Emission or Processes? An attempt to attribute the source of large simulation bias of aerosols in eastern China by global climate models

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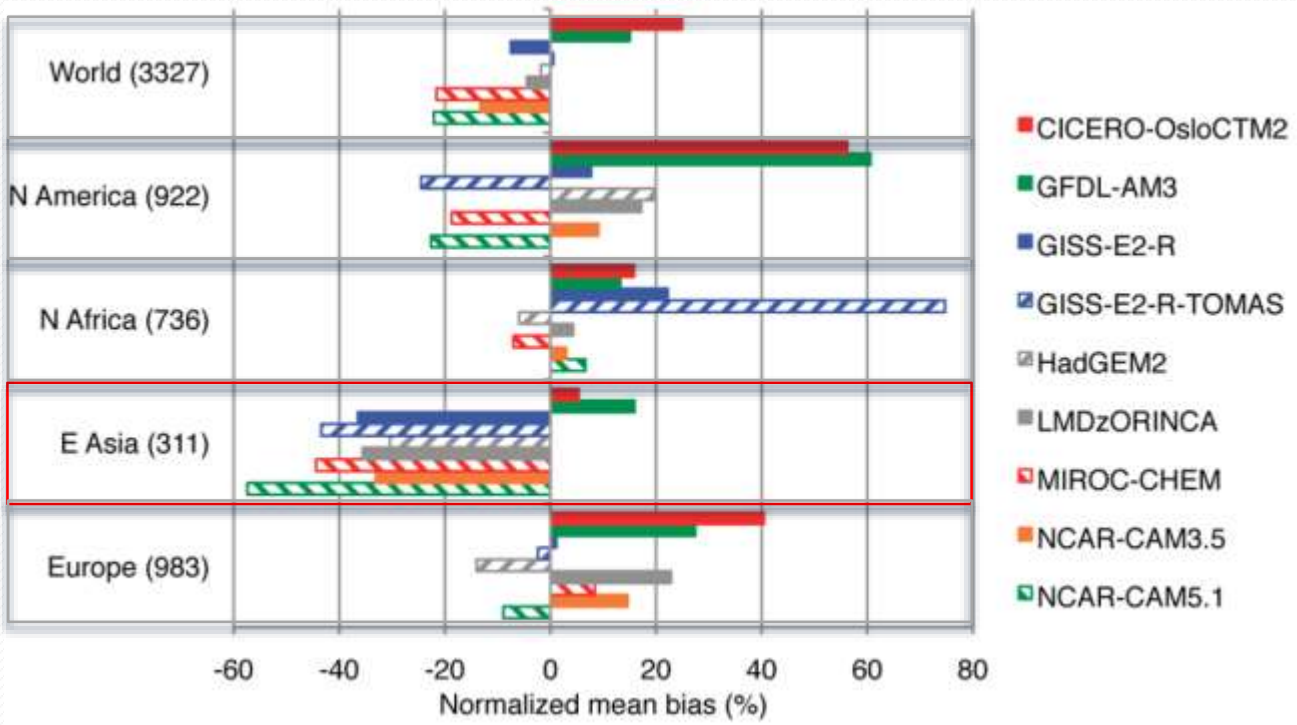
Outline

1. Motivation
2. The impact of emission on aerosol simulation in CAM5
3. Distinct impact of emission on primary and secondary aerosols
4. The radiative effects and the long–term trend
5. Conclusions

Motivation

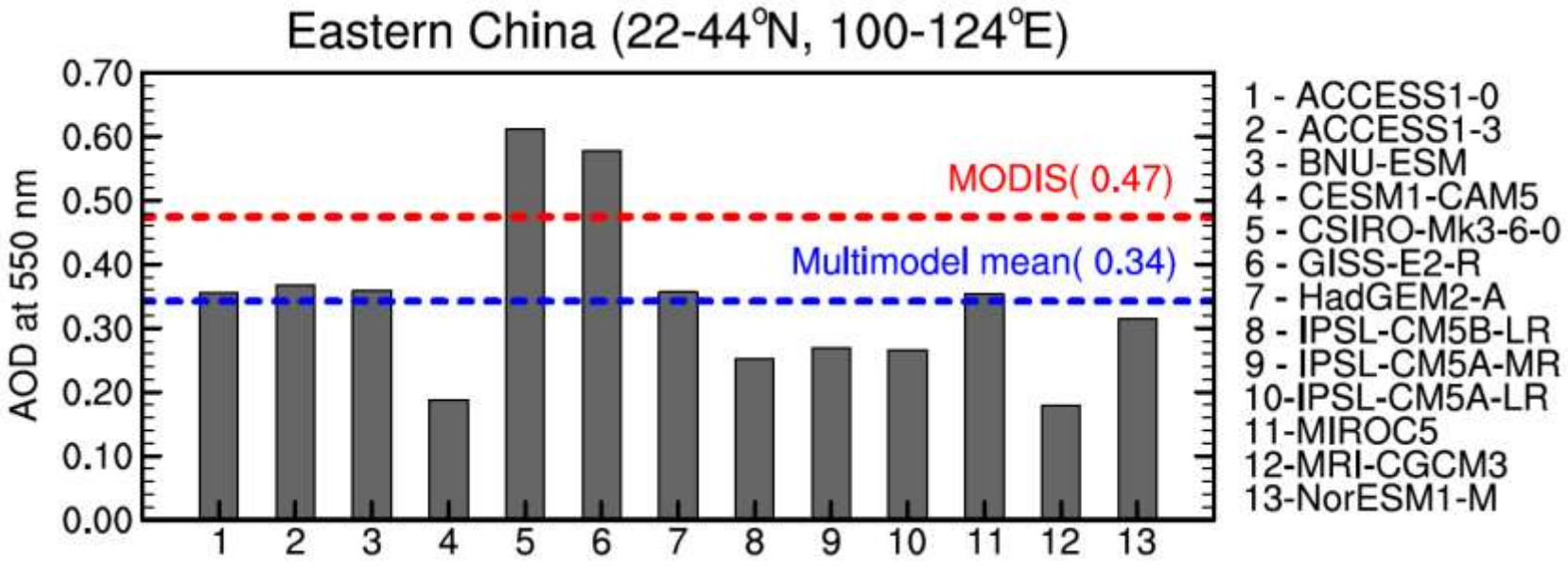


ACCMIP models v.s. AERONET AOD (Shindell et al., 2013)

AOD in Global climate models (GCMs) are low-biased in East Asia.

The AOD biases are substantially larger than the other part of the world.

Motivation



Annual averages of AOD by CMIP5 models in AMIP-type runs

China contributes to 15%±6% of the current negative (cooling) component of global radiative forcing (Li et al., 2016, Nature).

The aerosol forcing and climate effects could be much underestimated due to the large aerosol bias in China.

Possible reasons for the low-bias

➢ Emission

- ❑ The uncertainties of simulated surface concentrations of different aerosol species due to emission range from 3.9% to 40.0% over eastern China (Chang et al. 2015).
- ❑ Model experiments show that moderate (20%-30%) adjustments of regional emissions exert considerable influence on global AOD and aerosol radiative forcing (Yu et al., 2013; He and Zhang, 2014).
- ❑ The same IPCC AR5 emission inventory was used for ACCMIP models.

➢ Aerosol processes

- ❑ AeroCom inter-model diversity of aerosol largely depend on the treatment of aerosol processes and to a less extend on the emission (Textor et al. 2007).
- ❑ Modifications of the gas-phase chemistry and inorganic aerosol treatment in CAM5 improves the model performance of aerosol (He and Zhang, 2014).

➢ Missing nitrate, model resolution, collocation between aerosol and cloud ...

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Do the emission inventory or aerosol processes in GCMs leads to the low-bias?

  - AeroCom inter-model diversity of aerosol largely depend on the treatment of aerosol processes and to a less extend on the emission (Textor et al. 2007).
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- Missing nitrate, model resolution, collocation between aerosol and cloud ...

Method

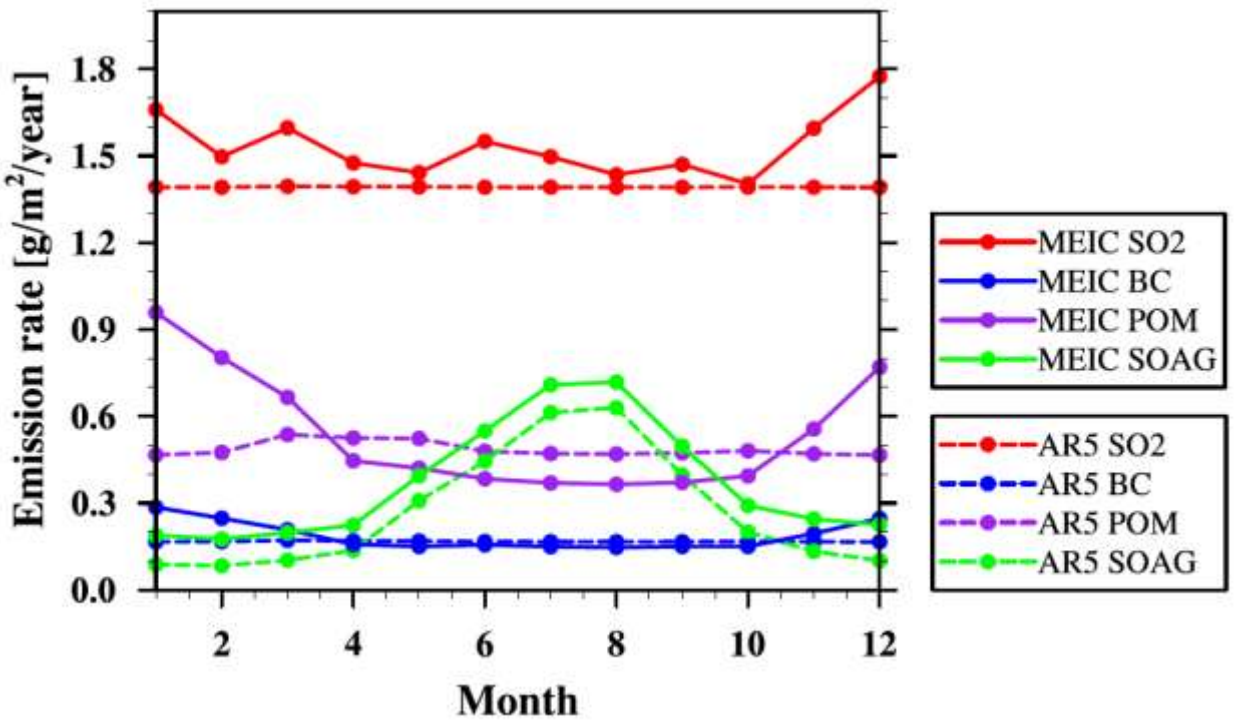
- CAM5 with 3-mode Modal Aerosol Model (MAM3)
  - Sulfate, black carbon (BC), primary organics matter (POM), secondary organic aerosol (SOA).
  - Aerosol Processes: gas and aqueous phase (in cloud) production, dry deposition, wet scavenging, water uptake, etc.

- Two model runs with AR5 (default) and MEIC emission in China.
  - IPCC AR5 emission dataset
    - based on 2000 emission, update every 10 years
    - no seasonal variation
  - Multi-resolution Emission Inventory for China (MEIC)
    - technology-based, rapid technology renewal, China's statistics, available in 2008, 2010, and 2012
    - seasonal variation (monthly)

- Same meteorology: nudged winds towards ERA-Interim in 2009.

