Applications and needs of clouds & aerosols in GCMs

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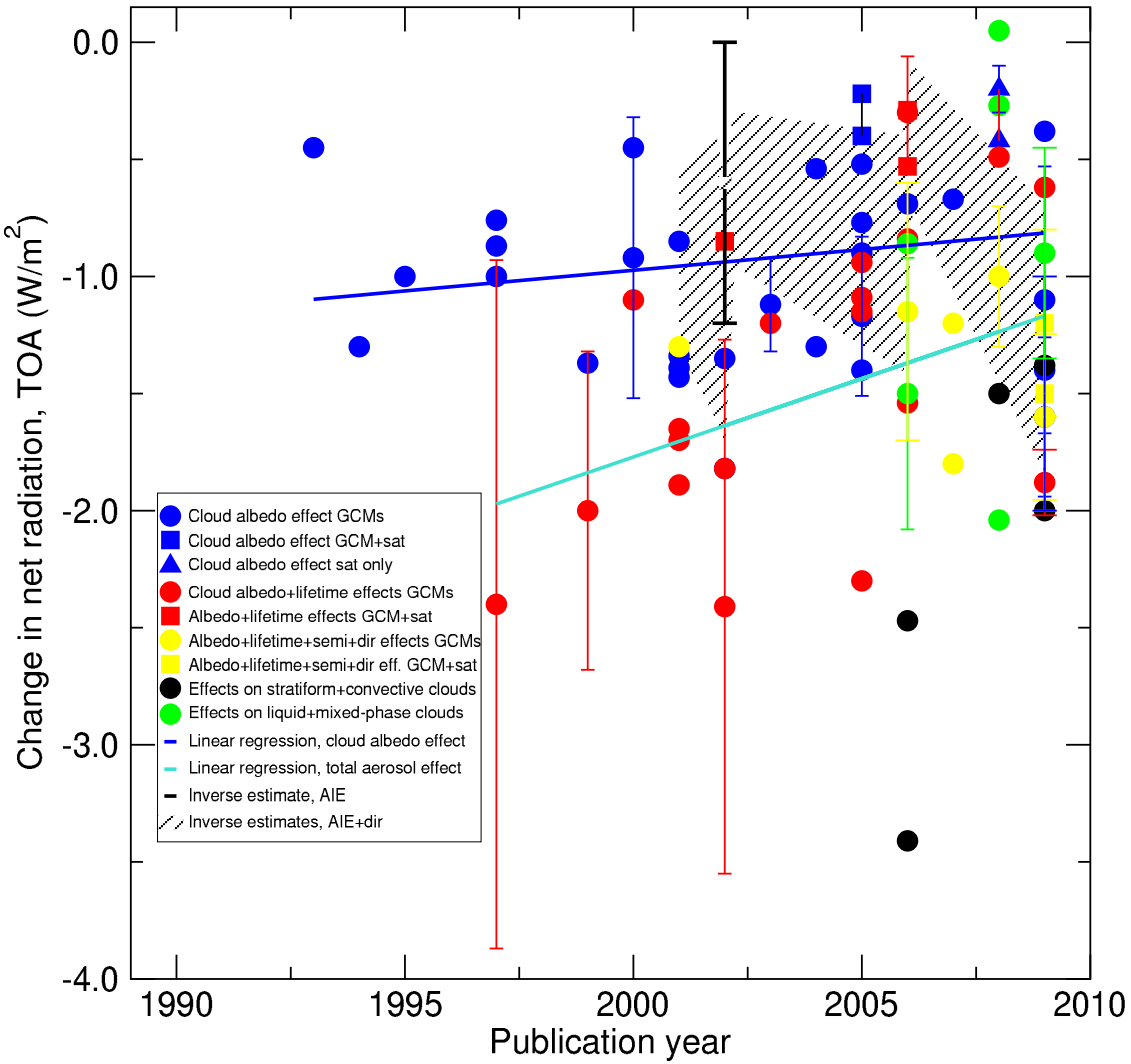
Acknowledgements:
J. Quaas

Published estimates of the aerosol indirect effect

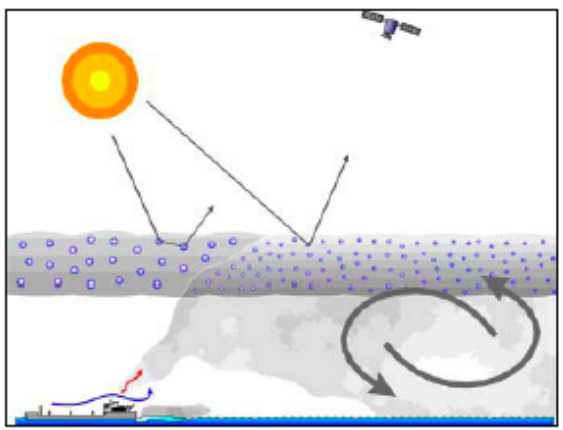
Anthropogenic changes in net radiation at the TOA



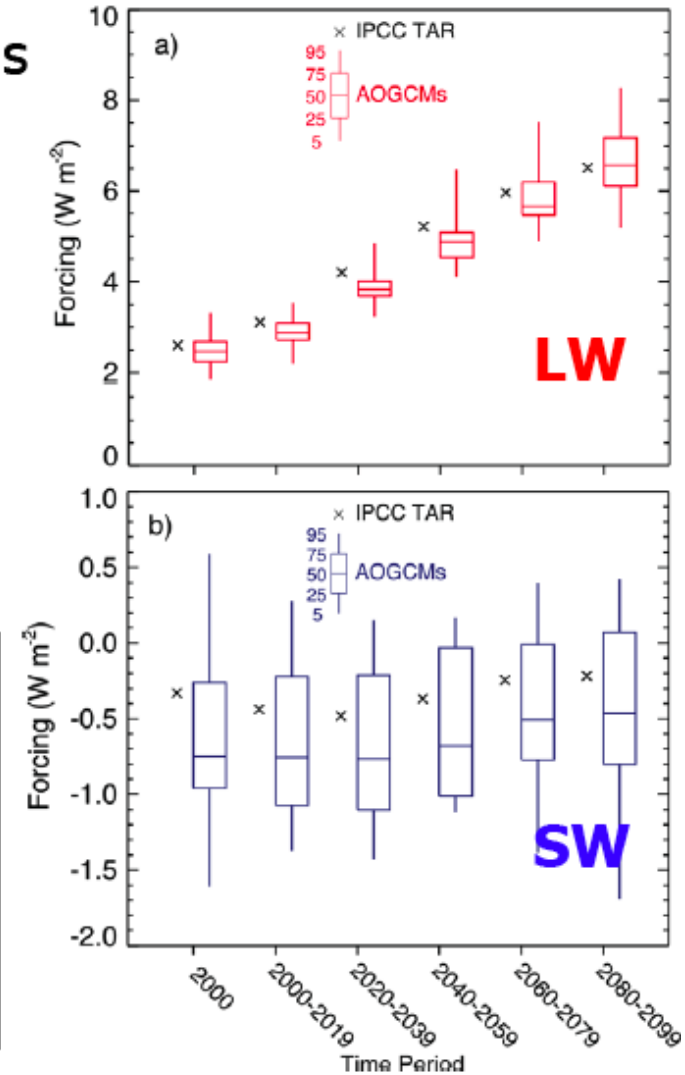
Cloud albedo effect: -0.9 W m^{-2} (Lohmann et al., ACPD, 2009)

IAE in the IPCC AR4 transient simulations

- ✓ Out of 23 models/model versions in Chapter 10 of IPCC AR4, 9 included aerosol indirect effects.
- ✓ 3 models included an online sulfur cycle
- ✓ All except one used empirical relationships to calculate cloud droplet number concentrations (CDNCs)
- ✓ Most models with AIE included 1st AIE only

