AEROCOM Mtg, Oct 3-6, 2011, Fukuoka

# Detecting aerosol effects from satellites and their limitations

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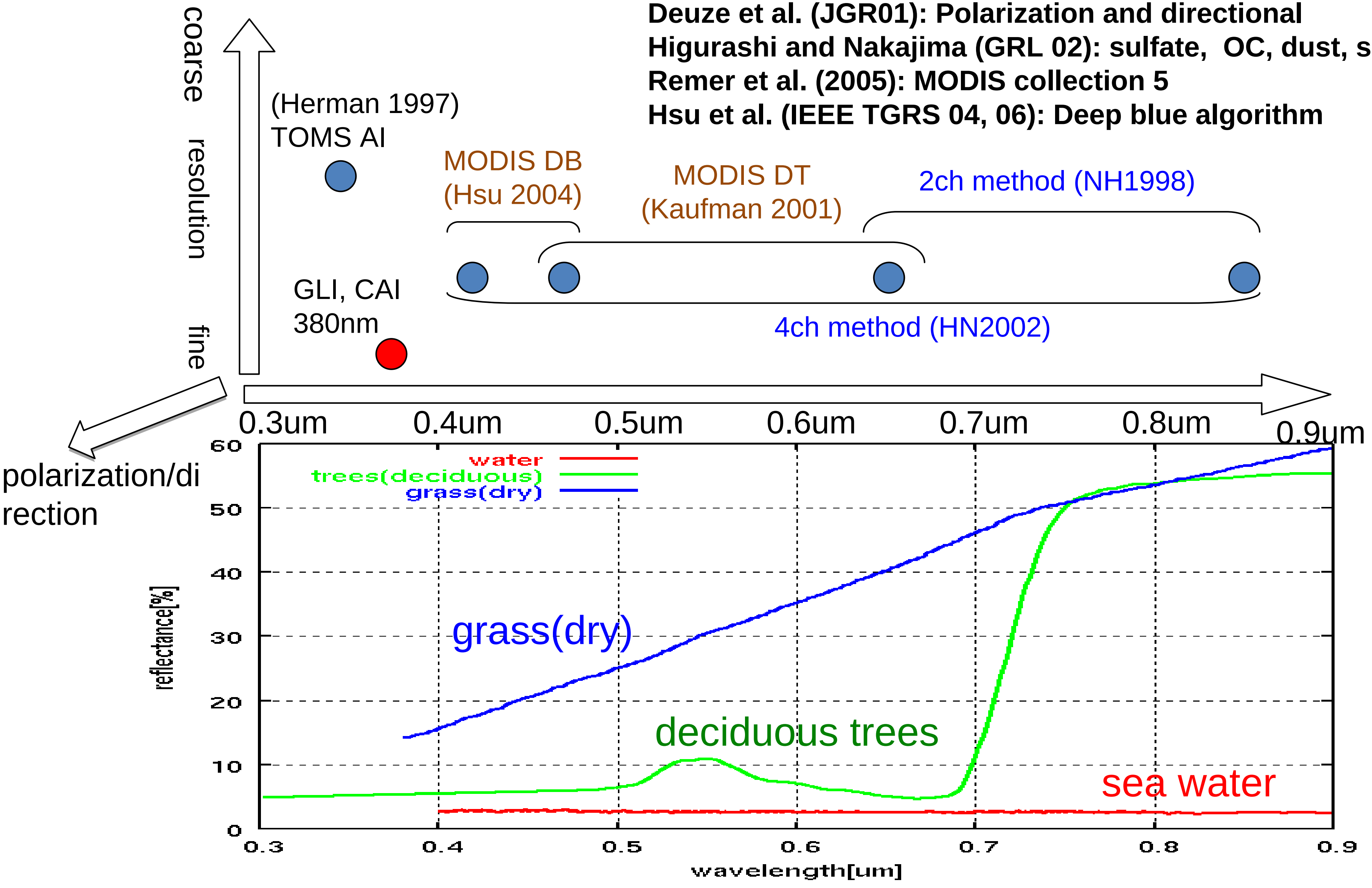
# UNEP ABC Project

- **Emission Gap Report (UNEP 2010); Integrated Assessment of Black Carbon and Tropospheric Ozone (UNEP 2011)**
- **ABC-Asia**
  - **ABC Climate Observatories**
  - **Impact study groups (Health, agriculture, and water)**
  - **Intensive Analysis Period (IAP from August 2010 for 1yr): Modeling G. (G. Carmichael)**

- **ABC-international**
  - **ABC-Asia**
  - **ABC-Africa**
  - **ABC-L. America**

# Passive aerosol remote sensing

**Herman et al. (JGR 97): TOMS AI**
**Nakajima and Higurashi (GRL 98): 2ch over ocean**
**Kaufman, Tanre, et al. (GRL01) Dust SSA**
**Deuze et al. (JGR01): Polarization and directional**
**Higurashi and Nakajima (GRL 02): sulfate, OC, dust, salt**
**Remer et al. (2005): MODIS collection 5**
**Hsu et al. (IEEE TGRS 04, 06): Deep blue algorithm**



coarse resolution fine

(Herman 1997)
TOMS AI

MODIS DB
(Hsu 2004)

MODIS DT
(Kaufman 2001)

2ch method (NH1998)

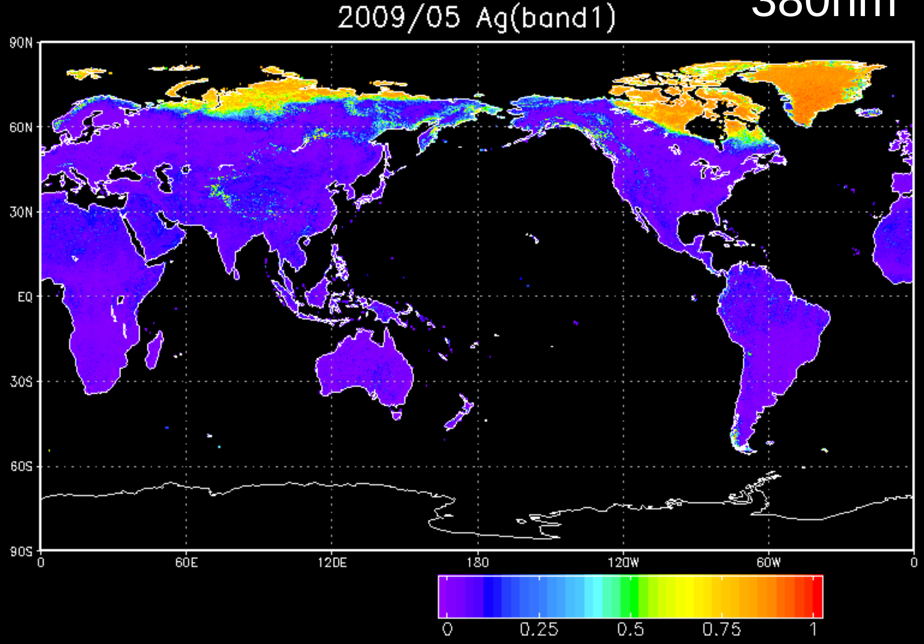
GLI, CAI
380nm

4ch method (HN2002)

