Estimate of aerosol indirect radiative forcing by combining satellite data and global models

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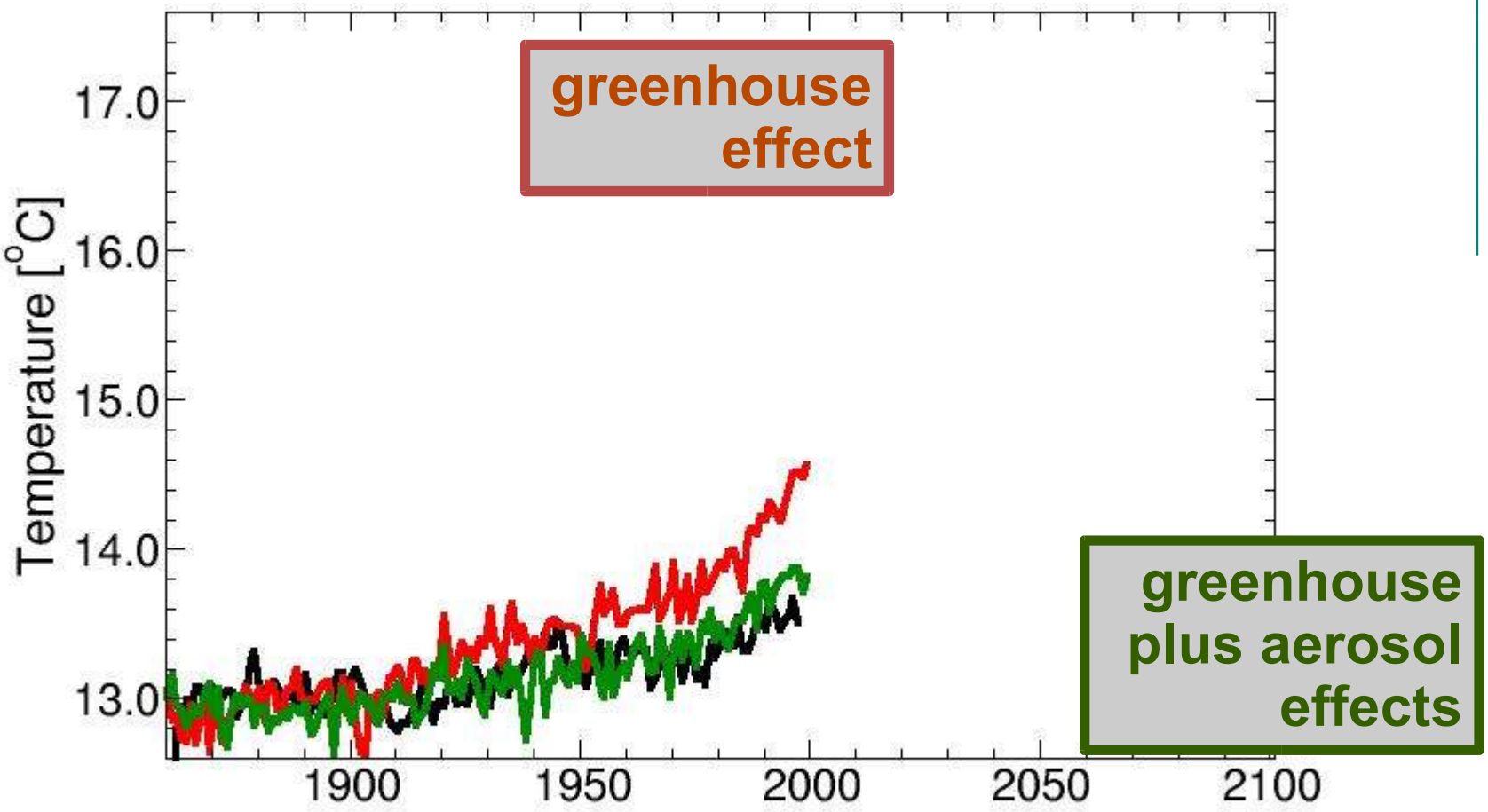
[4]Eidgenössische Technische Hochschule, Zürich

Outline

1. **Motivation**
2. Fitting **satellite-derived cloud-aerosol relationships** in GCMs
   a) **Cloud albedo effect** in LMDZ: droplet radius – aerosol concentration
   b) **Combined indirect effect** in LMDZ and ECHAM: CDNC – AOD
3. **Outlook**: Future requirements

Importance of aerosol indirect radiative forcing: **Climate sensitivity**



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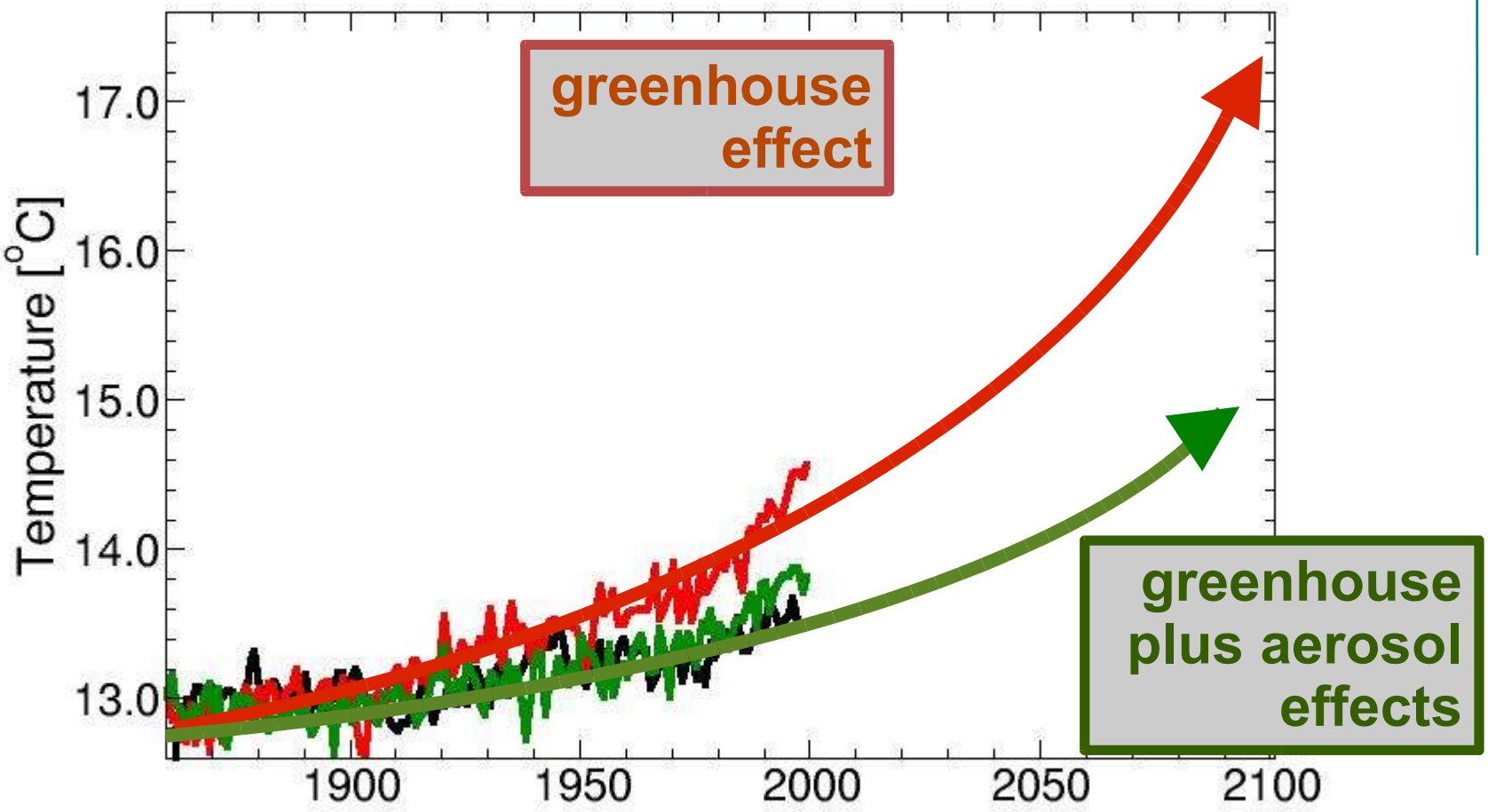

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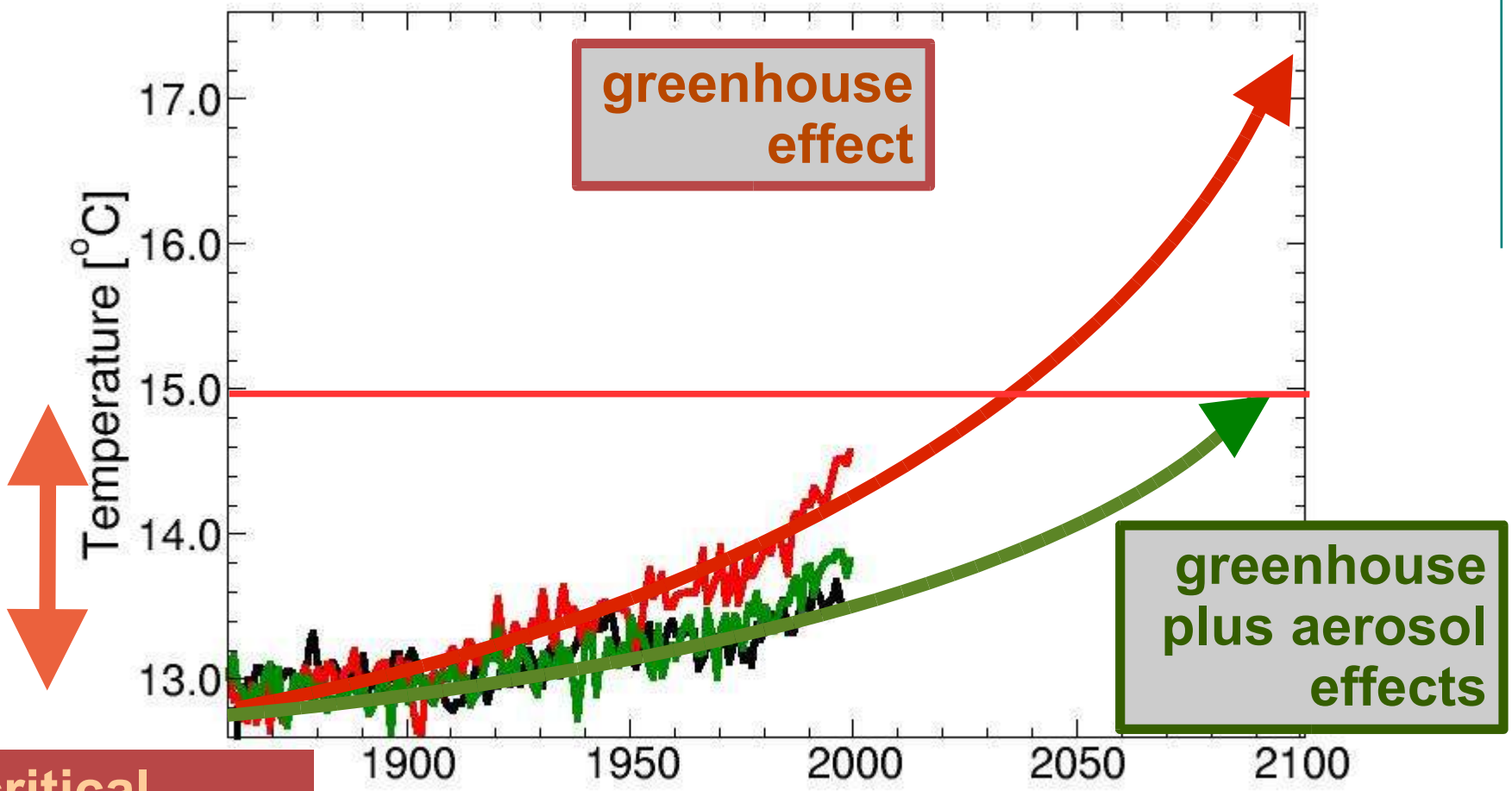

critical value: +2°C

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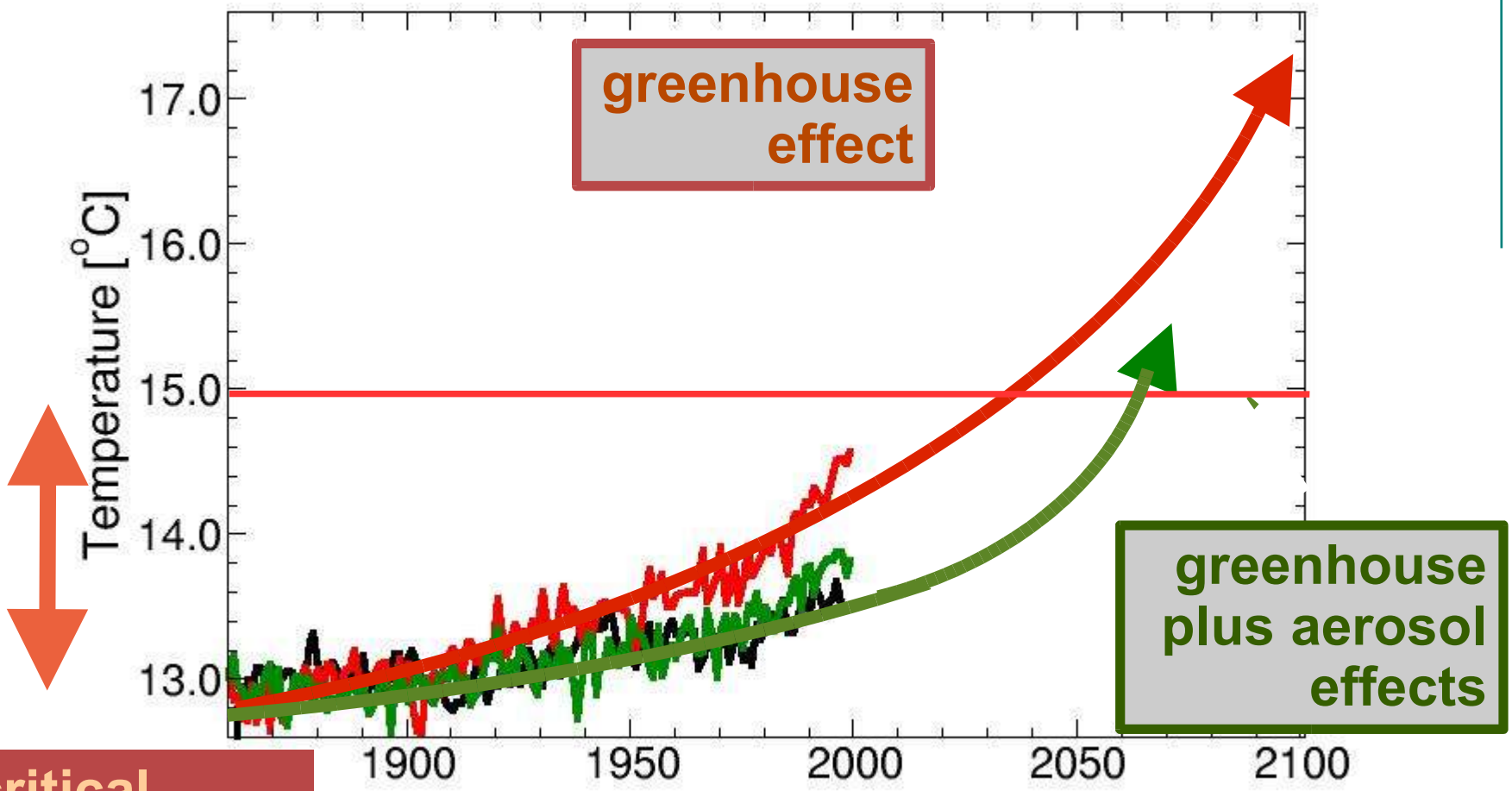
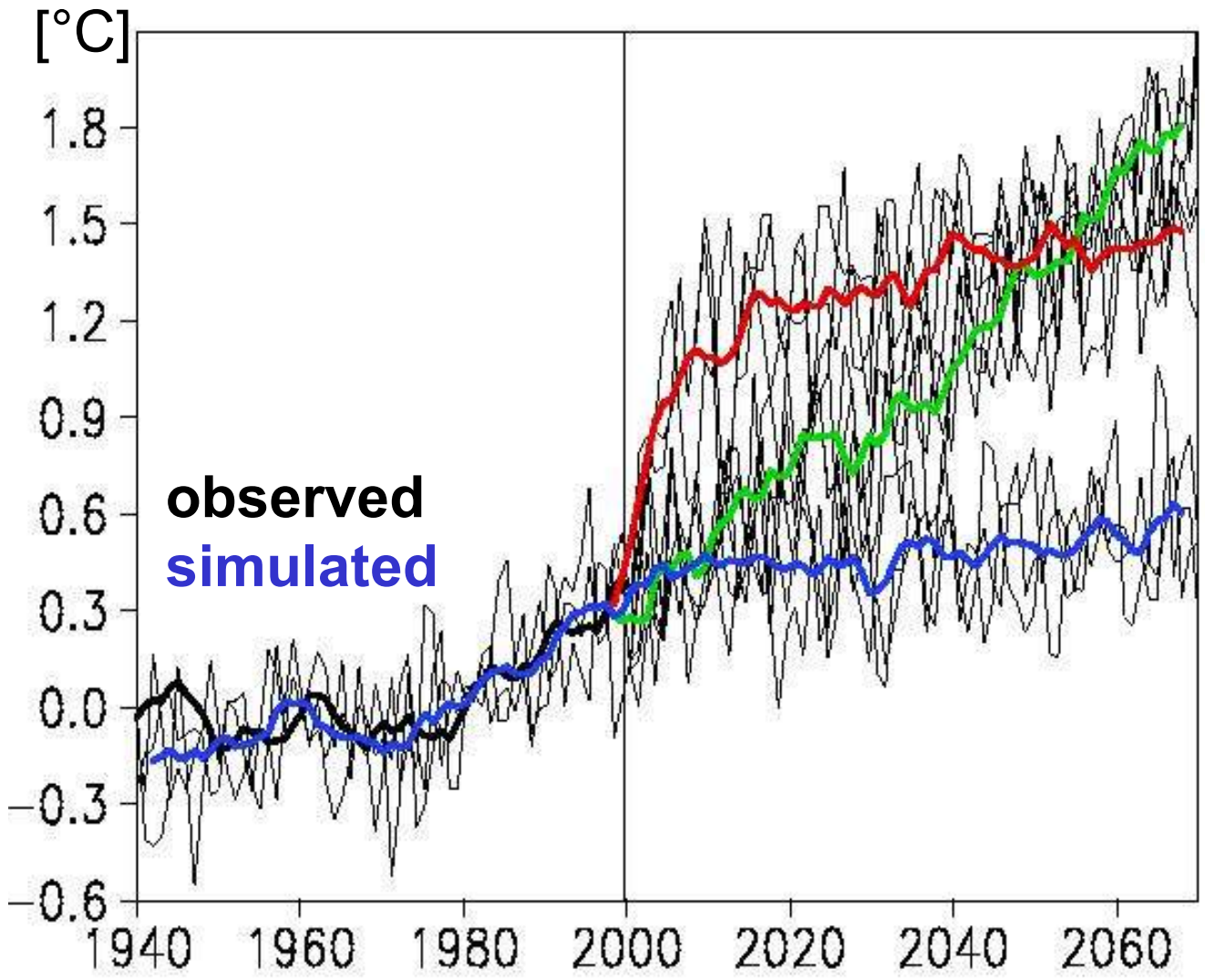


critical value: +2°C

e.g., Dufresne et al., GRL 2005

Global annual mean surface air temperature (deviation from 1961-1990)

