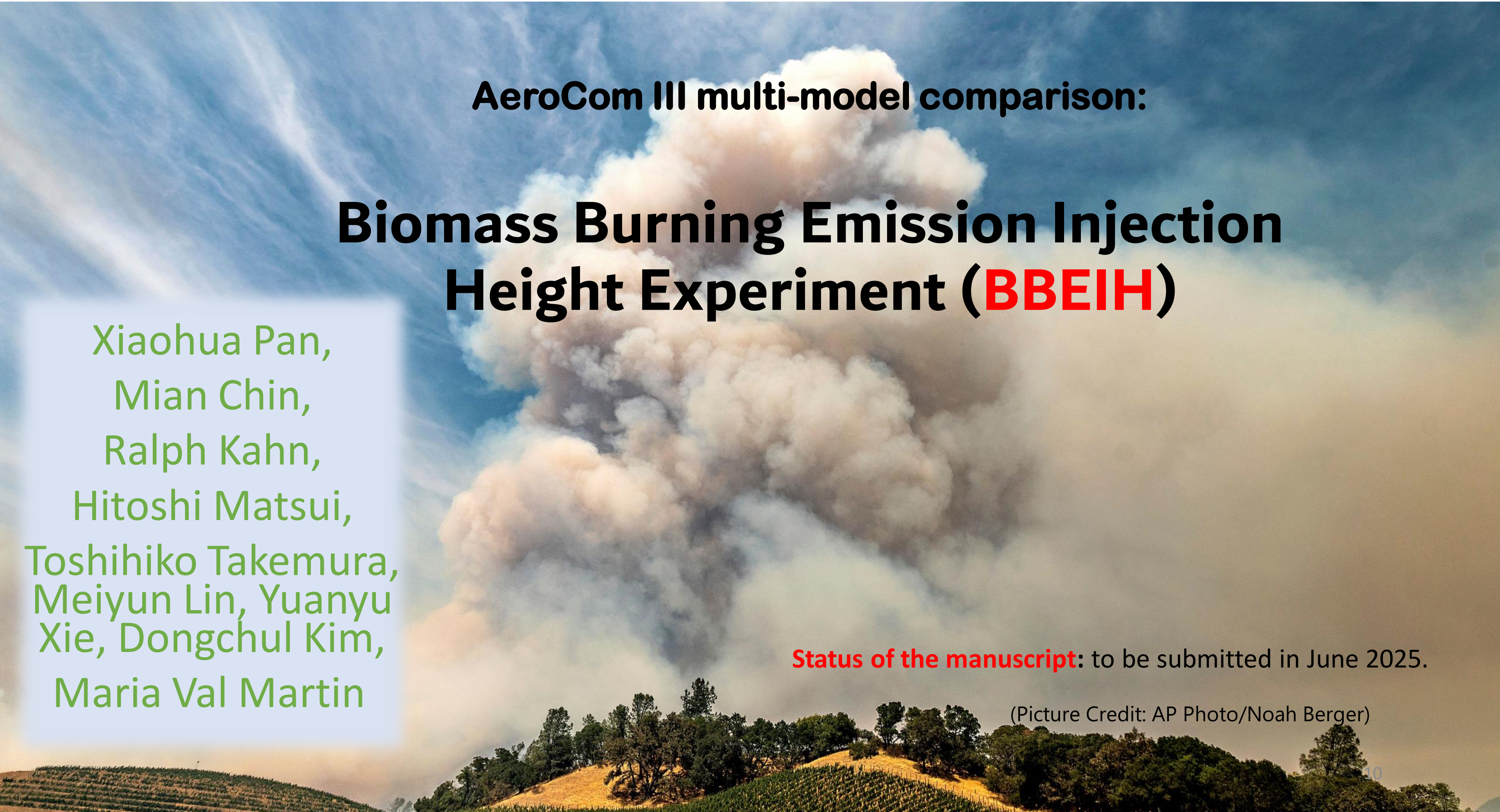
  - **C**: **high AOD**, **high & complex background**, low confidence: NH Africa, SE Asia, China
    need ways to separate BB smoke from other aerosol types

  - **D**: **low total AOD**, sporadic burning events, low confidence: Europe Australia, LAmerica
    use other/additional approaches to evaluate BB aerosol here

Source Strength Study Conclusions:
Implications for model constraints

- Their own constraints, and ***the required measurements are currently lacking***:
  - OA/OC ratio
  - Aerosol removal rates (determines loads)
  - Hygroscopic properties and chemical and physical interactions
  - Optical properties (e.g., mass extinction efficiency)

- Additional measurements and methodology development needed to ***isolate BB signal in satellite data*** (e.g., multi-angle, multi-spectral polarimetric imagers)



AeroCom III multi-model comparison:

Biomass Burning Emission Injection Height Experiment (BBEIH)

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Status of the manuscript: to be submitted in June 2025.

(Picture Credit: AP Photo/Noah Berger)

Objective: Explore the sensitivity of model simulations **to the biomass burning (BB) aerosol injection height (BBEIH)** and **source-strength** varies across different models.