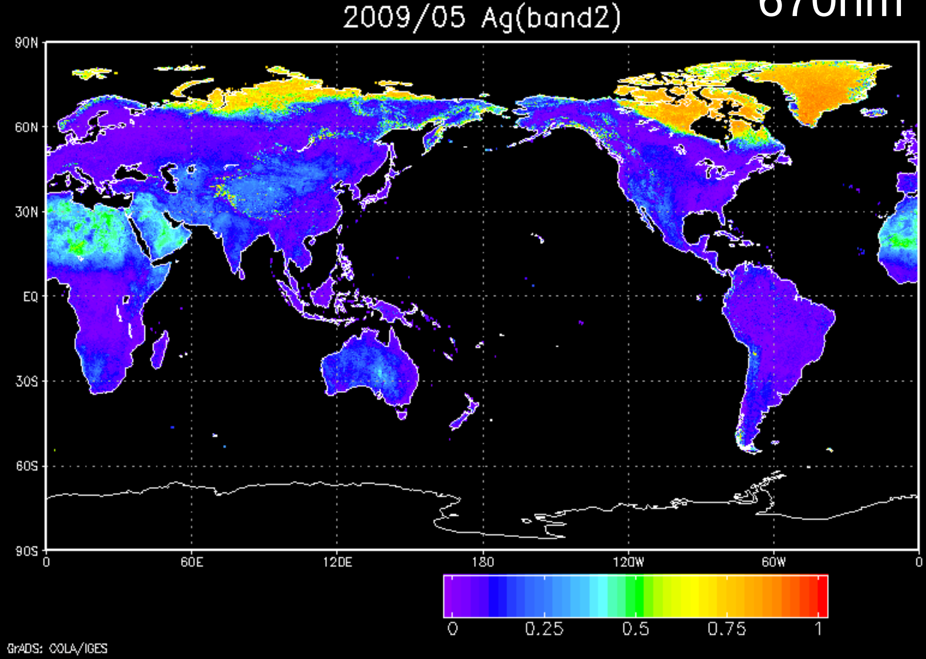
polarization/direction

GOSAT/CAI

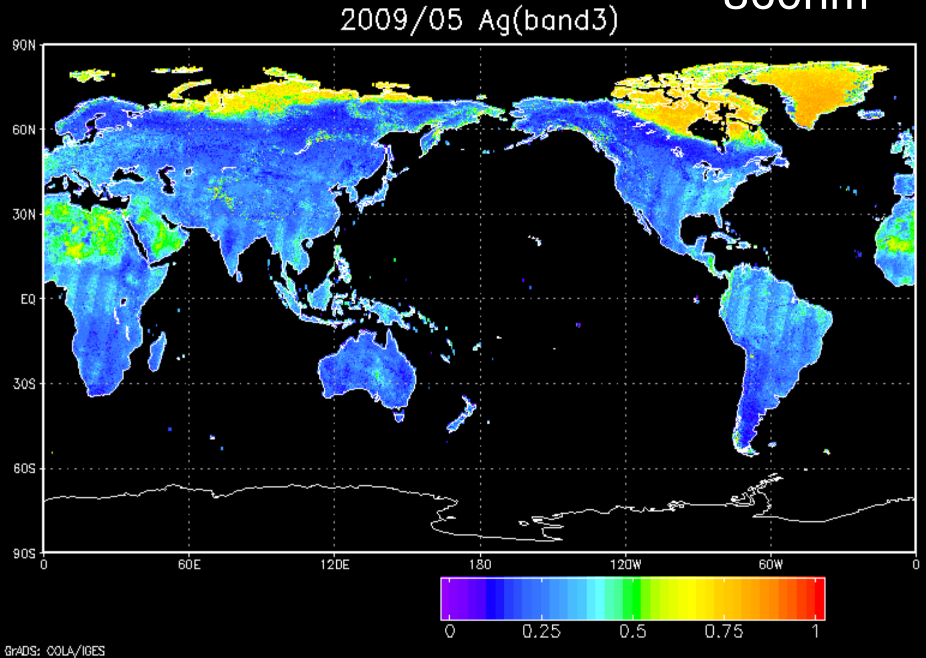
380nm



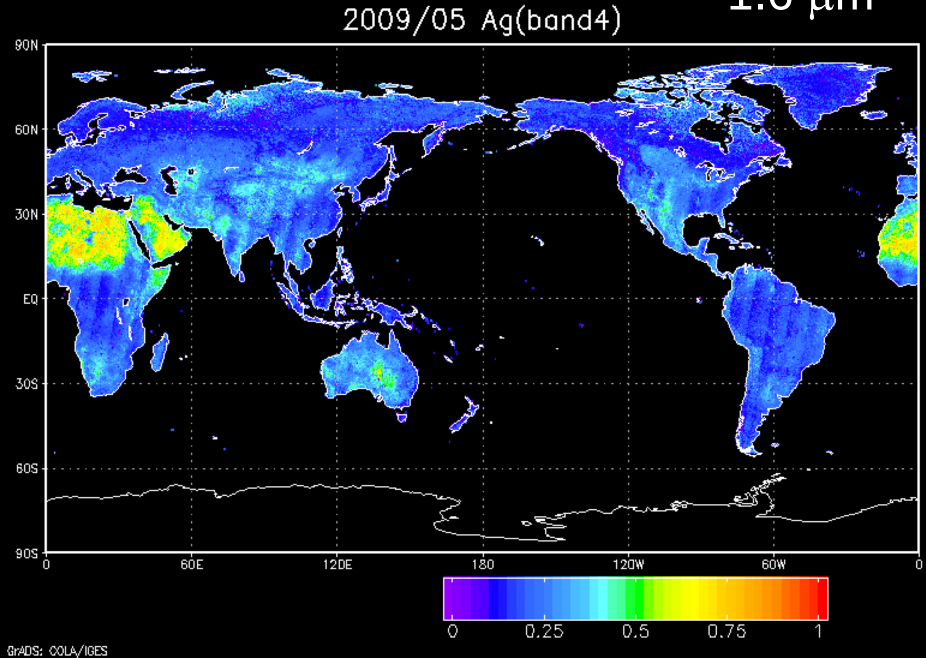
670nm



860nm

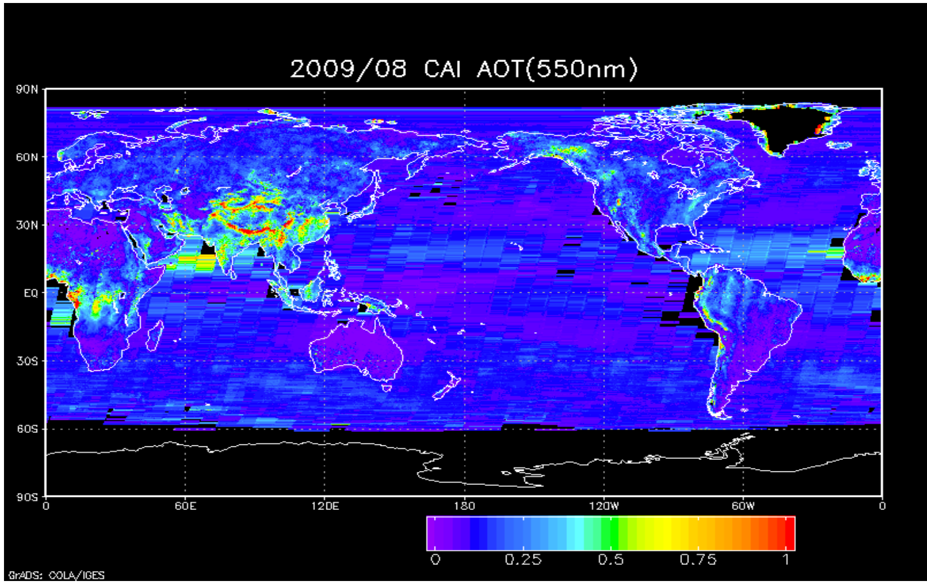


1.6 μm

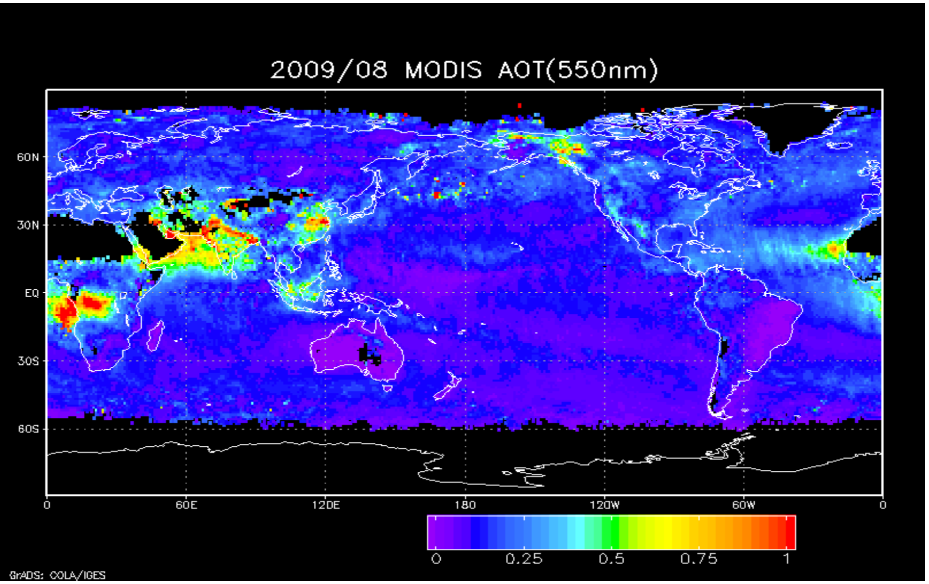


**S. Fukuda**

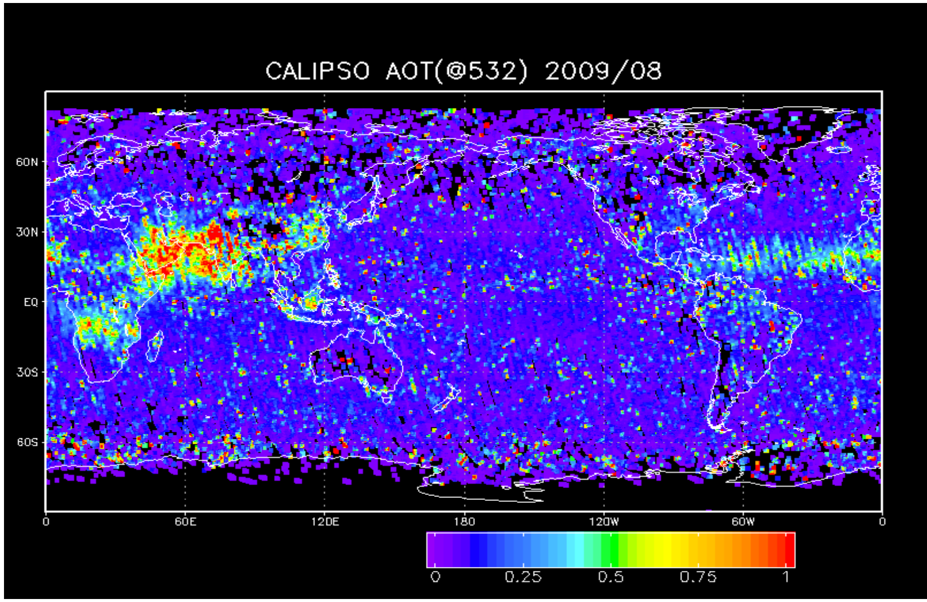
## GOSAT/CAI (380nm, 1km)