Max-Planck-Institut für Meteorologie
Max Planck Institute for Meteorology

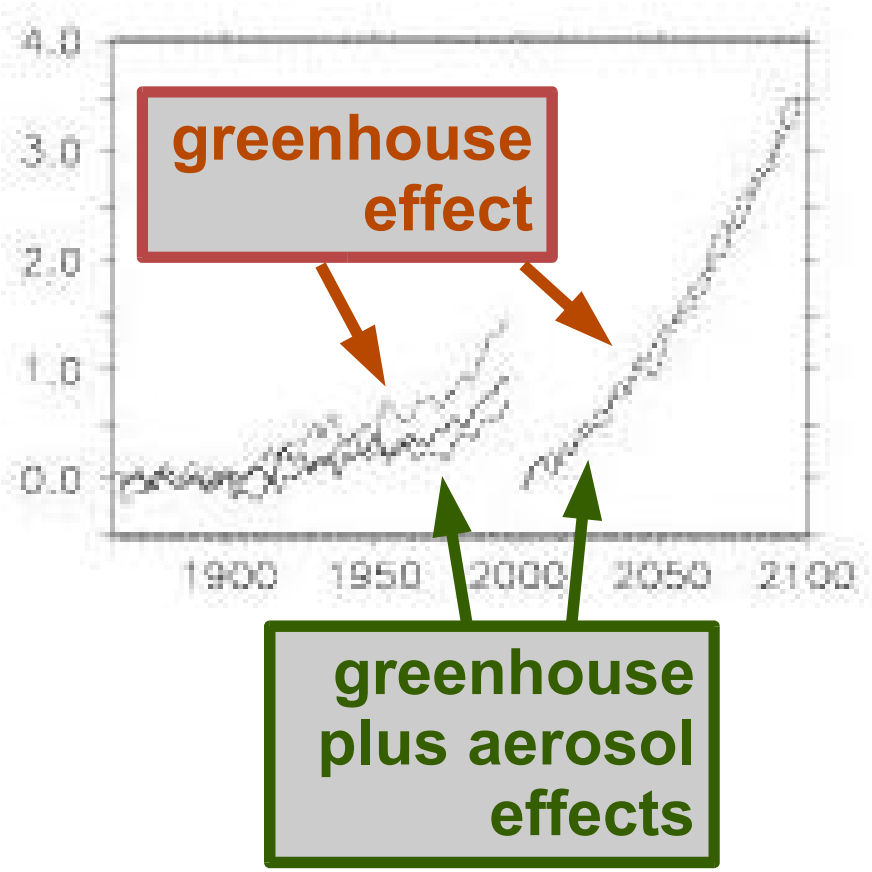


SRES B1

GHG‘s = const
SO4 (anthr.)=0

Constant concentrations (GHG‘s + SO4)

Brasseur and Roeckner, submitted to GRL



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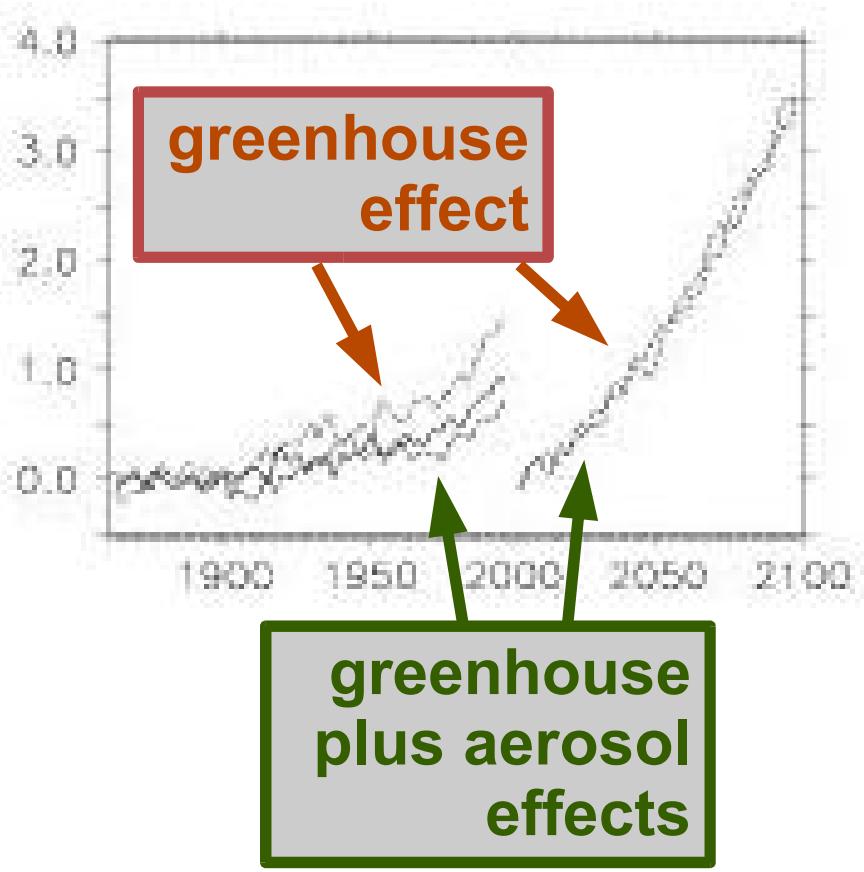

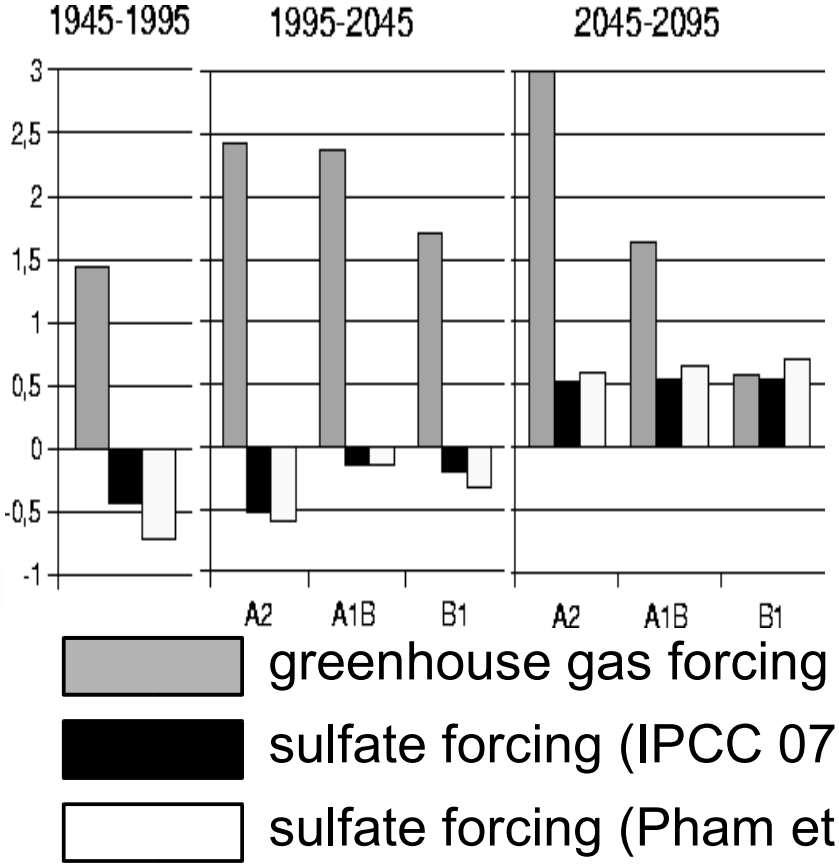

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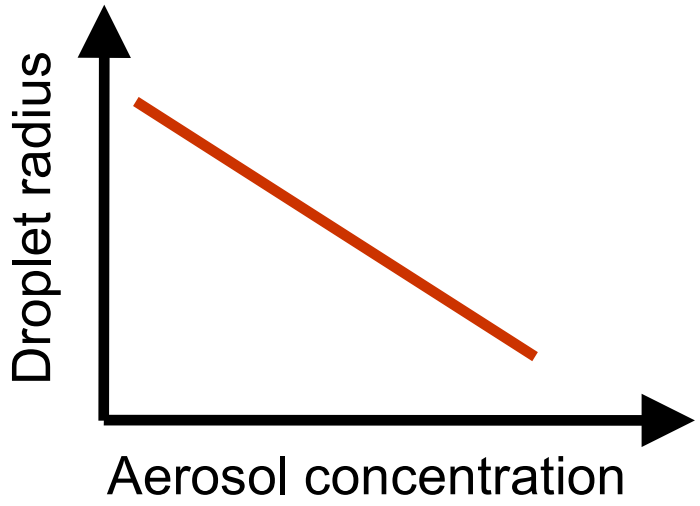
Approach to a better understanding: **Statistical relationship of cloud and aerosol properties**



- robust
- relative changes only
- valid in changing climate

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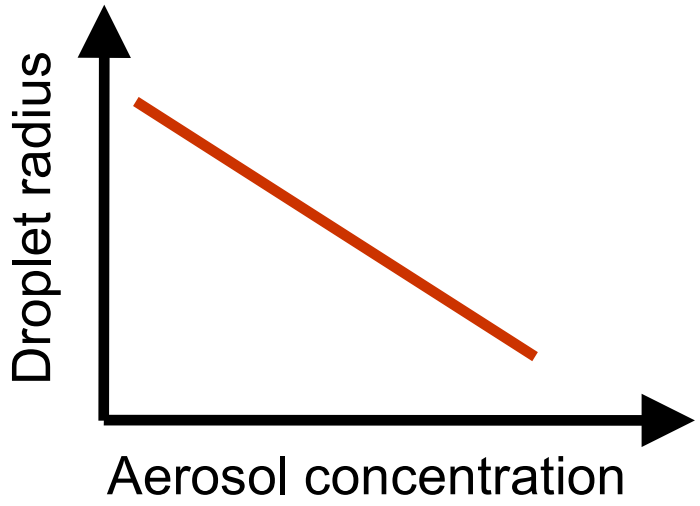

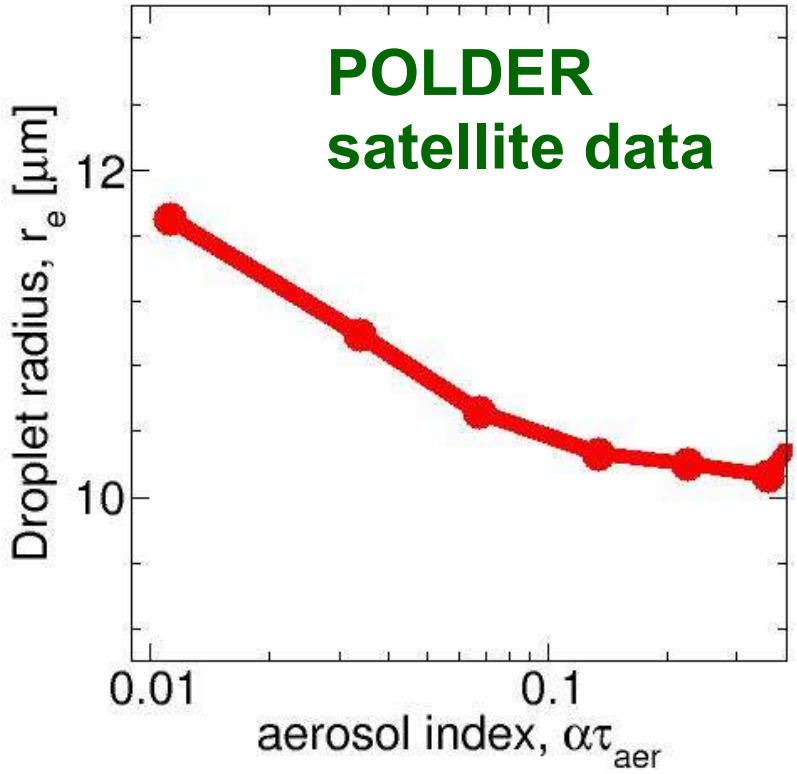

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Bréon et al., Science 2002; Quaas et al., JGR 2004

Parameterization of the indirect effects: **Empirical link between CDNC and aerosol concentration**

$$N_d = \exp (a_0 + a_1 \ln m_{aer})$$

N_d : Cloud droplet number concentration (CDNC; cm^{-3})

m_{aer} : aerosol mass concentration ($\mu g\ m^{-3}$)

Boucher and Lohmann, Tellus 1995

Parameterization of the indirect effects: **Empirical link between CDNC and aerosol concentration**

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originally: aircraft data

- ~10^2 datapoints
- regional data
- limited time-series
- in-situ

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- ~10^2 datapoints
- regional data
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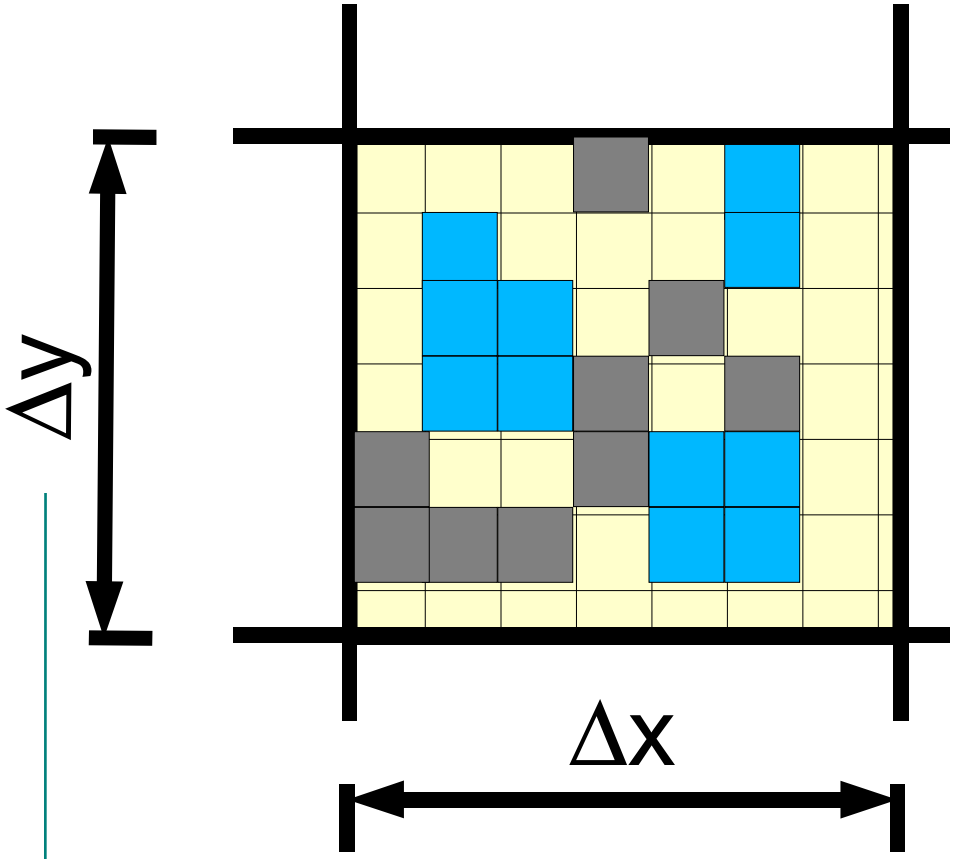
here: satellite data

- ~10^7 datapoints
- globally distributed
- long time-series
- no vertical resolution yet
- assumption on cloud-aerosol interaction

Boucher and Lohmann, Tellus 1995

Assumption on interaction between aerosols and clouds



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 3.75°

3 steps of increasing complexity:

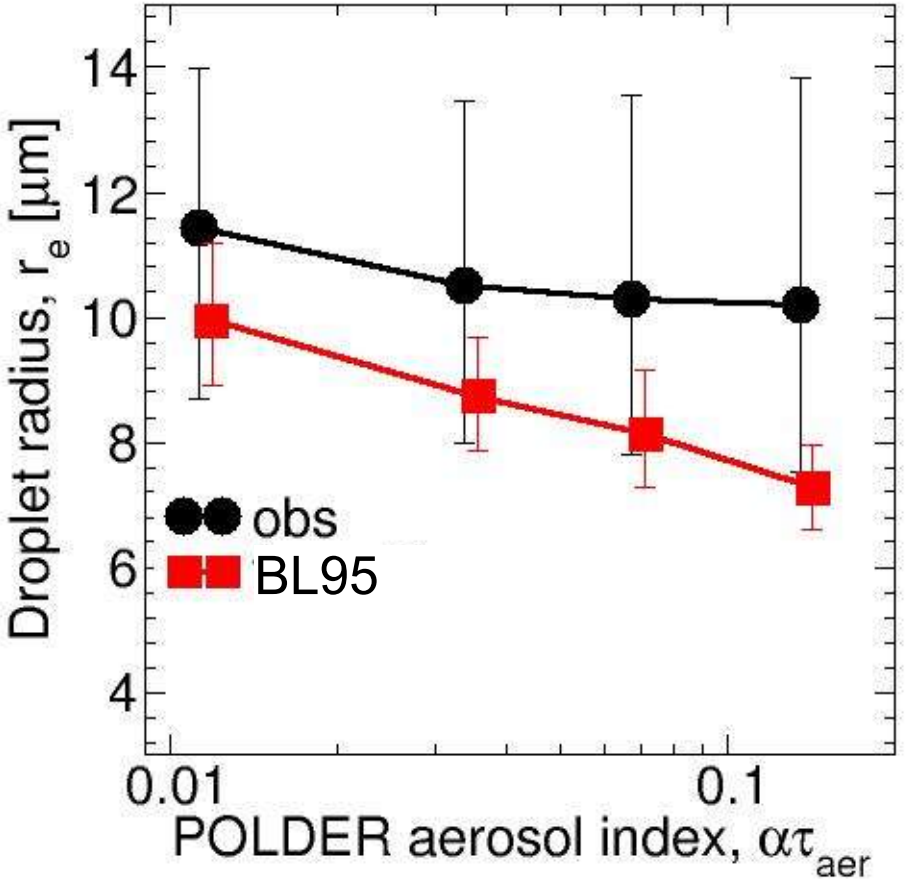
- Twomey effect only, aerosols off-line, sulfate aerosols only

1.