- How much the low-bias can be explained by changing emission? Analyze the aerosol processes focusing on seasonal variation.

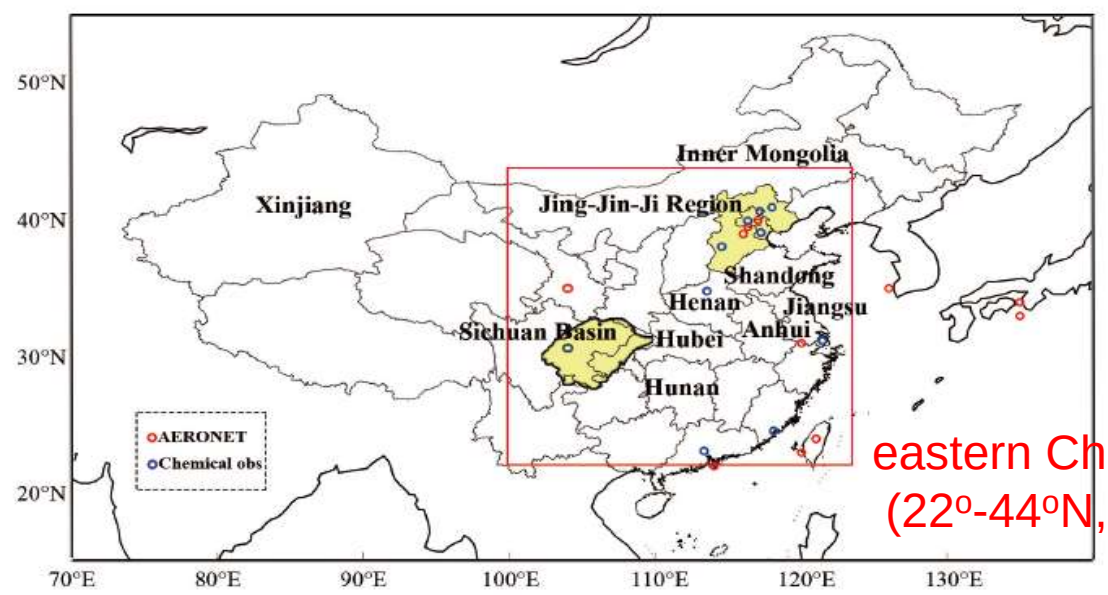
Seasonal variation of the emission inventories



Species	AR5	MEIC	Difference
SO2	12.08	13.60	12.57%
BC	1.40	1.59	13.35%
POM	3.91	4.38	12.04%
SOAG	1.95	2.86	46.88%

* SO2 is in (Tg S/year). BC, POM, SOAG are in (Tg C/year)

Study area and observational sites



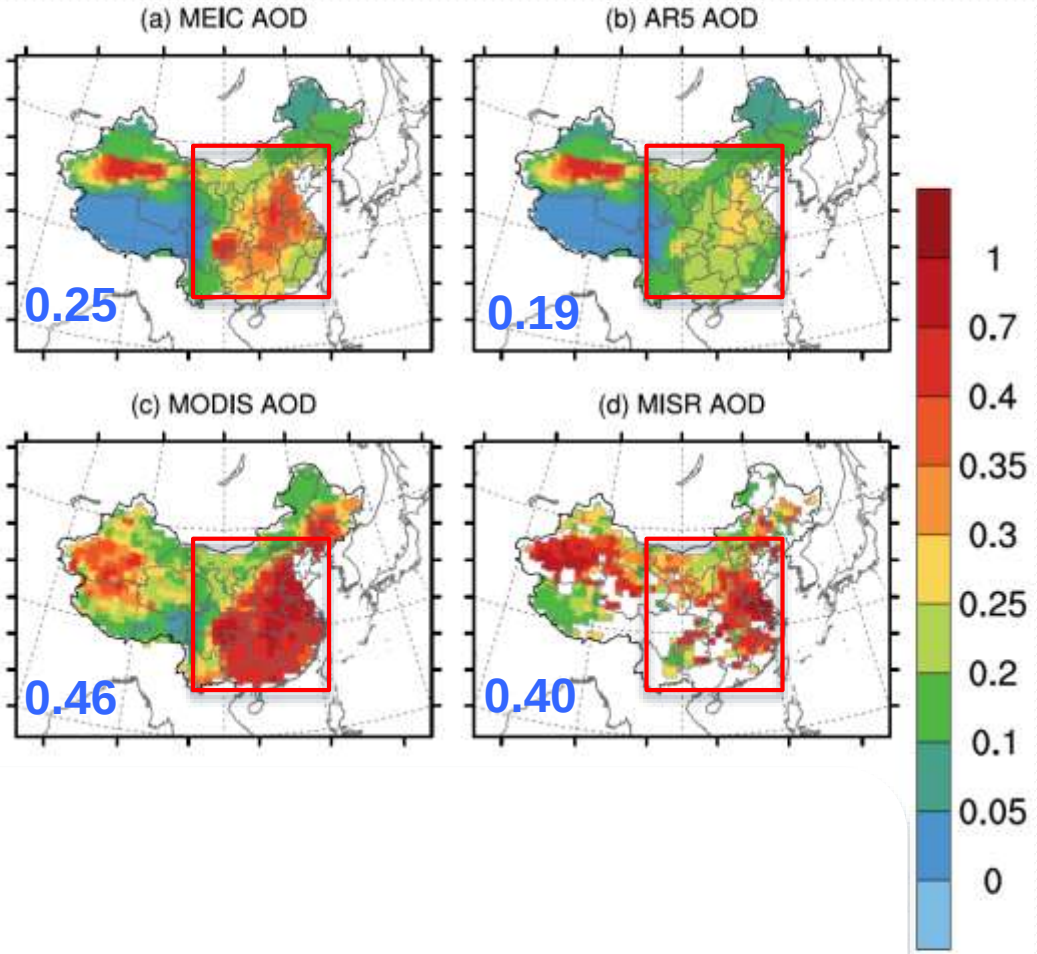
eastern China
(22°-44°N, 100°-124°E)

- Satellite retrievals of AOD from MODIS (Terra collection 6 deep blue and dark target combined) and MISR
- Ground-based retrievals of AOD and SSA at 12 AeroNet sites
- Surface observation of $PM_{2.5}$ chemical composition from literatures
- Radiative effect observation from CSHNET and literatures

The emission accounts for about a quarter of the modeled AOD low biases in eastern China

$$\frac{MEIC - AR5}{MODIS - AR5} = 22.18\%$$

$$\frac{MEIC - AR5}{MISR - AR5} = 28.37\%$$



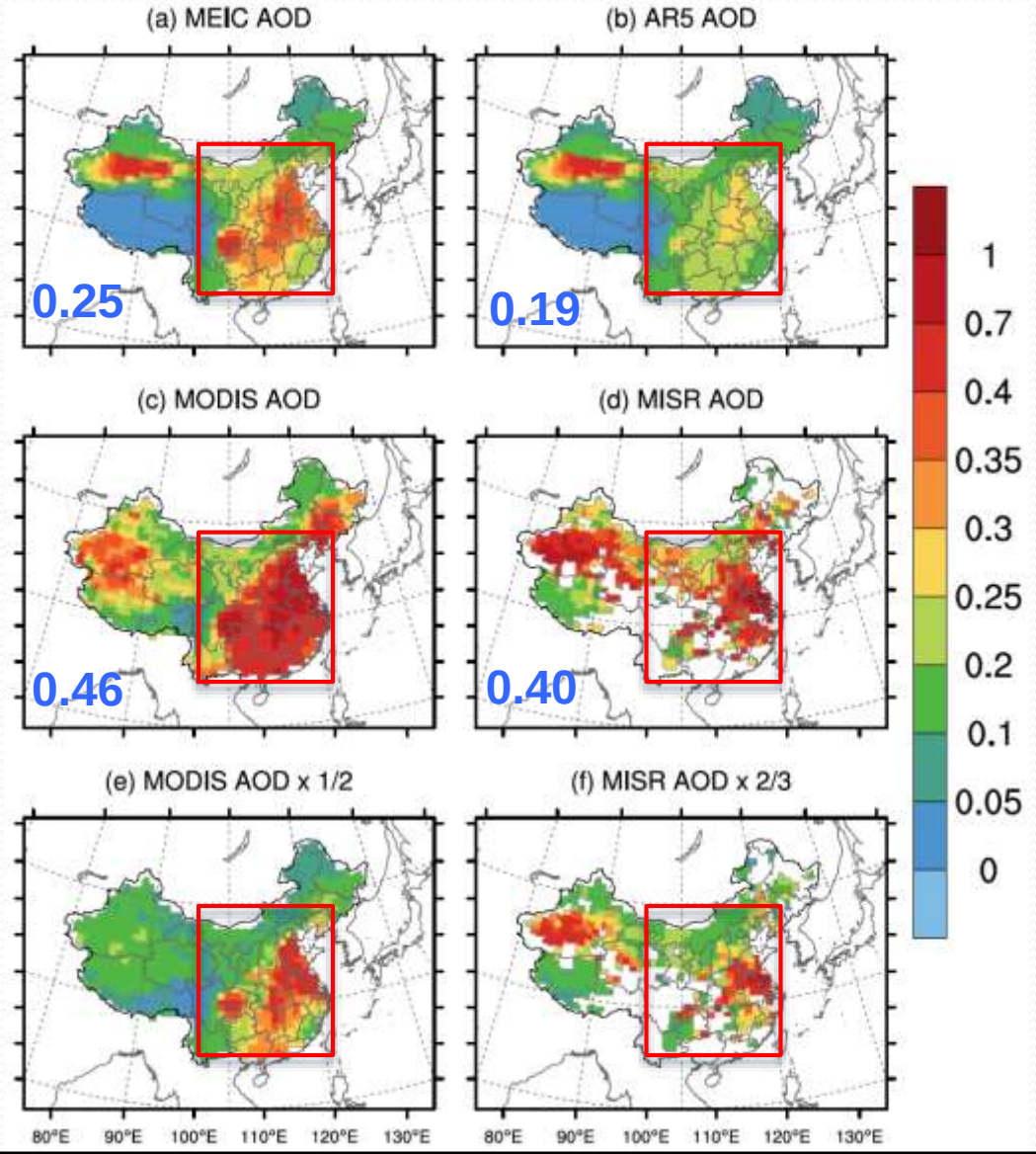
AOD is still underestimated by CAM5 with MEIC.