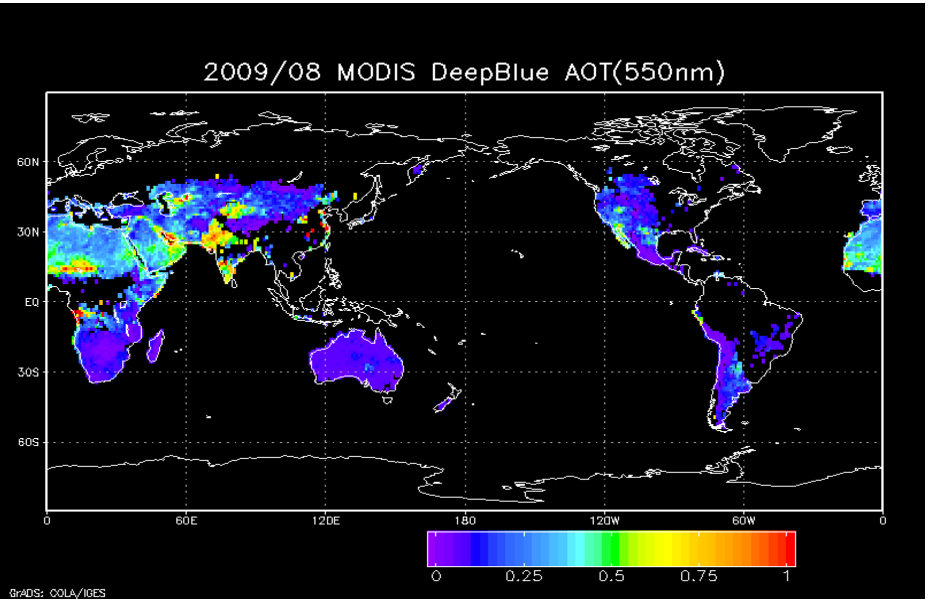
## MODIS Dark Target



## Calipso



## MODIS Deep Blue



# Assimilation of MODIS AOT and AERONET AOT & AE

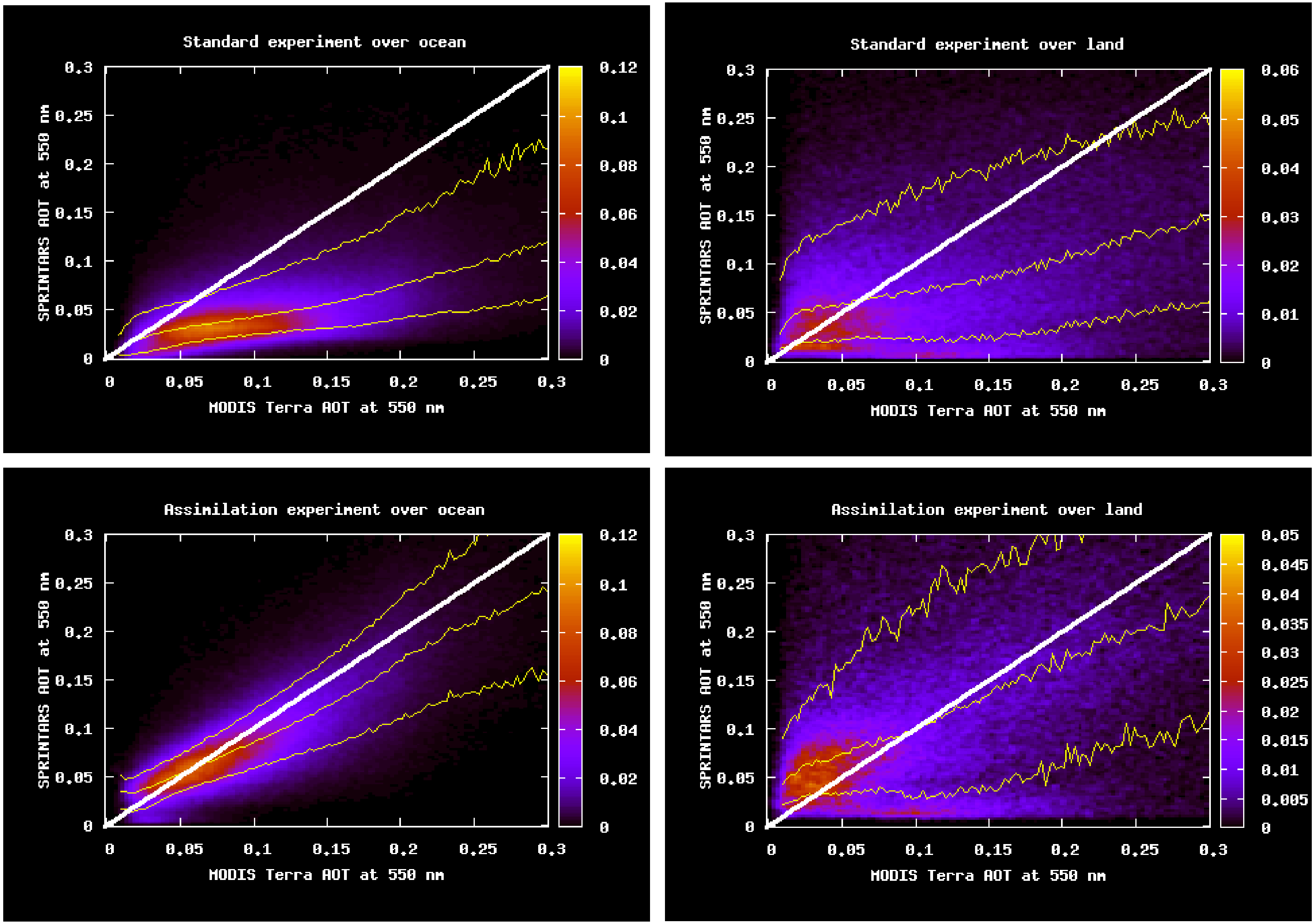
**N. Schutgens**

Ocean

Land

Standard

Assimilation



# Radiative forcing (RF)

- **Stratospheric-adjusted RF (ARF)**
- **TOA-RF and Tropopause-RF; almost same as instantaneous RF for aerosols**
- **24 hour mean-RF**
- **Direct aerosol RF (DARF), Indirect aerosol RF (IARF)**
- **1st kind IARF (Albedo effect)**
- **2nd kind IARF: SST-fixed short model runs**
- **New concept of adjusted RF (AF) to identify fast climate response forcings, *e.g.*, 2nd IARF, CO2, ... (Gregory et al. GRL2004):**

  $$\Delta N_{storage} = \Delta F - \alpha \, \Delta T$$

  **($\alpha$: feedback parameter; $\lambda = 1/\alpha$: sensitivity parameter)**
- **Depth of the storage for fast response? same process?**

# DARF (shortwave)

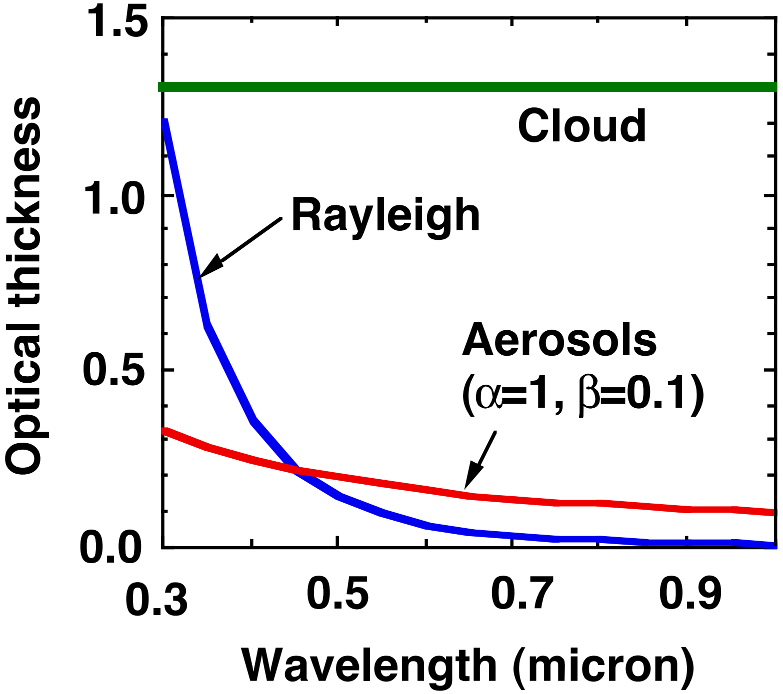
**Nakajima et al. (JGR 07)**

$$RF_{toa} \approx \underbrace{-T_u^2 SD[\omega b - 2A(1-\omega f)]^{\zeta}}_{\text{efficiency factor } \beta_a} \Delta\tau_{700}$$

$$f = \frac{1+g}{2}, \quad b = \frac{1-g}{2}, \quad \zeta = 1.12$$

$$A_n \approx \frac{\omega b}{2(1-\omega f)}$$

- **$\tau_{700}$, Aerosol optical thickness (AOT) at 700nm; *S*, solar constant; *D*, Sunshine duration; *Tu* , upper atmosphere transmittance; $\omega$, Single scattering albedo (SSA); *g*, Asymmetry factor; *A*, underlying layer reflectance**
- **$\alpha$, Angström exponent (AE)** $\tau_\lambda = \tau_0 \lambda^{-\alpha}$
- **DARF(AOT550 & AE) = DARF(AOT700)**
- **$A_n$, Neutral reflectance (1-SSA)**
- **Size effects from *g* and SSA**
- **Geogr. distr. effects from *D* and <cos$\theta_0$>**



