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Aerosol water uptake in global aerosol models:

dominant factors and their impacts on direct and indirect aerosol effects

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Max-Planck-Institut für Meteorologie

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SciDAC Scientific Discovery through Advanced Computing

Why does the aerosol water uptake matter?

- Aerosol wet size distribution
  - Extinction → direct effect
  - CCN → indirect effect
- Refractive indices → direct effect

What determines the water uptake of aerosols?

- Aerosol mass, composition and dry size
  - Raoult effect : decrease of equilibrium RH over an aqueous solution due to solutes
  - Kelvin effect : increase of equilibrium water vapor pressure over a curved surface
  - Hysteresis effect
- Relative humidity

Aerosol water burden in AeroCom I models

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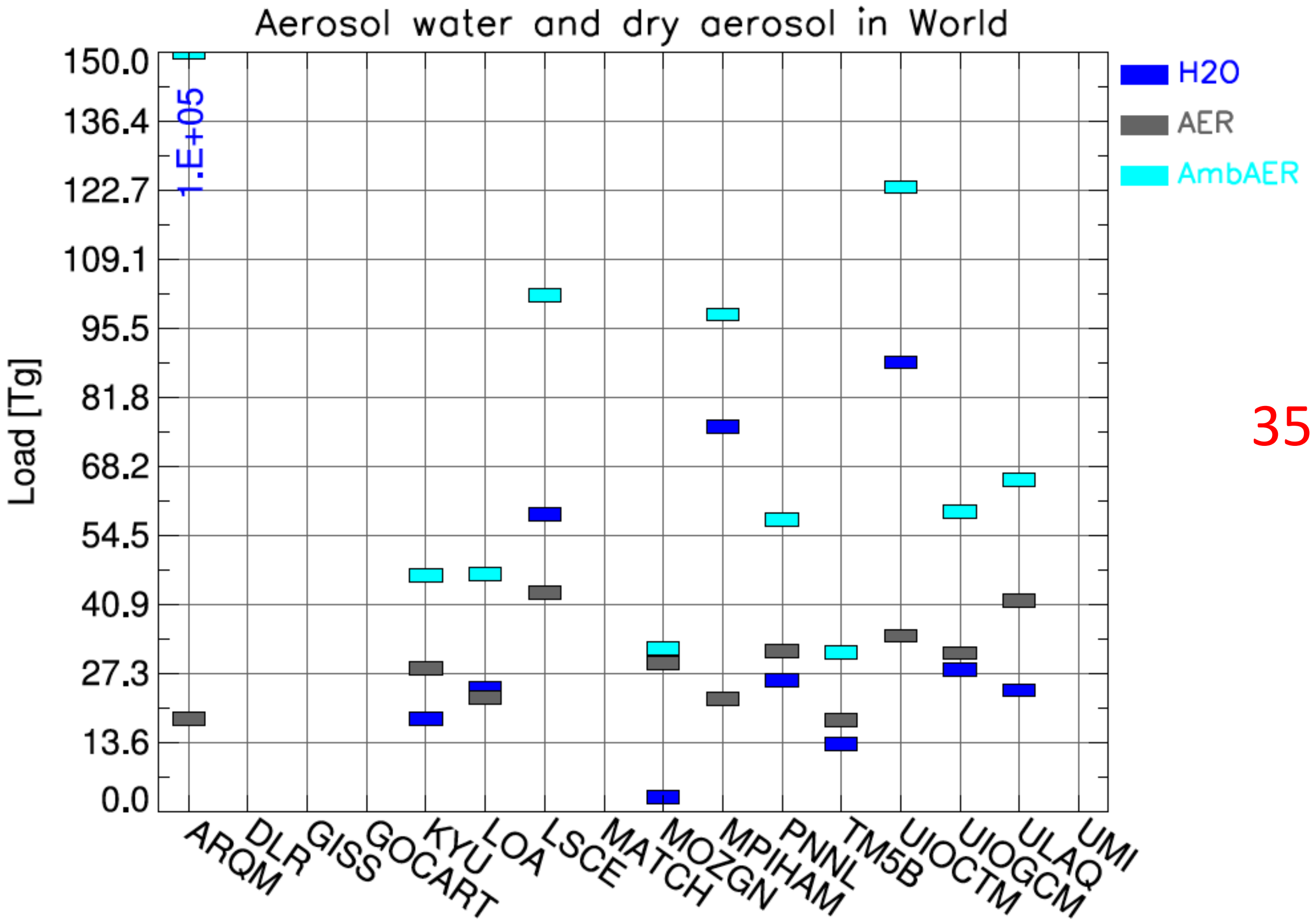
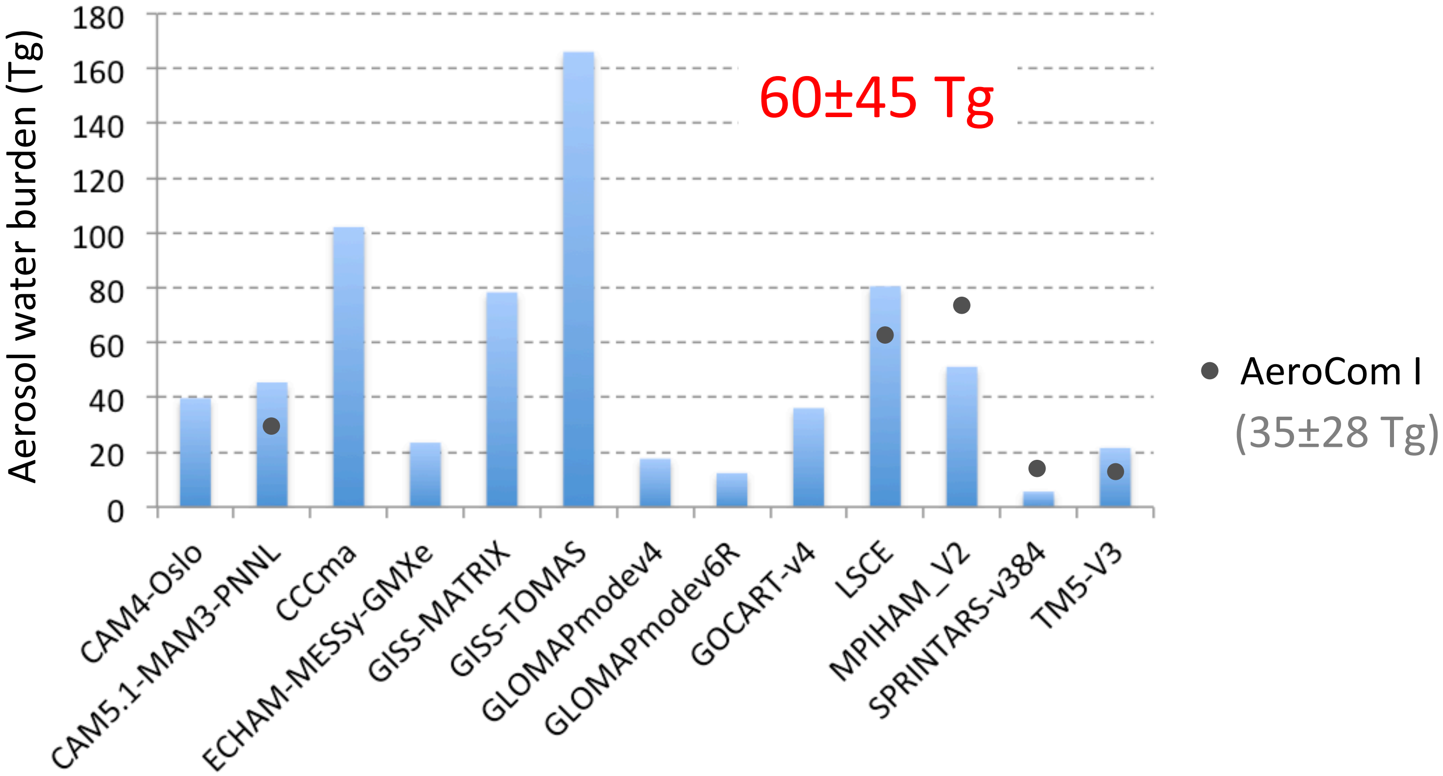


