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

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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
Importance of aerosol indirect radiative forcing: Climate sensitivity

Temperature [°C]

17.0
16.0
15.0
14.0
13.0

1900 1950 2000 2050 2100

greenhouse effect

greenhouse plus aerosol effects
Importance of aerosol indirect radiative forcing: Climate sensitivity
Importance of aerosol indirect radiative forcing: Climate sensitivity

critical value: +2°C
Importance of aerosol indirect radiative forcing: Climate sensitivity

critical value: +2°C
e.g., Dufresne et al., GRL 2005
Global annual mean surface air temperature (deviation from 1961-1990)

- SRES B1
  - GHG’s = const
  - SO4 (anthr.)=0

observed
simulated

Constant concentrations (GHG’s + SO4)

Brasseur and Roeckner, submitted to GRL
greenhouse effect

greenhouse plus aerosol effects
greenhouse effect

greenhouse plus aerosol effects

greenhouse gas forcing
sulfate forcing (IPCC 07)
sulfate forcing (Pham et al.)

Dufresne et al., submitted to GRL
Approach to a better understanding: Statistical relationship of cloud and aerosol properties

- robust
- relative changes only
- valid in changing climate
Approach to a better understanding: **Statistical relationship of cloud and aerosol properties**

- robust
- relative changes only
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**POLDER satellite data**

Bréon et al., Science 2002; Quaas et al., JGR 2004
Parameterization of the indirect effects: Empirical link between CDNC and aerosol concentration

\[ N_d = \exp \left( a_0 + a_1 \ln m_{aer} \right) \]

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

\( m_{aer} \): aerosol mass concentration (µg m\(^{-3}\))

*Boucher and Lohmann, Tellus 1995*
Parameterization of the indirect effects: **Empirical link between CDNC and aerosol concentration**

\[ N_d = \exp \left( a_0 + a_1 \ln m_{\text{aer}} \right) \]

originally: aircraft data
- \( \sim 10^2 \) datapoints
- regional data
- limited time-series
- in-situ

*Boucher and Lohmann, Tellus 1995*
Parameterization of the indirect effects: Empirical link between CDNC and aerosol concentration

\[ N_d = \exp \left( a_0 + a_1 \ln m_{aer} \right) \]

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

- 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

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

$\Delta x \, / \, \Delta y$ : model resolution
here: $2.5^\circ \times 3.75^\circ$

Aerosol measurements
Cloud measurements
No retrieval
3 steps of increasing complexity:

- Twomey effect only, aerosols off-line, sulfate aerosols only
- Twomey effect only, aerosols on-line, multi-components aerosols
- Both (1\textsuperscript{st} and 2\textsuperscript{nd}) 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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3 steps of increasing complexity:

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

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

Quaas and Boucher, GRL, in preparation
2. Twomey effect only aerosols on-line (multi-components)

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3.
Problem with CDR: depends on cloud liquid water content

Aerosol concentration

Droplet radius

first effect only
Problem with CDR: depends on cloud liquid water content

- First effect only
- Both effects
CDNC instead of CDR

adiabatic cloud

Brenguier et al., JAS 2000; Schüller et al., JAM 2005
CDNC instead of CDR

adiabatic cloud

liquid water content

Brenguier et al., JAS 2000; Schüller et al., JAM 2005
CDNC instead of CDR

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Brenguier et al., JAS 2000; Schüller et al., JAM 2005
CDNC instead of CDR

adiabatic cloud

liquid water content

droplet number concentr.

droplet effective radius

Brenguier et al., JAS 2000; Schüller et al., JAM 2005
Instead: **Cloud droplet number concentration**

\[ r_{e,\text{top}} \sim N_d^{-1/3} H^{1/3} \]

\[ T_c \sim N_d^{1/3} H^{5/3} \]
CDNC instead of CDR

Instead: **Cloud droplet number concentration**

\[ r_{e,\text{top}} \sim N_d^{-1/3} H^{1/3} \]

\[ T_c \sim N_d^{1/3} H^{5/3} \]

combined:

\[ N_d \sim T_c^{1/2} r_{e,\text{top}}^{-5/2} \]