MEIC reproduces the spatial pattern of AOD

CAM5 AOD

Satellite AOD

MODIS x ½,
MISR x ⅔



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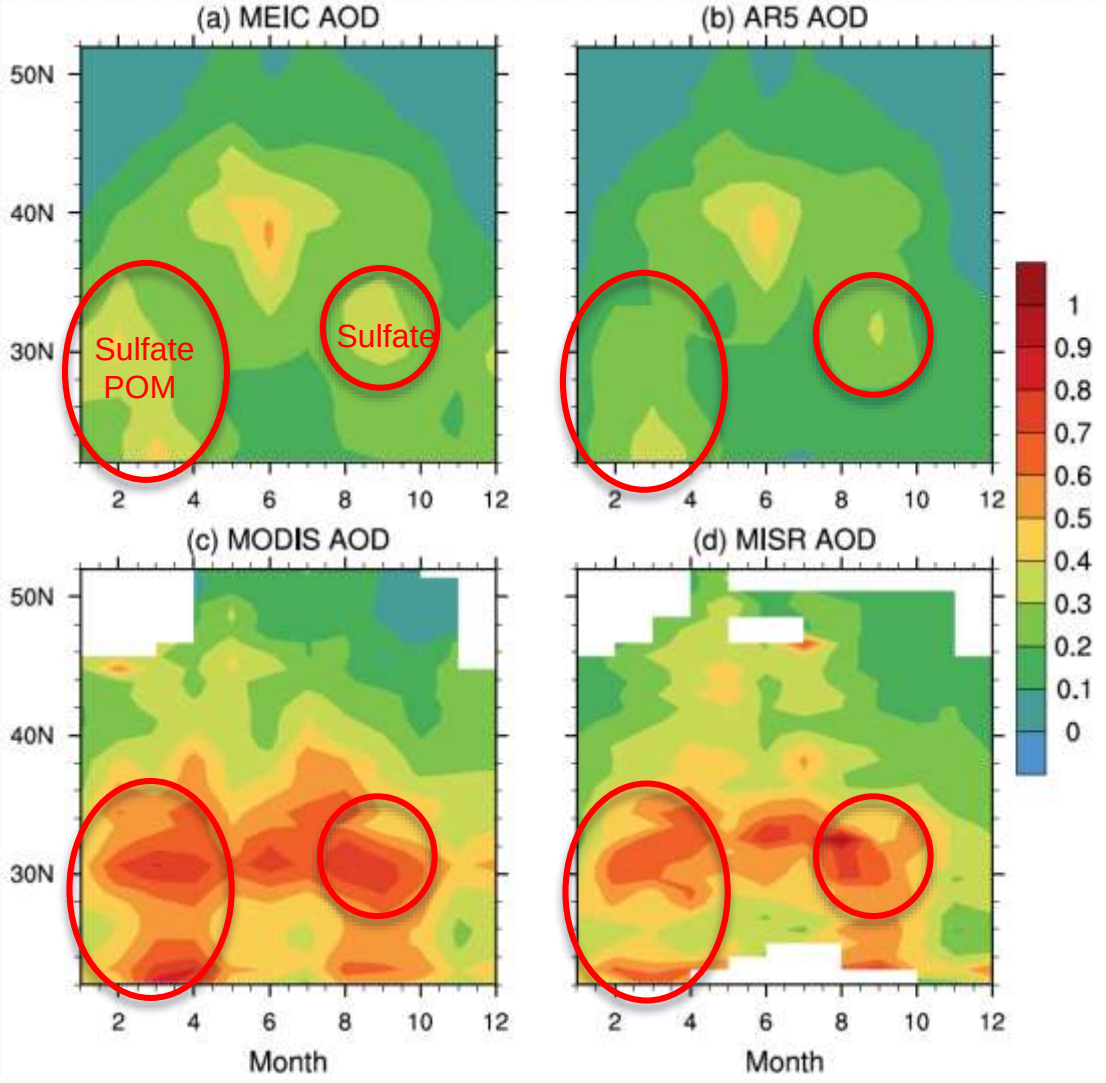
Improved seasonal variation of AOD by MEIC



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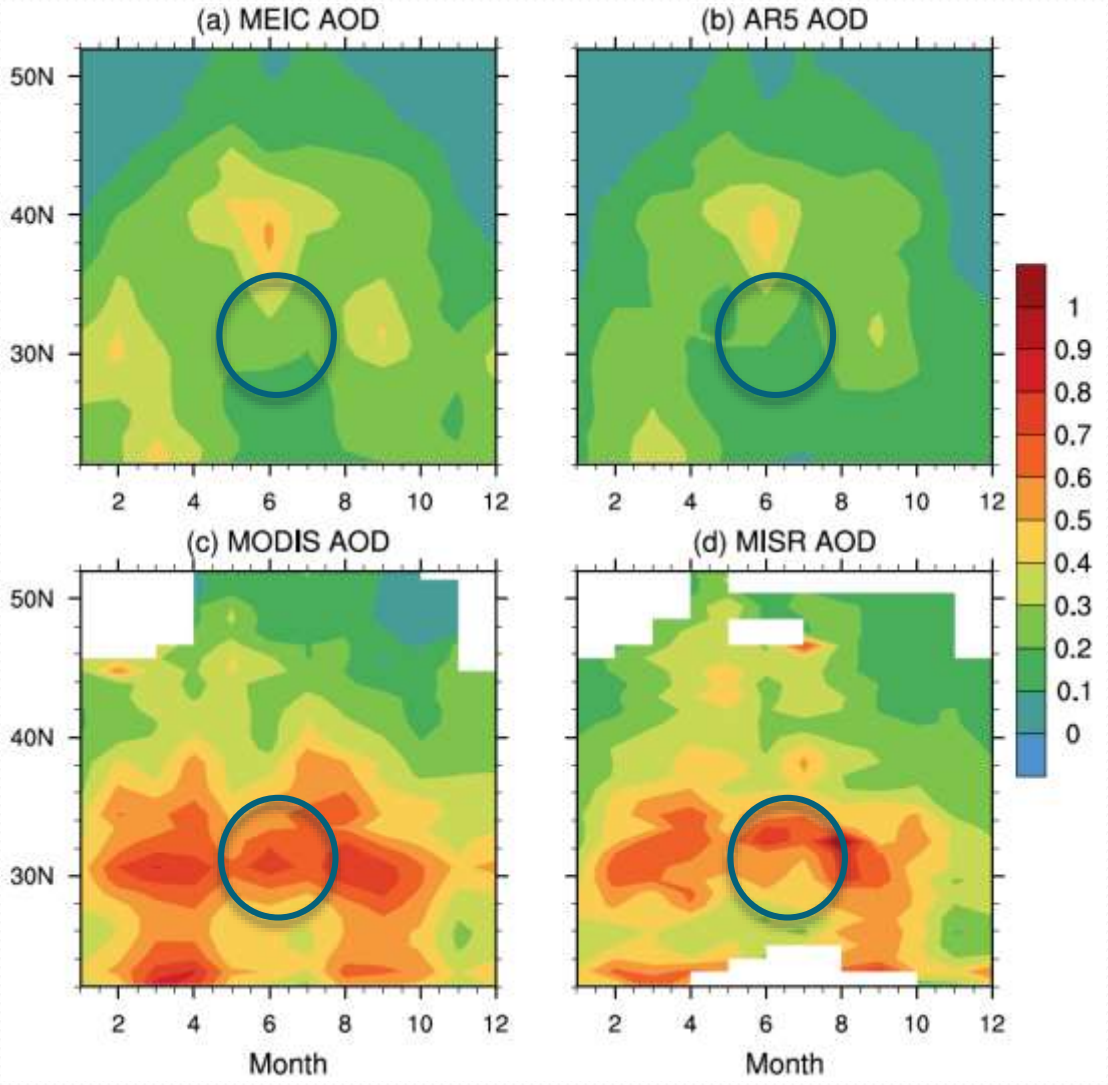
Missing summer maximum of AOD due to precipitation bias



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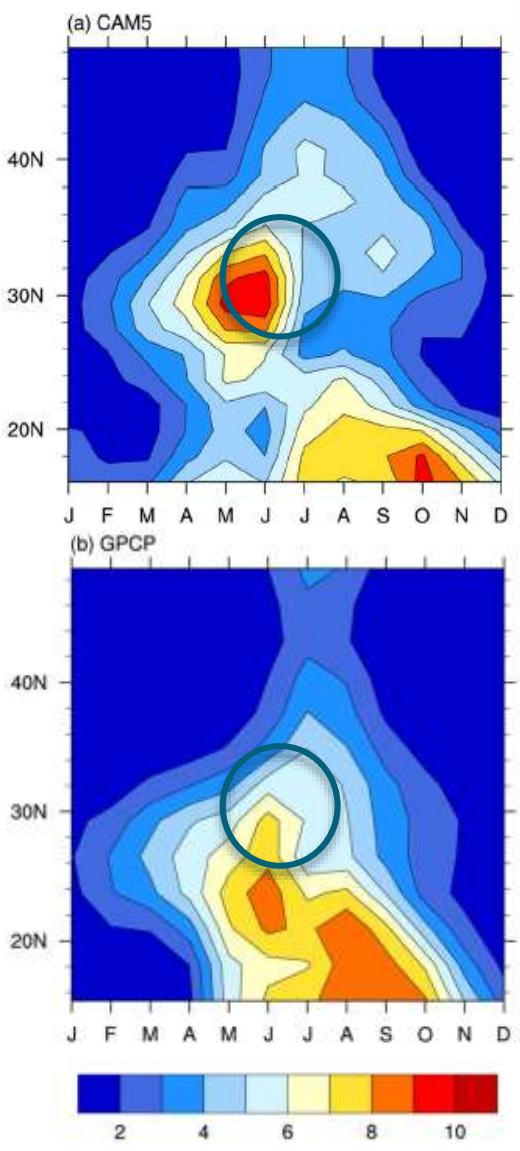
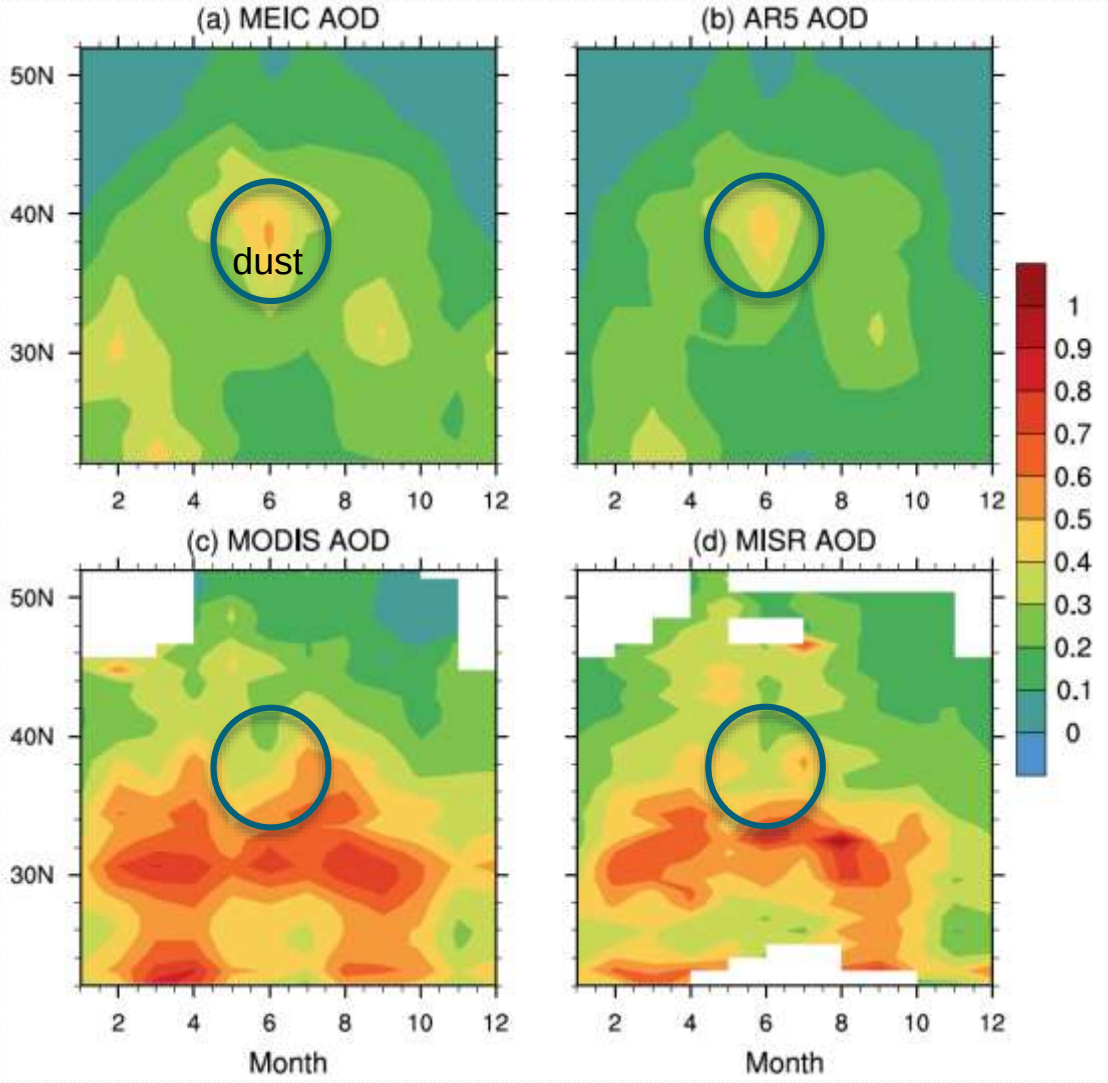
Precipitation