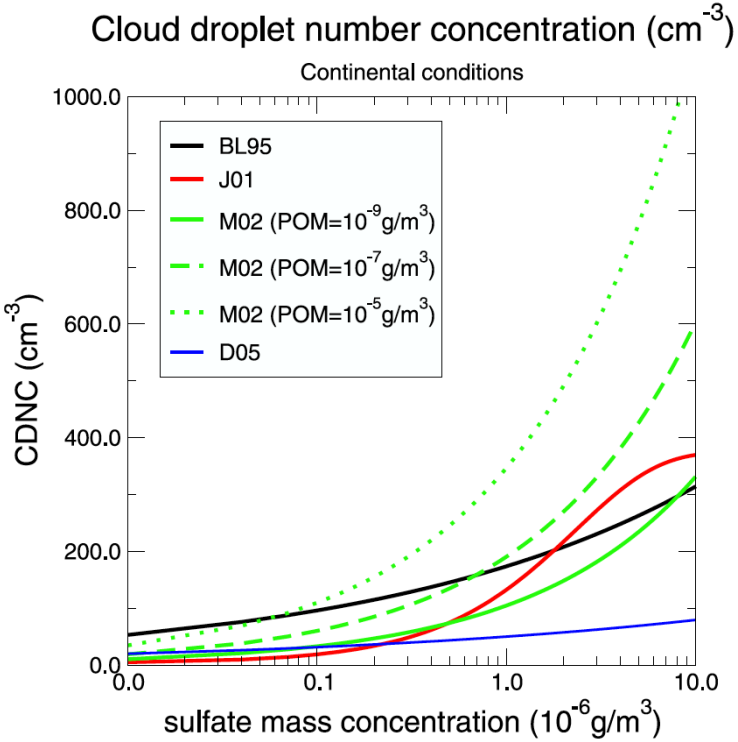


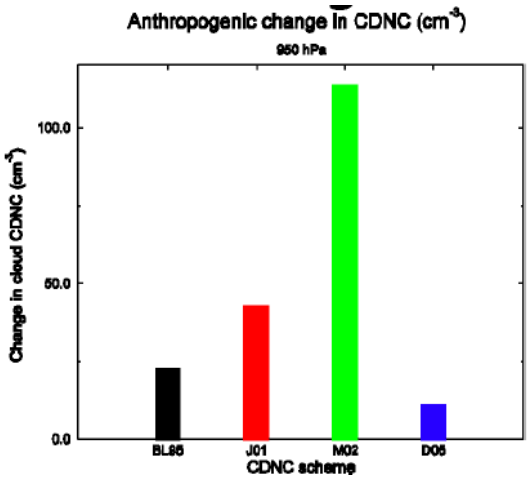
Courtesy of D. Rosenfeld

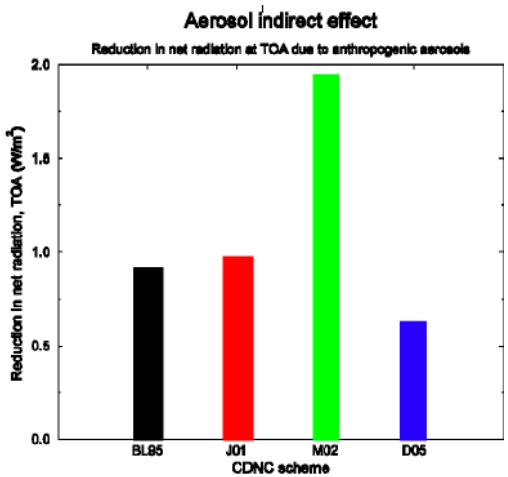


Storelvmo et al., GRL, 2009

IAE in the IPCC AR4 transient simulations



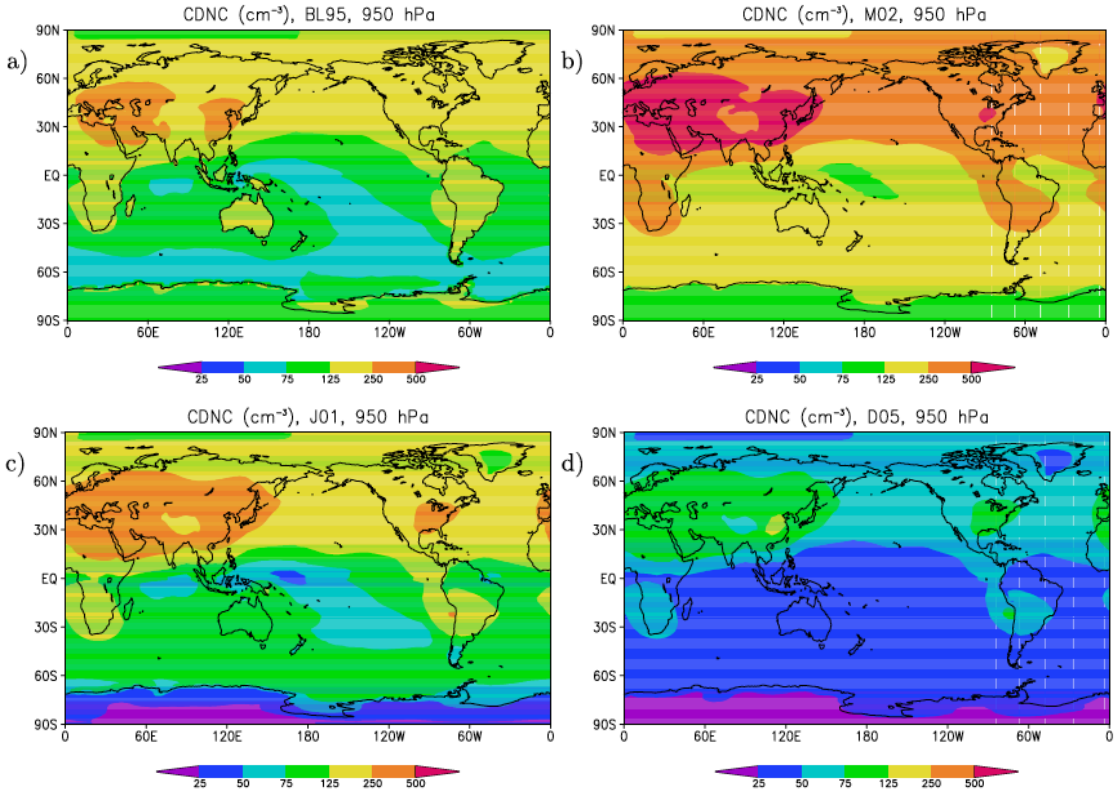


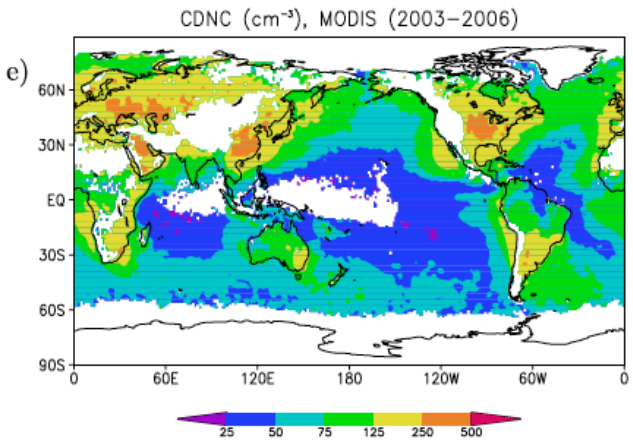


1.3 W m^{-2} of the 2.2 W m^{-2} spread in present-day shortwave forcing can be explained by these different methods to predict cloud droplet number from sulfate aerosols