- Twomey effect only, aerosols on-line, multi-components aerosols

- Both (1st and 2nd) indirect effects, aerosols on-line, multi-components aerosols

1. Twomey effect only aerosols off-line (sulfate only)



Quaas and Boucher, GRL, in preparation

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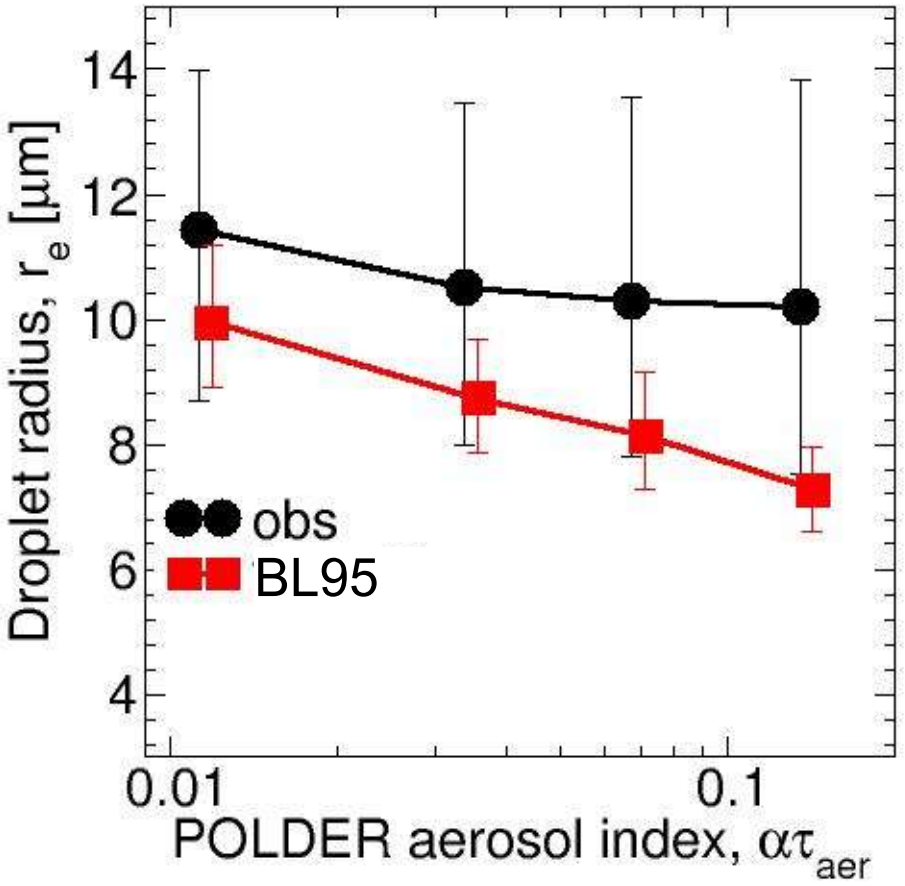

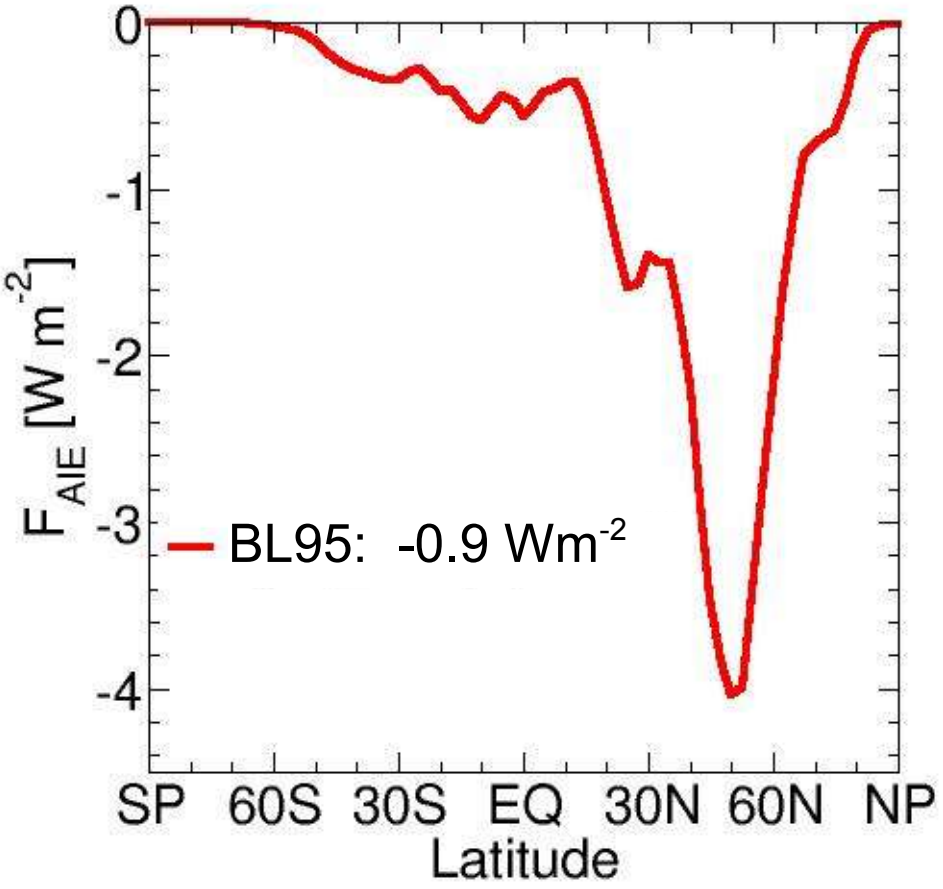

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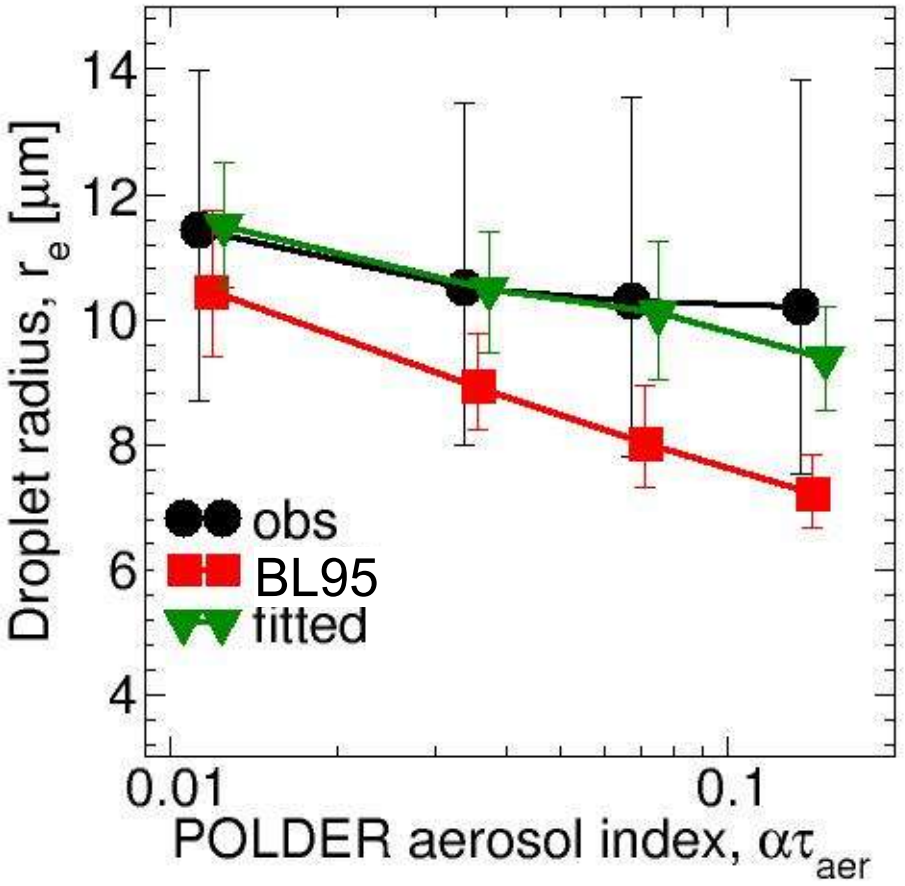

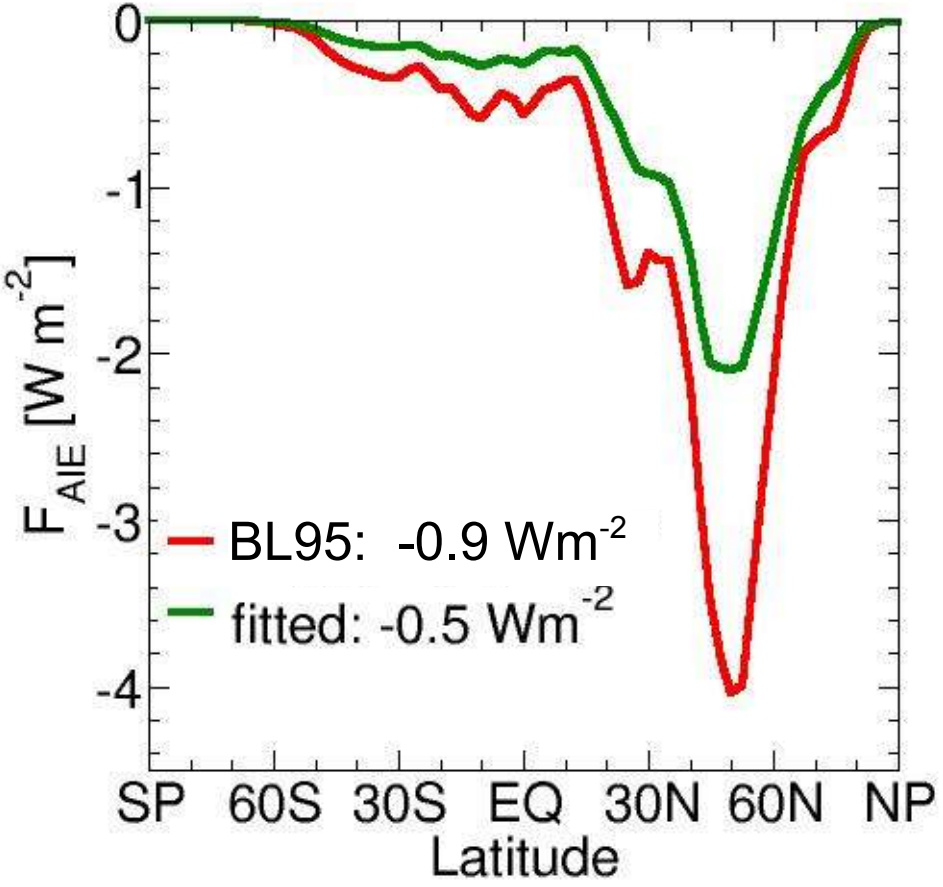

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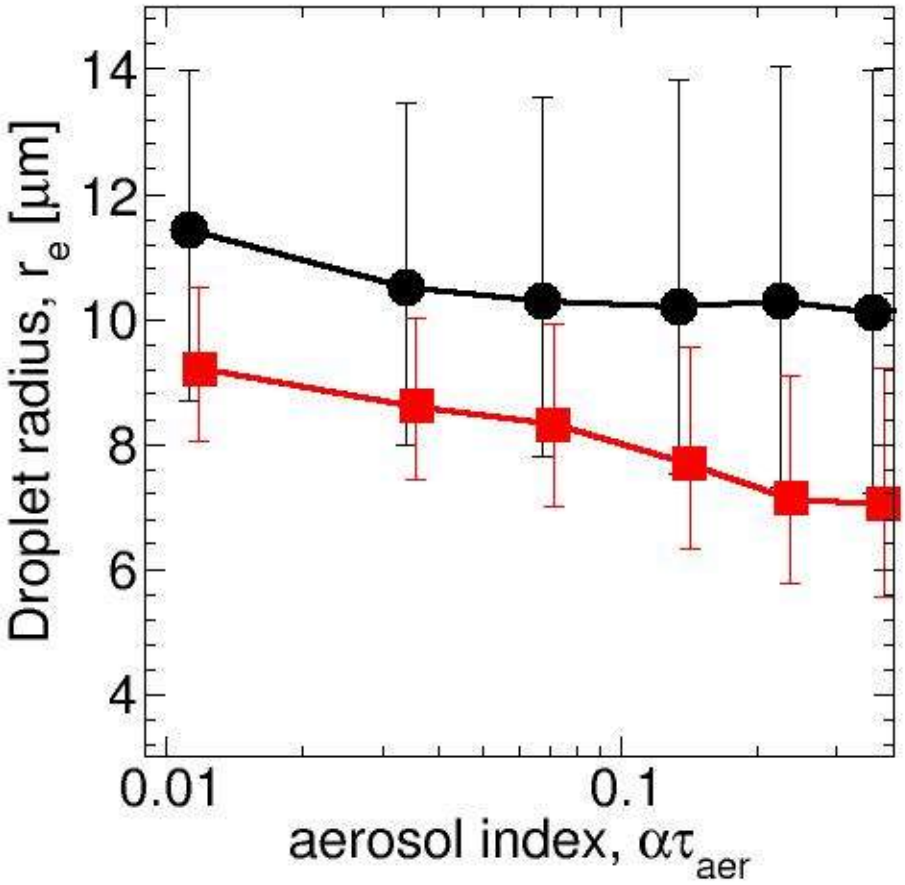
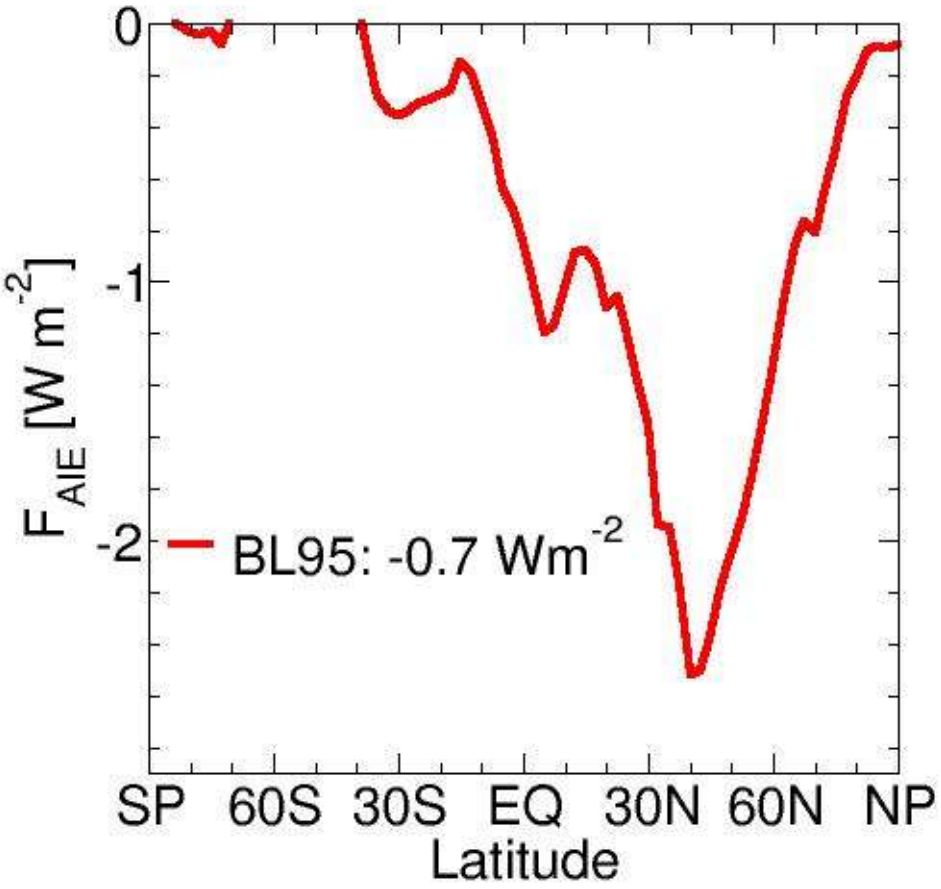
2. Twomey effect only aerosols on-line (multi-components)





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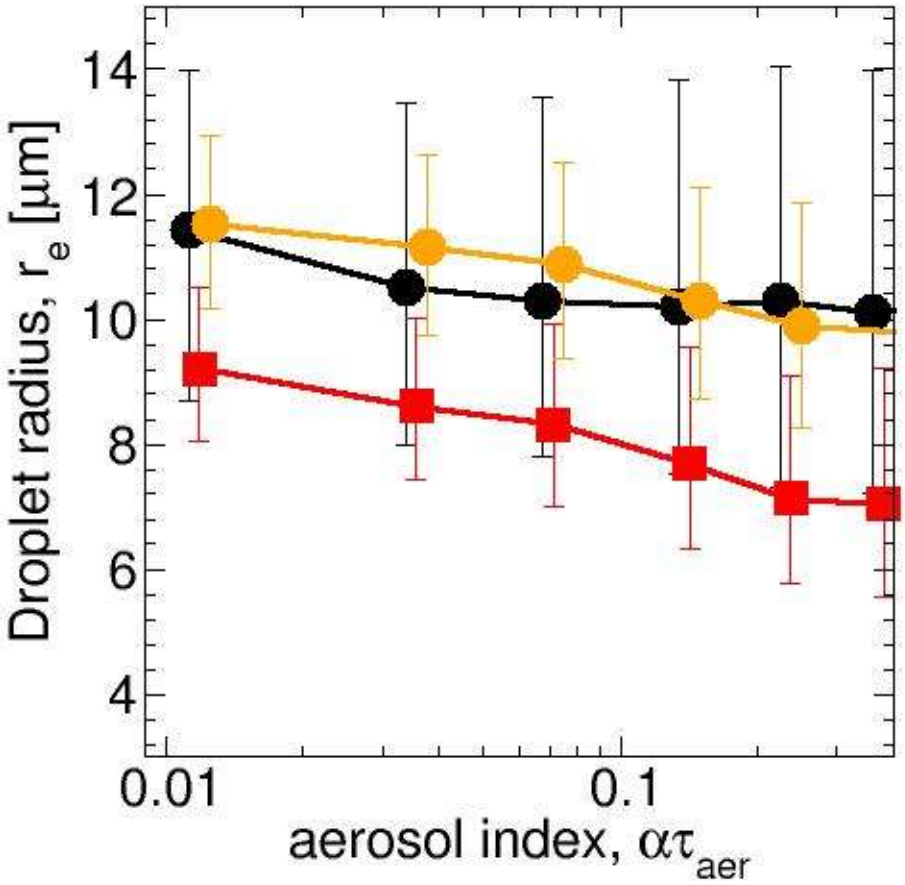

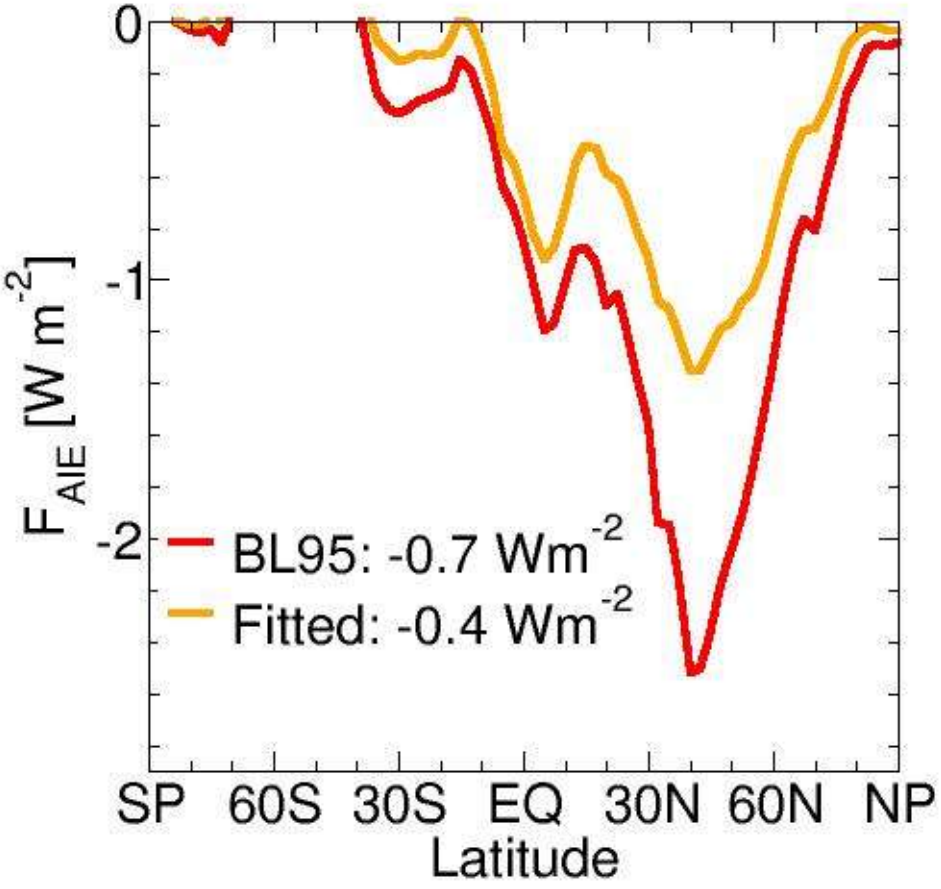

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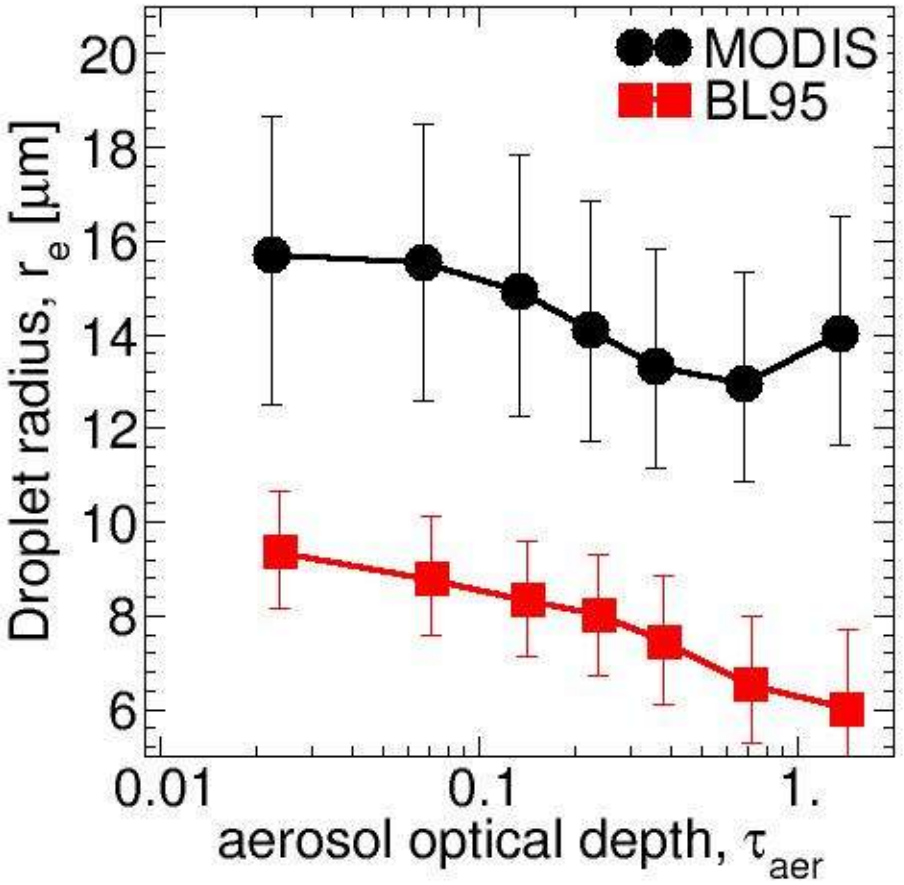