Surface total precipitation in mm d^{-1} from CAM5 and GPCP (Jiang et al., 2015)

Too much wet scavenging associated with East Asia summer monsoon precipitation that pushes too far to the north.

Modeled dust transport that is not observed by satellites



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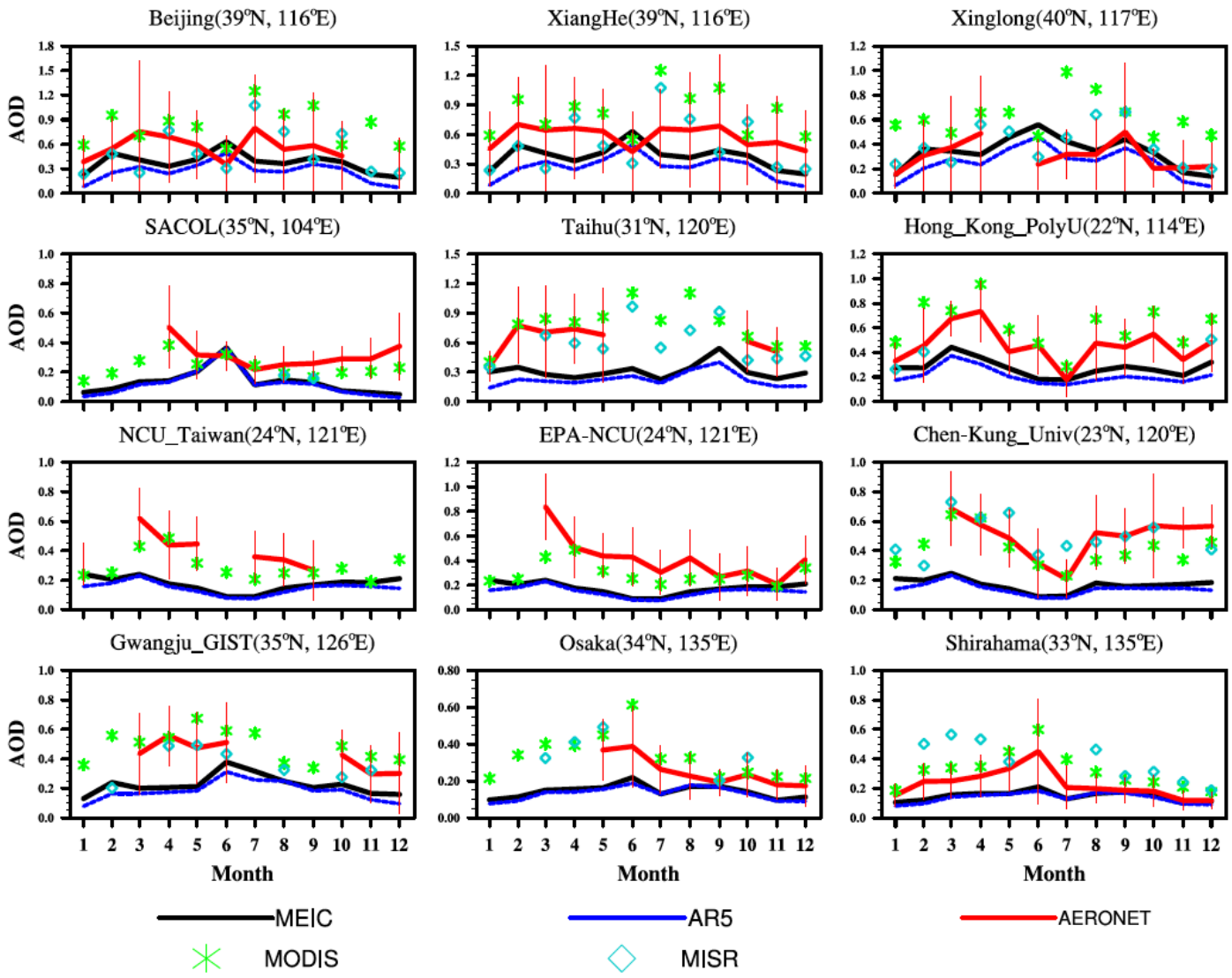
Seasonal variation of AOD comparing with AERONET



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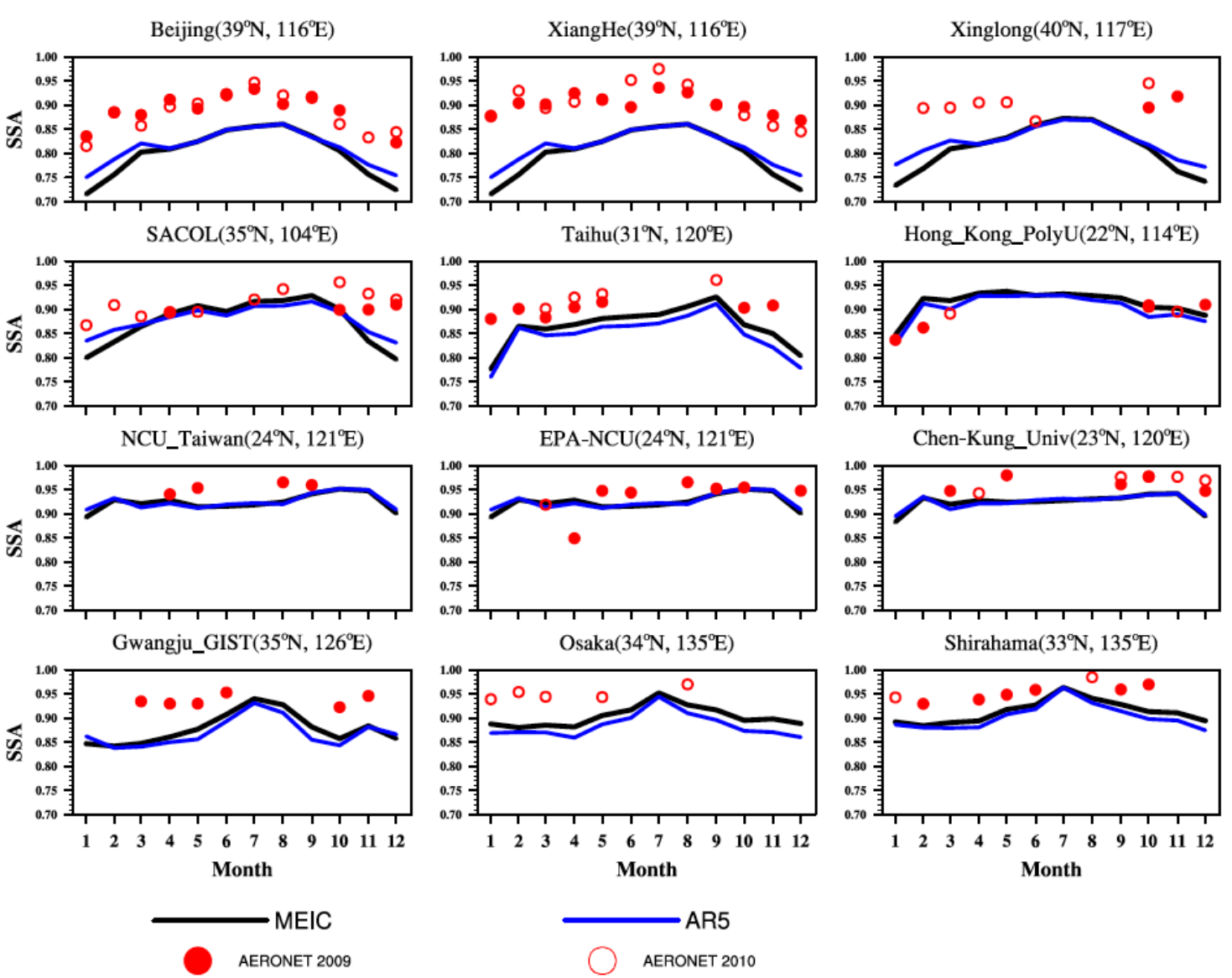
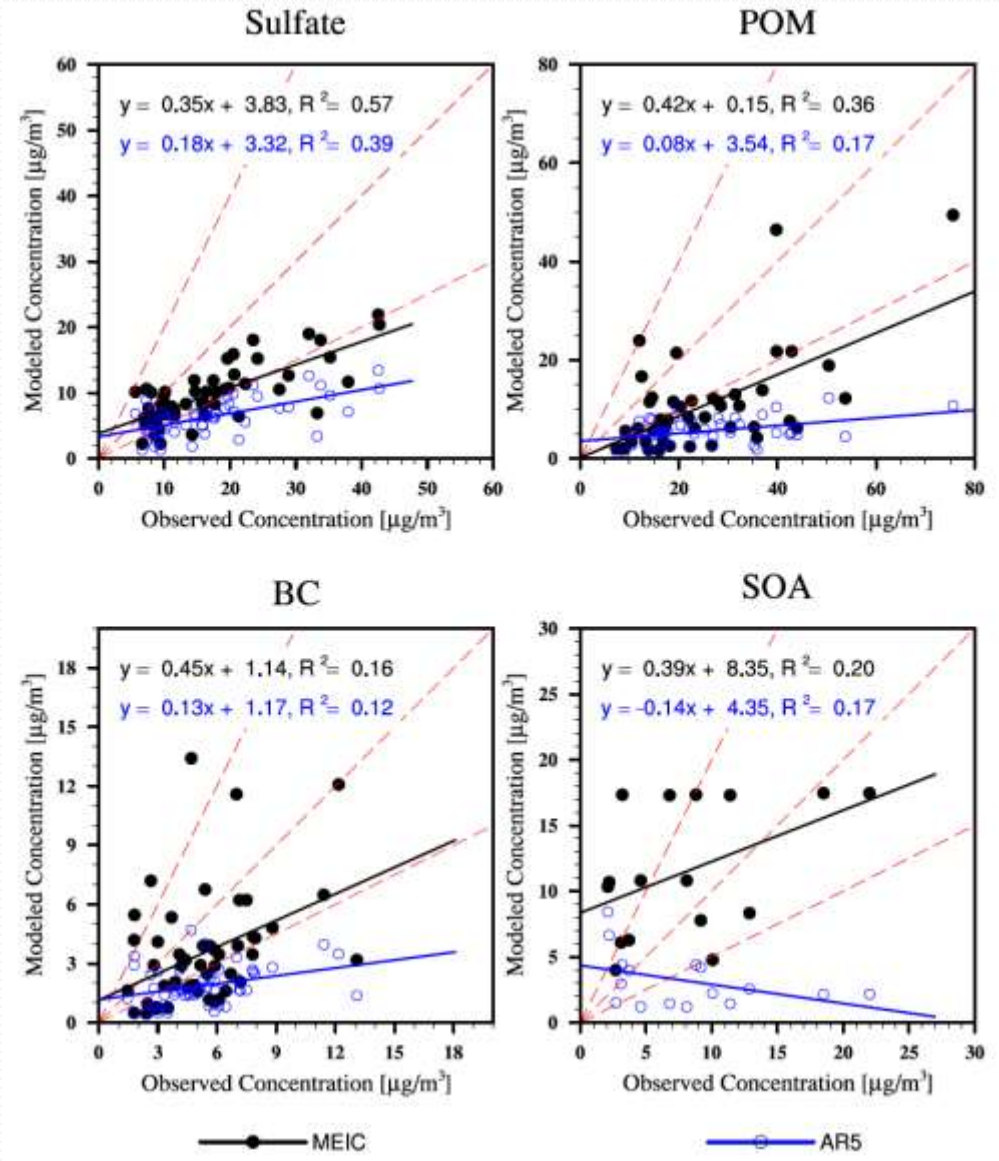
SSA modeled with MEIC and AR5 emissions compared with AERONET