Storelvmo et al., GRL, 2009

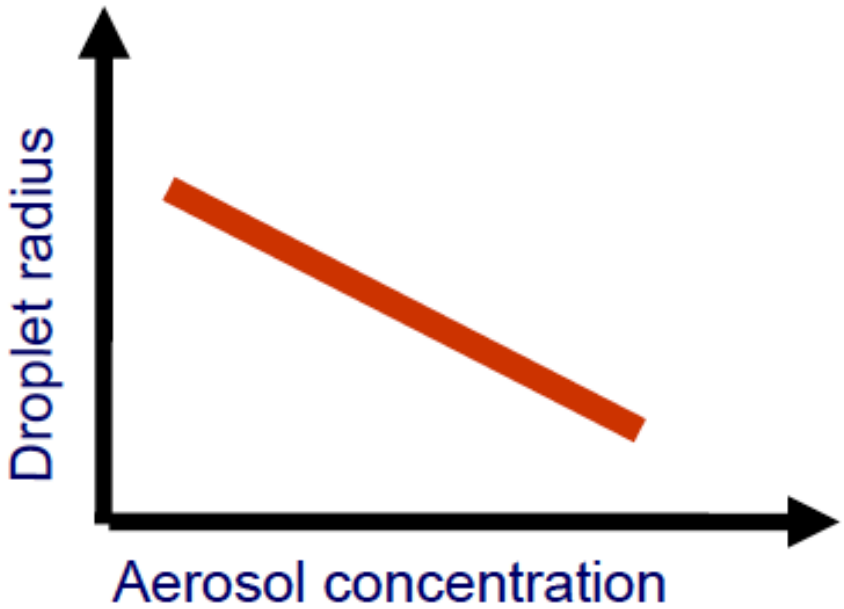
Comparison with observations

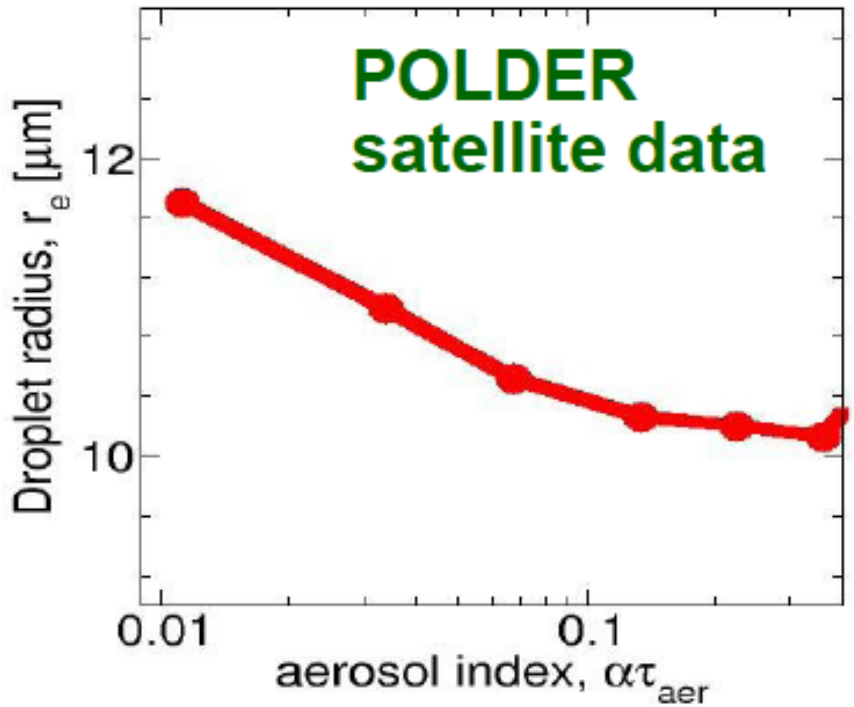




Storelvmo et al., GRL, 2009

Aerosol-cloud interactions from satellites



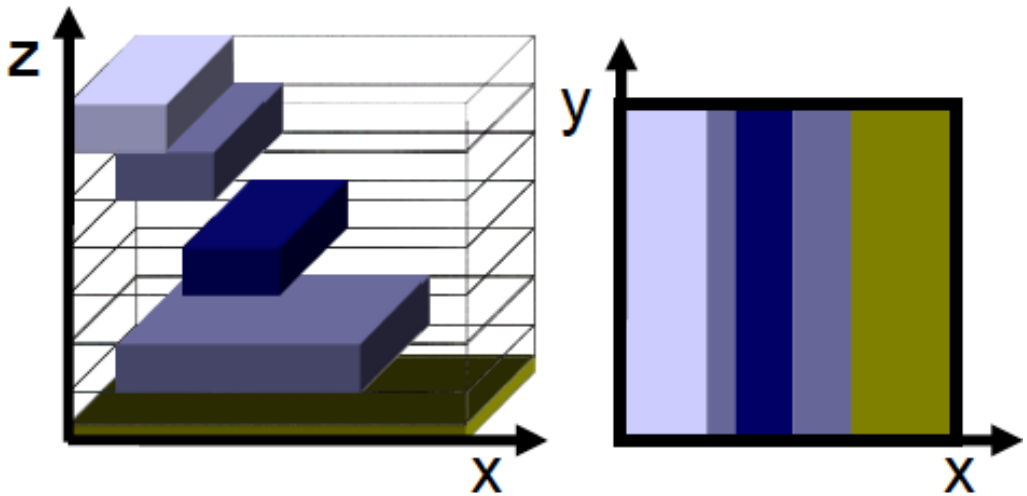


- robust
- relative changes only
- valid in changing climate

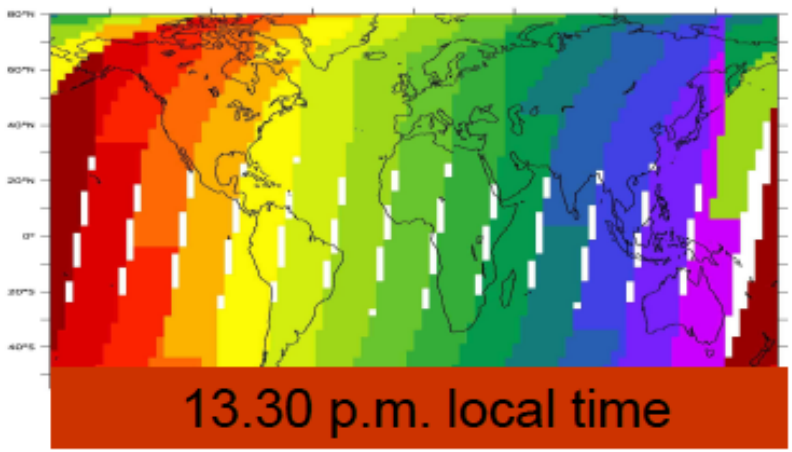
Breon et al., Science, 2002; courtesy: Johannes Quaas