35±28 Tg

Textor et al. (2006)

Aerosol water burden in 12 AeroCom II models

(preliminary results)



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Previous studies on evaluation of aw in global aerosol models and its impacts on direct/indirect aerosol effect

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Modeling side

- Textor et al. (2006) : Water uptake in AeroCom I models (EXP A)
- Textor AeroCom 2005 presentation: "*Humidification aspects in AeroCom A and B*" → RH and composition
- Sensitivities of AOD and RF (direct) to RH : e.g. Penner et al. (1998), Adams et al. (1999), Jacobson (2001), Bian et al. (2009)
- Sensitivities of RF (indirect) to aerosol hygroscopicity : Liu and Wang (2010)

Measurement/Retrieval side

- Schuster et al. (2009) : Retrieval of growth factors (R_{wet}/R_{dry}) from AERONET
- Greg Schuster AeroCom 2010 presentation: "Remote Sensing of Aerosol Composition"
    - Retrieval of AOD_{wat} / AOD from AERONET

Factors that we test in this study

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Same aerosol mass, composition, size, and RH – as predicted in ECHAM5-HAM2

- Aerosol water uptake parameterization
  - Various methods
    - ZSR with various water activity coefficients (Zadanovksii, 1948; Stokes and Robinson, 1966) : take aerosol as a solution of mixed electrolytes
      - Jacobson et al. (1996)
      - Jacobson (1998) book "Fundamentals of Atmospheric Modeling"
      - ISORROPIA (V1.7)
    - Köhler theory based (Ghan et al., 2001; Liu et al., 2012)
    - kappa-Köhler theory based (Petters and Kreidenweis, 2007; O'Donnell et al., 2011) : can easily be applied for non-electrolytes
      - Sensitivity to specified hygroscopicity (sulfate 0.1-0.7, sea salt 0.04-1.2)
  - RH ceiling (90%, 95%, 99%, 99.9%)
  - Treatment of the hysteresis effect (not shown)
- Sub-grid variability of RH

Sensitivity of aerosol water uptake (Growth Factor) to RH, dry size, and composition

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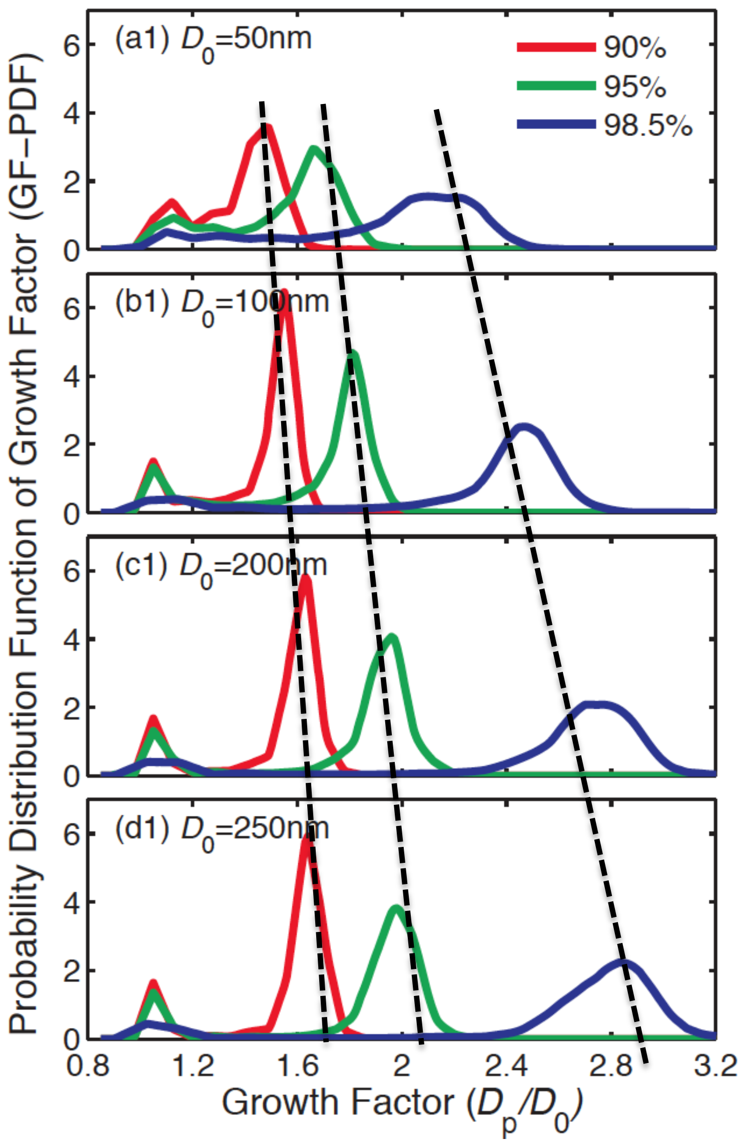