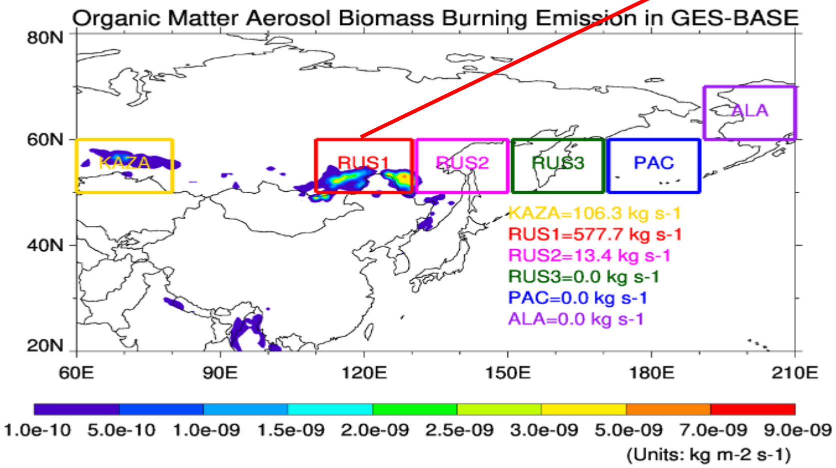
Case study: **Siberian wildfires** during April 2008
(From Petrenko et al. (2025): high confidence region due to high BB and low background)

Experiments: Four global aerosol models, each conducting four experiments.

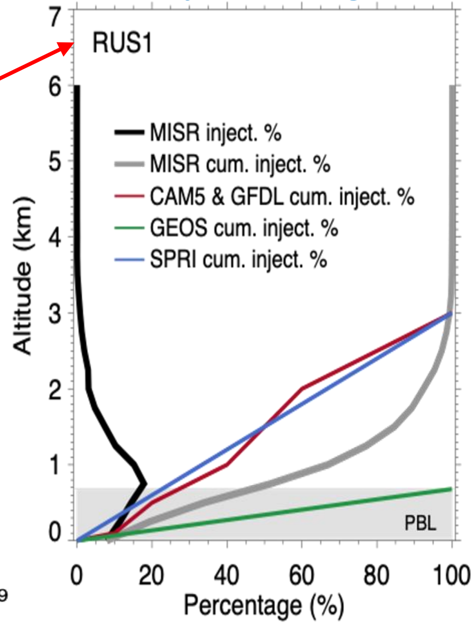
Exp.	BB emission	BB emission injection height
BASE	Daily GFED4.1s	Default in each model
BBIH	Same as BASE	MISR plume injection height
BBEM	Daily FEER *	Same as BASE
NOBB	None	N/A

*FEER has 21% more BB in RUS1

Spatial Distribution of BB Emission (GFED4.1s)

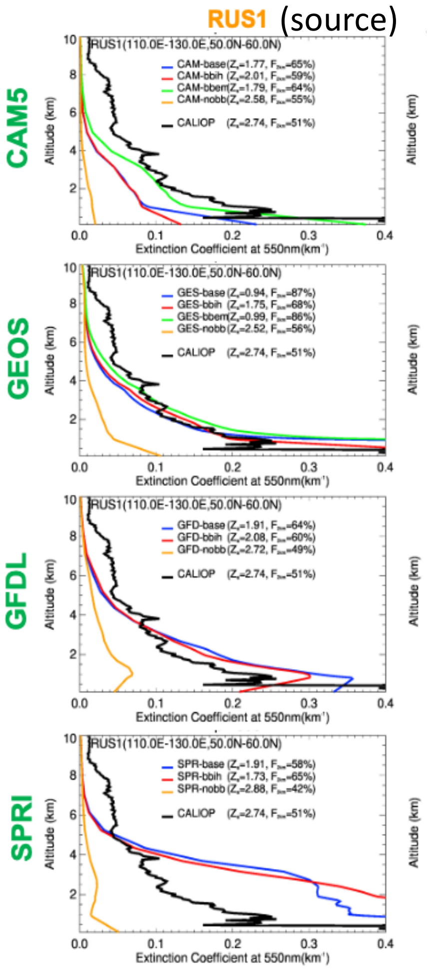


Profile of BB Emission Injection Height



In RUS1, across all different schemes, nearly all smokes are injected below 3 km.

Vertical profiles of aerosol extinction at 550nm in April 2008



Main Conclusions

CALIOP: Detected ***aerosol layers above 6 km*** from the source to downwind regions— absent in all model simulations;
Also, model aerosol extinction **downwind** (PAC) **reduced much more than observed**.

BASE: All ***models overestimate aerosol extinction below 2 km near source*** (RUS1); significantly ***underestimate AOD downwind*** (PAC).

BBEM: Emission ***source strength increase insufficient*** to reduce these model biases.

BBIH: ***MISR injection improved near-surface AOD fraction*** in 3 models, ***but no improvement downwind*** (PAC) across all models.

<u>Implications</u>: All models need to ***loft more smoke above 3 km*** in Siberia and ***reduce aerosol removal rate*** during downwind transport.