The simulated surface concentrations of all species are improved with MEIC



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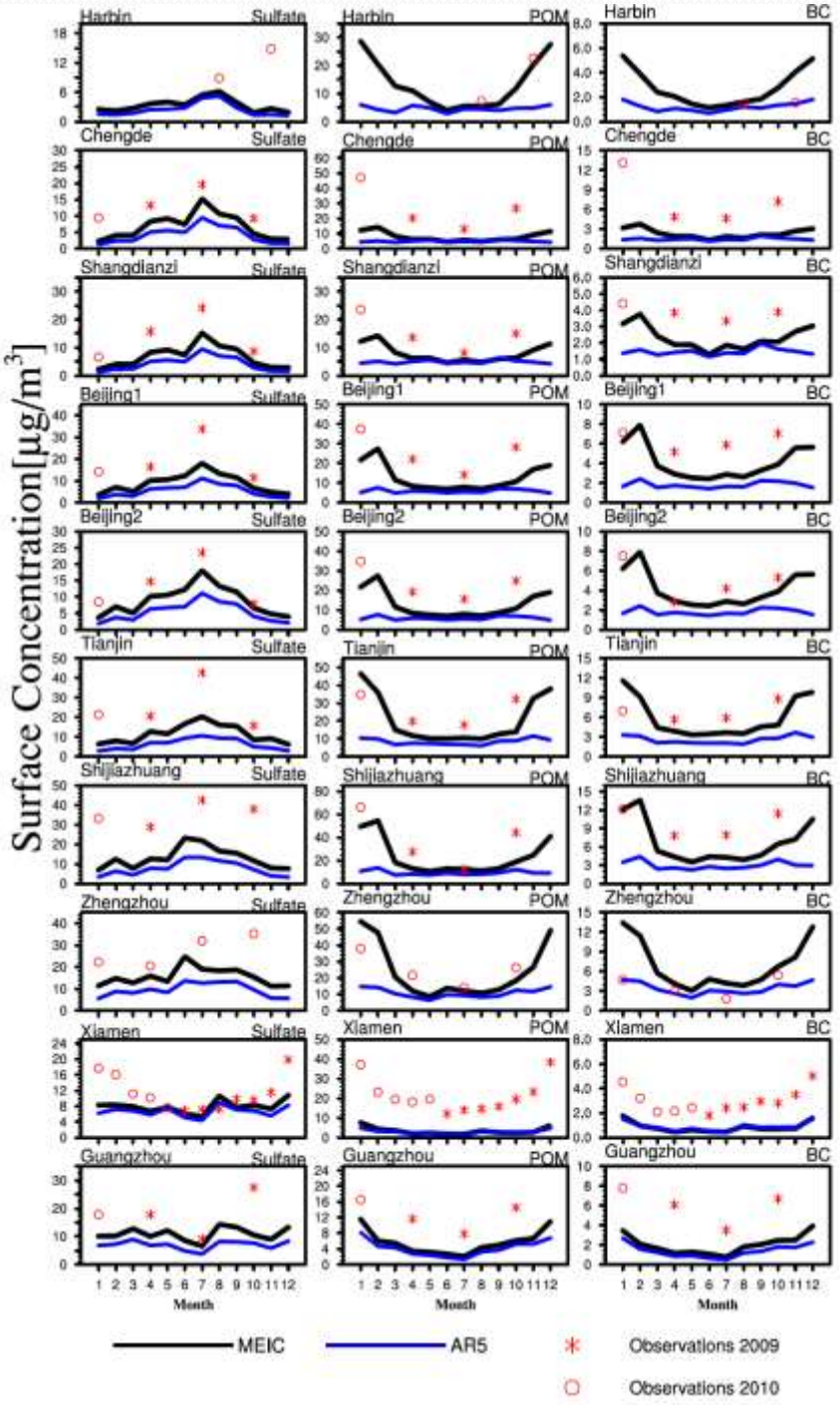
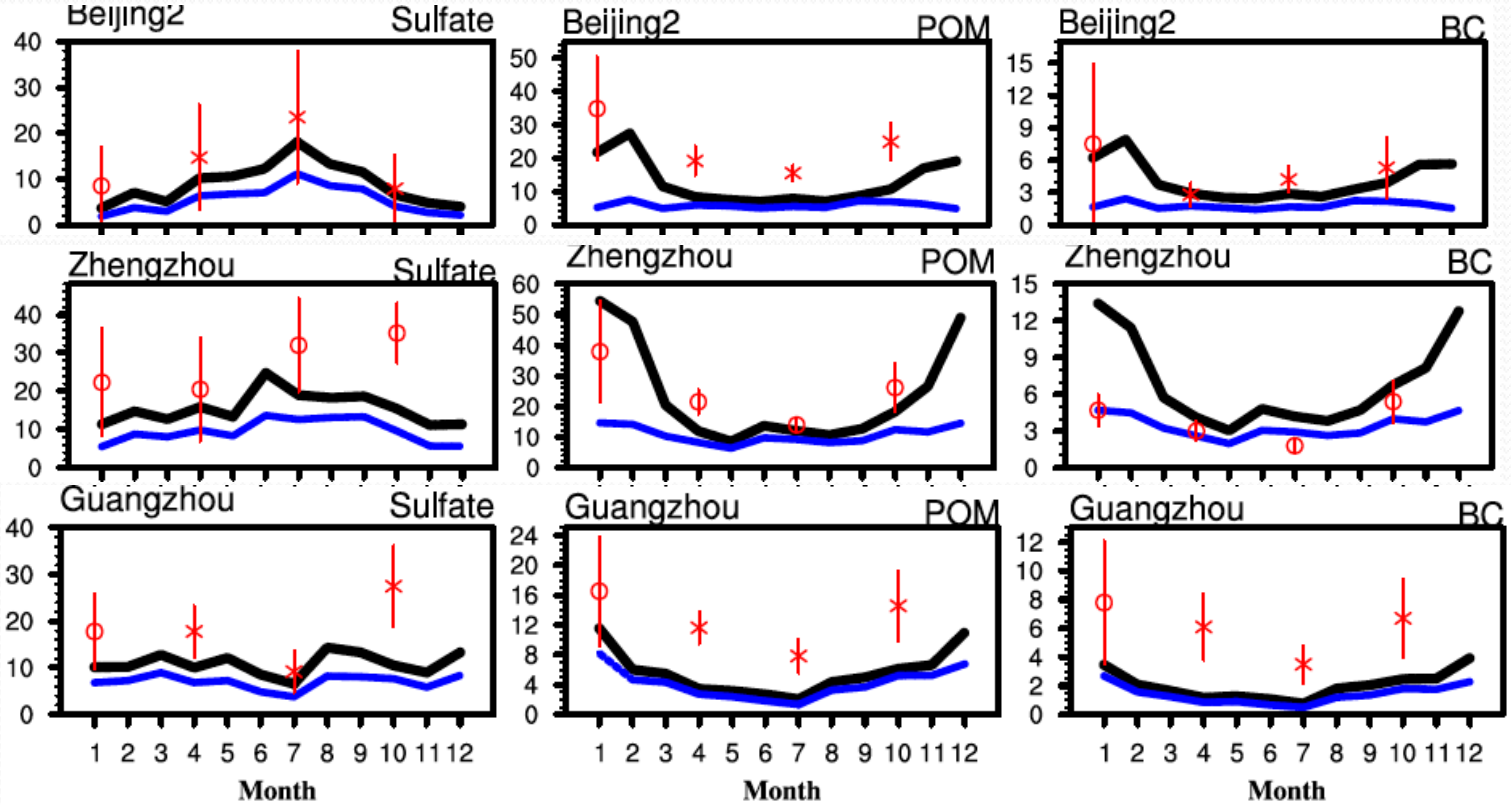


Seasonal variation of sulfate, BC, and POM

- The impact of emission on seasonal variation of sulfate is not obvious.
- MEIC emission significantly increases and improves the model simulations of BC and POM concentrations.