Aerosol-cloud interactions from satellites

- 2D cloud top quantities from 3D cloud field using overlap assumption

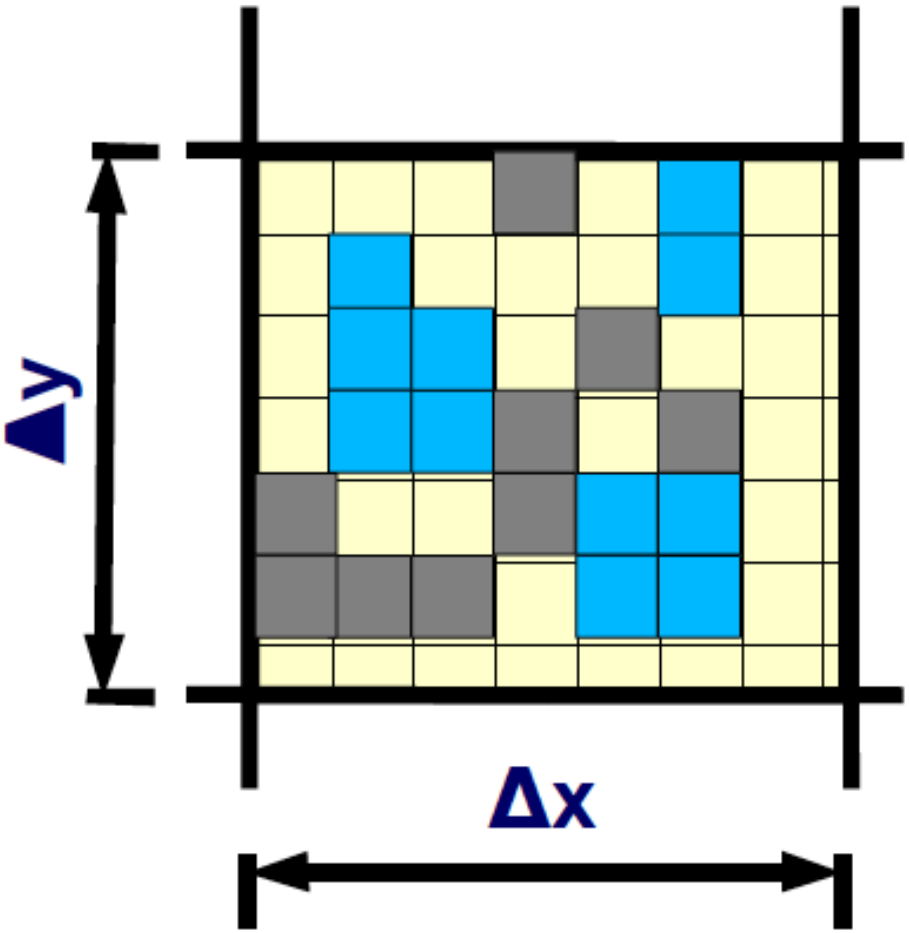


- Sampling of daily fields at satellite overpass time
- Visible clouds only ($\tau_c > 0.3$)



Quaas et al., JGR, 2004

Aerosol-cloud interactions from satellites



Aerosol measurements

Cloud measurements

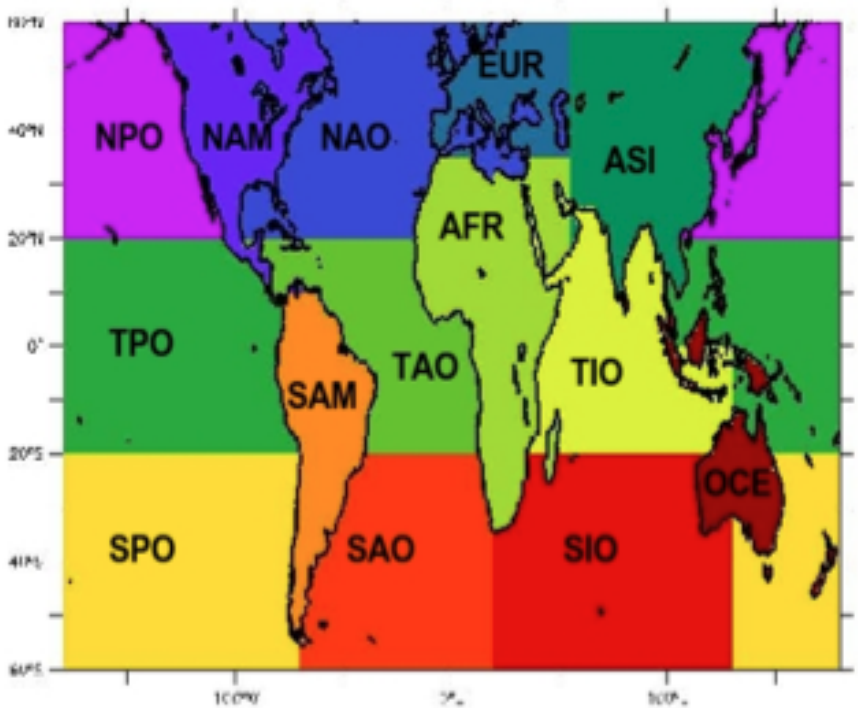
No retrieval

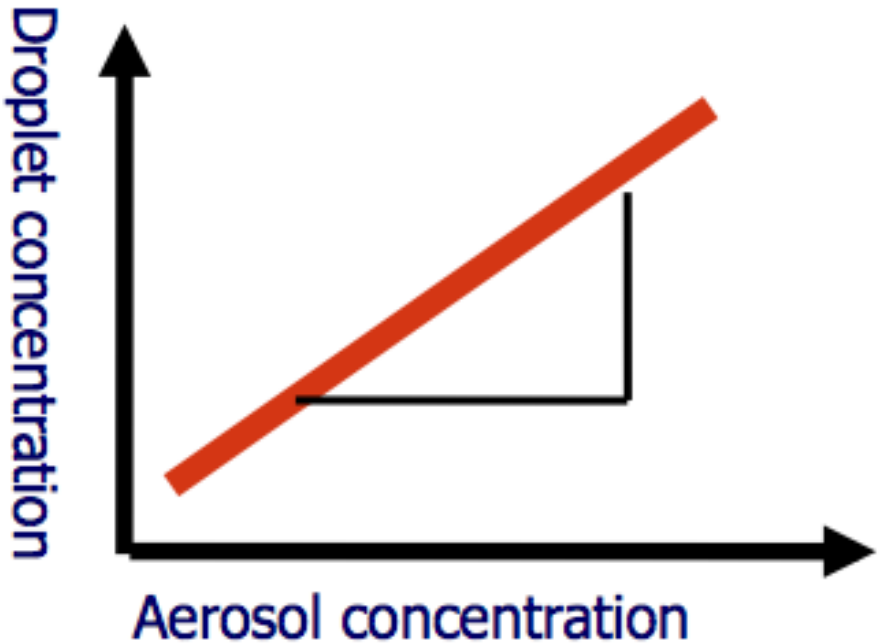
Method adopted:
relate aerosol and cloud quantities within a model gridbox (daily values)