# IARF (shortwave)

$$A_c \approx 1-\frac{1-A_g}{1+(1-A_g)c\tau_c}, \quad c=\frac{1-g_c}{2}\sqrt{3}$$

$$\Delta F_i = -\underbrace{T_u^2 S < \mu_0 > D n_L (1-A_c)^2 c\tau_c}_{\beta_i} \underbrace{\frac{d\ln\tau_c}{d\ln N_a}}_{\text{correlation slope } b_{cot}} \Delta\ln N_a$$

$$\Delta F_n = -\underbrace{T_u^2 S < \mu_0 > D(A_c - A_g)_c}_{\beta_n} \underbrace{\frac{dn}{d\ln N_a}}_{b_n} \Delta\ln N_a$$

- ***Ag*, ground albedo; $\tau_c$, Cloud optical thickness (COT); $n_L$, Low level cloud fraction; *n*, cloud fraction; Na, column aerosol number; $<\mu_0>$, mean cos(solar zenith angle)**
- **Liquid water path $LWP = c\,\rho\,RE_{top} * COT$**

**where RE, effective cloud particle radius; *c*=2/3 for homogeneous cloud, =5/9 for adiabatic cloud (Brenguier et al., JAS2000)**

- **Cloud susceptibility rapidly decreases with COT**

# Total ARF

- **All effects are equally important for the present COT range**
- **GCM: cloud amount change is not fully discussed**

$$ARF = -(1-n)\beta_a \Delta\tau_a - n_L \beta_{ac} \eta \Delta\tau_a - n_L \beta_i b_{COT} \Delta \ln(N_a) - \beta_n b_n \Delta \ln(N_a)$$

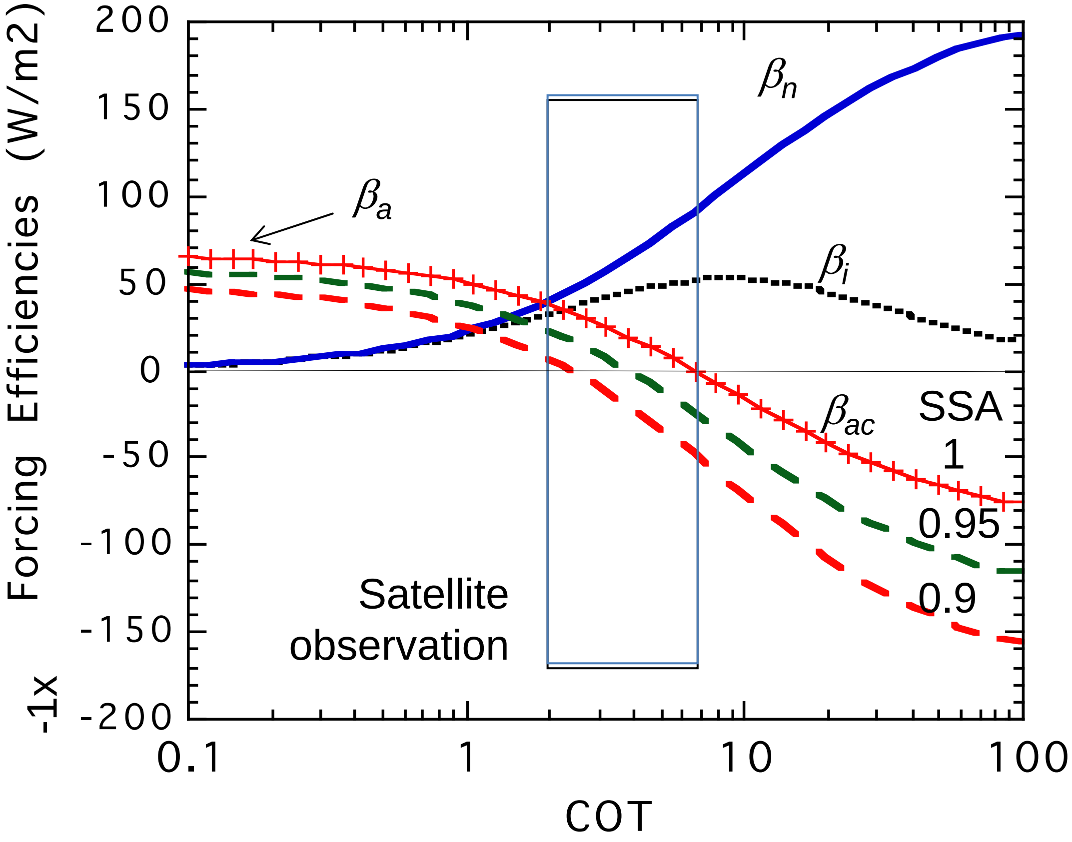
**direct clear** **direct cloudy** **indirect** **cloud amount change**

$$\beta_i = T_{u,c}^2 Q \cdot (1-A_c)^2 c\tau_c,$$

$$b_{COT} = d\ln\tau_c / d\ln N_a$$

$$\beta_n = T_u^2 Q(A_c - A_g)$$

$$b_n = dn / d\ln N_a$$



- $\beta$, efficiency
- $b$, correlation slope

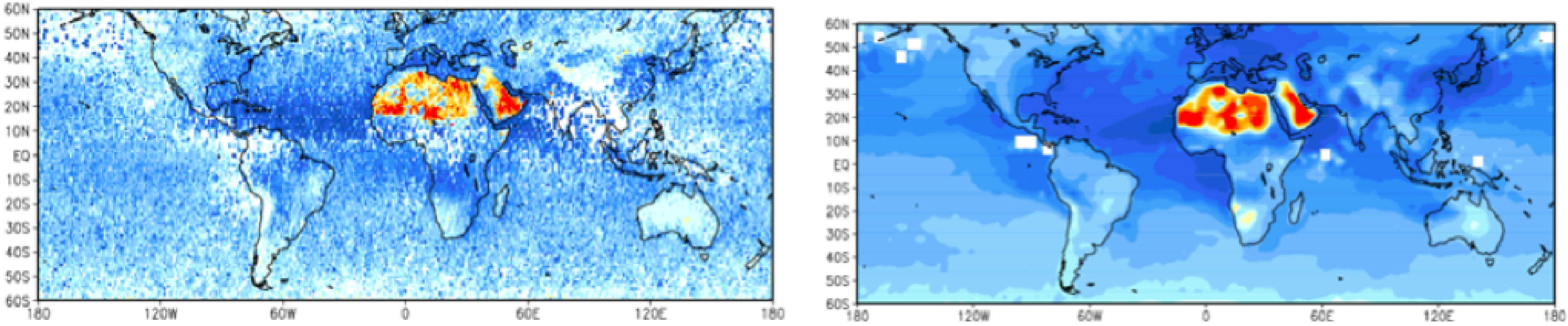
# DARF

## clear sky

**CALIPSO**

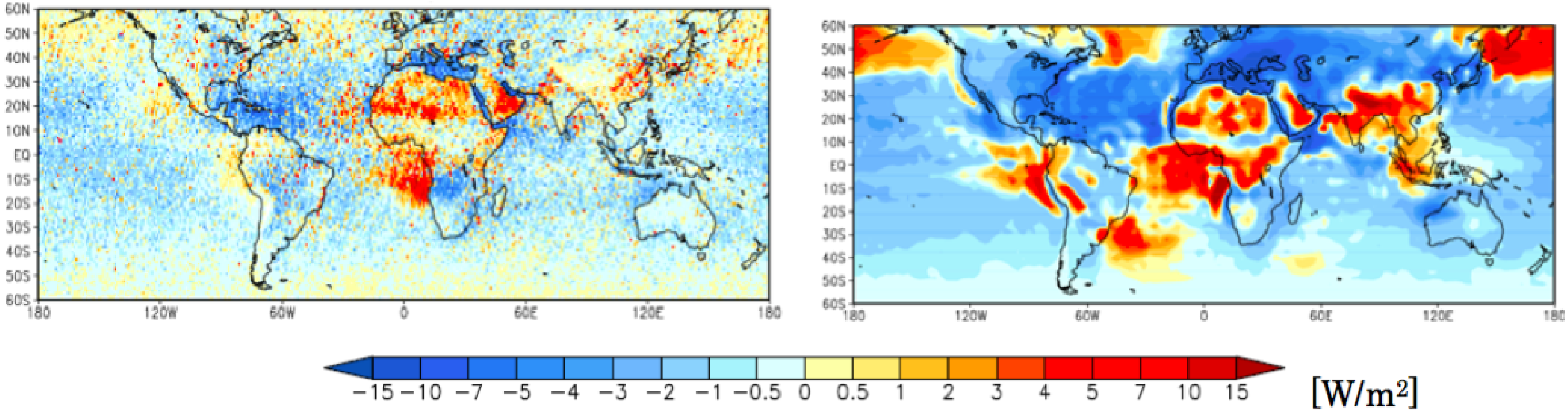
2007 summer (June, July, and August)