Seasonal variation of sulfate, BC, and POM (Zoom in)



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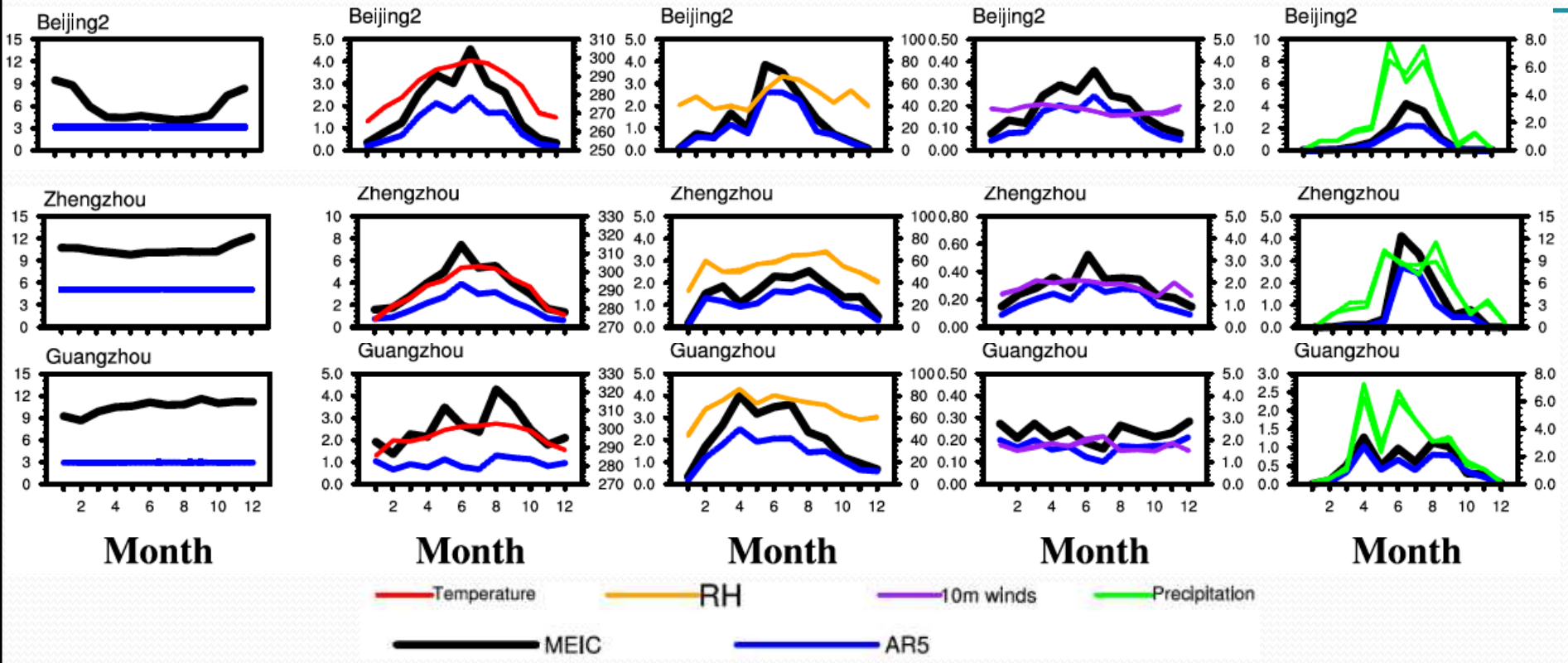
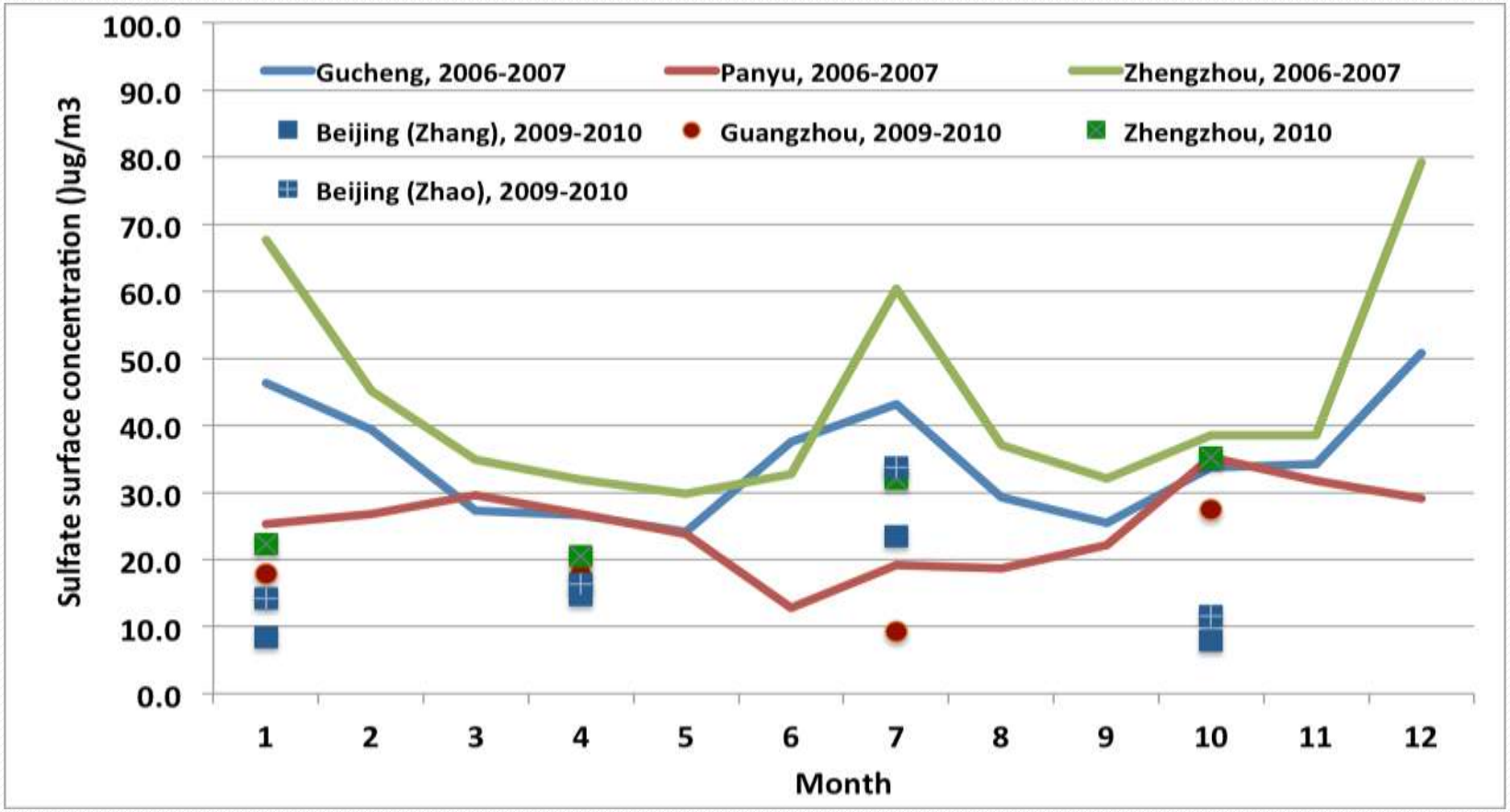
The gas and aqueous phase peak in the summer

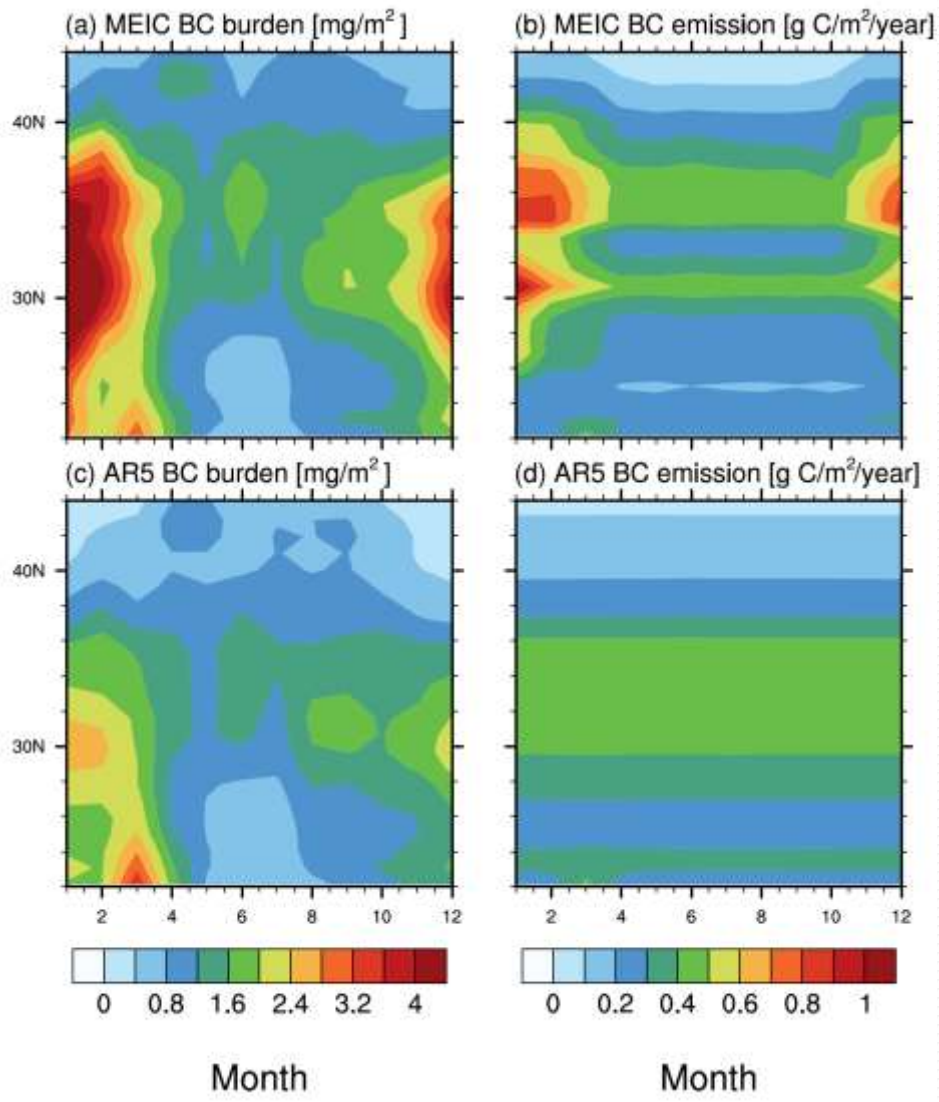


- The gas-phase chemistry is most active in the summer due to the temperature-dependence of the reaction rate in the oxidation of SO_2 by OH.
- More production of OH radical by photolysis that is more active in the summer.
- The aqueous-phase formation peaks in the summer due to high relative humidity and thus more cloud water.