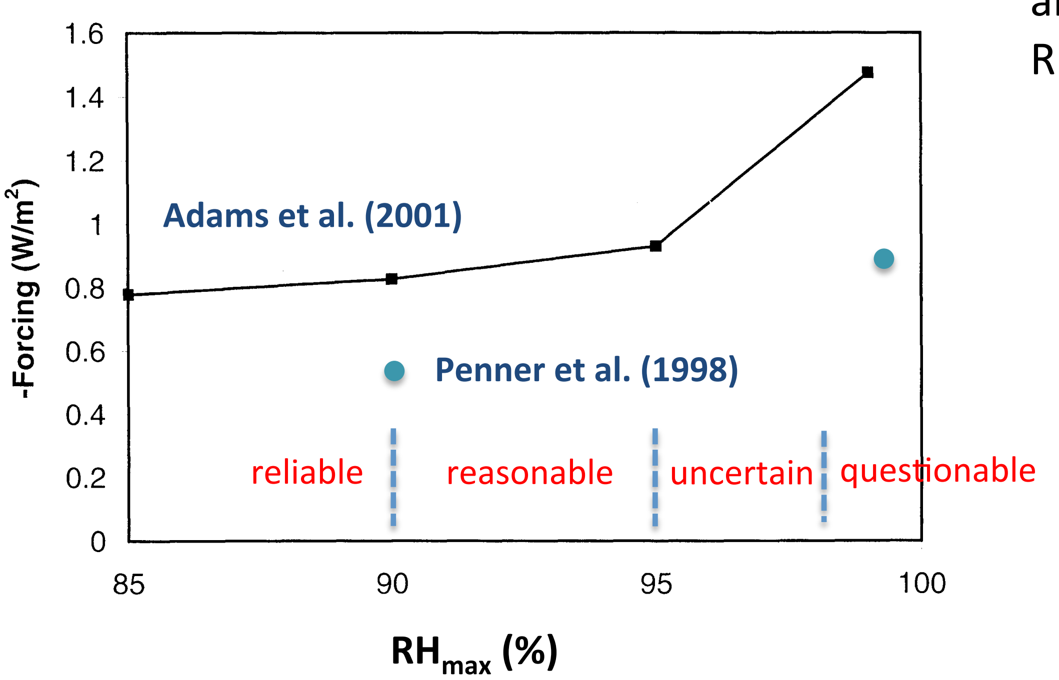
Hygroscopic properties of aerosol particles at high RH in the North China Plain

Aerosol water uptake is very sensitive to RH (>90%), the sensitivity is larger when aerosol size is larger.

Liu et al. (2011)

RH ceiling (RH_{max})

Penner et al. (1998) and Adams et al. (2001)



Most AeroCom I models (Textor et al., 2006) assume:

RH_{max} : **95% - 100%**

Measurement quality

Sensitivity to RH_{max}

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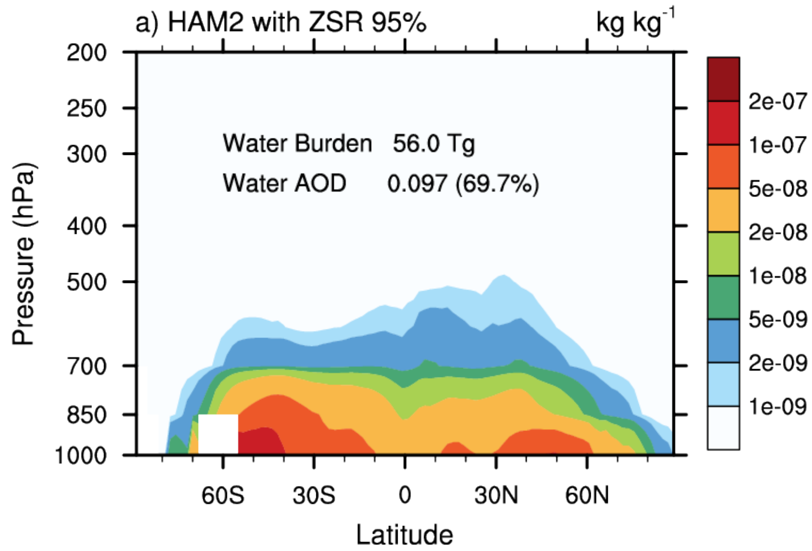
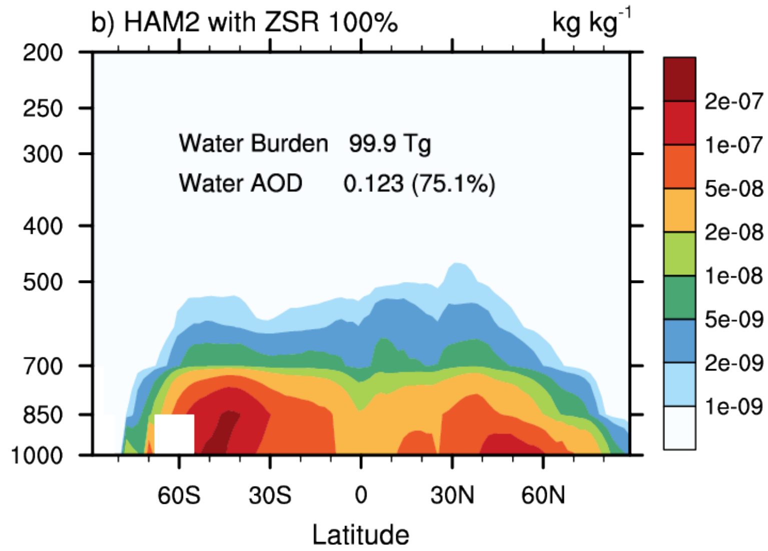
ZSR with RH_{max}=95%