**SPRINTARS**



## whole sky

2007 summer (June, July, and August)



**Oikawa et al. (preparing)**

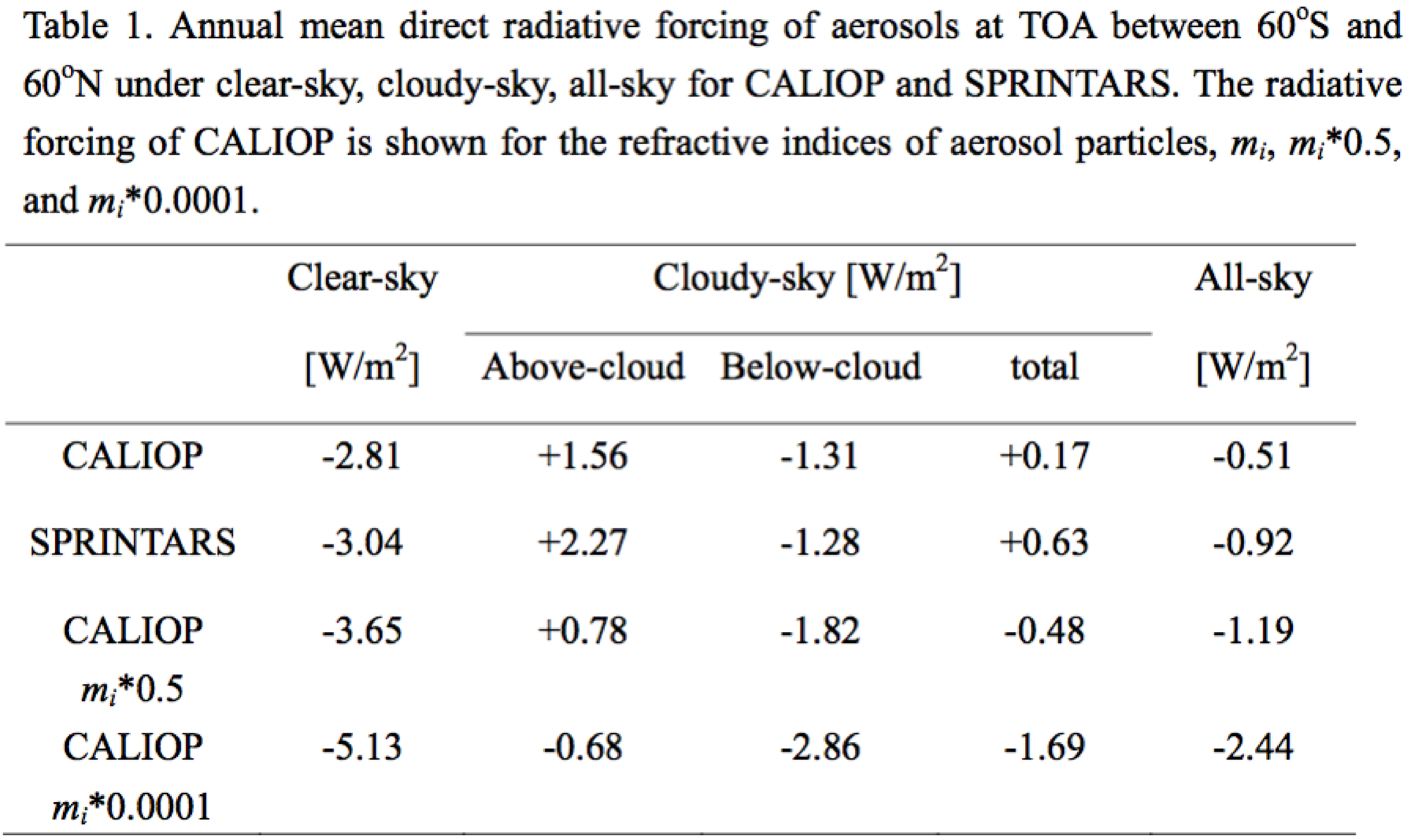


Table 1. Annual mean direct radiative forcing of aerosols at TOA between 60°S and 60°N under clear-sky, cloudy-sky, all-sky for CALIOP and SPRINTARS. The radiative forcing of CALIOP is shown for the refractive indices of aerosol particles, $m_i$, $m_i$*0.5, and $m_i$*0.0001.

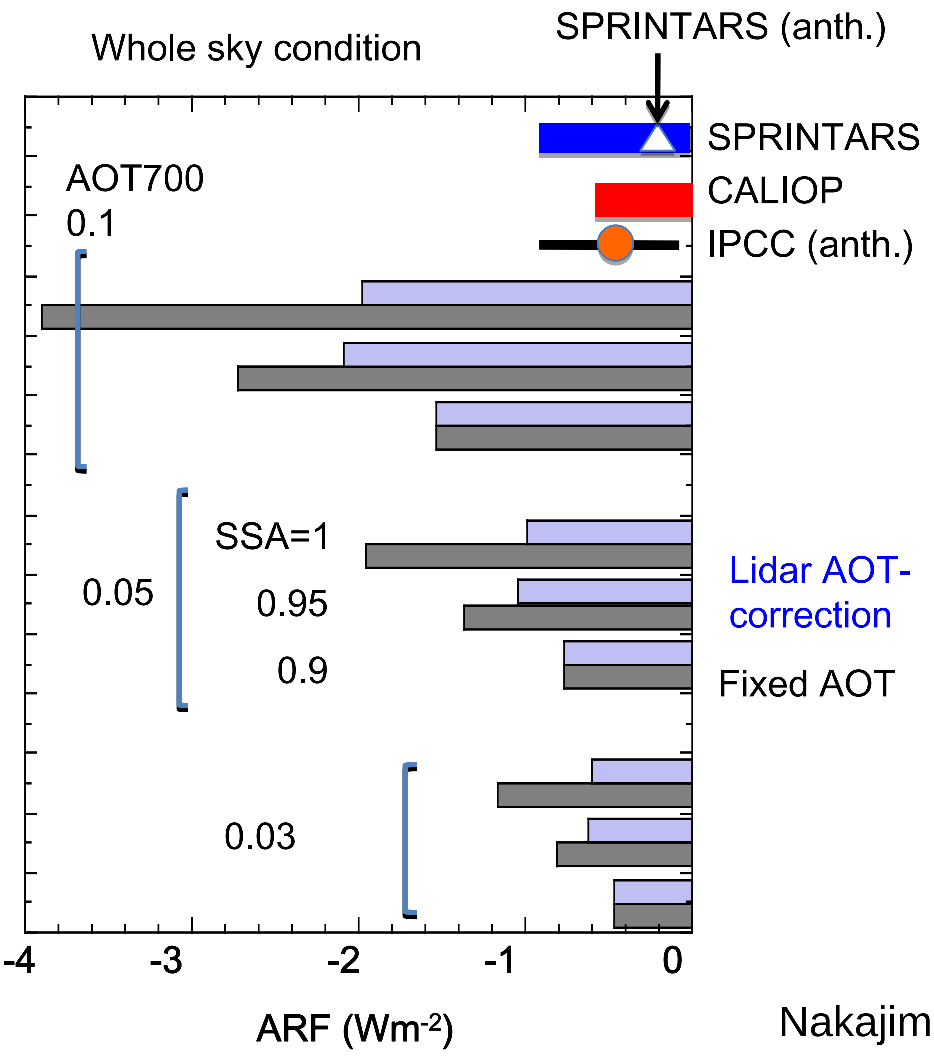
| | Clear-sky [W/m$^2$] | Cloudy-sky [W/m$^2$] | | | All-sky [W/m$^2$] |
|---|---|---|---|---|---|
| | | Above-cloud | Below-cloud | total | |
| CALIOP | -2.81 | +1.56 | -1.31 | +0.17 | -0.51 |
| SPRINTARS | -3.04 | +2.27 | -1.28 | +0.63 | -0.92 |
| CALIOP $m_i$*0.5 | -3.65 | +0.78 | -1.82 | -0.48 | -1.19 |
| CALIOP $m_i$*0.0001 | -5.13 | -0.68 | -2.86 | -1.69 | -2.44 |