Contrasting seasonal variation by CAWNET



Seasonal variations of both the emission and meteorology play important roles



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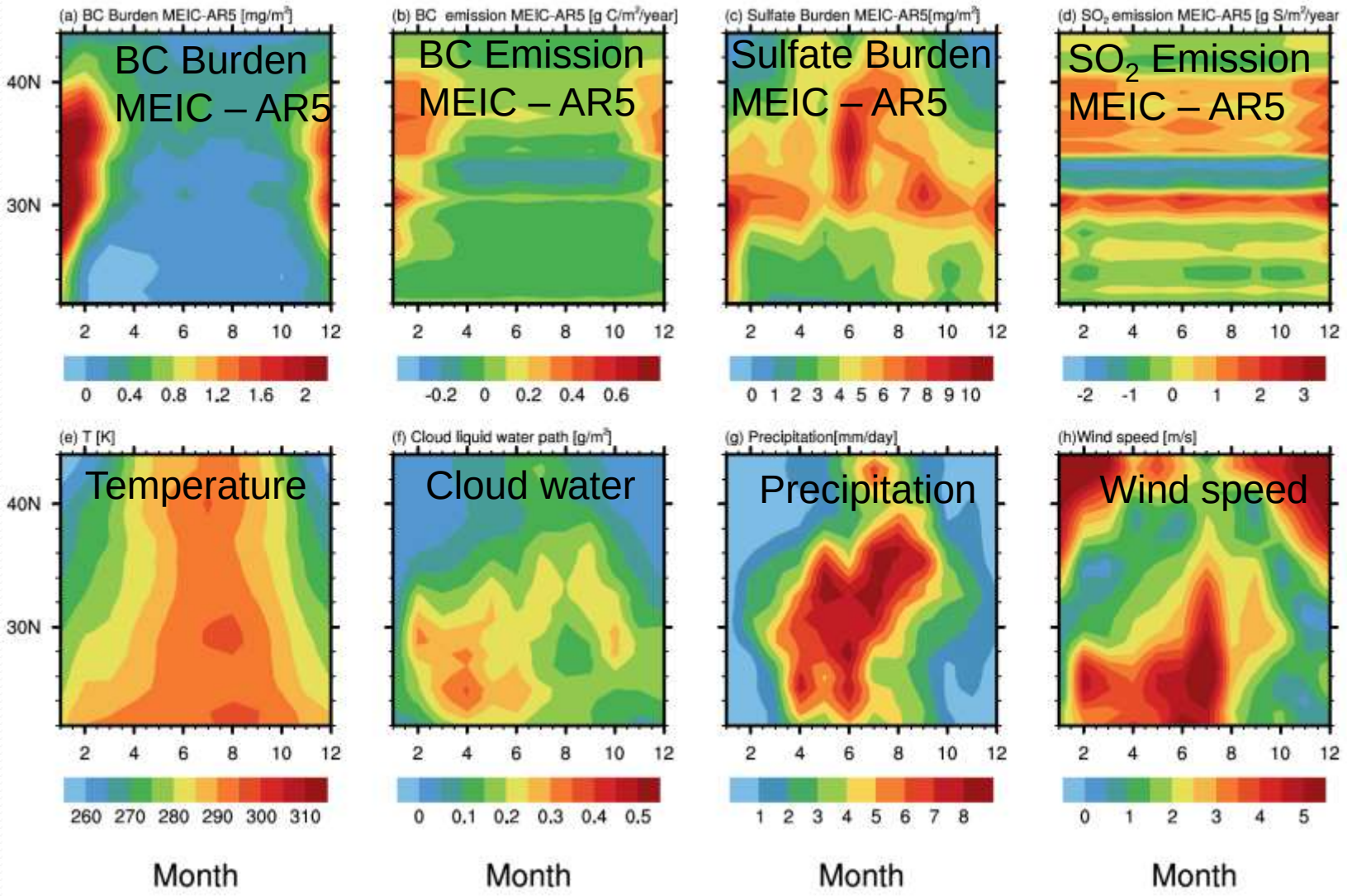
The impacts of emission on primary and secondary aerosols are different



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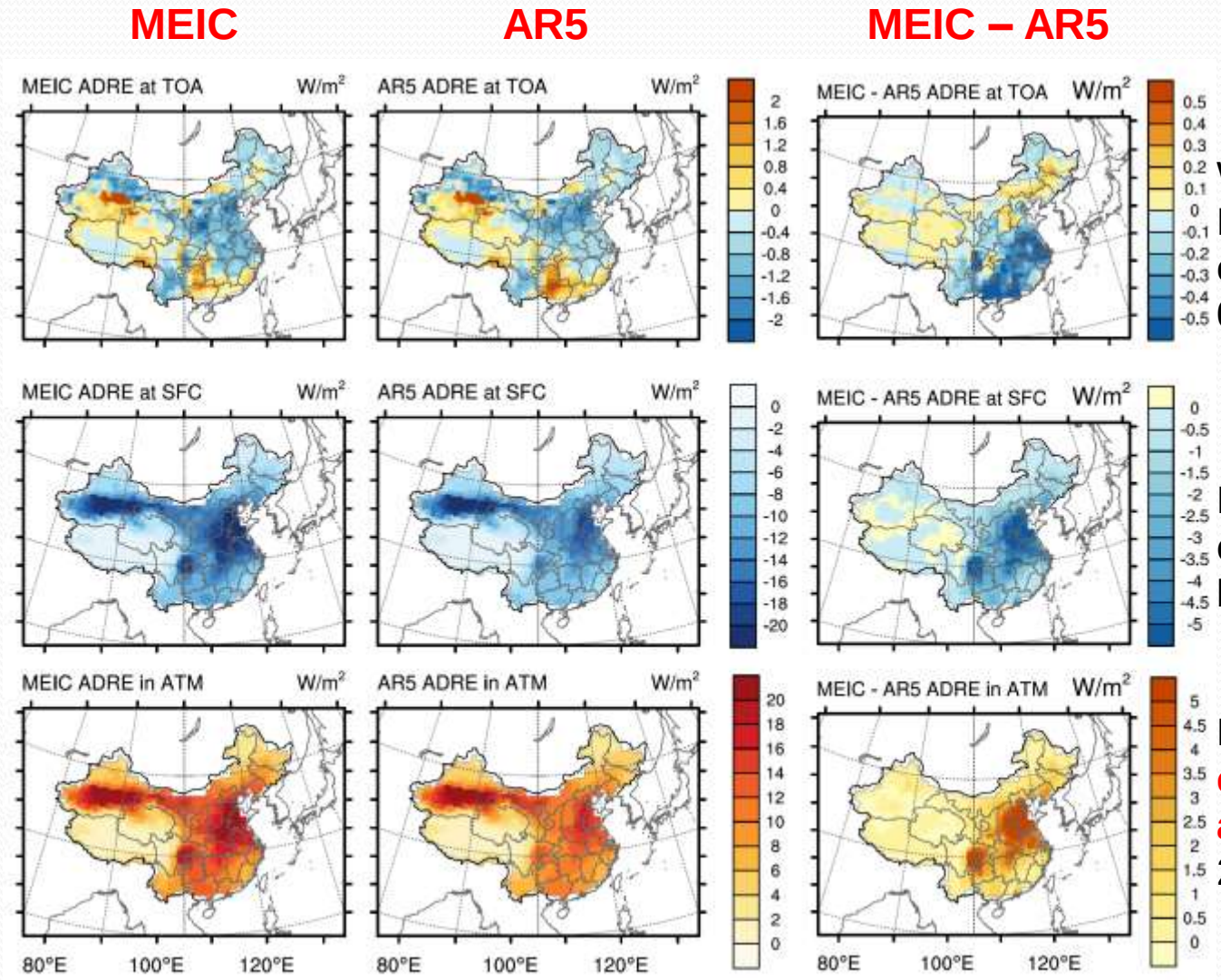
Aerosol direct radiative forcing (ADRE)



With MEIC: Enhanced cooling effect **at TOA** by -0.19 Wm^{-2}

Enhanced cooling effect **at surface** by -2.42 Wm^{-2}

Enhanced warming **effect in the atmosphere** by 2.23 Wm^{-2}

MEIC estimate the averaged aerosol DRF at TOA, surface, and atmosphere to be -0.50, -12.76, 12.26 Wm^{-2} over eastern China

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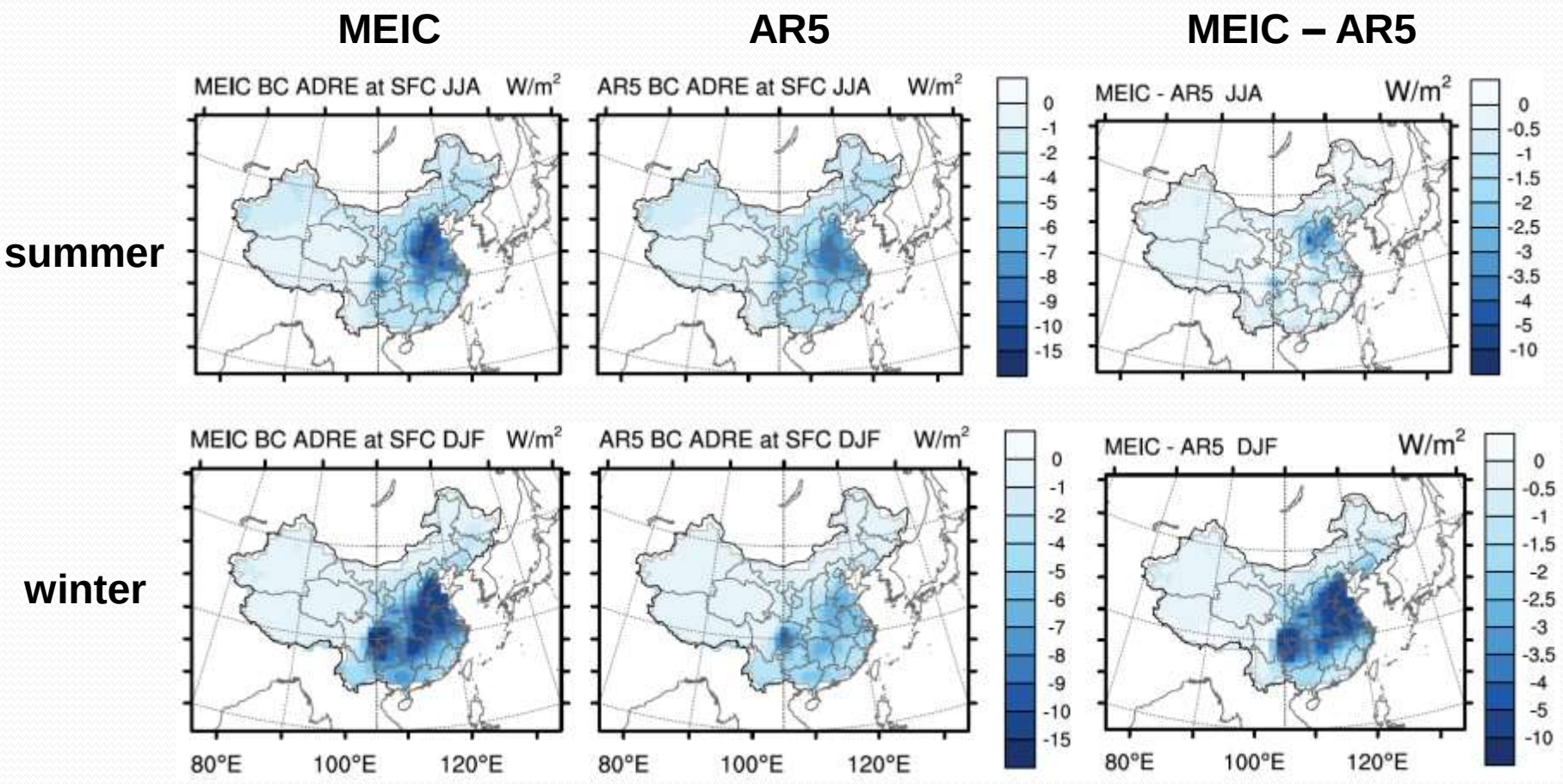
About 12% to 47% difference of the anthropogenic emission rates