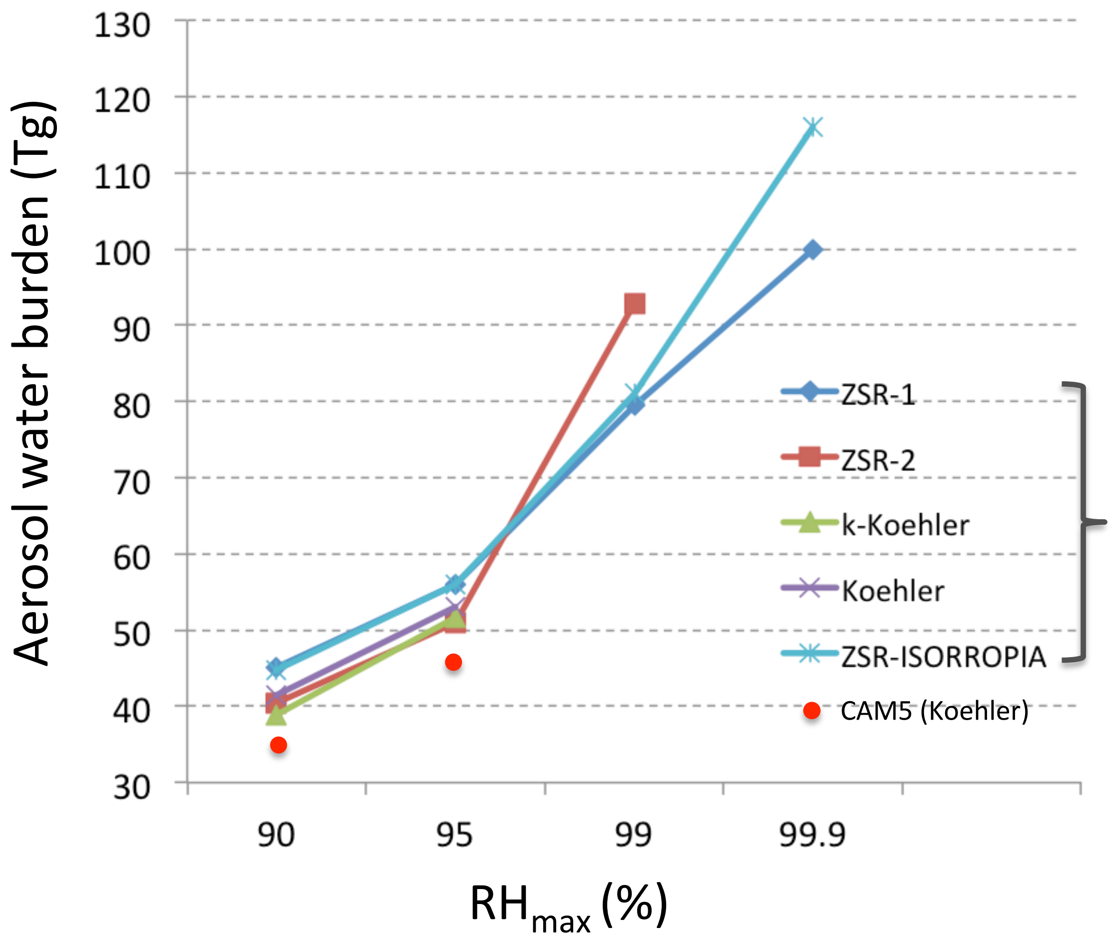
ZSR with Rh_{max}=100%



ECHAM5-HAM2, T63L31, year 2000 nudged run

Sensitivity to parameterization scheme

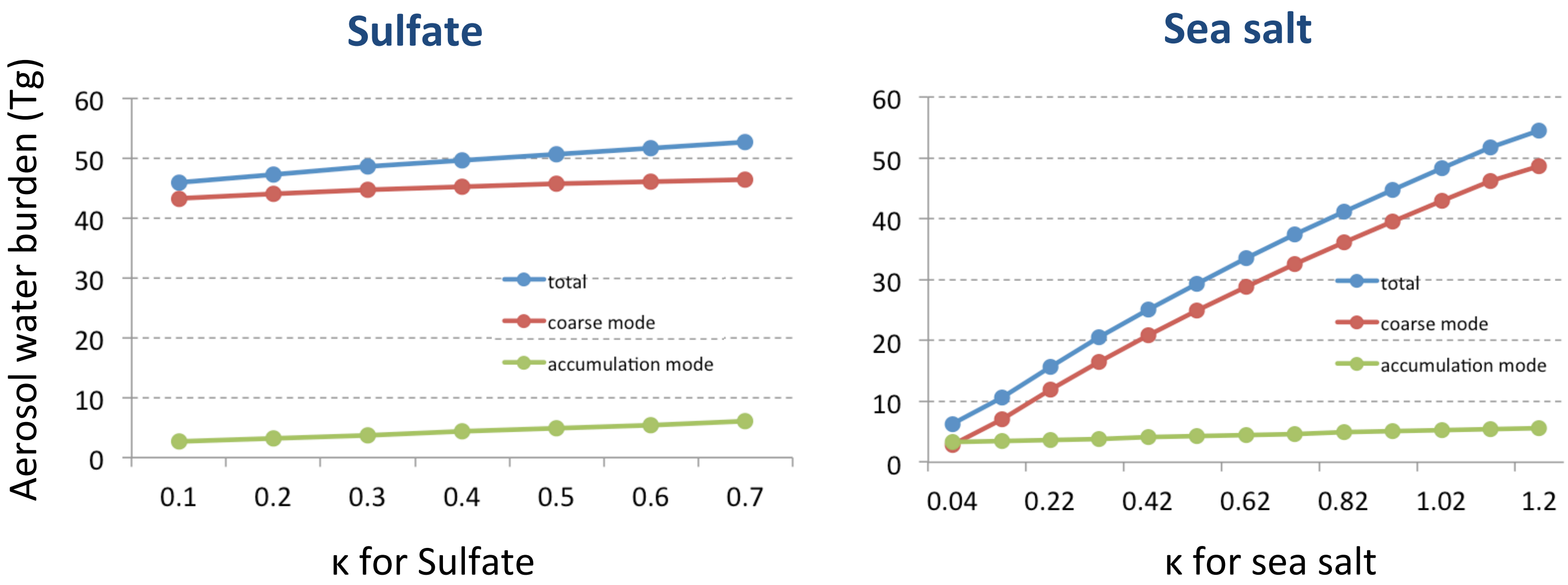
ECHAM5-HAM2: T63L31, year 2000 nudged simulation, PD emission
CAM5: 2°×2.5°, 5-year climatology, PD emission



Computed using the same aerosol dry mass, composition, and dry size

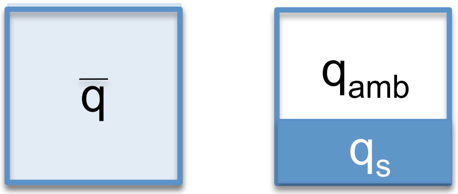