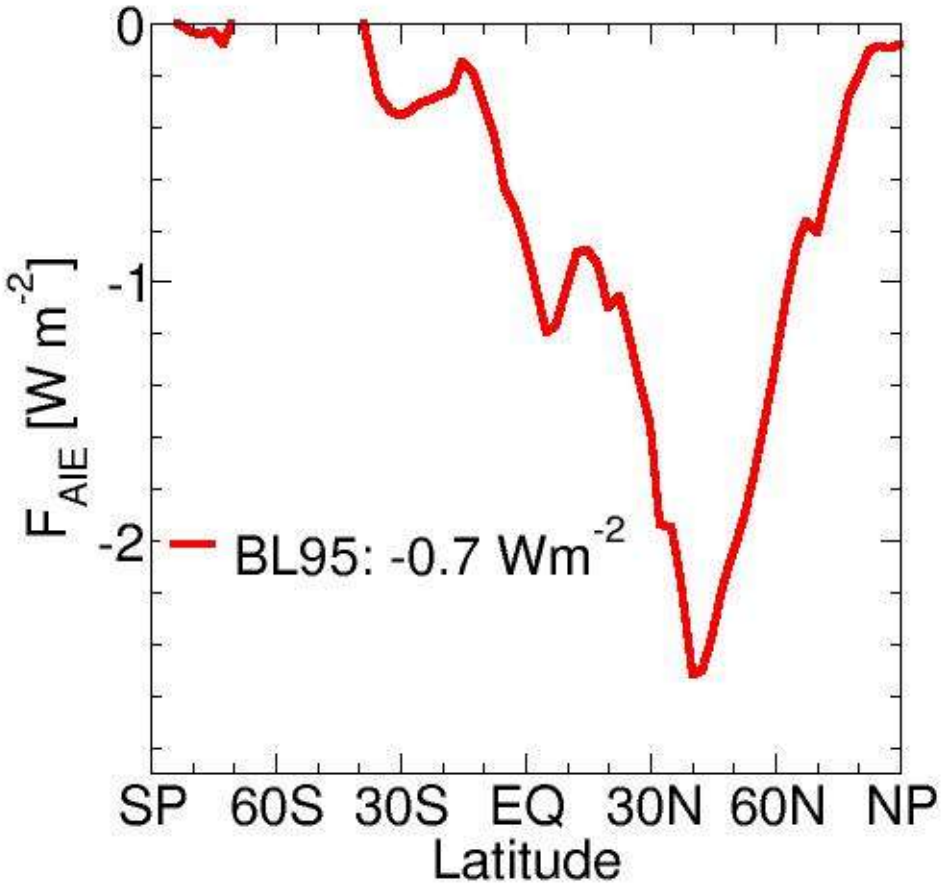

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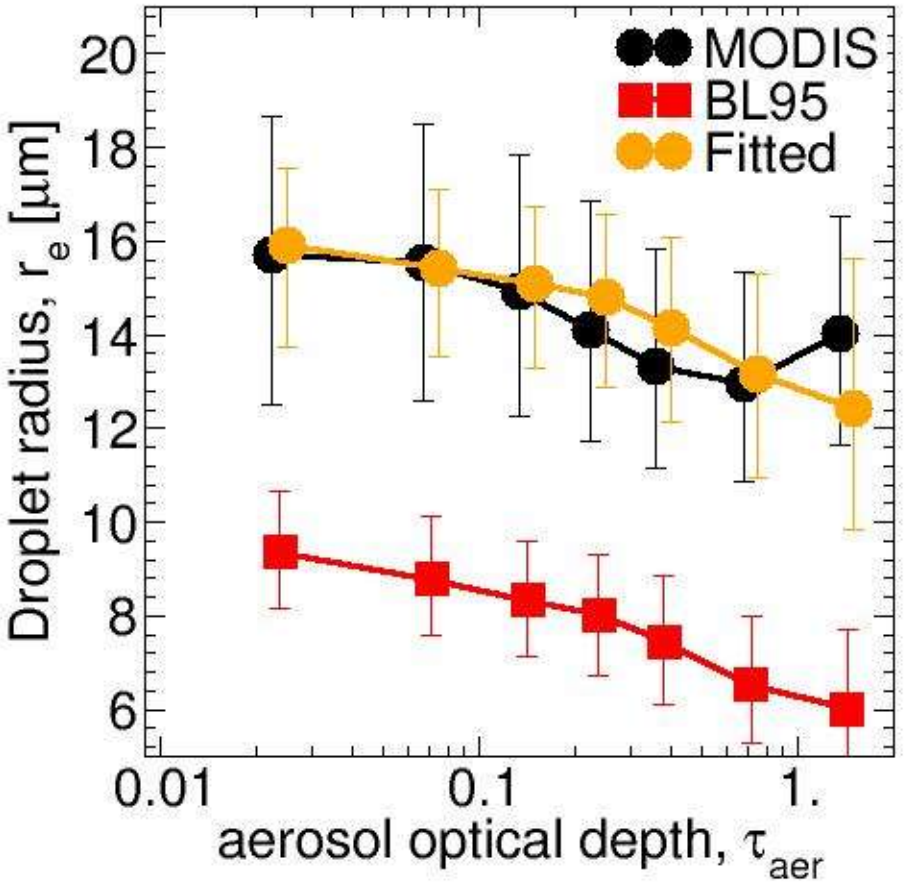

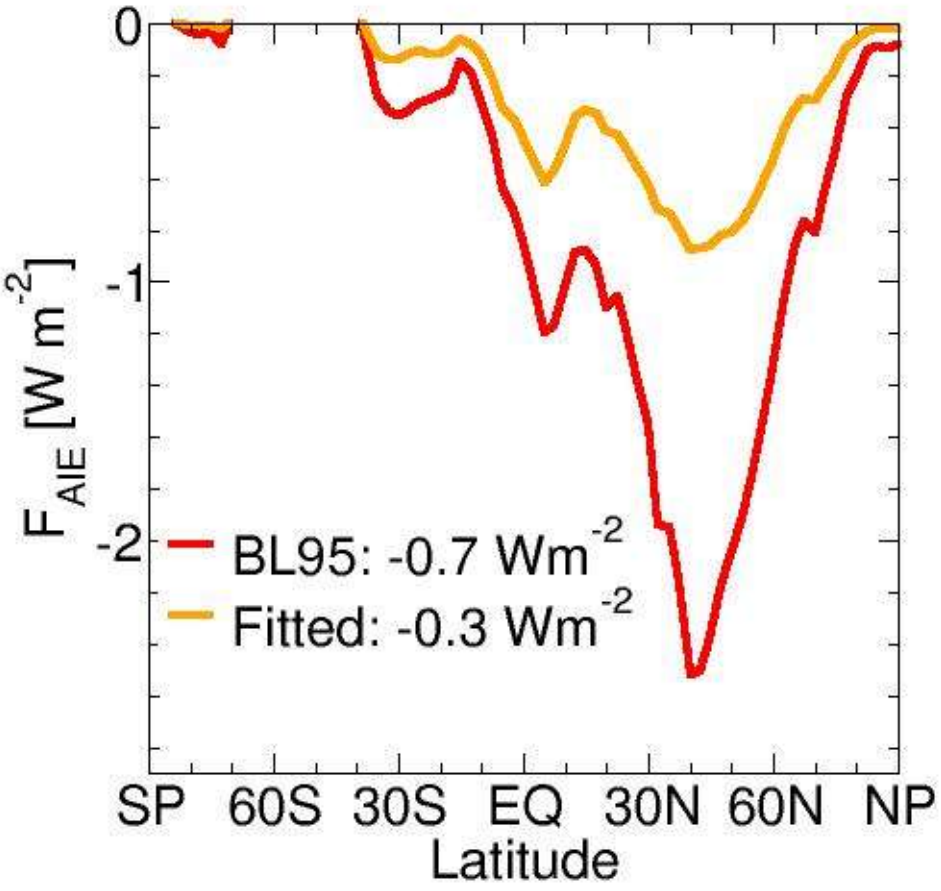

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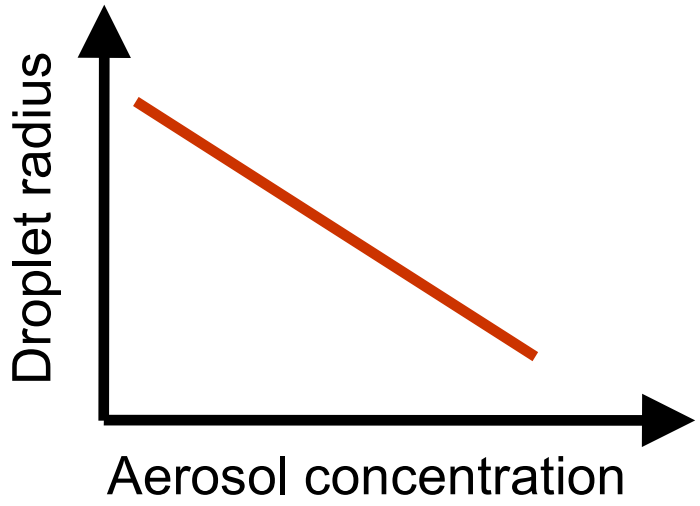
Problem with CDR: **depends on cloud liquid water content**



first effect only

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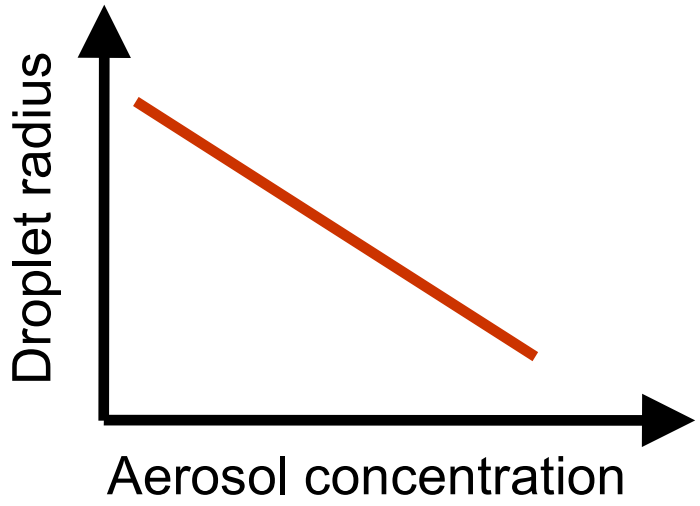

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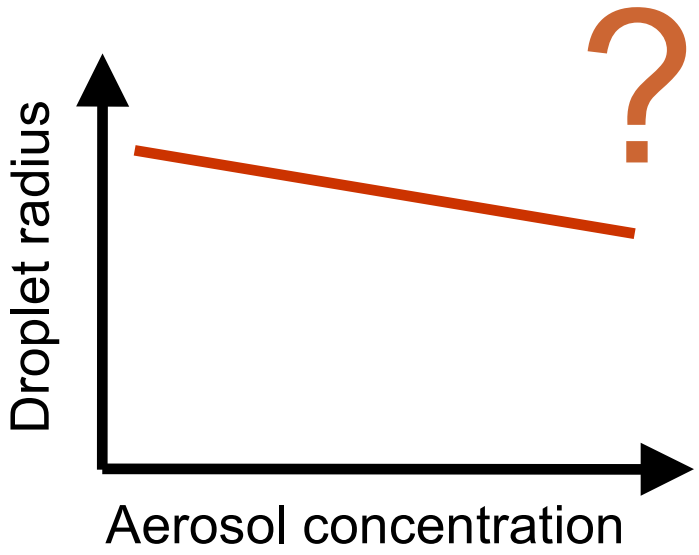
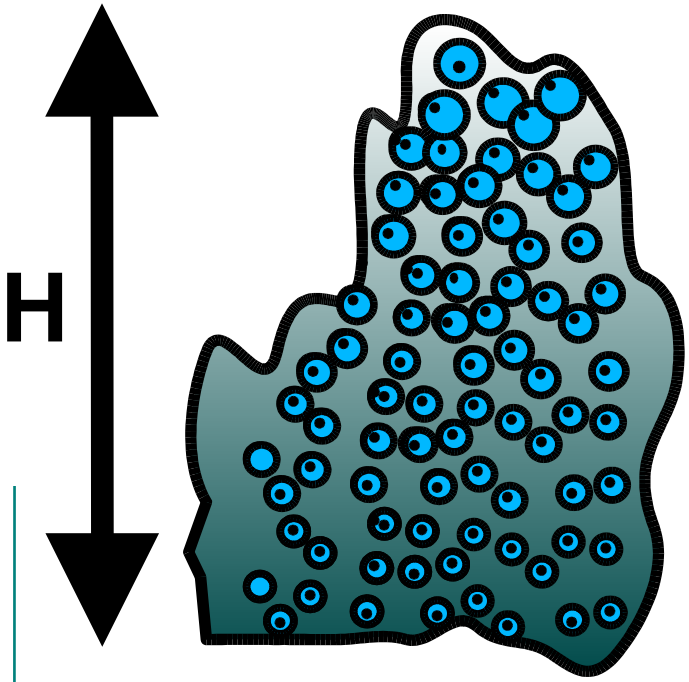


both effects

CDNC instead of CDR



adiabatic cloud

Brenguier et al., JAS 2000; Schüller et al., JAM 2005

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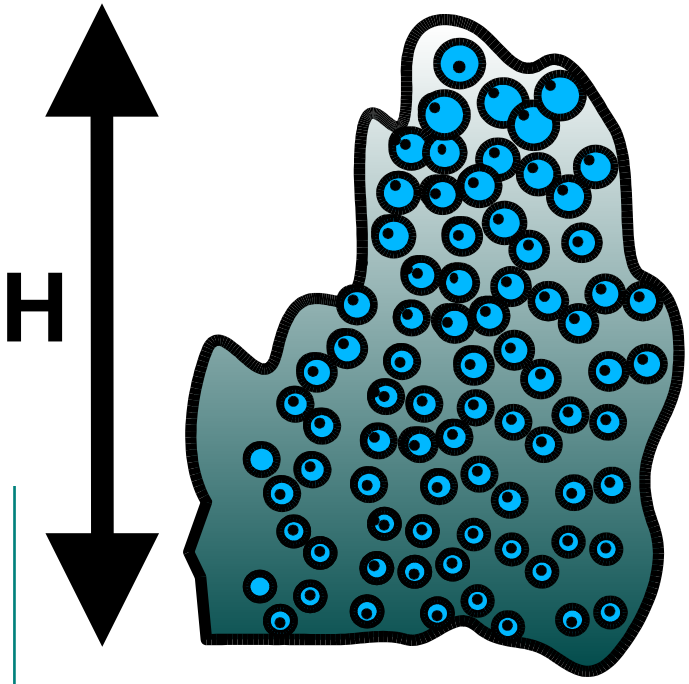

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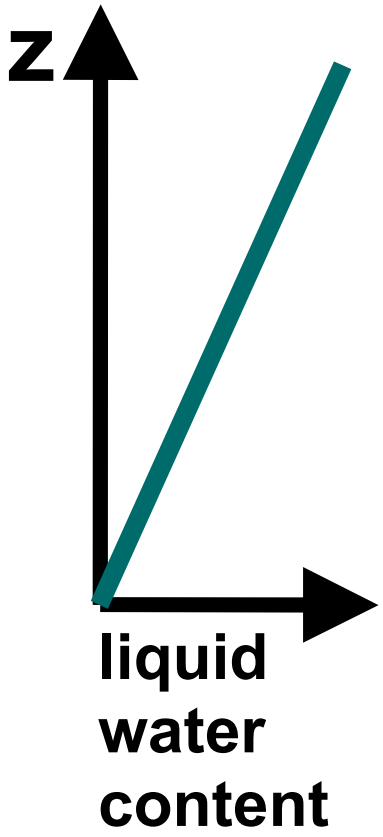

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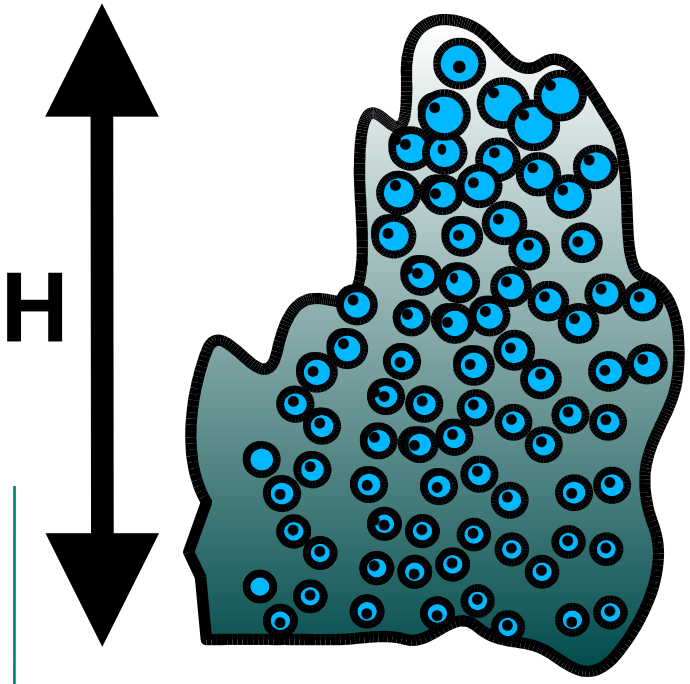