About 30% difference of the total AOD of all species

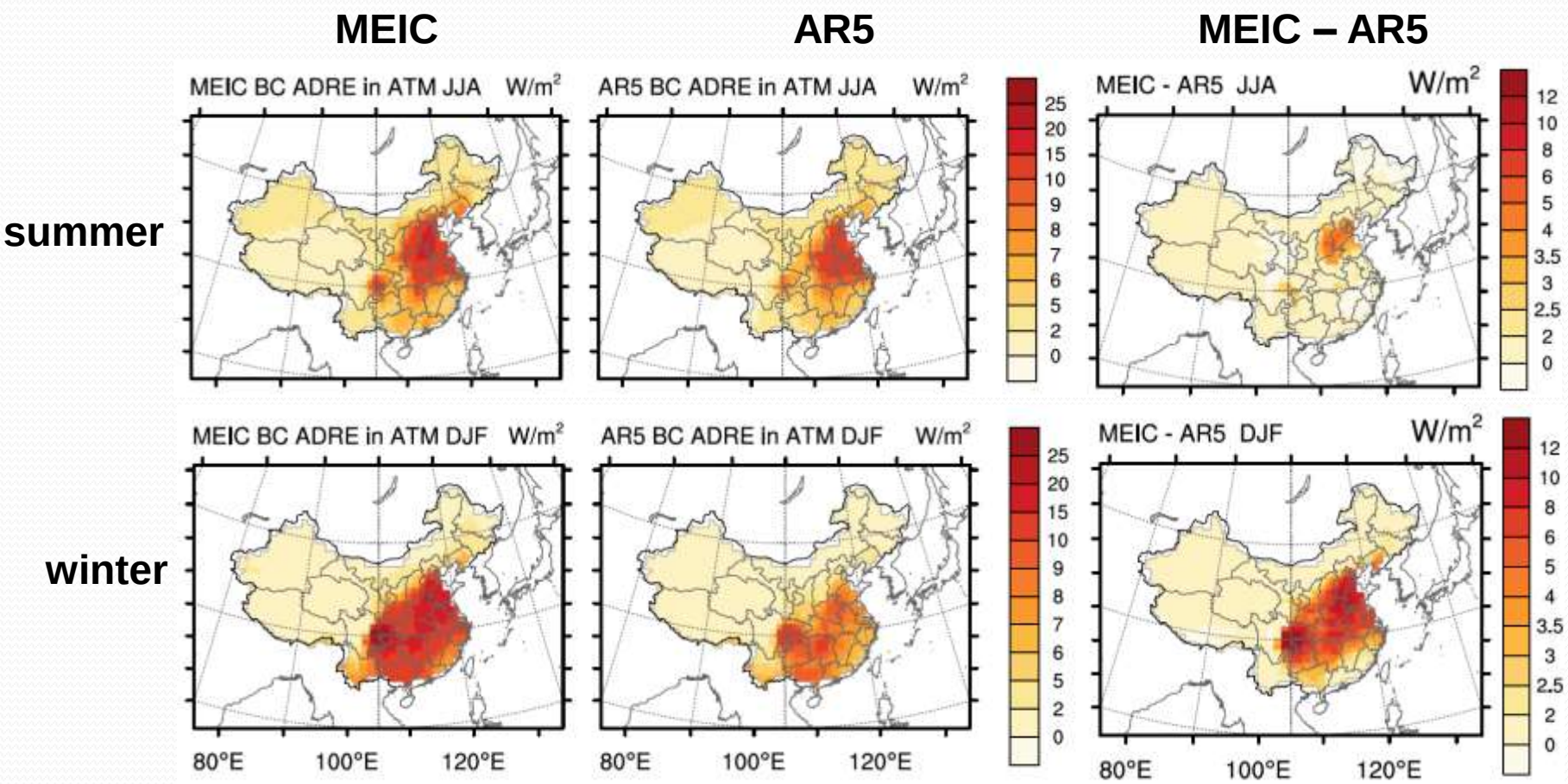
About 22% difference of ADREs at the surface and in the atmosphere
About 63% of the ADRE at TOA

The impacts of the emission on AOD and ADRE are significant.

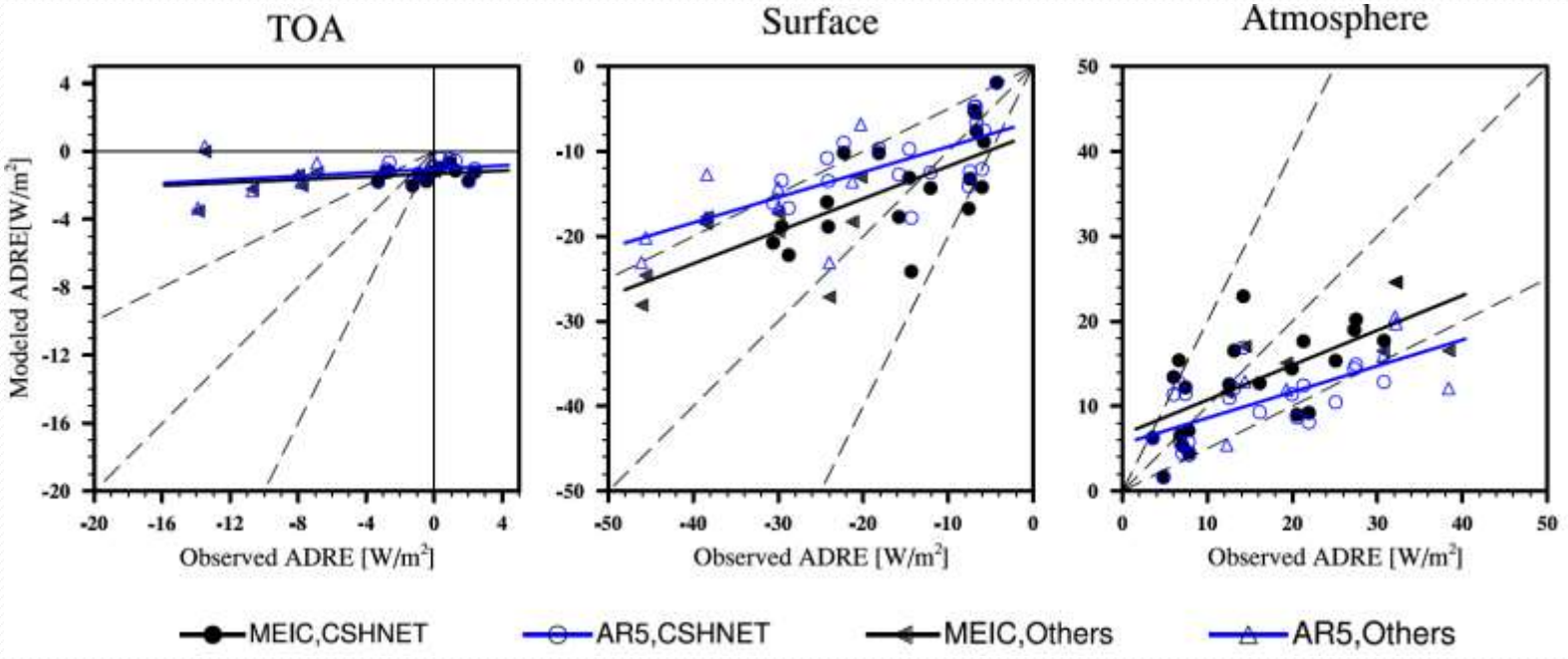
The impact of emission on ADRE of BC is more significant than the meteorological effects



So does atmospheric warming due to BC

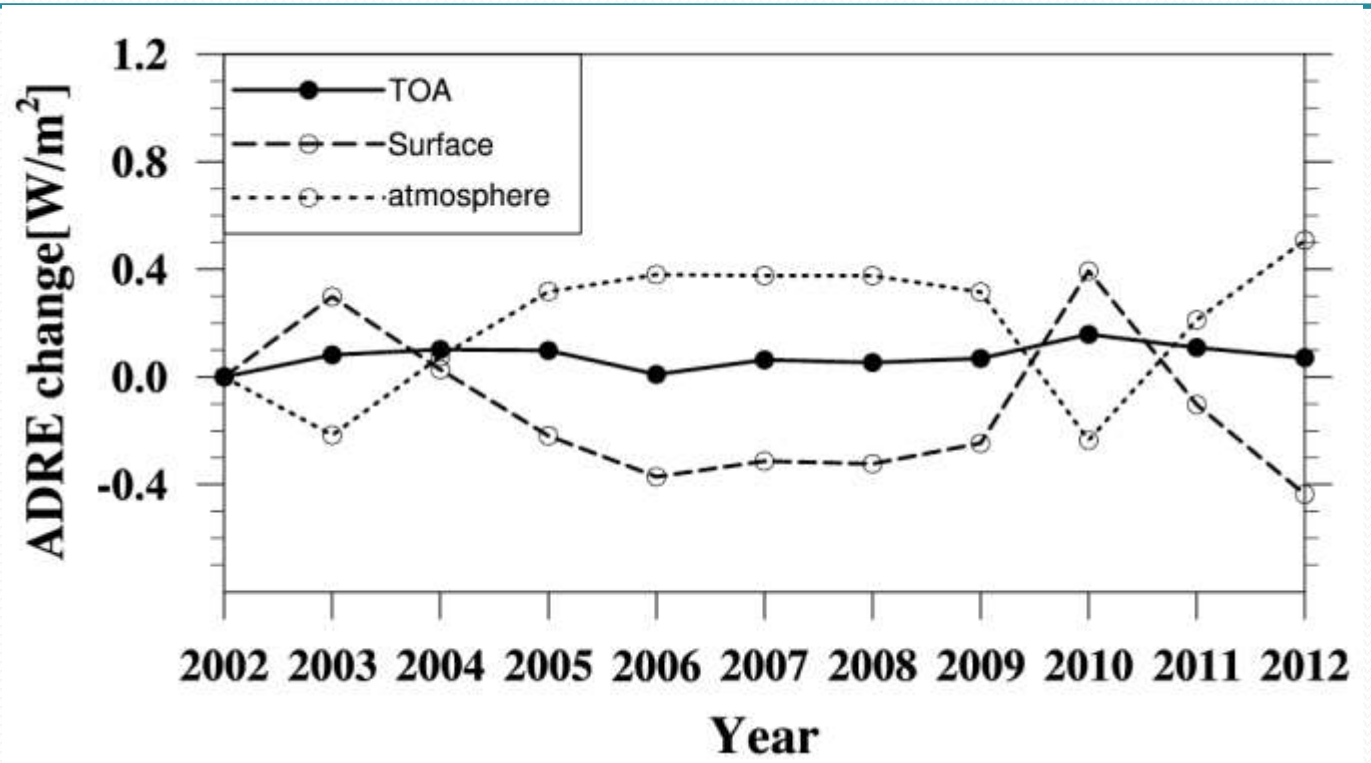


Modeled ADREs are improved with MEIC, but still underestimated



Observational data from Chinese Sun Hazemeter Network (CSHNET) (Xin et al., 2007; Li et al., 2010) and other literatures.

The ADRE from 2002-2012



- The decadal changes of ADRE at surface (-0.44~0.39 W/m^2) and in the atmosphere (-0.23~0.51 W/m^2) are smaller than the difference of the ADREs simulated by MEIC and AR5 emission in 2009 (-2.42 W/m^2 and 2.23 W/m^2 at surface and in the atmosphere, respectively).
- It highlights the uncertainty of the emission inventories and the need of constraining the emission inventories of aerosol and precursors by in-situ and satellite observations.

Summary

- This research highlights the critical importance of improving aerosol and precursor emissions and aerosol processes for the modelling of aerosols and aerosol effects in East Asia.
- The new aerosol and precursor gases emission MEIC explains 22% to 28% of the AOD low-biases in eastern China in a GCM compared to satellite observations.
- Analysis of the aerosol processes in the model shows the gas phase and in-cloud aqueous-phase formation of sulfate aerosol peaks in the summer due to higher temperature, photolysis rate, and relative humidity.
- Some important mechanisms, such as production through heterogeneous reactions of SO_2 on pre-existing aerosols should be included in the model.
- The new emission inventory estimates the averaged aerosol direct radiative forcing at TOA, surface, and atmosphere to be -0.50, -12,76, and 12.26 W/m^2 over eastern China, which are enhanced by -0.19, -2.42, and 2.23 $W\ m^{-2}$ compared with the AR5 emission.