Sensitivity to hygroscopicity

ECHAM5-HAM2, T63L31, year 2000 nudged run
Multiple water uptake calculations using different κ values
(but with the same aerosol mass, composition, and size)



- κ-Koehler theory based method (default κ values: 0.6 for sulfate, 1.12 for sea salt, 0.06 for POA, and 0.037 for SOA)

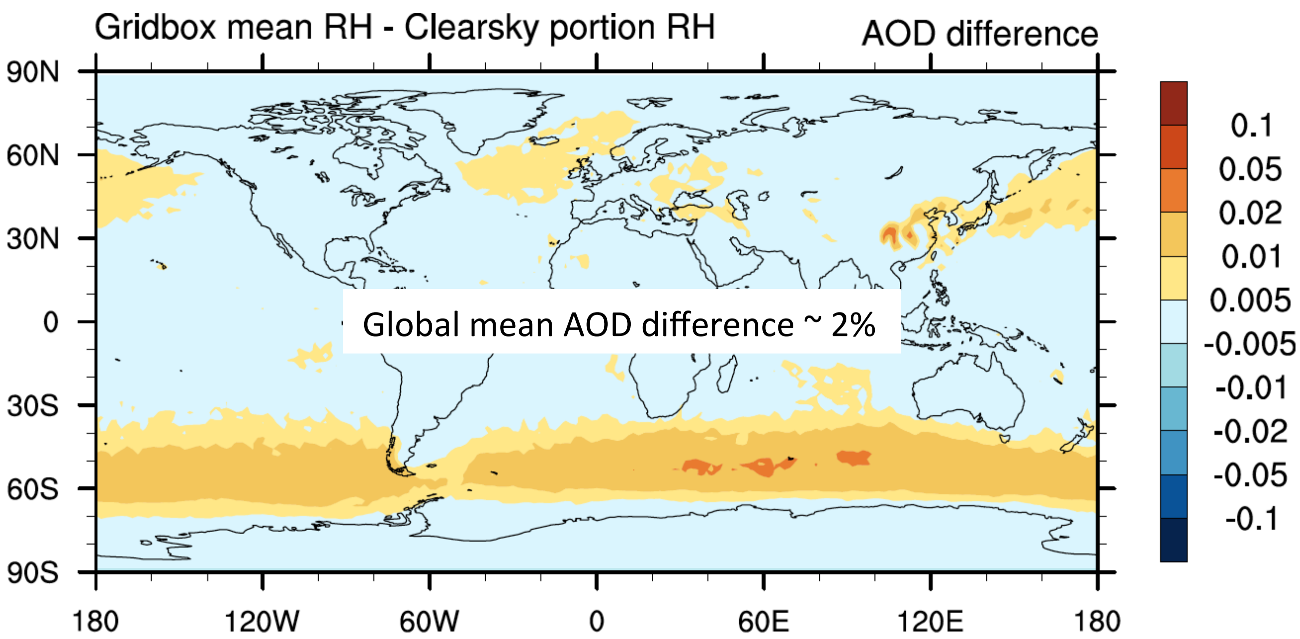
Clear-sky portion RH vs. grid-box mean RH