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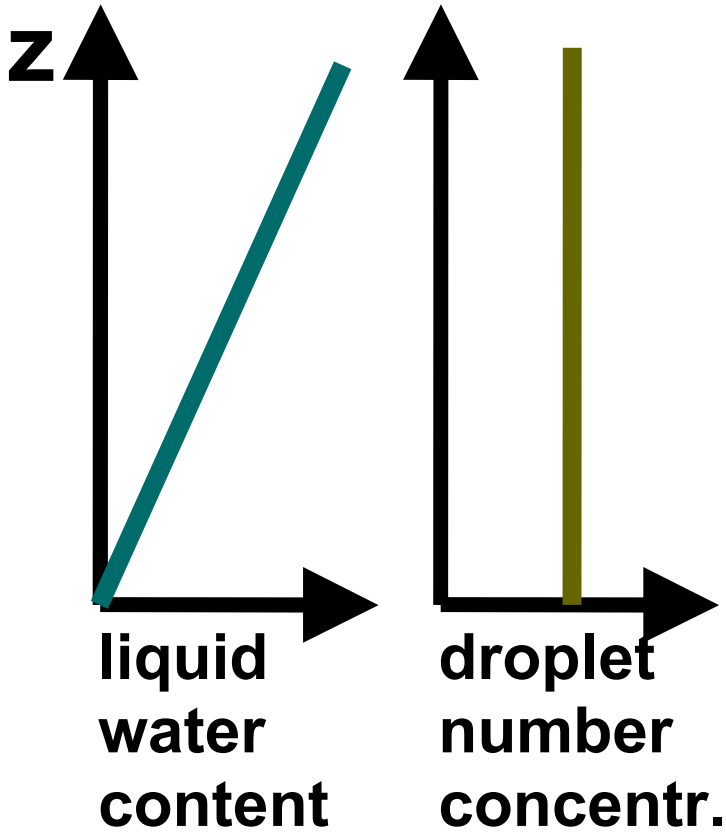

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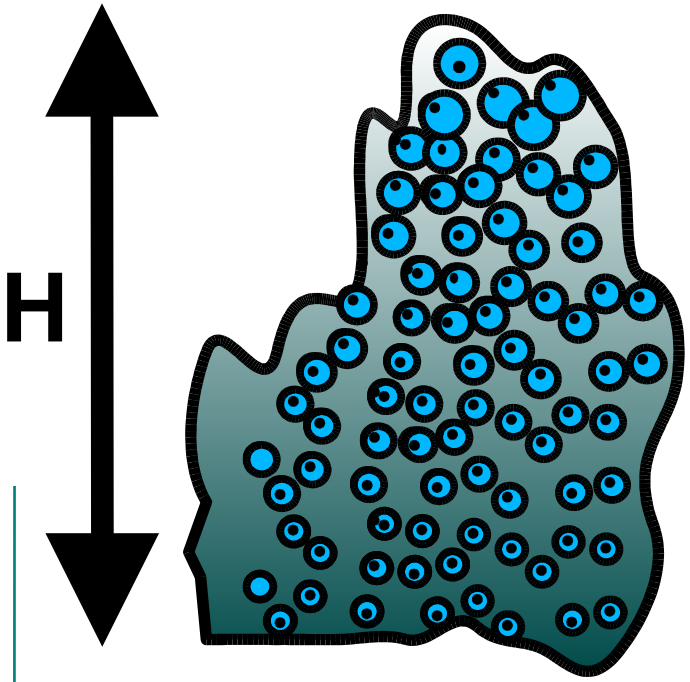

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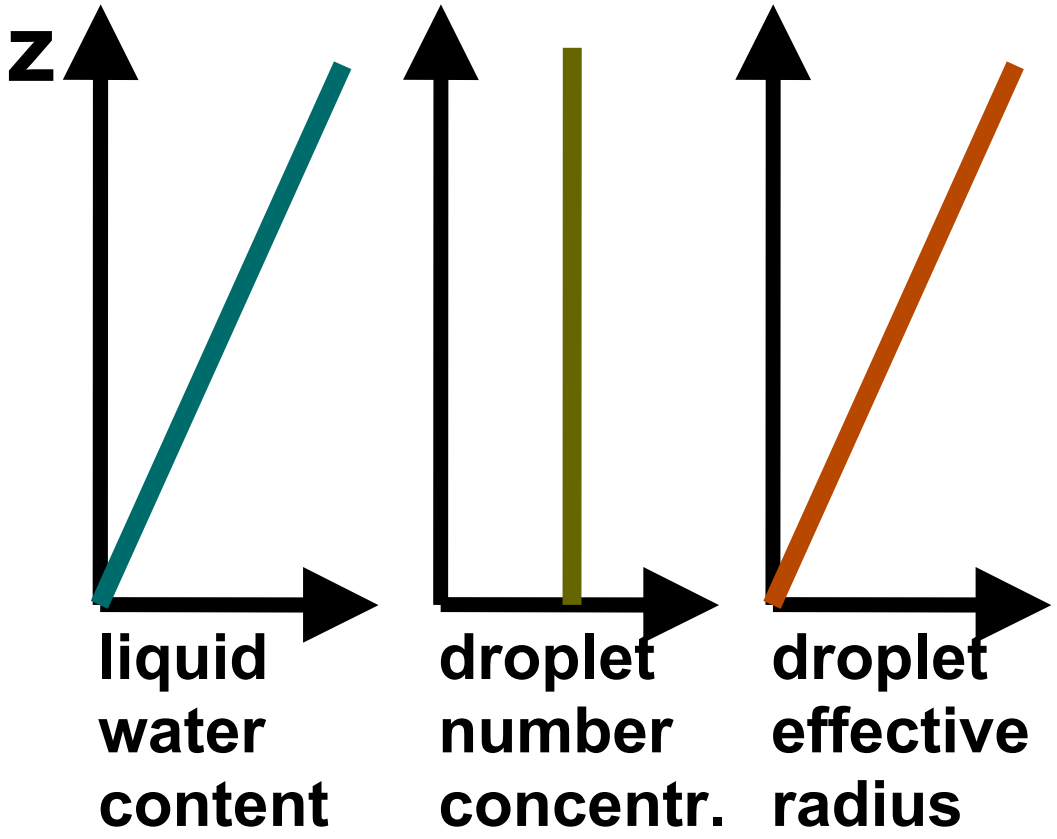

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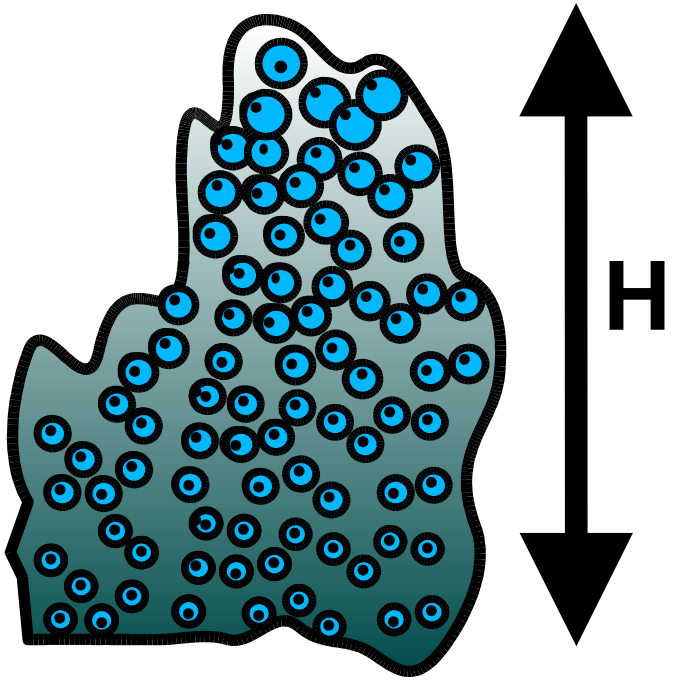
CDNC instead of CDR

Instead: **Cloud droplet number concentration**

$$r_{e,top} \sim N_d^{-1/3} H^{1/3}$$

$$\tau_c \sim N_d^{1/3} H^{5/3}$$



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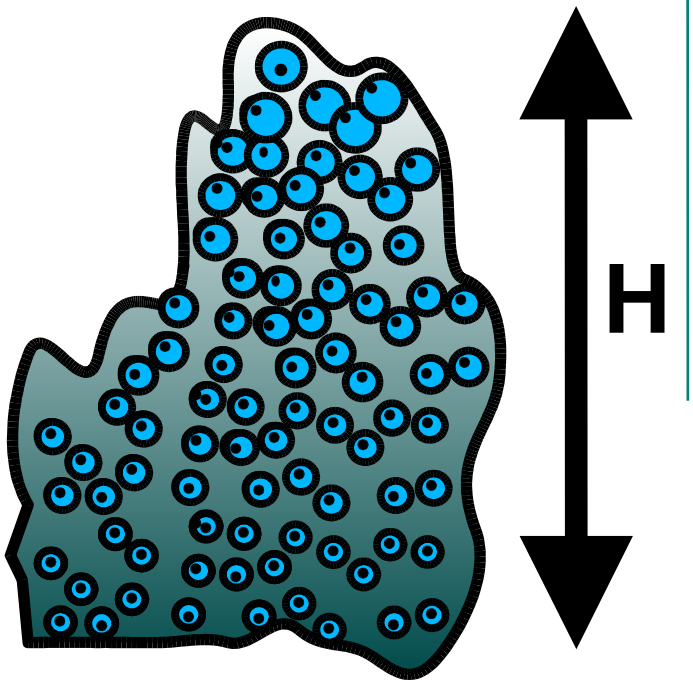
combined: $N_d \sim \tau_c^{1/2} r_{e,top}^{-5/2}$



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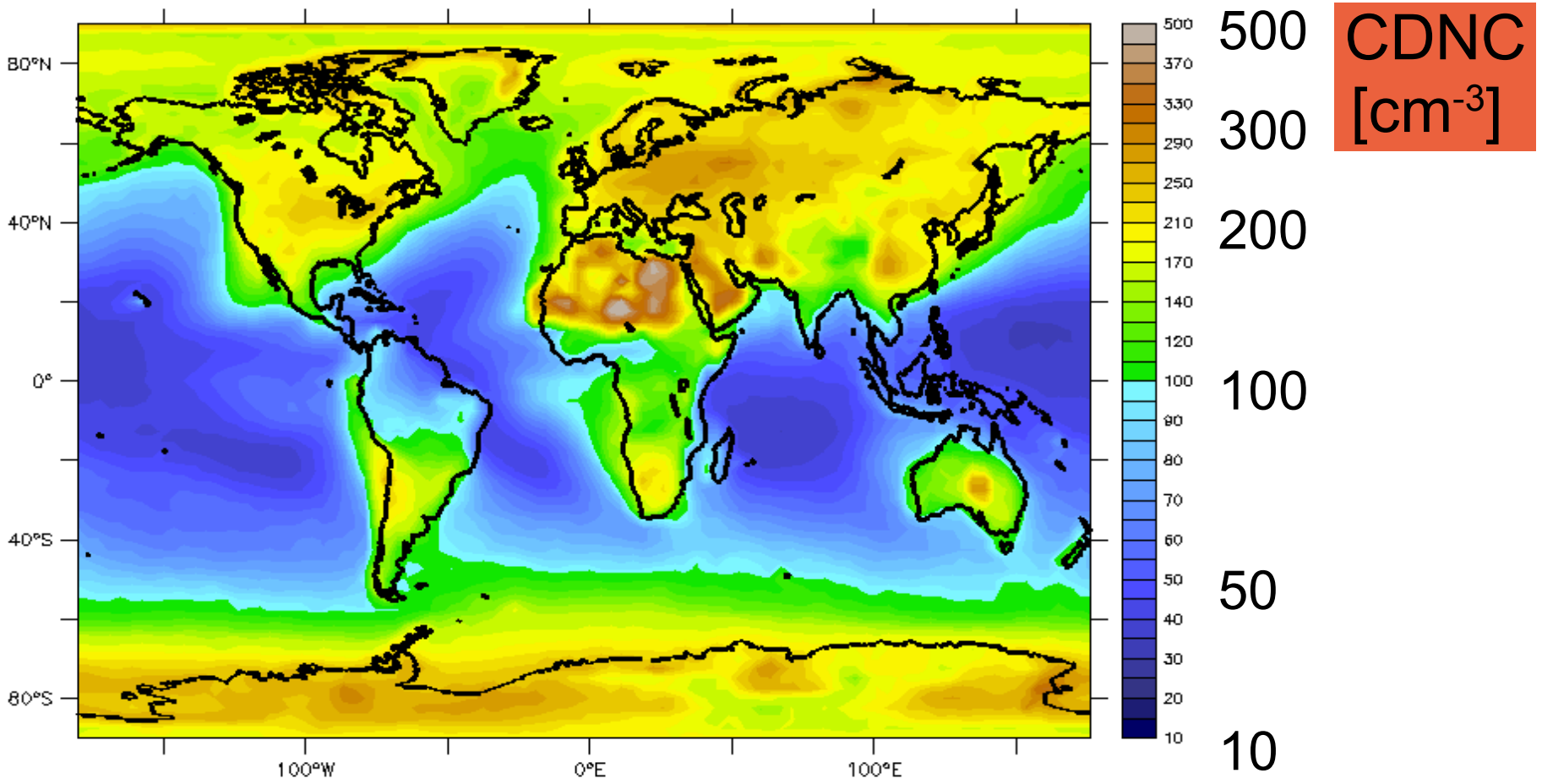
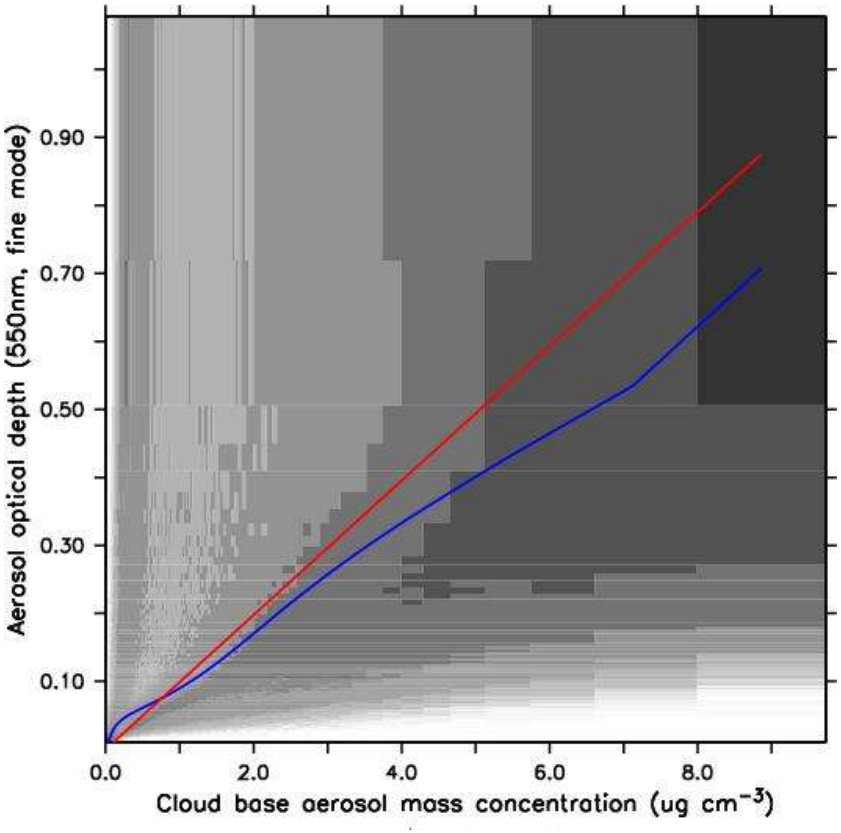


MODIS for 03/2000 - 02/2005

Model: AOD vs. m_{aer}



Quaas, Boucher, Lohmann, and Jones, in preparation

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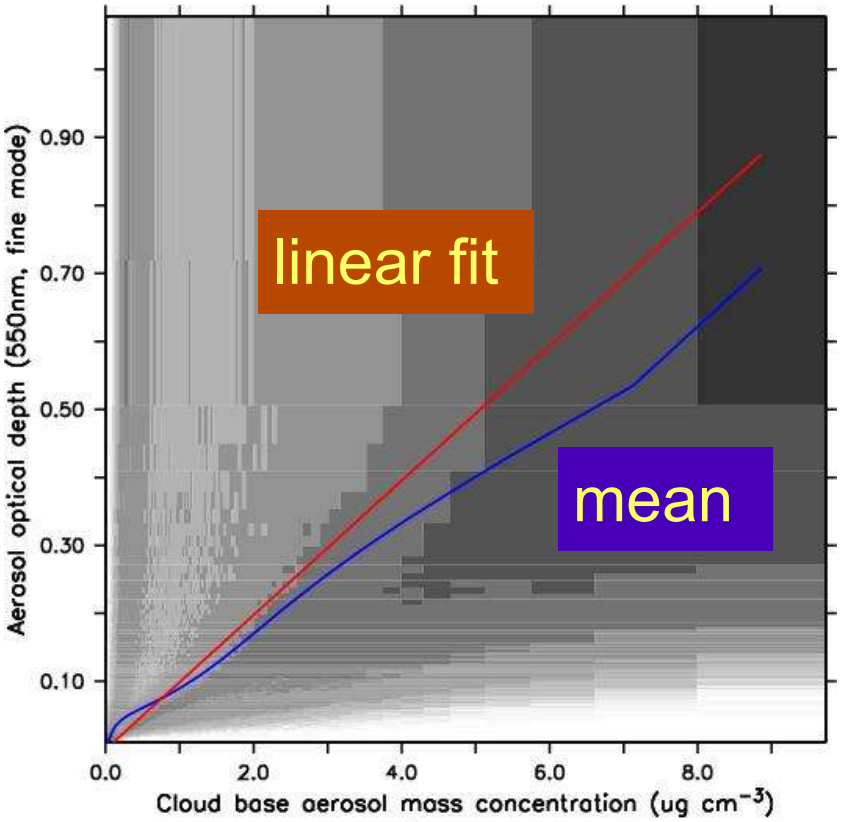

$$\tau_{aer} = \gamma\, m_{aer,\,base}$$

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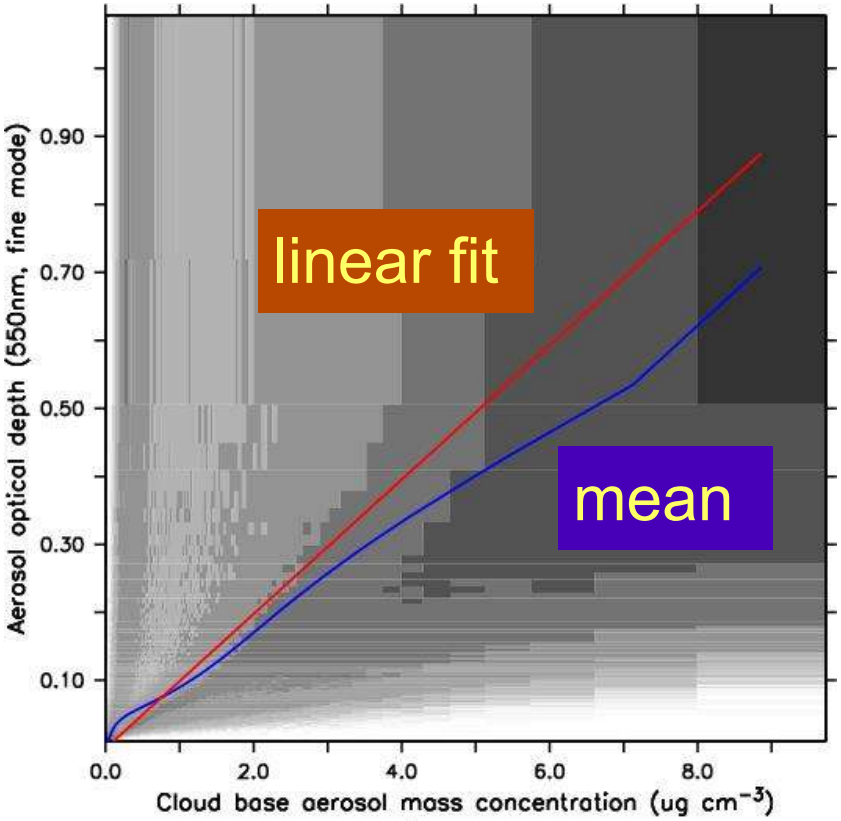