**Oikawa et al. (preparing)**

# Aerosol direct effect of 2007

$$\tau_{a,lidar}\exp(-2\tau_{a,lidar}) = \frac{S_{lidar}}{S_{true}}\tau_{a,true}\exp(-2\tau_{a,true}):\quad \omega_a\uparrow\quad causes\quad \tau_{a,lidar}\downarrow$$

$$\tau_{a,532} = 0.082$$

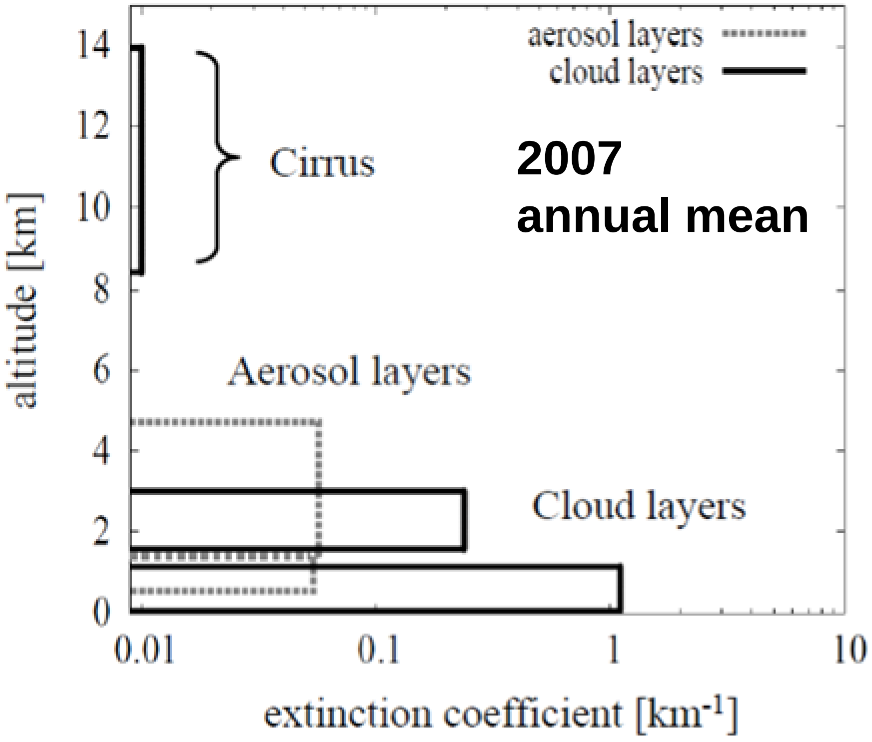


- **More or less similar situation even for passive sensors**

Nakajima, Oikawa, Winker (preparing)

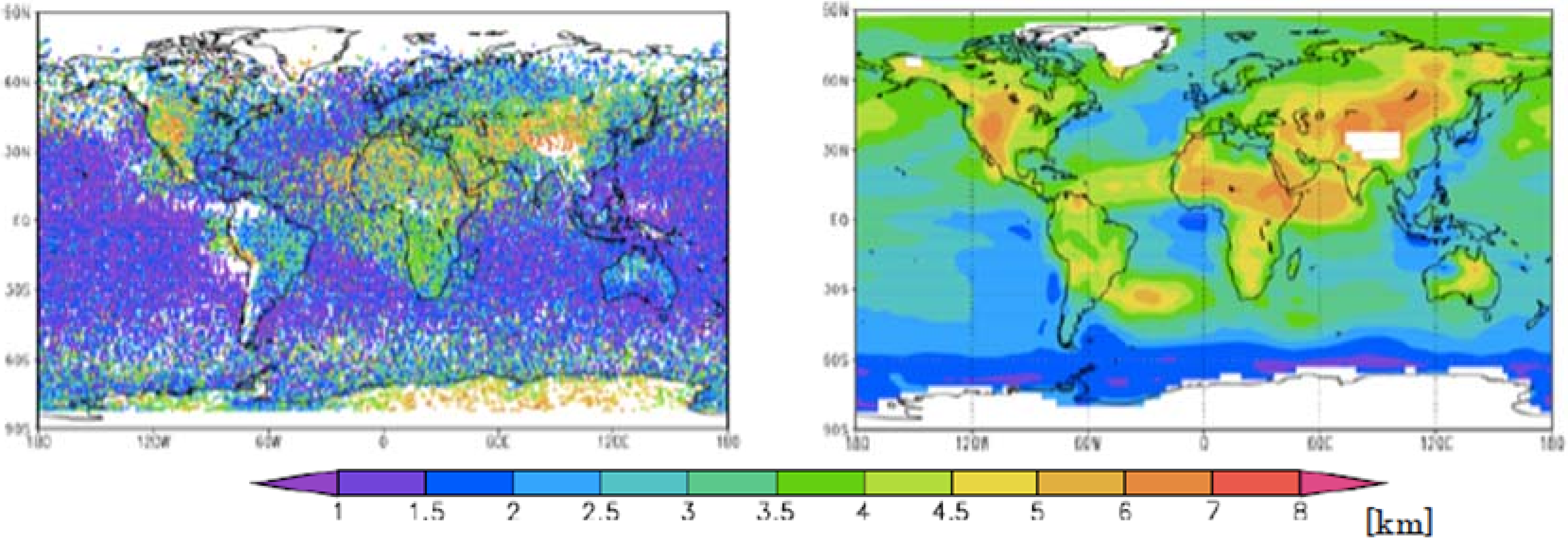
# Other uncertainty factors
# e.g., Height of aerosol layer

- How to mix CALIPSO-observed aerosols with clouds?



2007 annual mean

2007 summer (JJA)



Oikawa et al. (preparing)

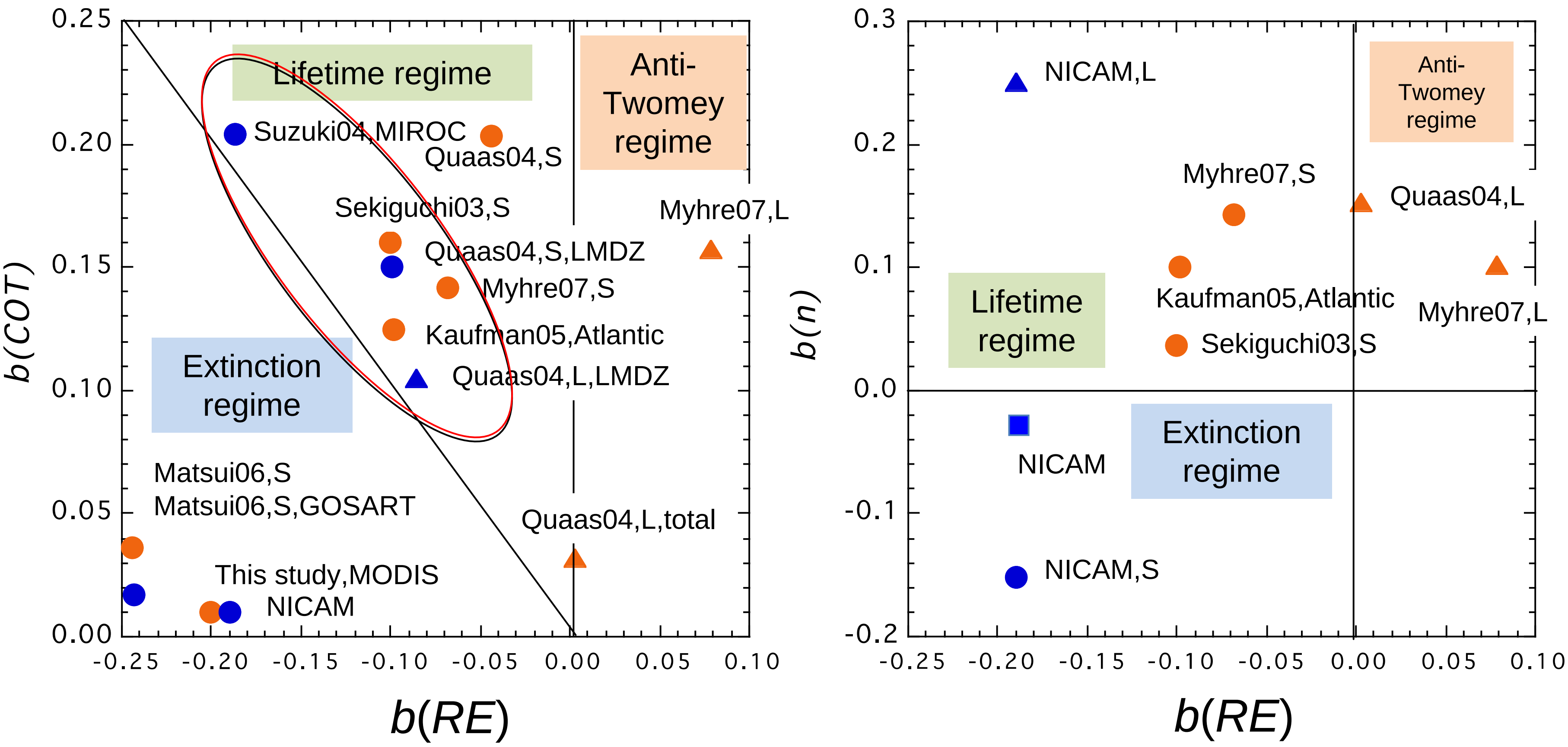
# Correlation slopes of low-level cloud parameters vs $N_a$