Δx / Δy : model resolution
here: 2.5° x 2.5°

Quaas et al., JGR, 2004

Estimate from satellite data

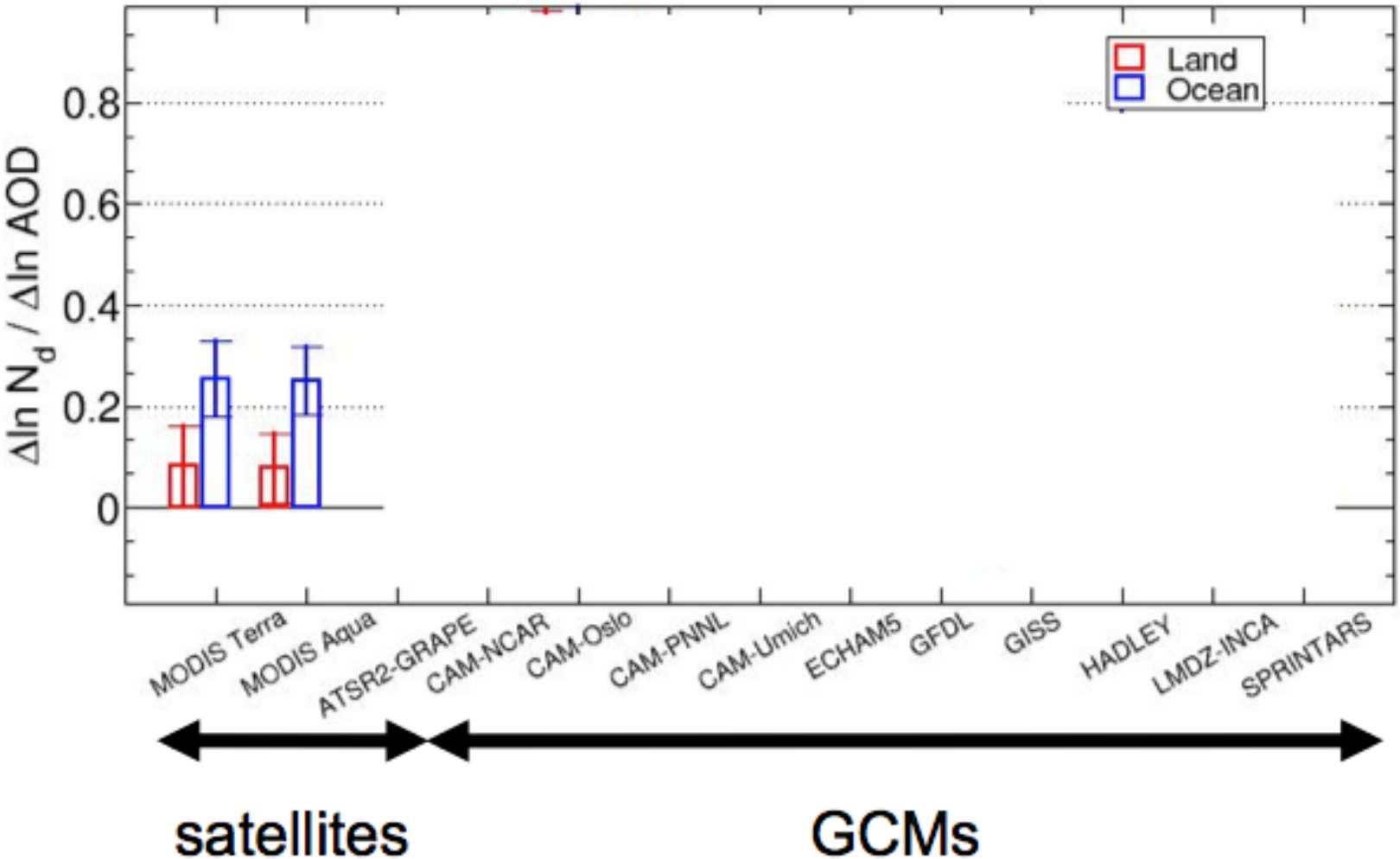




Analyse separately
- 14 different regions
- 4 seasons (MAM,JJA,SON,DJF)

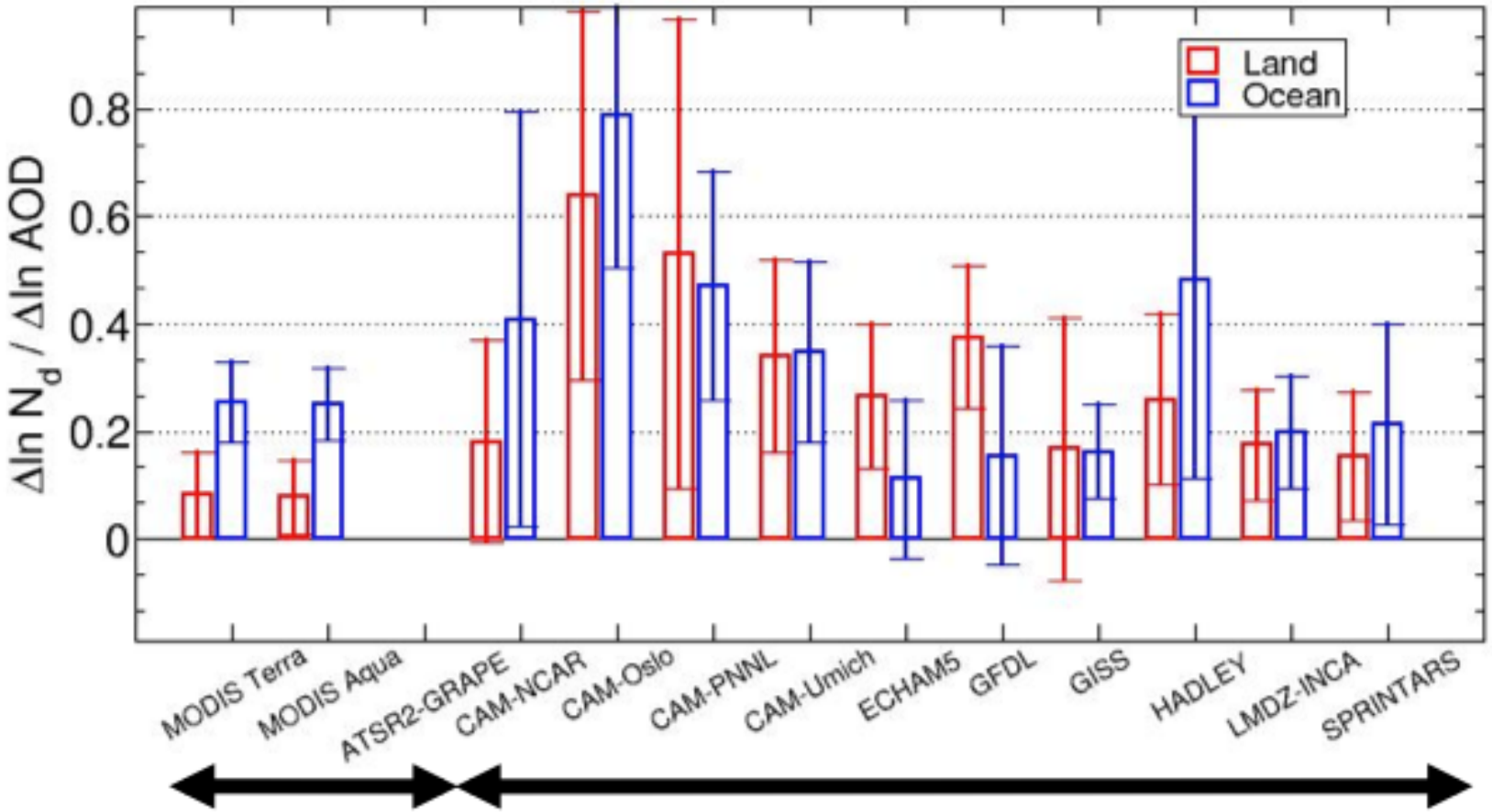
Quaas et al., JGR, 2008

Cloud droplet number concentration (N_d) vs. aerosol optical depth (AOD)