Brenguier et al., JAS 2000; Schüller et al., JAM 2005
CDNC instead of CDR

MODIS for 03/2000 - 02/2005
Model: AOD vs. $m_{\text{aer}}$

Aerosol optical depth ($550\text{nm}$, fine mode) vs. Cloud base aerosol mass concentration ($\mu g \text{ cm}^{-3}$)
\[ \tau_{\text{aer}} = \gamma m_{\text{aer, base}} \]
Model: AOD vs. $m_{\text{aer}}$

\[ T_{\text{aer}} = \gamma m_{\text{aer, base}} \]

MODIS: AOD vs. CDNC

Quaas, Boucher, Lohmann, and Jones, in preparation
Model: AOD vs. $m_{\text{aer}}$

- Linear fit

MODIS: AOD vs. CDNC

- Mean
- Exponential fit

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

$N_d = \exp(b_0 + b_1 \ln \tau_{\text{aer}})$

Quaas, Boucher, Lohmann, and Jones, in preparation
\[ \tau_{\text{aer}} = \gamma \ m_{\text{aer, base}} \]

\[ N_d = \exp (b_0 + b_1 \ln \tau_{\text{aer}}) \]

\[ N_d = \exp (a_0 + a_1 \ln m_{\text{aer}}) \]

\[ a_0 = b_0 + a_1 \ln \gamma = 4.3 \]

\[ a_1 = b_1 = 0.3 \]

Quaas, Boucher, Lohmann, and Jones, in preparation
Both indirect effects aerosols on-line (multi-components)

Quaas, Boucher, Lohmann, and Jones, in preparation
3a. Both indirect effects of aerosols on-line (multi-components)

Quaas, Boucher, Lohmann, and Jones, in preparation
Both indirect effects aerosols on-line (multi-components)

Satellite-derived parameterization:
- CDNC – AOD(FM) relationship fits well
- good aerosol distribution

Quaas, Boucher, Lohmann, and Jones, in preparation
Both indirect effects aerosols on-line (multi-components)

Quaas, Boucher, Lohmann, and Jones, in preparation
Estimate of the 2\textsuperscript{nd} aerosol indirect effect

Quaas, Boucher, Lohmann, and Jones, in preparation
Estimate of the 2nd aerosol indirect effect

Quaas, Boucher, Lohmann, and Jones, in preparation
Both indirect effects
aerosols on-line
( ECHAM4 )

Quaas, Boucher, Lohmann, and Jones, in preparation
3b. Both indirect effects aerosols on-line (ECHAM4)

Quaas, Boucher, Lohmann, and Jones, in preparation
Both indirect effects aerosols on-line (ECHAM4)

\[ N_d = 0.1 \left[ N_a \frac{w}{w + cN_a} \right]^{1.27} \]

Fit done by dividing w by 2.

Lin and Leaitch, 1997
3b. Both indirect effects aerosols on-line (ECHAM4)

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
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Rumsfeld, 2002
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3. Outlook: Future requirements
Evaluation of indirect effects in GCMs: What would we need ideally?

- Cloud albedo effect
- Cloud lifetime effect
- Semi-direct effect
- Ice cloud effect

aerosols dynamics clouds

Lohmann et al., submitted to BAMS
**Evaluation of indirect effects in GCMs: What would we need ideally?**

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An Institute of the Max Planck Society
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?

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| Required Coverage   | All Cloud Types:  
- shallow convective  
- deep convective  
- stratiform  

| All Regions:  
- arctic  
- mid-latitudes  
- sub-tropics  
- tropics  
  (each over **land and ocean**) |
| All Seasons |
**Evaluation of indirect effects in GCMs:**

**How to get it? Remote sensing?**

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<tr>
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<td>Water content (1,3,4,5)</td>
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<td>Autoconversion rate (4,5)</td>
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<td>Aerosol type (-)</td>
<td></td>
<td>(drizzle rate and size distribution) (4,5)</td>
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- (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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   a) Different model versions / satellite datasets: Cloud albedo effect reduced by 50% to -0.3 to -0.5 Wm$^{-2}$
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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