**Nakajima and Schulz (MIT press 2009)**

$$b(LWP) = b(RE) + b(COT)$$

$$LWP = c\rho RE_{top} \times COT$$

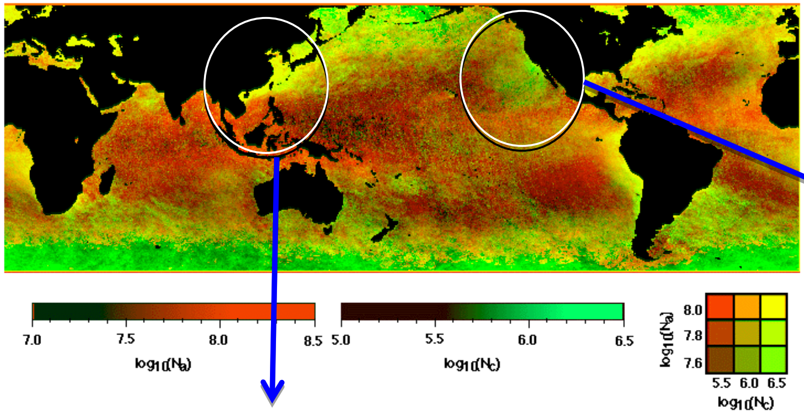
$$b(RE) = \frac{d\ln r_e}{d\ln N_a}, \quad b(COT) = \frac{d\ln \tau_c}{d\ln N_a}, \quad b(n) = \frac{dn}{d\ln N_a}$$



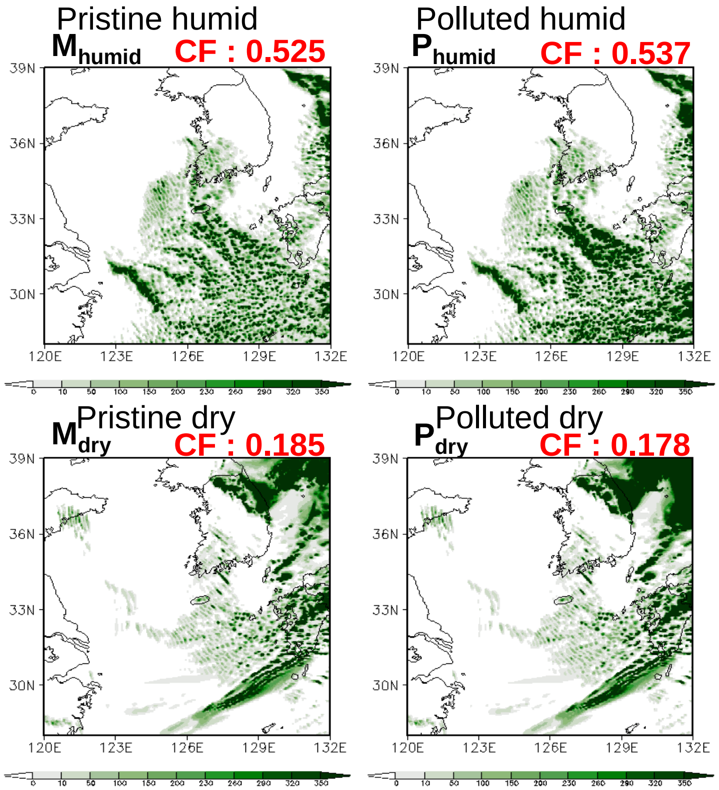
# Study of aerosol-cloud-precipitation interaction

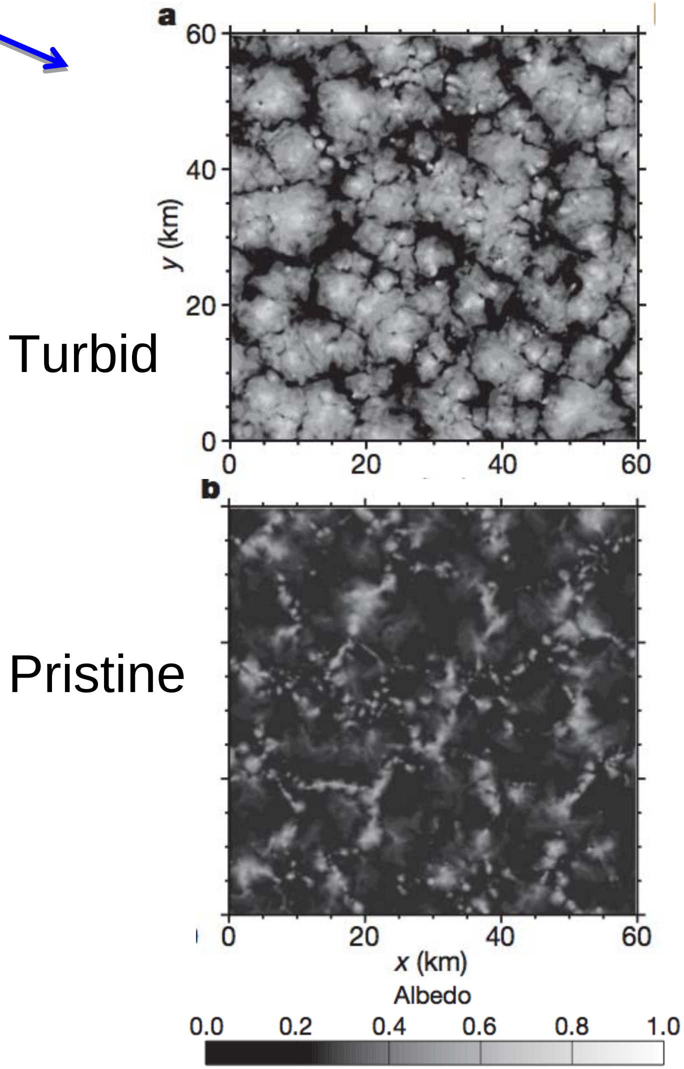
- **CCN recycling**
- **Atmos. stability**

Nakajima et al. (GRL '01)



