

# Evaluation of aerosol indirect effects: cloud albedo susceptibility

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- Radiative forcing cloud albedo indirect effect, next factor
- Closure for the satellite-derived forcing

Acknowledgments:

Joyce Penner, Philip Stier, Yi Ming, Olivier Boucher, BJ Sohn, Bill Rossow, et al.



# Cloud susceptibility

Radiative forcing by the cloud albedo effect (liquid clouds, solar):



$$\Delta F_{\text{ind}} = f_{\text{cld,liq}} \bar{F} \downarrow \frac{\partial \alpha}{\partial \ln N_d} \frac{d \ln N_d}{d \ln \tau_a} \Delta \ln \tau_{a,\text{ant}}$$

$\alpha$  – Top-of atmosphere planetary albedo

$N_d$  – Cloud droplet number concentration

$\tau_a$  – Aerosol optical depth

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Liquid cloud  
fraction


Daily-mean  
insolation

Anthropogenic  
fraction of  
aerosol

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Sensitivity of  
droplet  
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Liquid cloud fraction:  
available  
from MODIS

Daily-mean insolation:  
readily available

Sensitivity of droplet number concentration to aerosol:  
AEROCOM  
IND2 (but: B. Grandey's work)

Anthropogenic fraction of aerosol:  
Bellouin et al. (Nature 2005)

# Cloud susceptibility

Radiative forcing by the cloud albedo effect (liquid clouds, solar):

$$\Delta F_{\text{ind}} = f_{\text{cld,liq}} \bar{F} \downarrow \left[ \frac{\partial \alpha}{\partial \ln N_d} \frac{d \ln N_d}{d \ln \tau_a} \Delta \ln \tau_{a,\text{ant}} \right]$$

Liquid cloud fraction:  
available from MODIS

Daily-mean insolation readily available

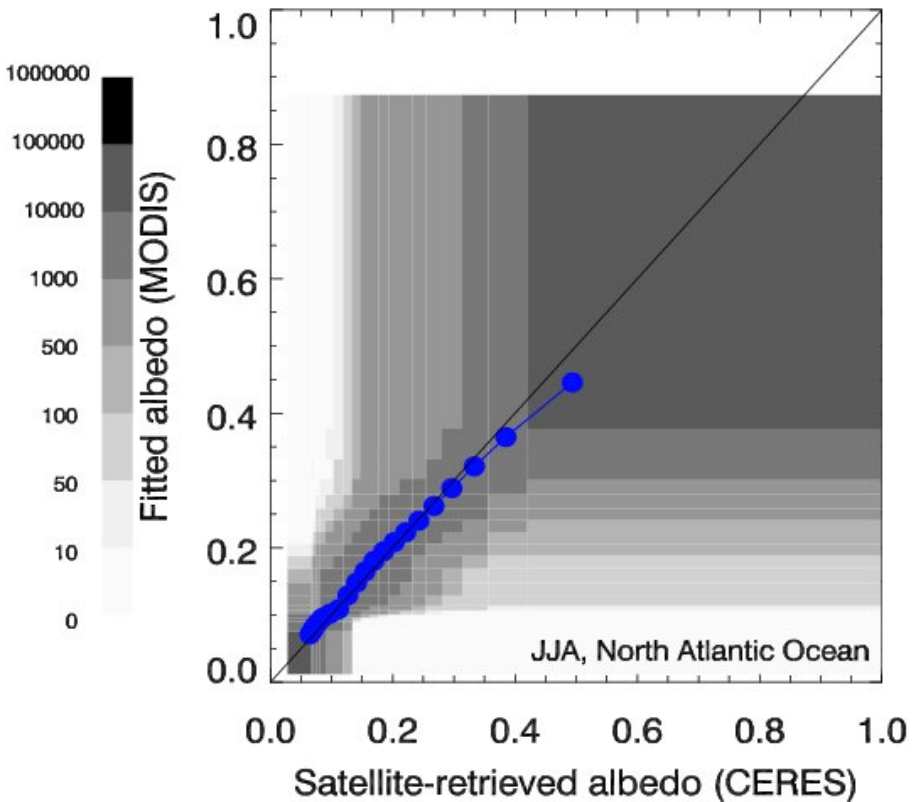
Sensitivity of planetary albedo to droplet number concentration (at constant cloud cover and liquid water path)

Sensitivity of Anthropogenic aerosol: in et al. e 2005)