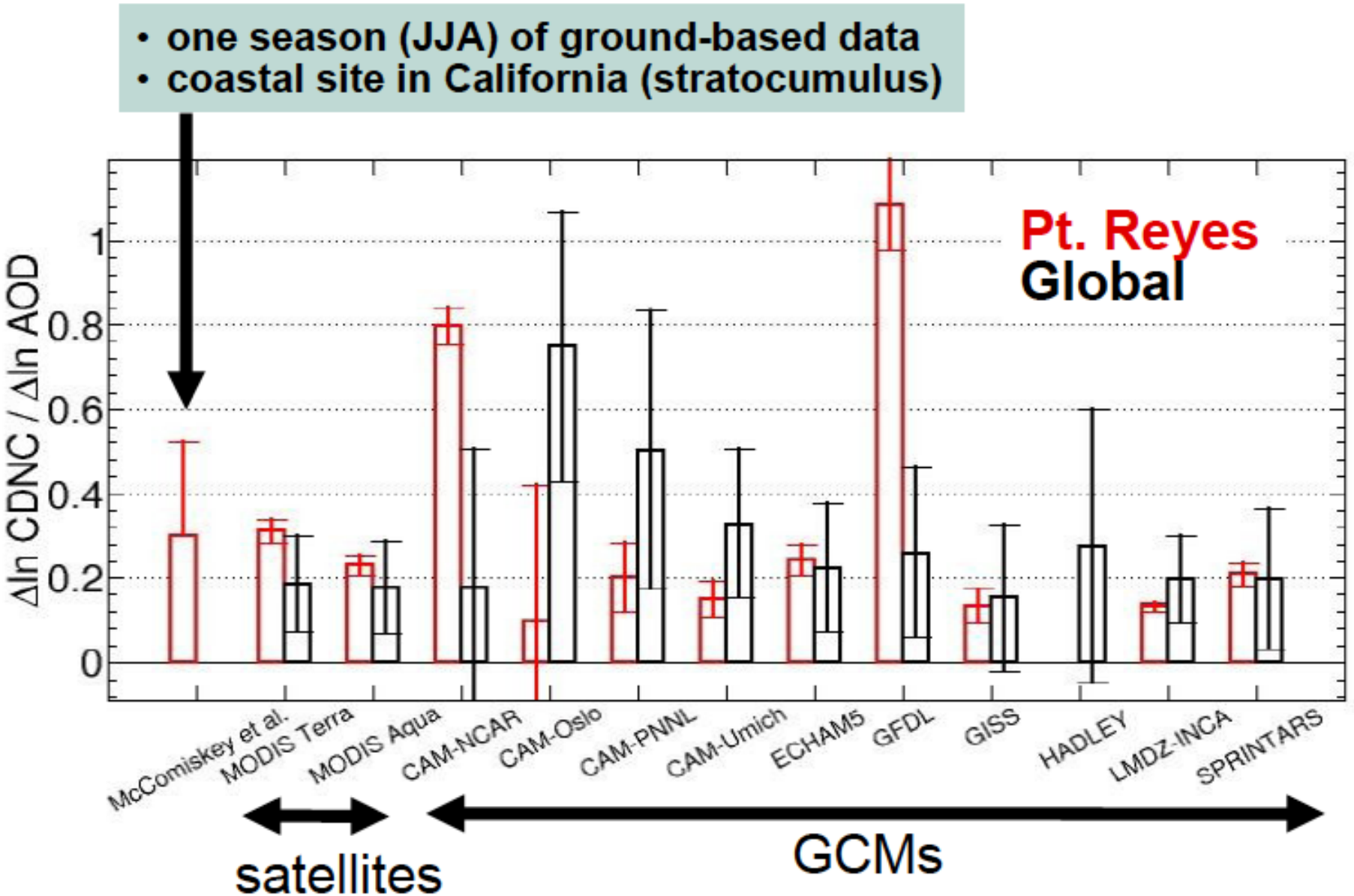


Quaas et al., ACP, 2009

Cloud droplet number concentration (N_d) vs. aerosol optical depth (AOD)