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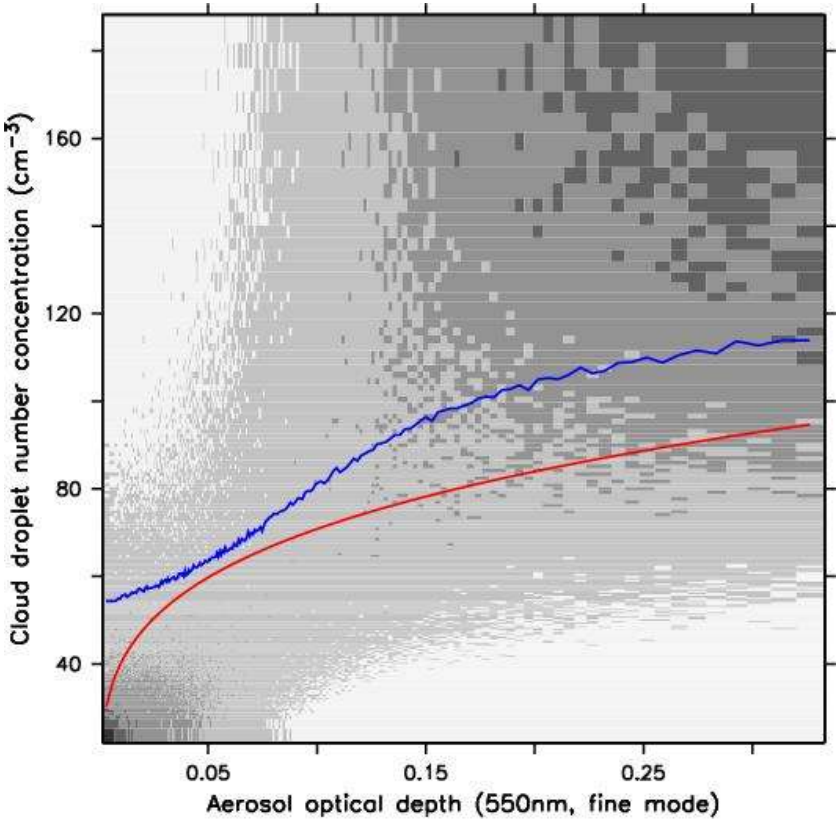

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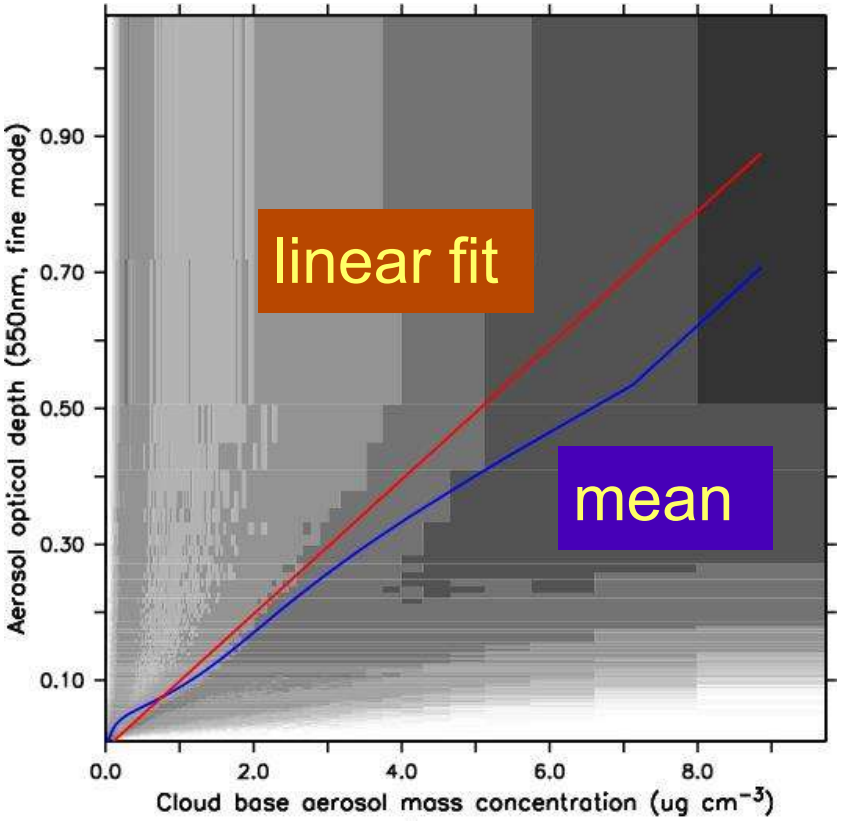

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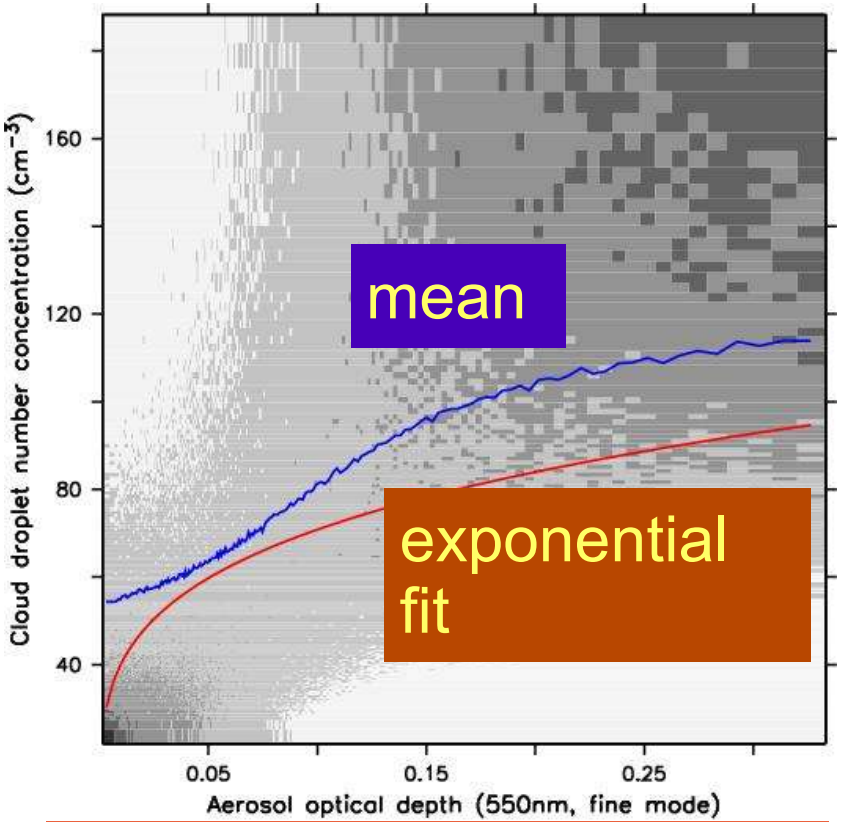

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Quaas, Boucher, Lohmann, and Jones, in preparation

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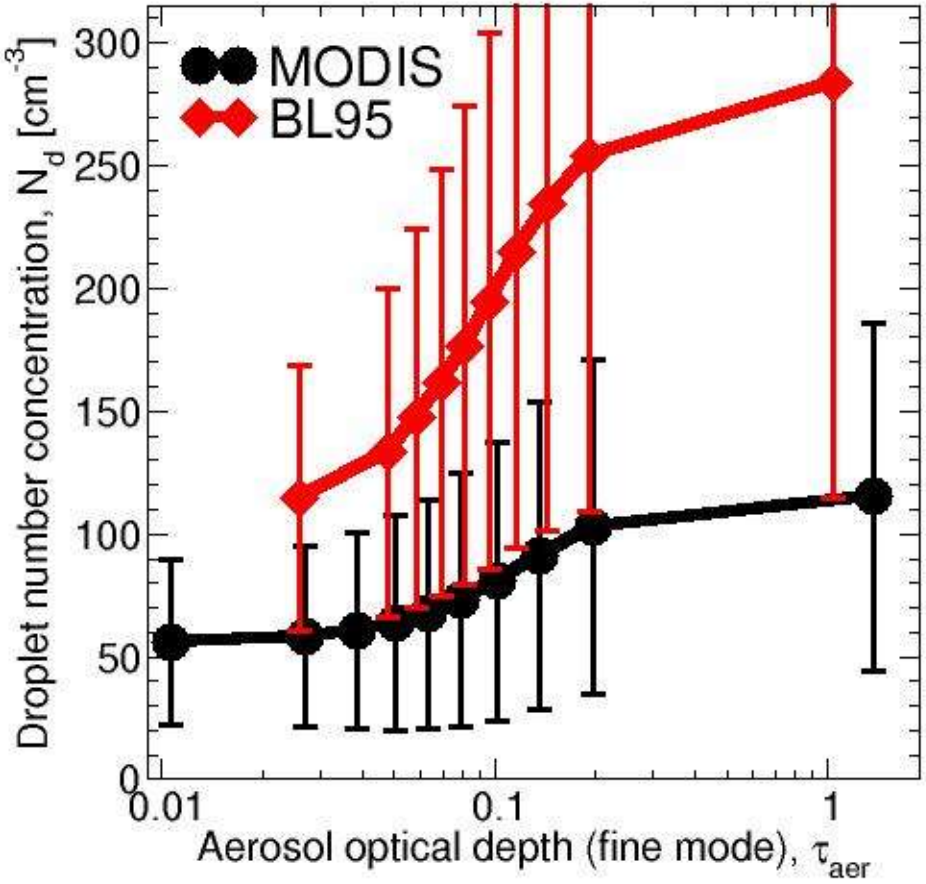
$$N_d = \exp (a_0 + a_1 \ln \; m_{aer} \;)$$

$$a_0 = b_0 + a_1 \ln \gamma = 4.3$$

$$a_1 = b_1 \qquad = 0.3$$

Quaas, Boucher, Lohmann, and Jones, in preparation

3a. Both indirect effects aerosols on-line (multi-components)



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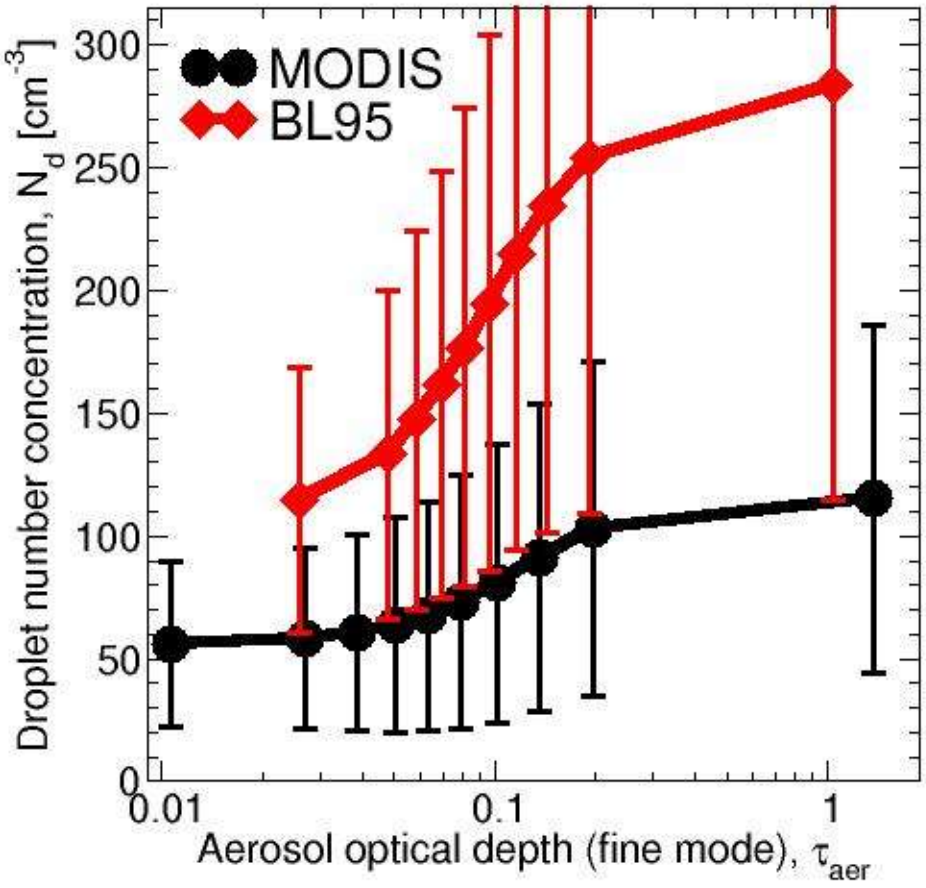

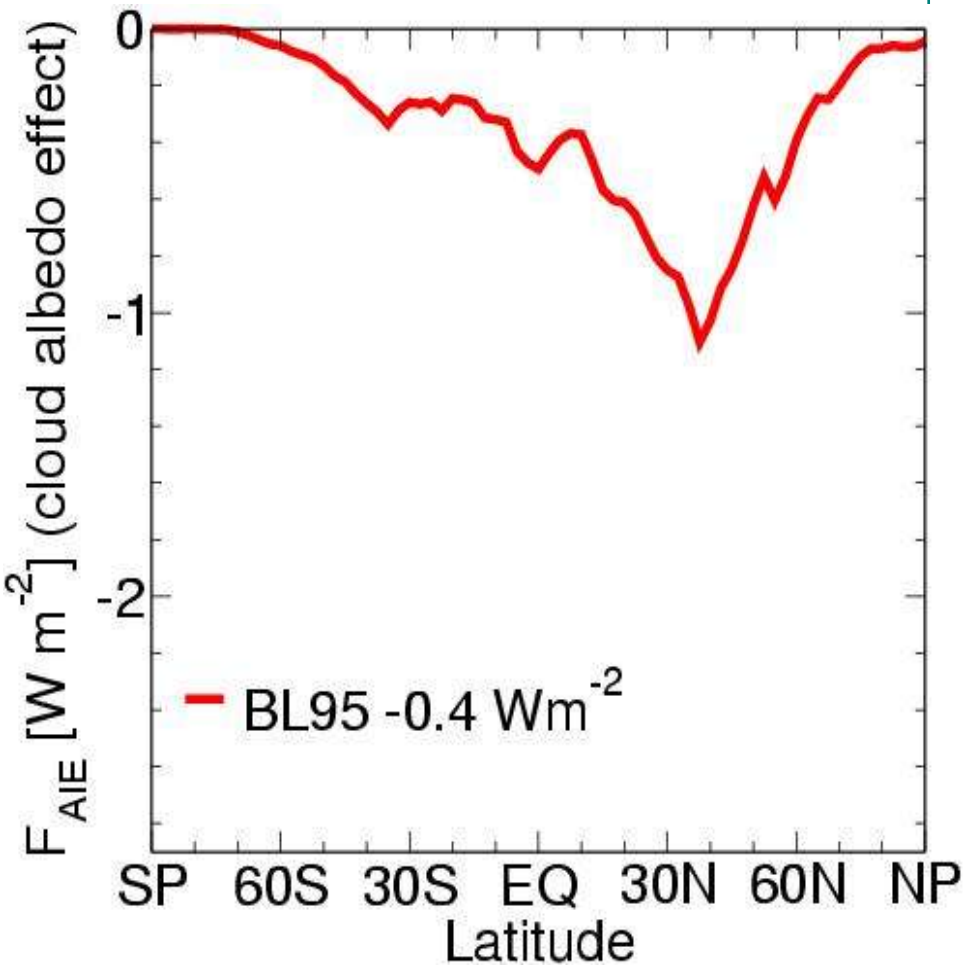

Quaas, Boucher, Lohmann, and Jones, in preparation

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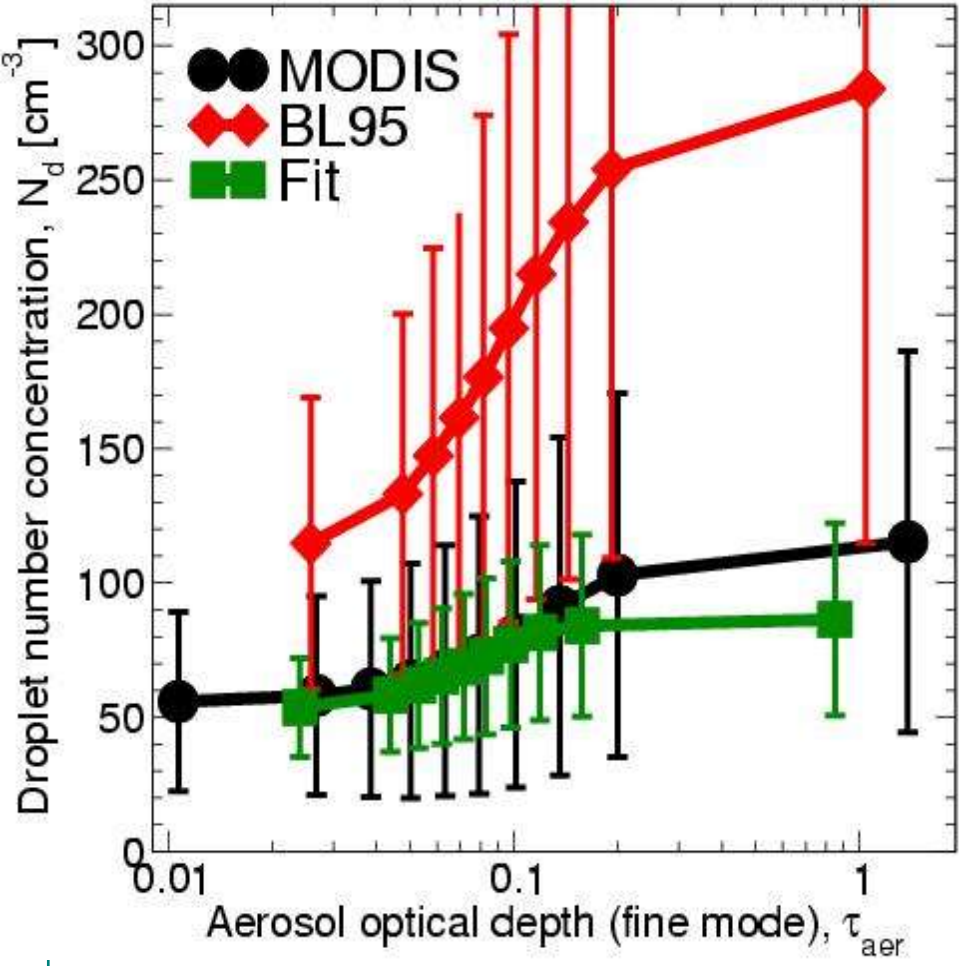

Satellite-derived parameterization:

- CDNC – AOD(FM) relationship fits well
- good aerosol distribution

Quaas, Boucher, Lohmann, and Jones, in preparation

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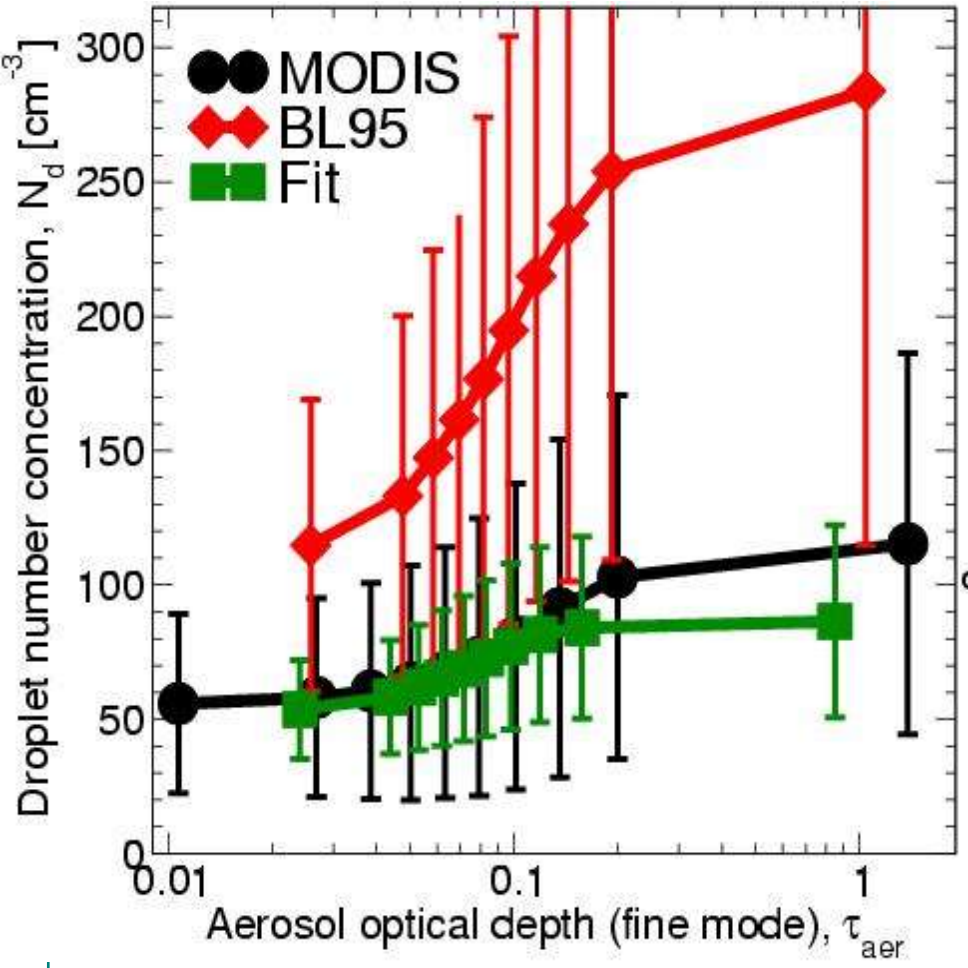
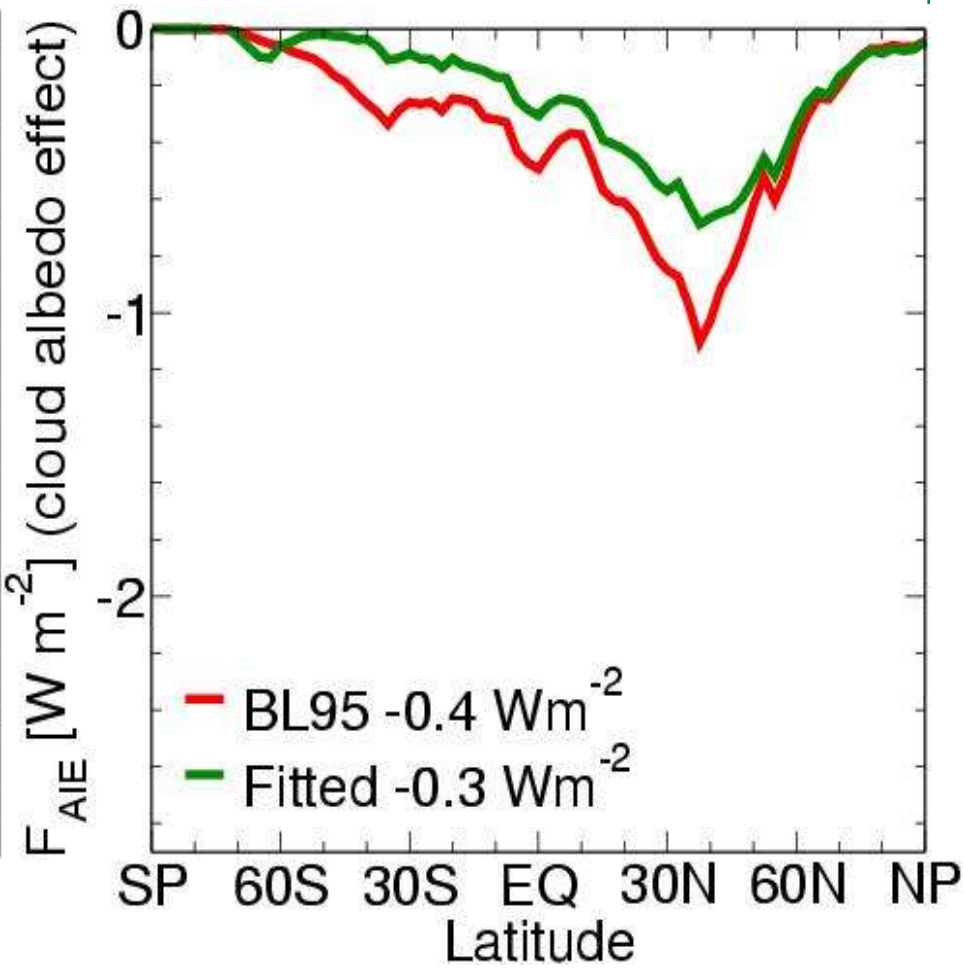
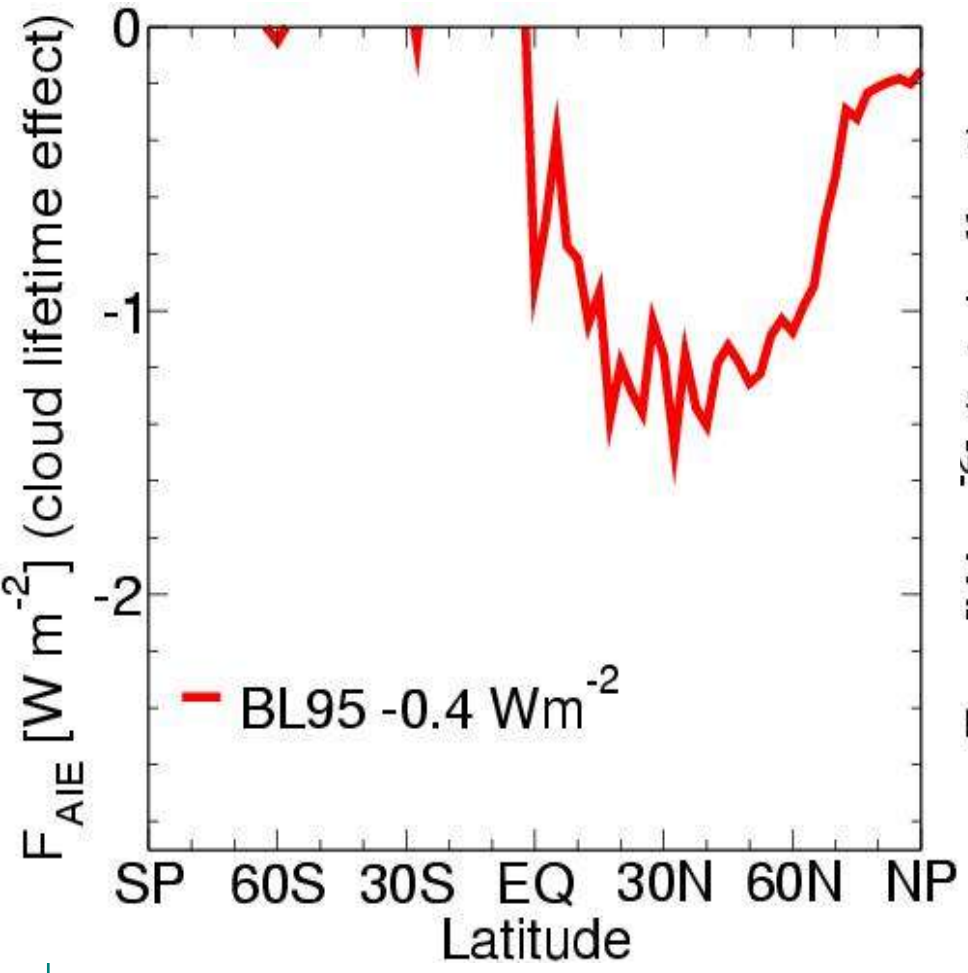
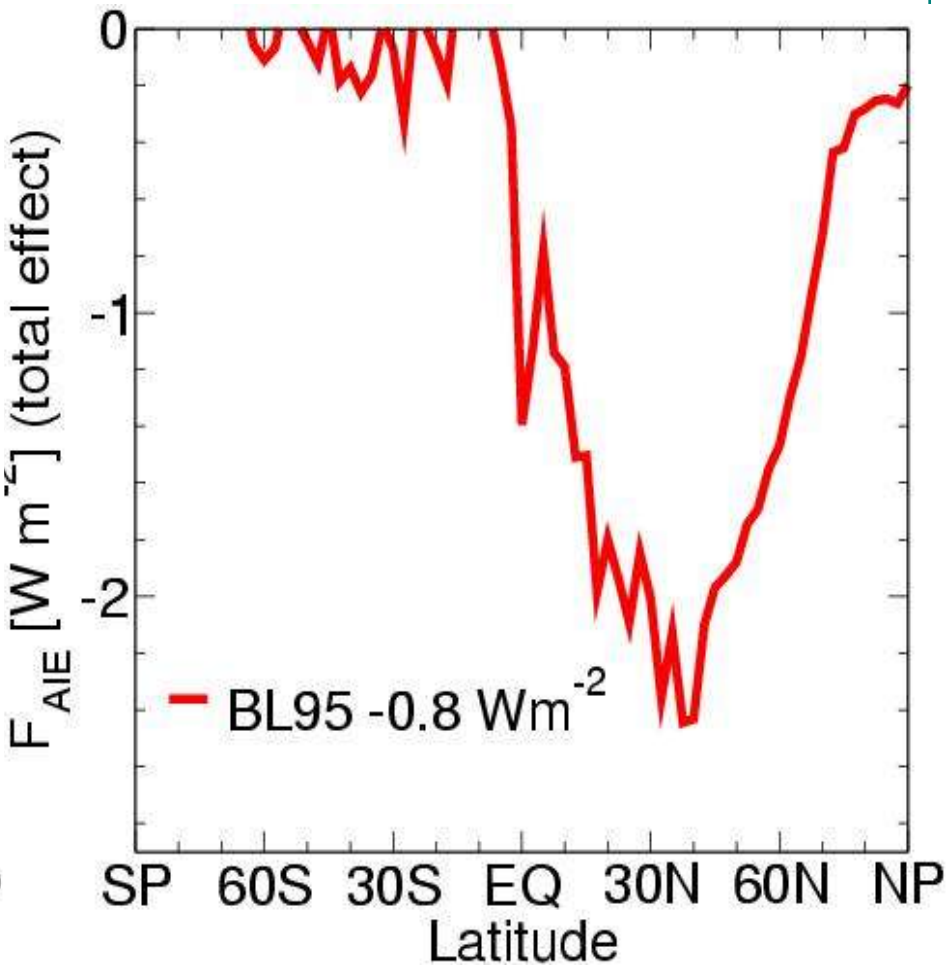




Quaas, Boucher, Lohmann, and Jones, in preparation

Estimate of the 2nd aerosol indirect effect





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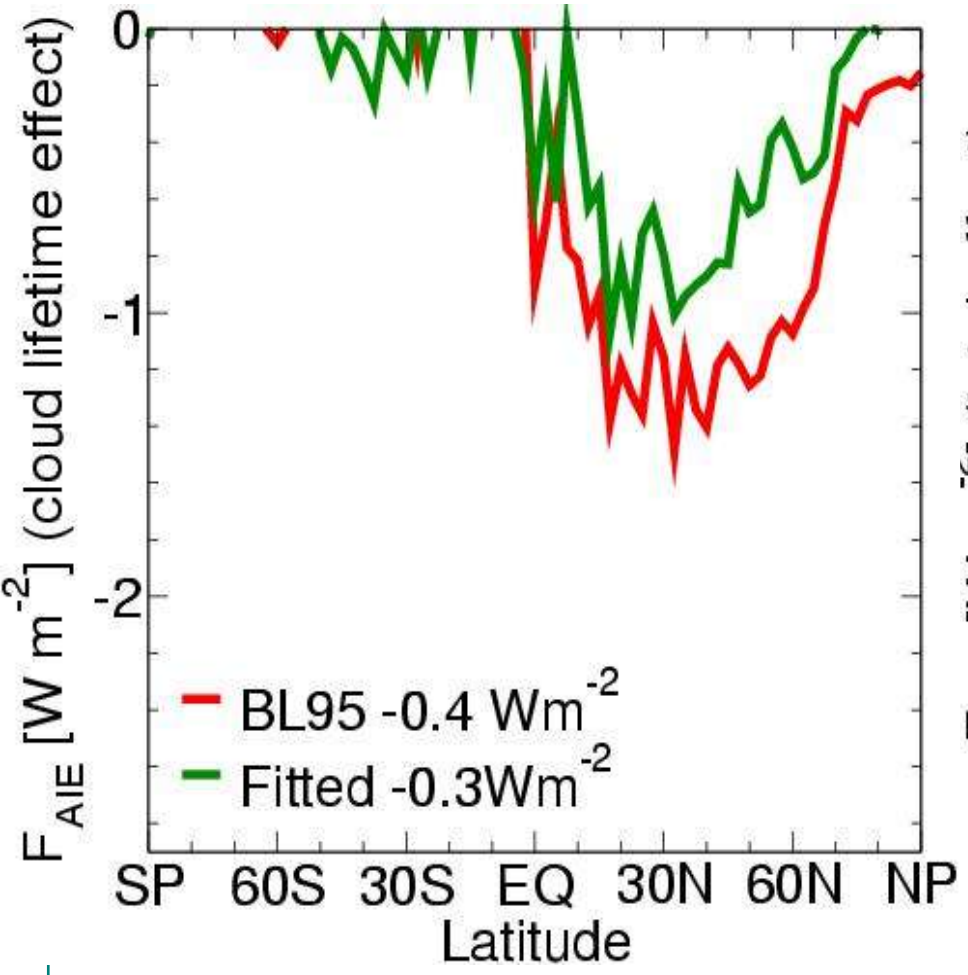
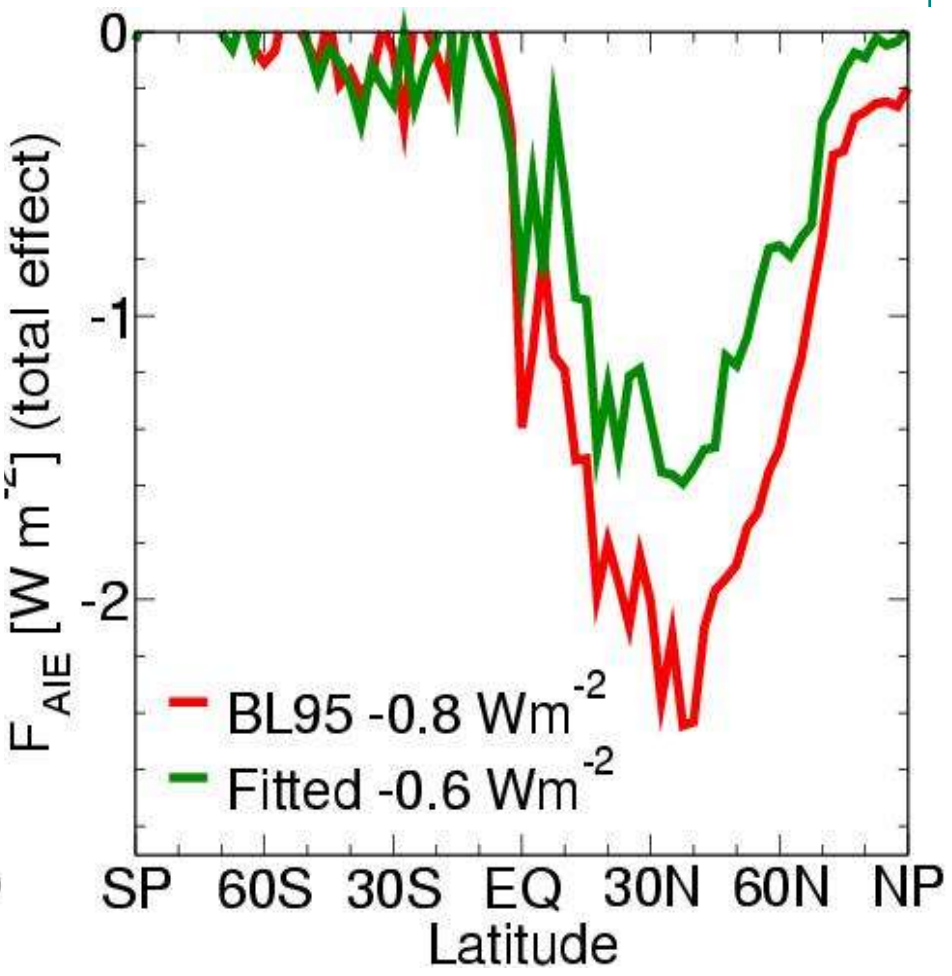
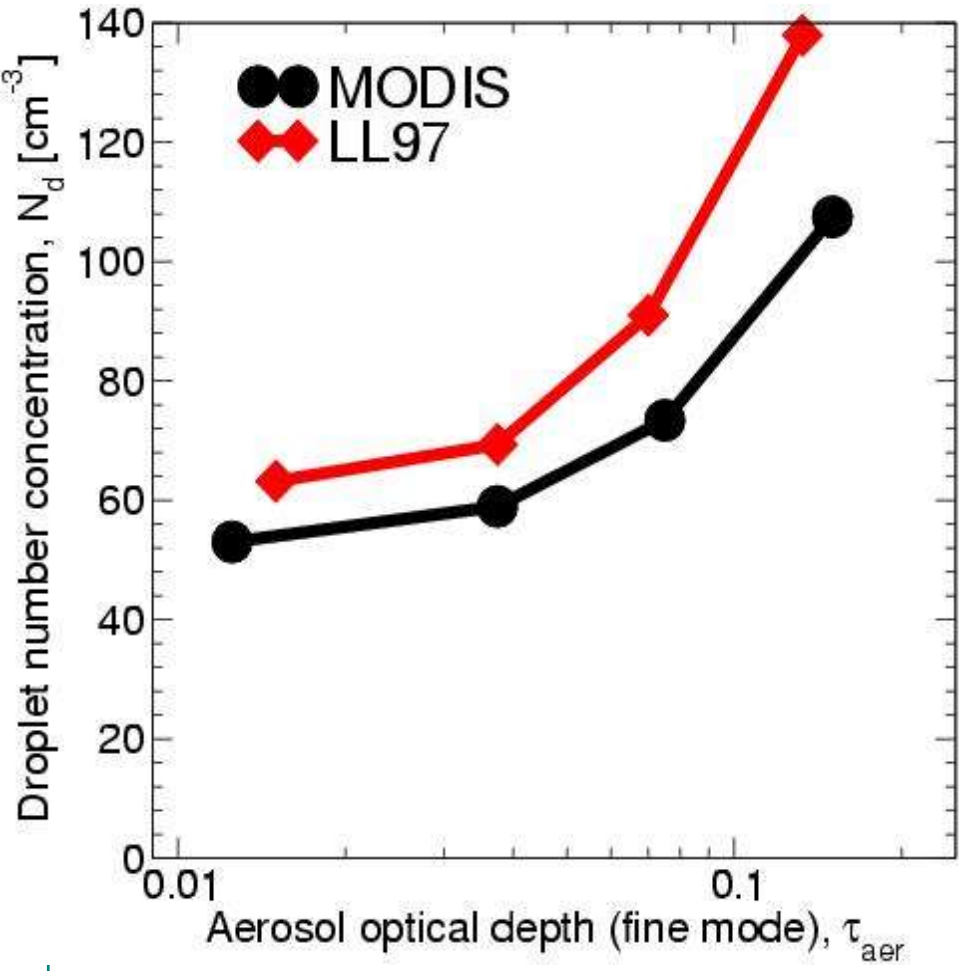