# Cloud susceptibility

$$\alpha = \alpha(\tau_a; f, L, N_d)$$

Fit from satellite data



MODIS

aerosol optical thickness,  $\tau_a$

cloud fraction,  $f$

liquid water path,  $L$

droplet number concentration,  $N_d$

CERES

planetary albedo,  $\alpha$

$$\alpha \approx (1 - f) [a_1 + a_2 \ln \tau_a] + f [a_3 + a_4 f \tau_c]^{a_5}$$

$$\tau_c = \beta L^{\frac{5}{6}} N_d^{\frac{1}{3}}$$

# Cloud susceptibility

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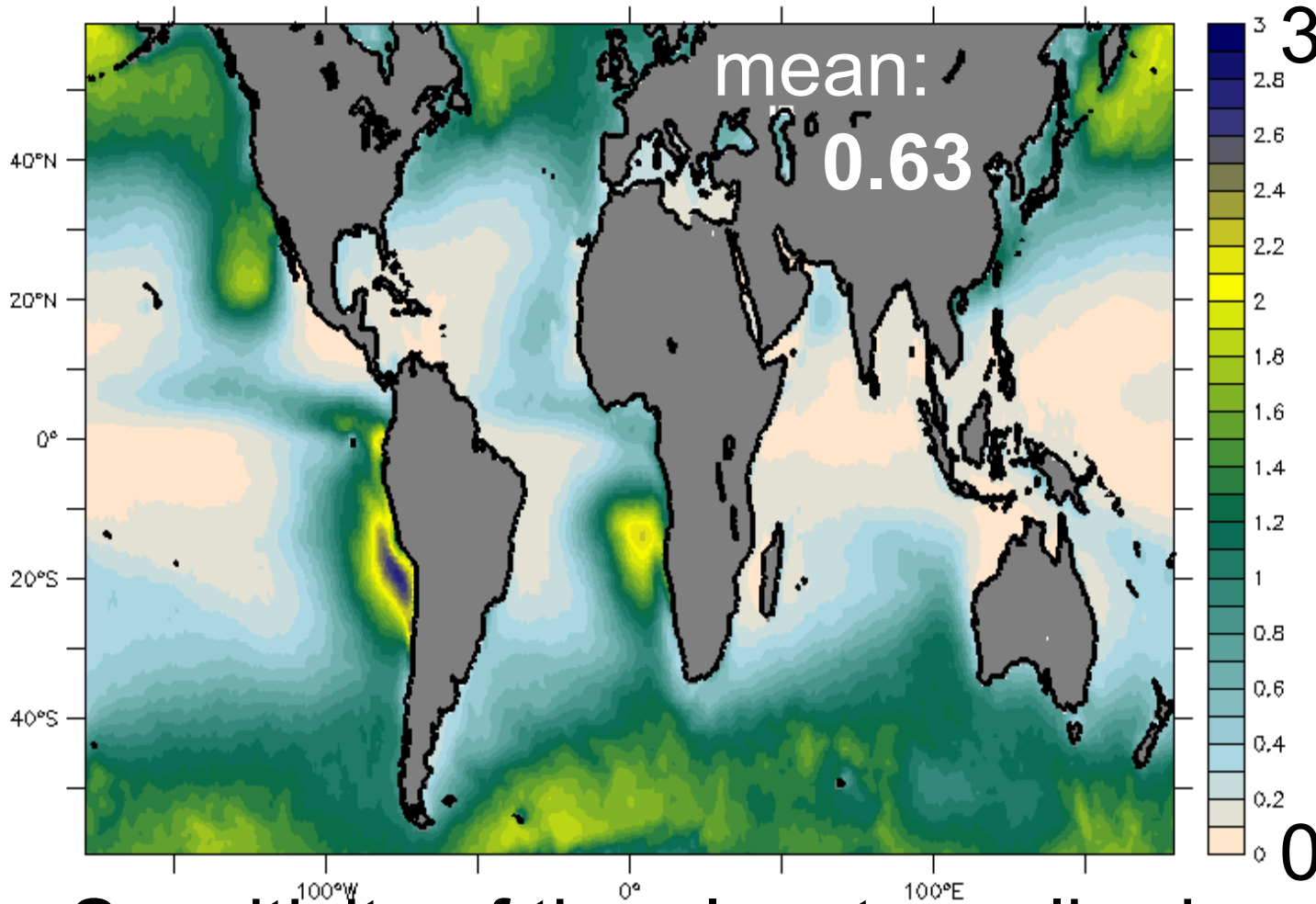
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$$\left[ \frac{\partial \alpha}{\partial \ln N_d} \right]_{f, L}$$



# Cloud susceptibility




$$\left[ \frac{\partial \alpha}{\partial \ln N_d} \right]_{f,L}$$

Sensitivity of the planetary albedo to a doubling in  $N_d$  [%].