$$\overline{q} = q^s f^{cl} + q^{amb}(1 - f^{cl})$$

$$RH^{amb} = \frac{q^{amb}}{q^s}$$

Stier et al. (2005)



Global total aerosol water burden difference : ~ 6%

Impact on direct aerosol effect (sulfate)

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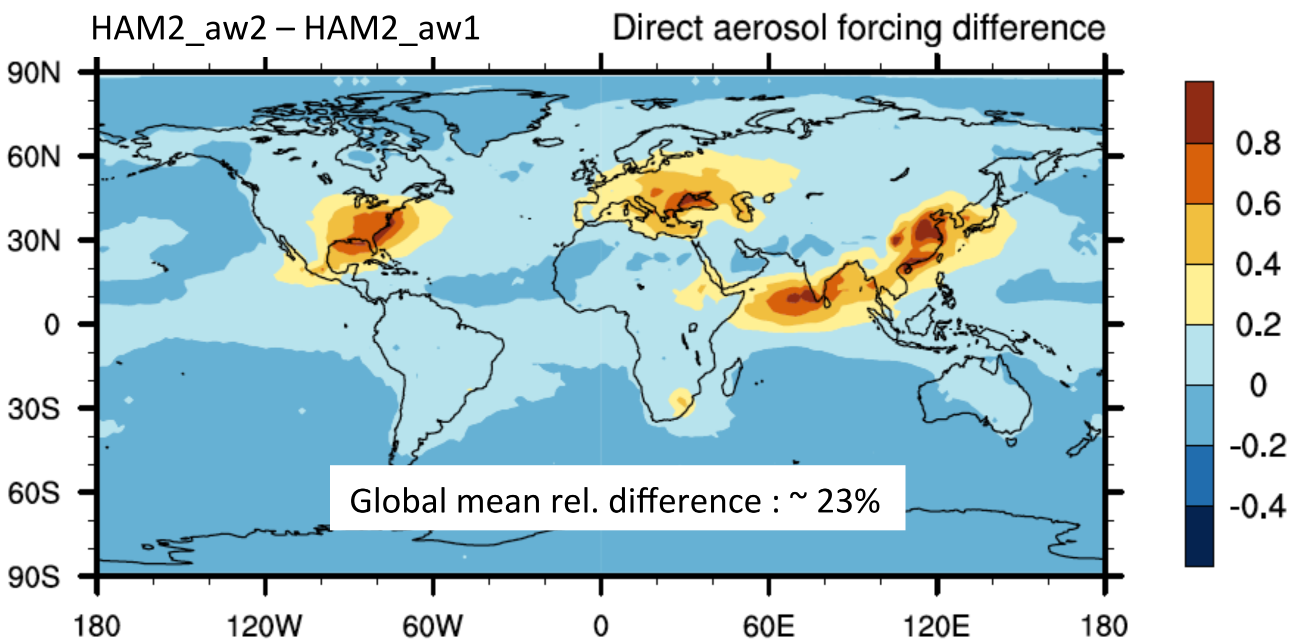
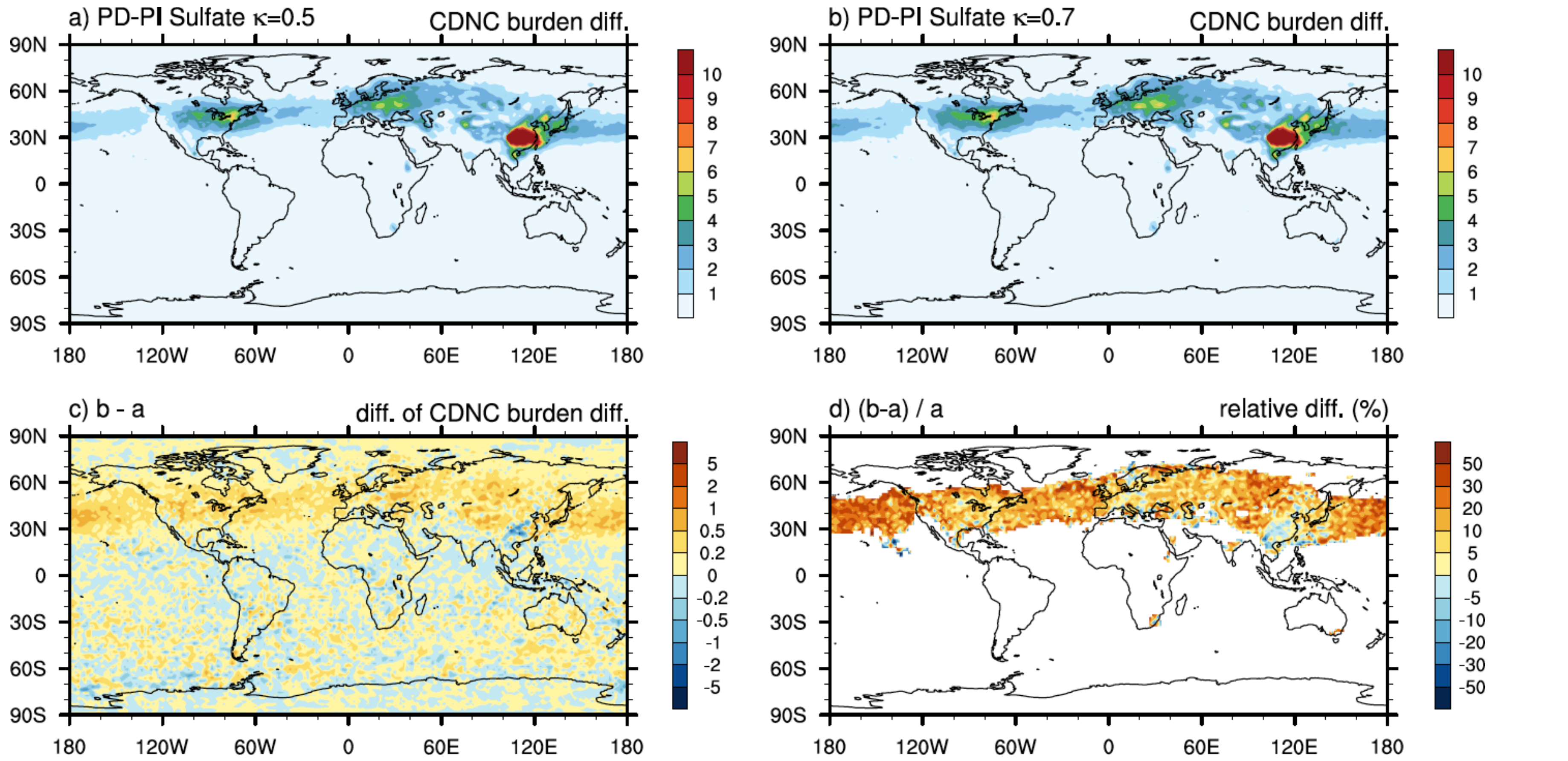


	Model	MEC ($m^2\ g^{-1}$)	RF ($W\ m^{-2}$)	NRF ($W\ m^{-2}$)	NRFM ($W\ g^{-1}$)
Sulfate	HAM2_aw2	9.1	-0.26	-13.2	-119
	HAM2_aw1	8.1	-0.32	-12.3	-150
	AeroCom I	9.1±2.7	-0.35±0.15	-19.0±7.0	-161±41

Impact on aerosol indirect effect



Δ RFP (indirect effect only) : ~ -0.1 W/m^2

Summary

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- Dominant factors :
  - RH ceiling: high non-linearity of aw at higher RH (>90%)
  - Simulated sea salt mass (contributes to >80% water burden)
  - Hygroscopicity
  - Sub-grid variability of RH (Using clear-sky RH reduces water burden by 6%)
- Significant impact on anthropogenic direct aerosol forcing (sulfate).
- Significant impact on CDNC burden, non-negligible impact on simulated indirect aerosol forcing.

Thanks !