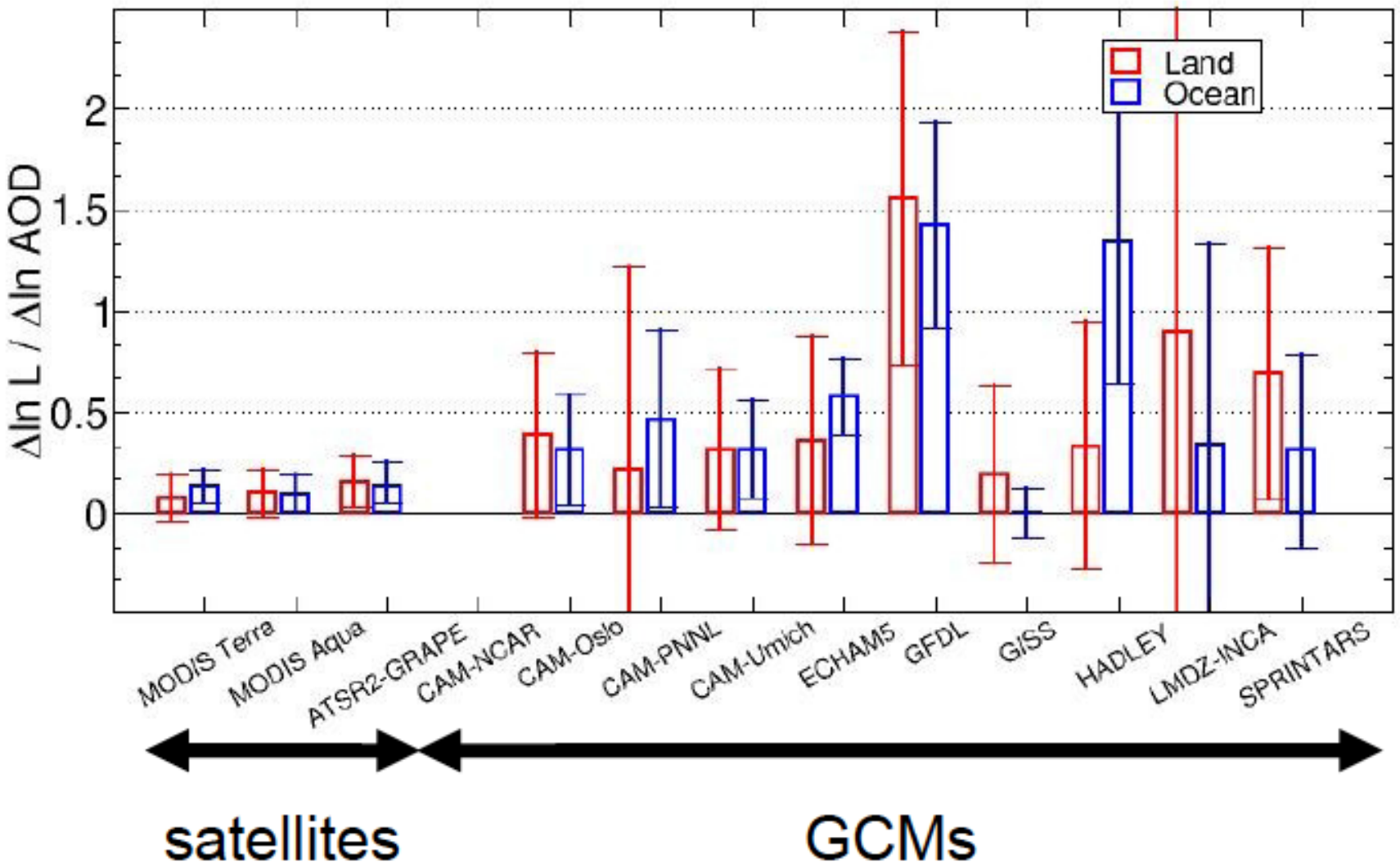


Quaas et al., ACP, 2009



Quaas et al., ACP, 2009

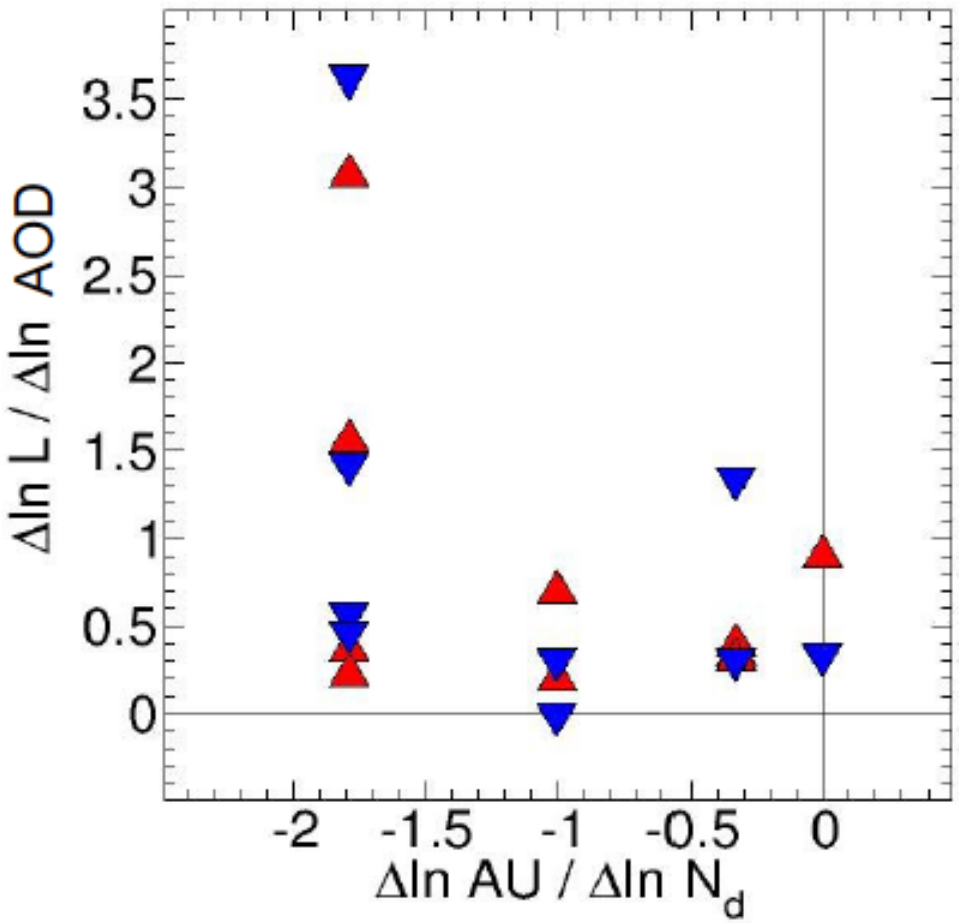
Liquid water path (L) vs. AOD



Quaas et al., ACP, 2009

Second indirect aerosol effect

Second aerosol indirect effect implemented overly simplistic in GCMs



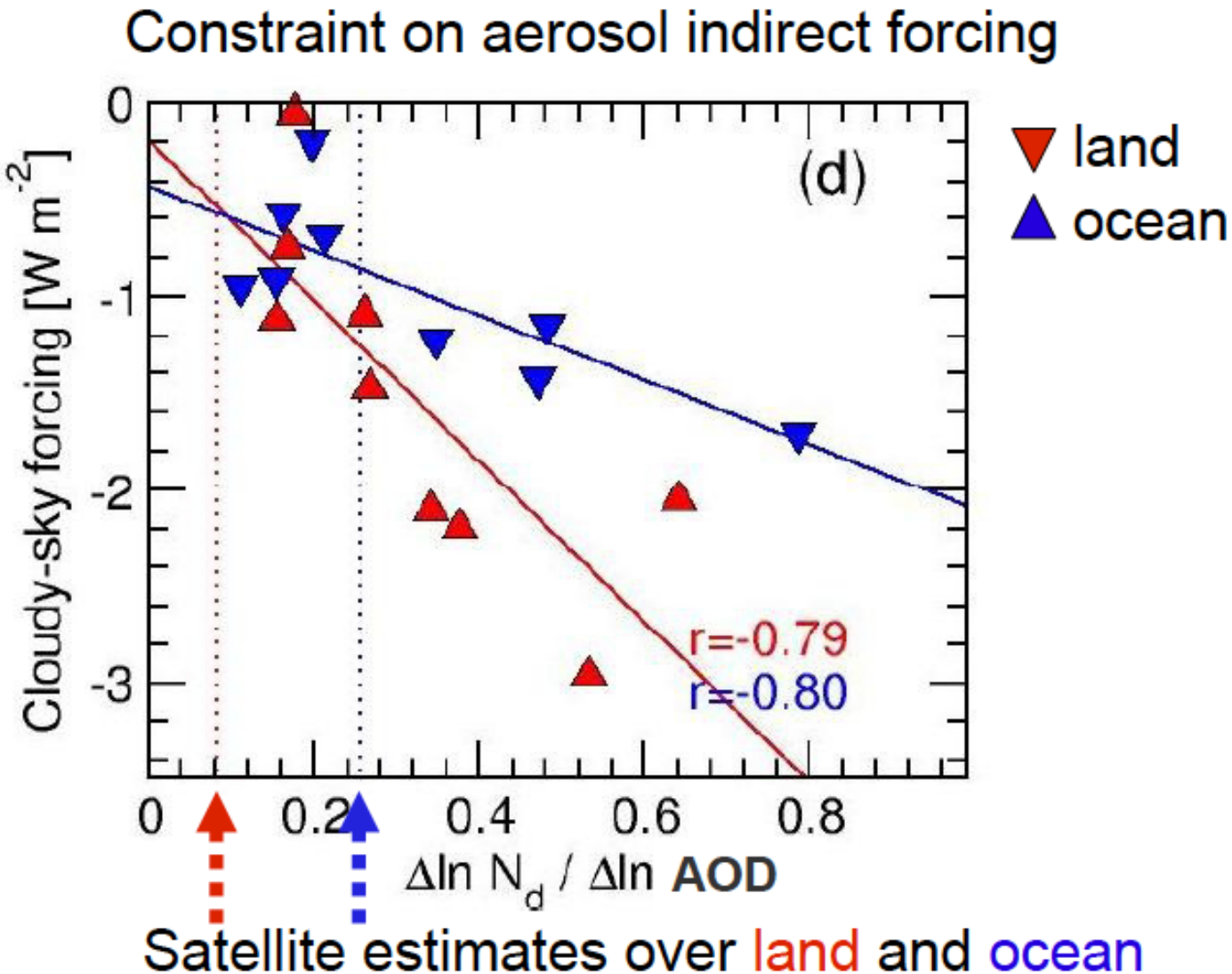
Precipitation by autoconversion (AU) depends on cloud droplet number concentration N_d