# Cloud susceptibility

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Alternative: off-line radiative transfer

→ albedo change for a unit  $N_d$  change

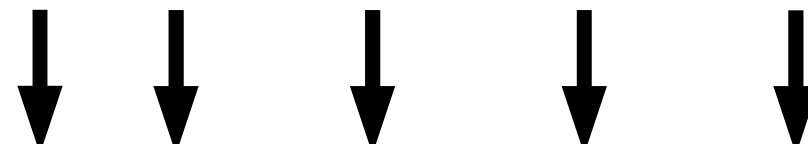
(<> partial radiative perturbation method for feedback analysis  
<> radiation intercomparison)

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All factors from GCM:  
Radiative forcing estimate  
(satellite-like)

Credit: Joyce Penner, Gordon conference 2009  
<> Myhre, Science 2009

# Cloud susceptibility

Indirect effect as flux perturbation

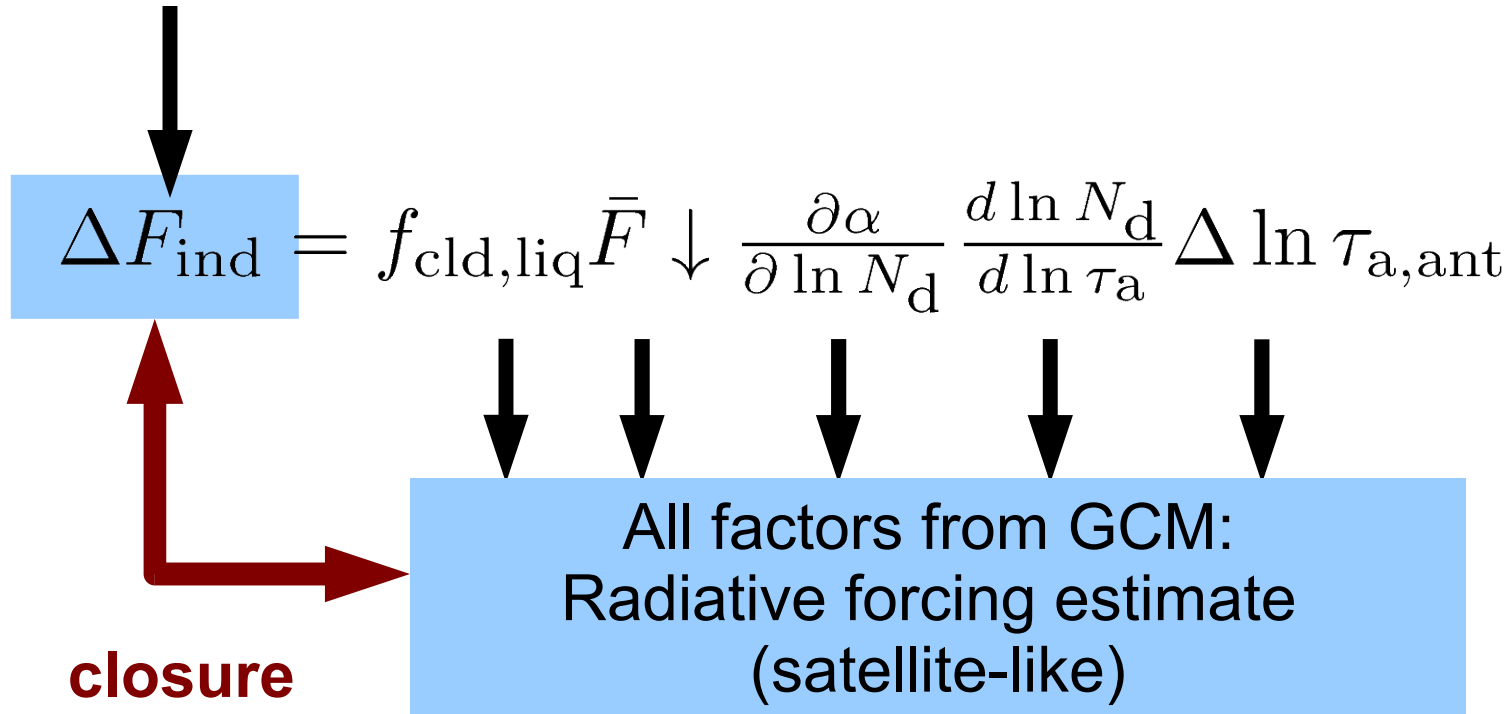
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# Cloud susceptibility

Indirect effect as flux perturbation



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# Cloud susceptibility

Needed input:

Statistical method: As IND2 (10.30 am satellite sampling)

Offline radiation: Instantaneous 3D T, q, cloud fraction, cloud water path, cloud droplet number concentrations

Closure: Radiative flux perturbation by cloud albedo effect only (no direct, semi-direct, and second indirect effects)