Quaas, Boucher, Lohmann, and Jones, in preparation

3b. Both indirect effects aerosols on-line (ECHAM4)



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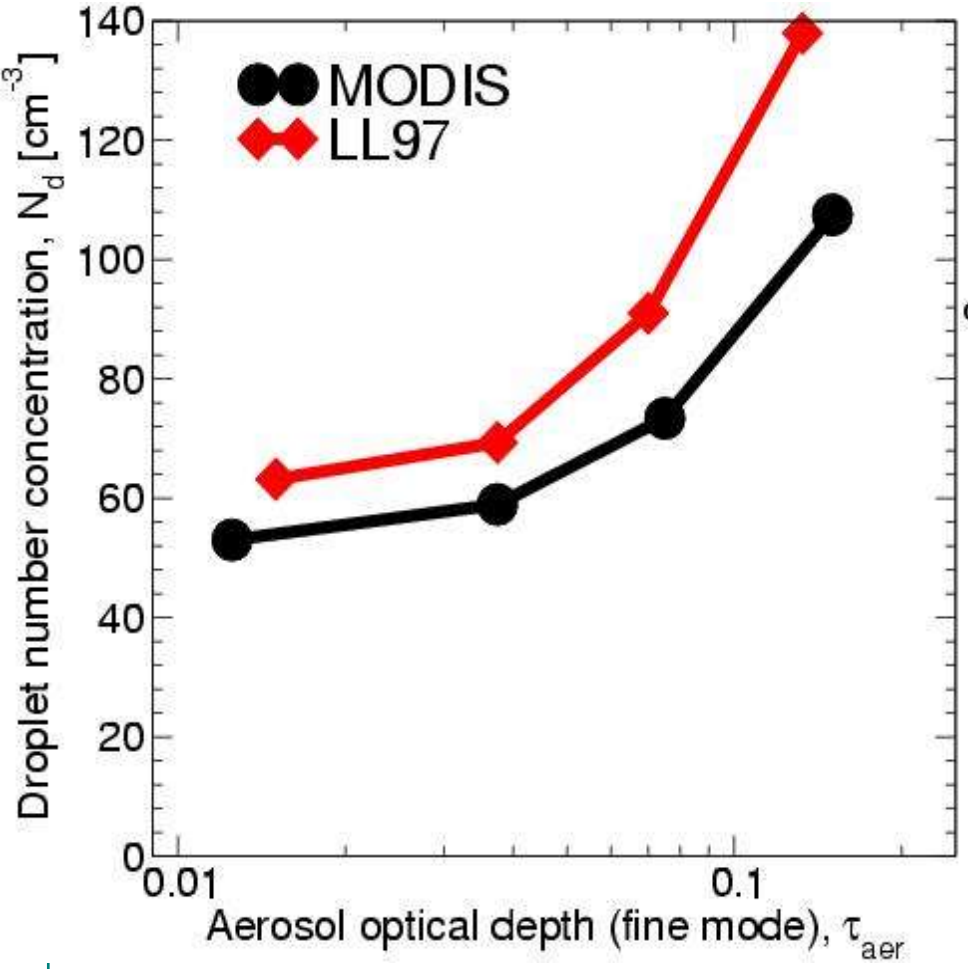

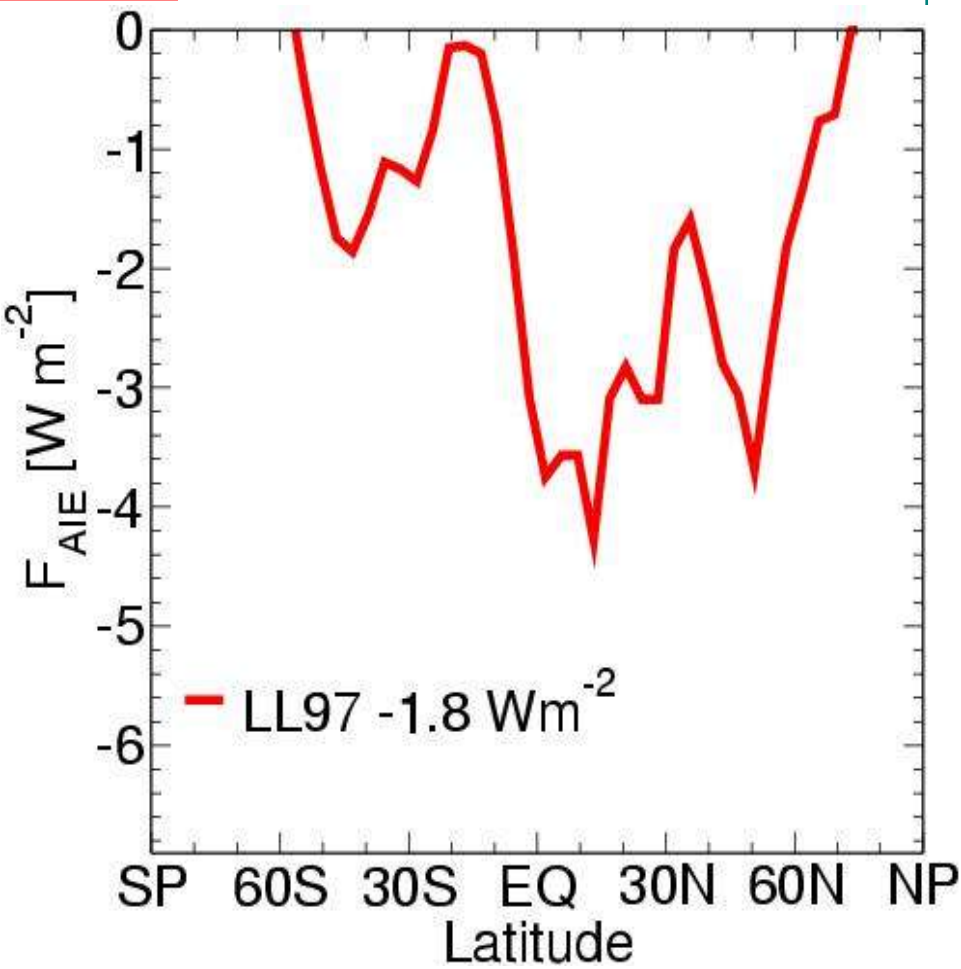

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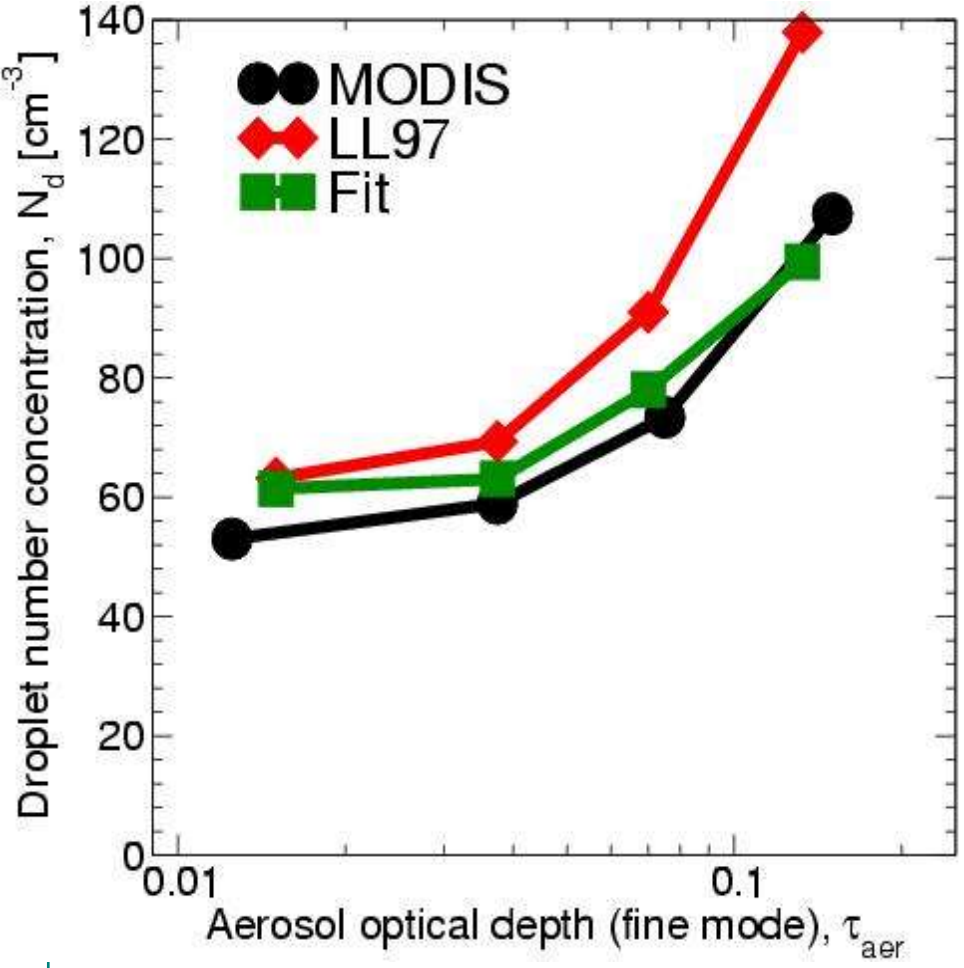

$$N_d = 0.1\,[N_a\, w/(w + cN_a)]^{1.27}$$

Fit done by dividing w by 2.

Lin and Leaitch, 1997

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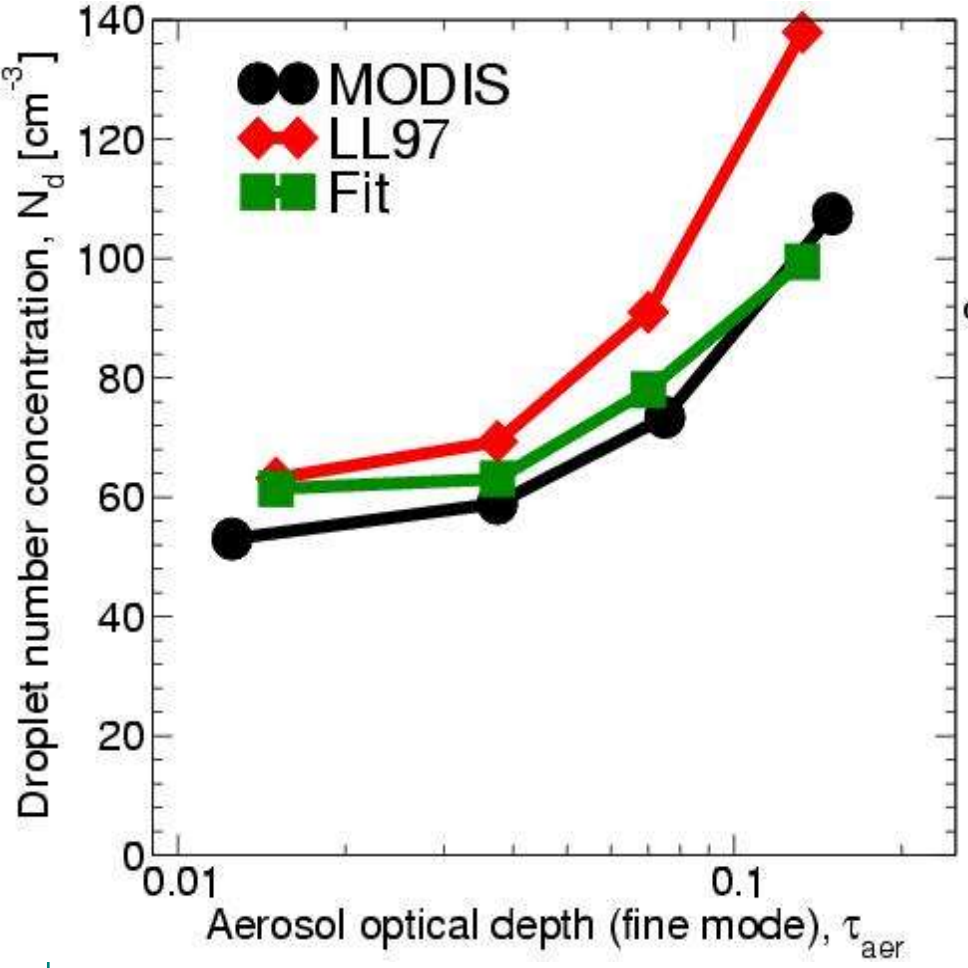

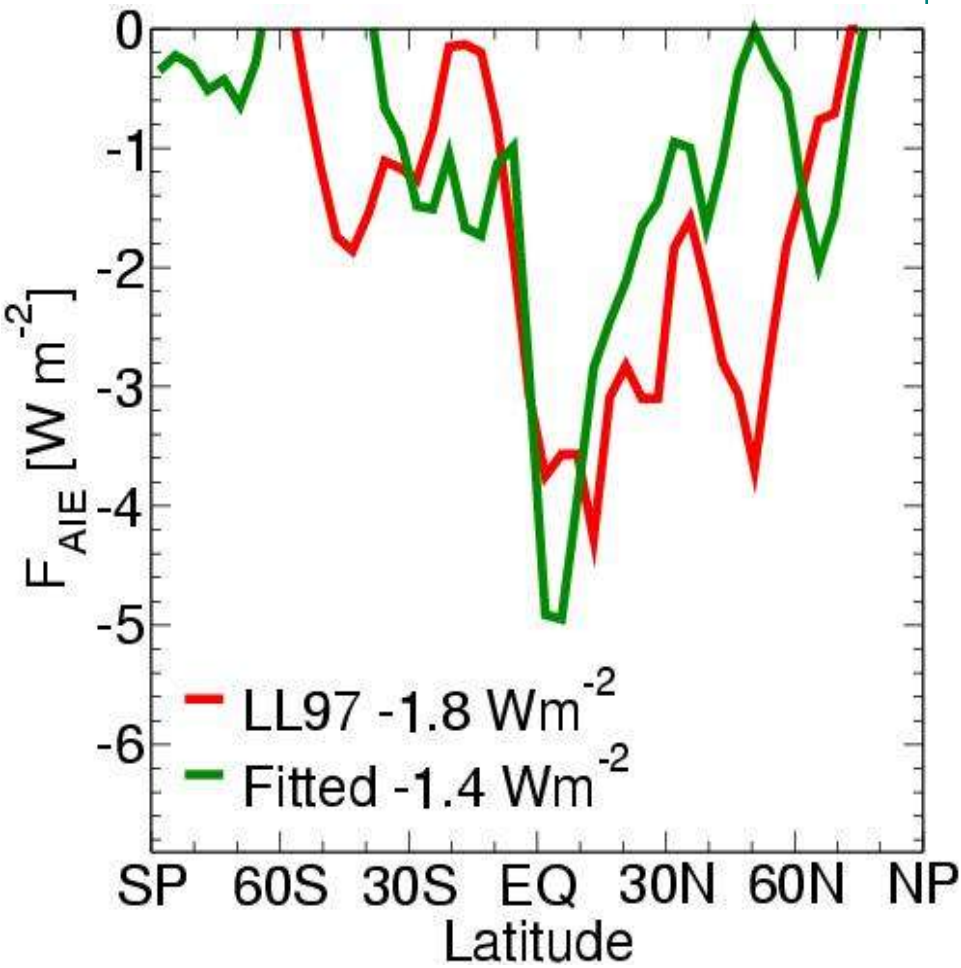

Quaas, Boucher, Lohmann, and Jones, in preparation

The Unknown

There are known knowns.
These are the things
We know we know.

And there are known unknowns.
That is to say, there are things,
We know we don't know.

But there are also unknown unknowns.
These are the ones
We don't know we don't know.

Rumsfeld, 2002

Cloud albedo effect

Cloud lifetime effect

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Ice cloud effect

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Outline

1. **Motivation**
2. Fitting **satellite-derived cloud-aerosol relationships** in GCMs
   - a) **Cloud albedo effect** in LMDZ: droplet radius – aerosol concentration
   - b) **Combined indirect effect** in LMDZ and ECHAM: CDNC – AOD
3. **Outlook**: Future requirements

Evaluation of indirect effects in GCMs: **What would we need ideally?**

	aerosols	dynamics	clouds
Cloud albedo effect			
Cloud lifetime effect			
Semi-direct effect			
Ice cloud effect			

Lohmann et al., submitted to BAMS

Evaluation of indirect effects in GCMs: **What would we need ideally?**

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Cloud albedo effect	number concentration size distribution soluble fraction	vertical wind speed relative humidity	number concentration size distribution water content
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Evaluation of indirect effects in GCMs: **What would we need ideally?**

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Ice cloud effect	number concentration size distribution soluble fraction aerosol type	vertical wind speed relative humidity	number concentration size distribution water content

Evaluation of indirect effects in GCMs: **What would we need ideally?**

required resolution	temporal: 1h	horizontal: 300m	vertical: 100m

Evaluation of indirect effects in GCMs: **What would we need ideally?**

required resolution	temporal: **1h**	horizontal: **300m**	vertical: **100m**
required coverage	**all cloud types:** - shallow convective - deep convective - stratiform	**all regions:** - arctic - mid-latitudes - sub-trocpics - tropics (each over **land and ocean**)	**all seasons**

Evaluation of indirect effects in GCMs: **How to get it? Remote sensing?**

Max-Planck-Institut für Meteorologie
Max Planck Institute for Meteorology

aerosols	**dynamics**	**clouds**
number concentration **(1,2,3)** size distribution **(2,3)** soluble fraction **(1)** single scattering albedo **(1,2)** aerosol type **(-)**	vertical wind speed **(4)** relative humidity **(1,3,4)**	number concentration **(1,3,4)** size distribution **(1,3,4)** water content **(1,3,4,5)** autoconversion rate (drizzle rate and size distribution) **(4,5)**

(1) spectral sensors
(2) sky-photometer
(3) lidar
(4) radar
(5) micro-wave sensors

Outline

2. Fitting **satellite-derived cloud-aerosol relationships** in GCMs

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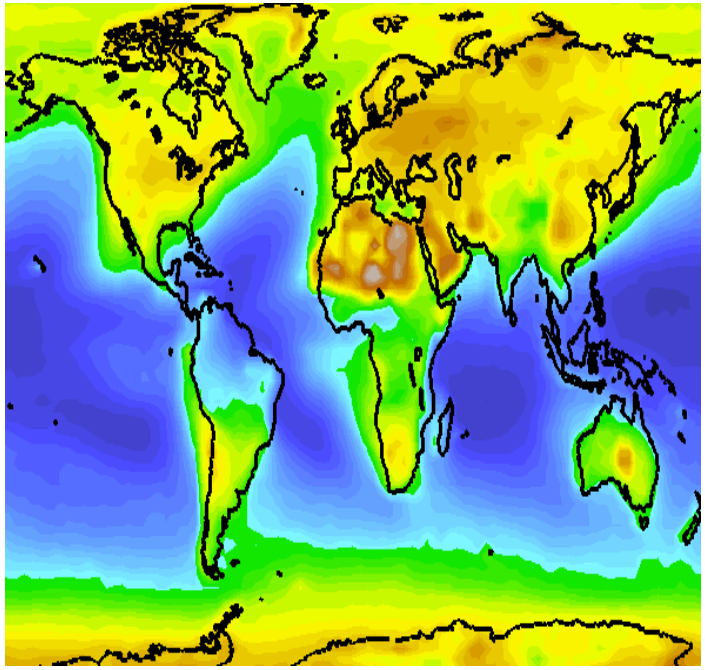
3. **Outlook**: More effort using remote upcoming sensing data needed

Thank you.



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