$$AU \sim N_d^x$$

$$x \in \{-1.79, -1.0, -0.33, 0\}$$

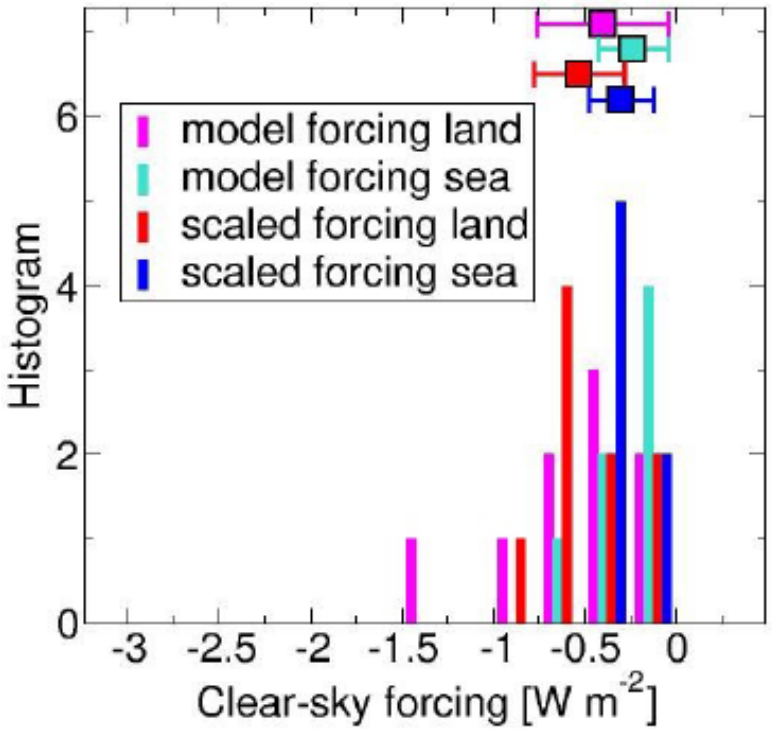
Quaas et al., ACP, 2009

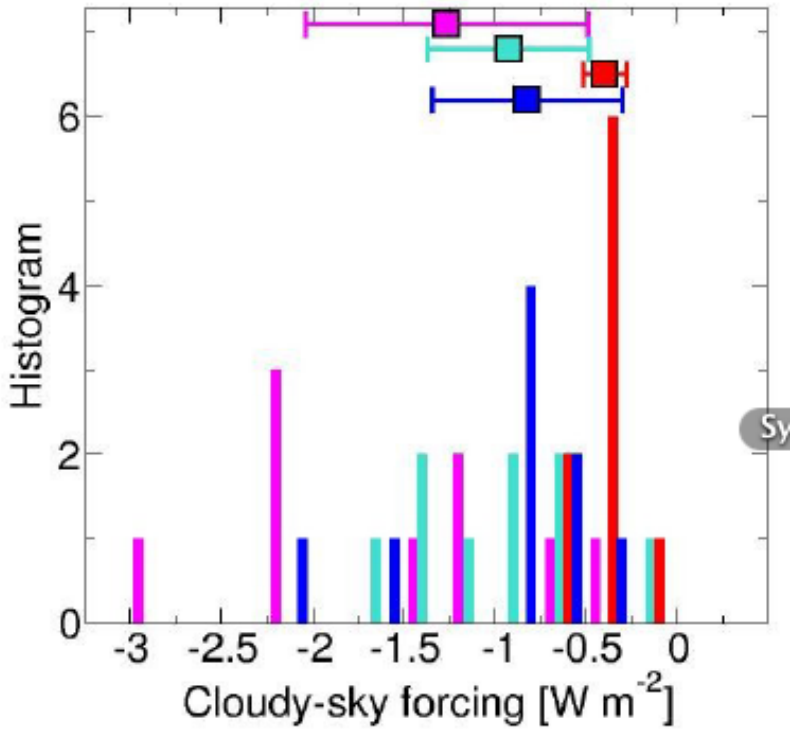
Scaled forcing estimate



Quaas et al., ACP, 2009

Scaled forcing estimate

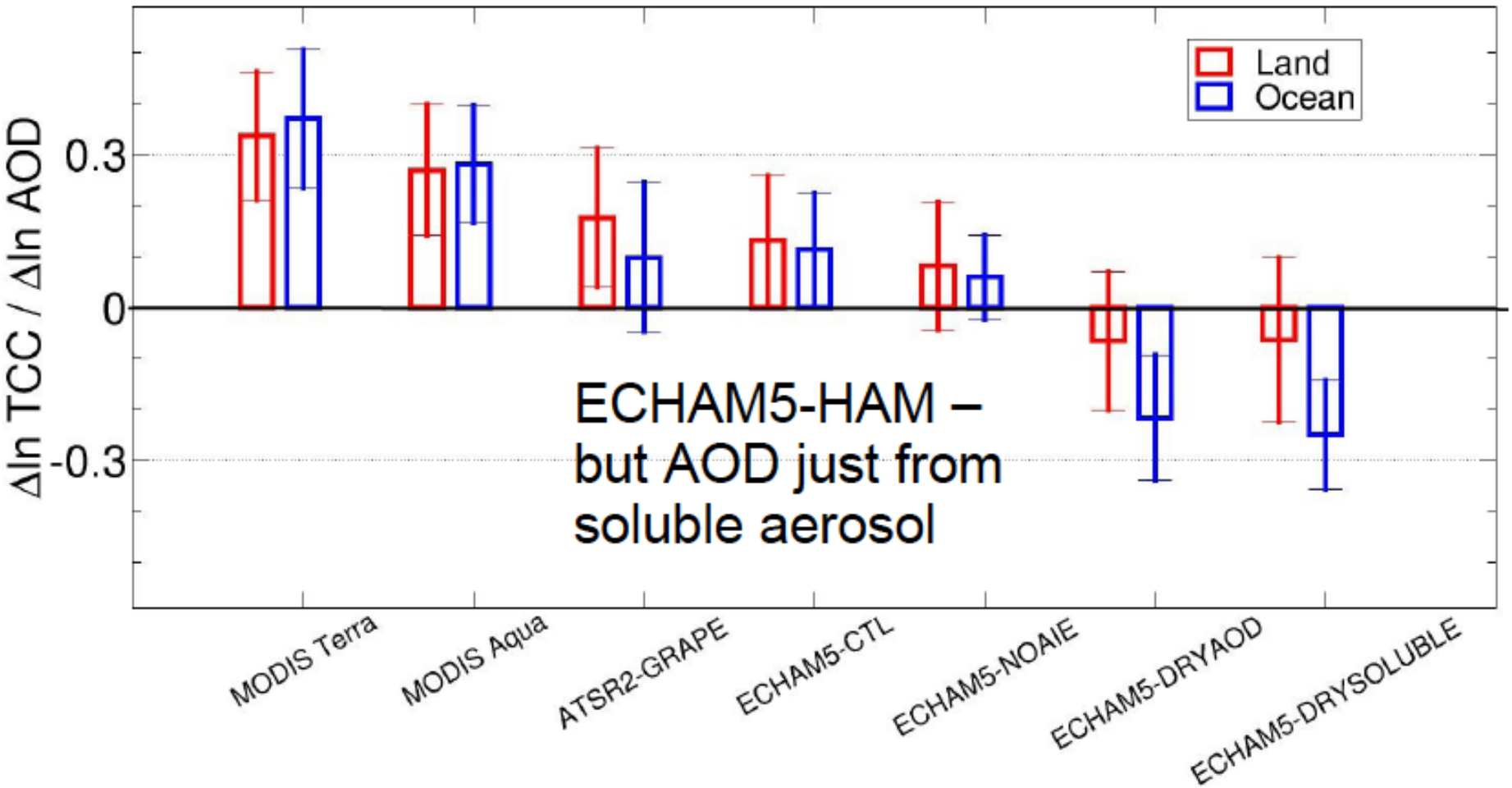




estimate	modelled	scaled
clear	**-0.27±0.23**	**-0.38±0.19**
cloudy	**-1.13±0.51**	**-0.70±0.37**
total	**-1.53±0.60**	**-1.15±0.43**

Quaas et al., ACP, 2009

Relationship total cloud cover - AOD



Quaas et al., ACPD, 2009

Conclusions

- The cloud droplet number conc. - AOD relationship is better captured over the oceans
- Second indirect effect in terms of autoconversion yields a too strong liquid water path - AOD relationship
- Scaled forcing estimate:
  - Clear sky (direct effect): -0.4$\pm$0.2 W m^{-2}
  - Cloudy sky (indirect effect): -0.7$\pm$0.4 W m^{-2}
- The cloud cover - AOD relationship is mostly attributable to aerosol swelling

Needs

Table 1. Physical parameters related to aerosols, clouds, and dynamics needed to evaluate parameterizations of aerosol indirect effects.

Parameter	Description	Typical value or range	
N_a	Aerosol number concentration	10^6–10^{11} m^{-3}	Aerosols
SD_a	Aerosol size distribution	Lognormal	
SF_a	Soluble fraction of aerosol population	0–1	
AT	Aerosol type	—	
SSA	Single-scattering albedo	0.6–0.99	
BC(z)	Position of black carbon w.r.t. the cloud	Above/in/below	Clouds
CC	Cloud cover	0–1	
N_d	Cloud droplet number concentration	10^6–10^{10} m^{-3}	
N_i	Ice crystal number concentration	10^2–10^9 m^{-3}	
SD_d	Cloud droplet size distribution	Lognormal or gamma distribution	
SD_i	Ice crystal size distribution	Lognormal or gamma distribution	
LWC	Liquid water content	0–10^3 kg m^{-3}	
IWC	Ice water content	0–10^3 kg m^{-3}	
AU	Autoconversion rate	0–10^{-6} kg kg^{-1} s^{-1}	
ω	Vertical wind speed	–10 to 10 m s^{-1}	Environ-ment
RH	Relative humidity	20%–100% (up to 170% w.r.t. ice)	
TKE	Turbulent kinetic energy	0–10 m^2 s^{-2}	
T	Temperature	210–273 K	

Lohmann et al., BAMS, 2007

Needs

TABLE 2. Attribution of the parameters listed in Table 1 to the evaluation of the different aerosol indirect effect mechanisms, including the required data resolution.

Evaluation	Aerosols	Clouds	Large-scale environment	Required resolution (x, z, t)
Cloud albedo effect	N_a, SD_a, SF_a, AT	N_d, SD_d, LWC, CC	w, RH	1 km, 100 m, 1 h
Cloud lifetime effect	—	N_d SD_d, LWC, AU, CC	TKE	1 km, 100 m, 1 h
Semi-direct effect	N_a, SSA, BC(z)	LWC, CC	RH	10 km, 1 km, 6 h
Aerosol effects on mixed-phased and ice clouds	N_a, SD_a, SF_a, AT	N_i, SD_i, IWC, CC	w, RH, T	1 km, 100 m, 1 h

Lohmann et al., BAMS, 2007