LWP





**Iguchi et al. (JGR 09); I.-J. Choi et al. (APCD 10)**

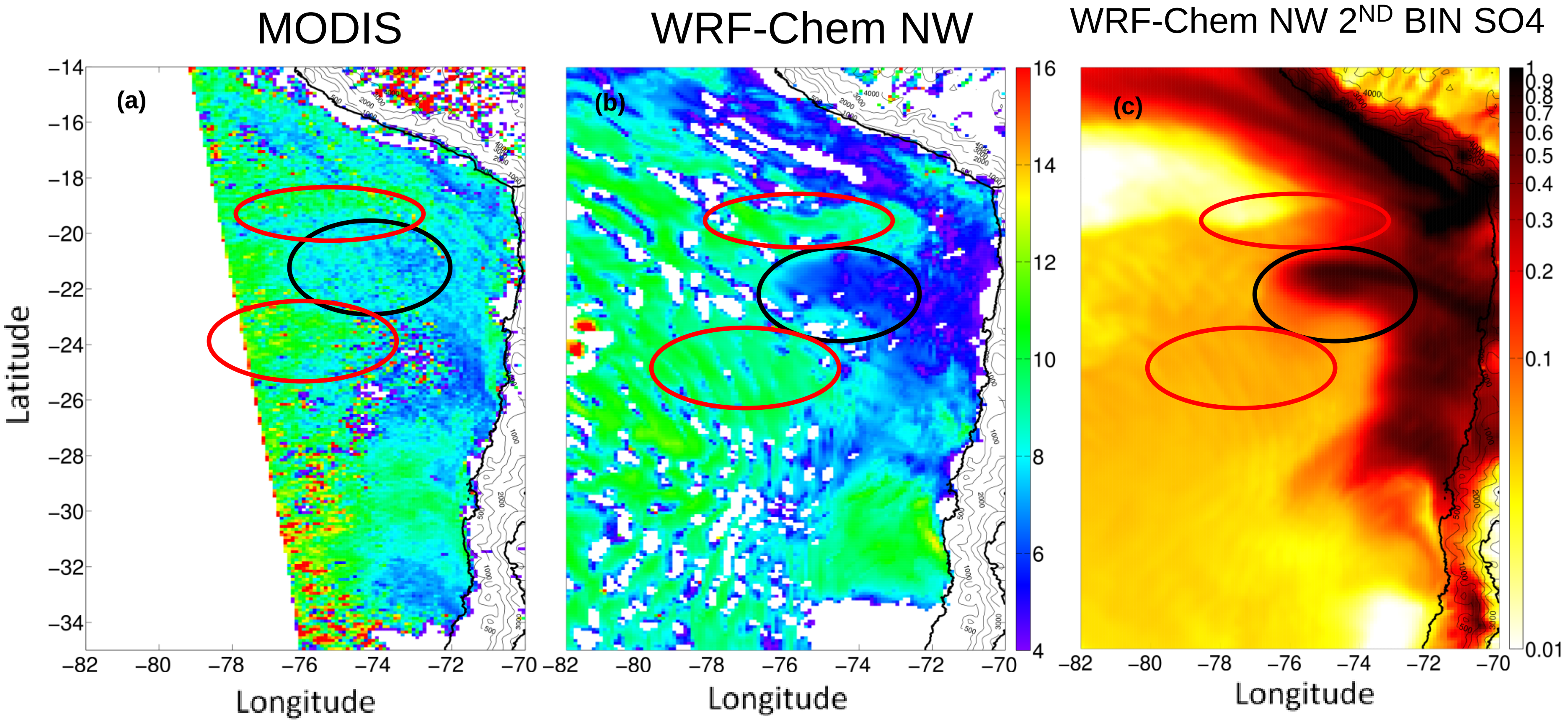
**Feingold et al. (Nature10)**

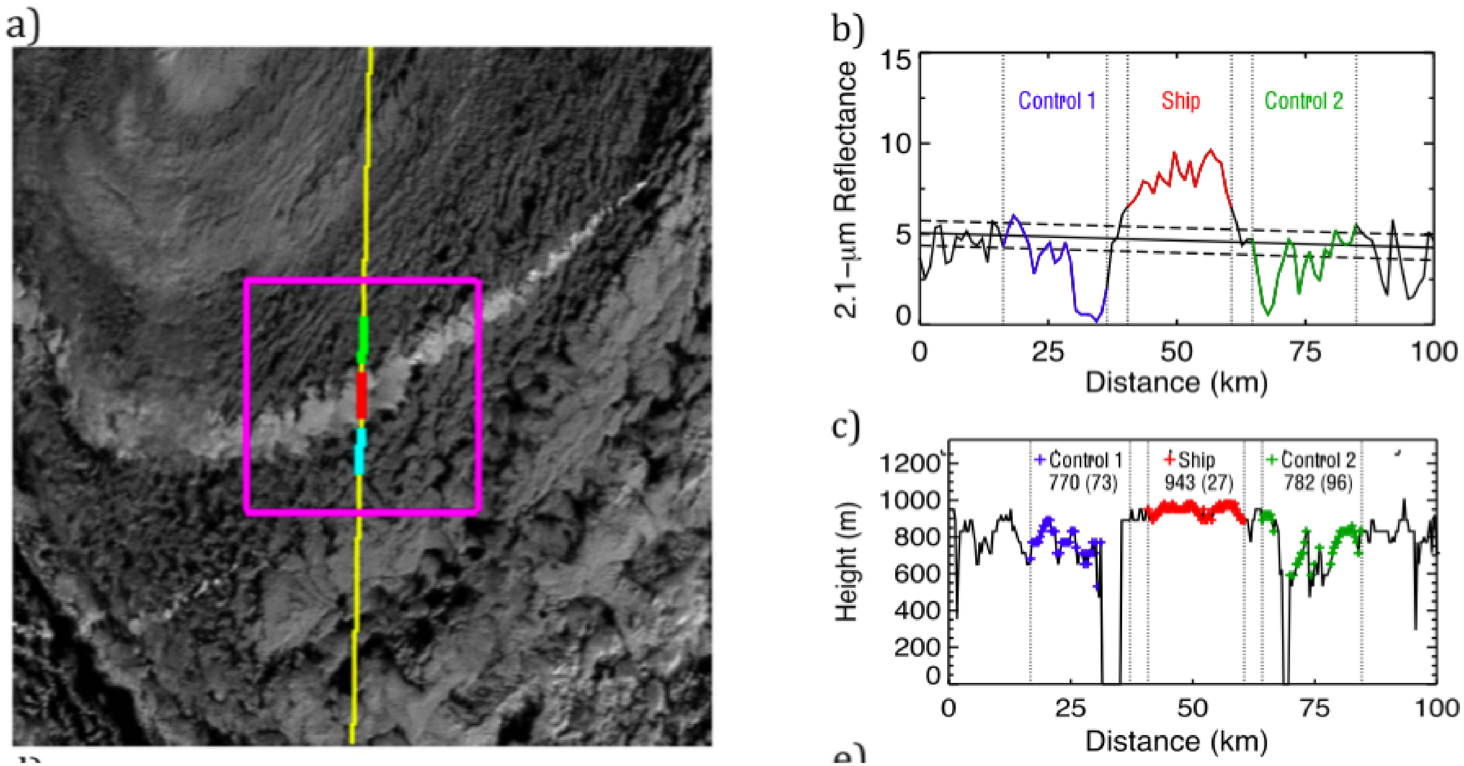
# Anthropogenic plumes alter clouds *in observations & WRF-Chem*

**courtesy**
**G. Carmichael**

**in the VOLALS regional experiment off west coast of S. America**

**Scavenging effect off in WRF-chem; DMS input**
**+ aerosol number concentration**
**- cloud effective radius**





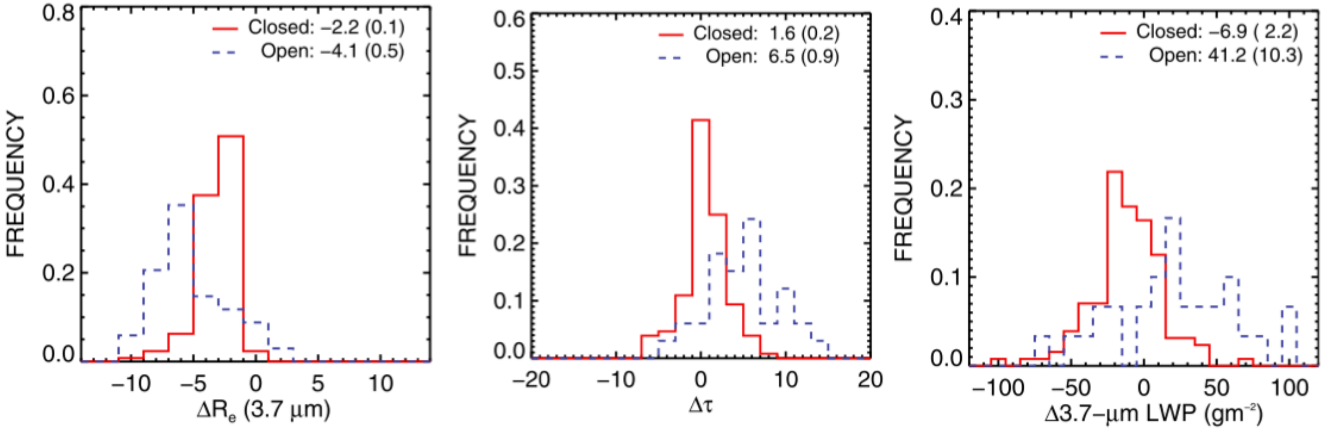
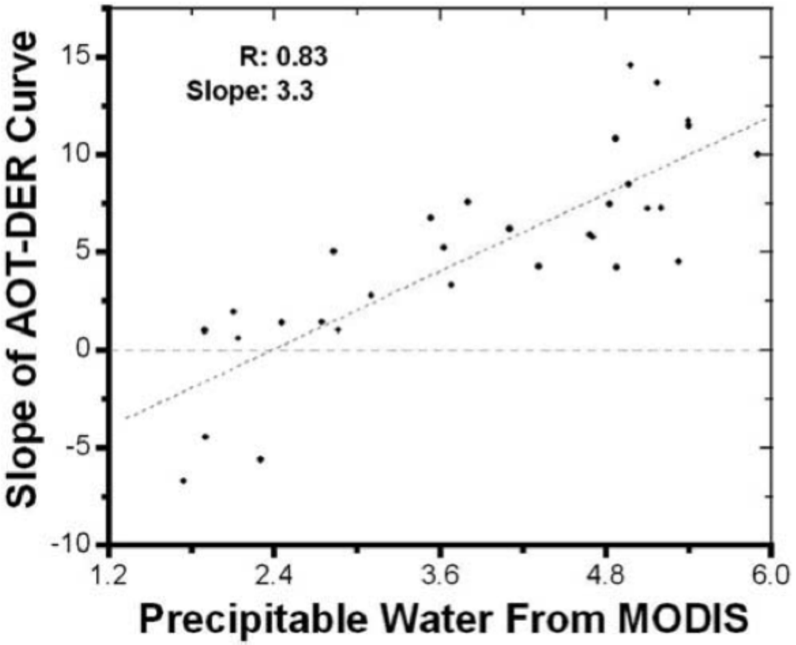


**Figure 5.** Differences in (left) droplet radii $\Delta R_e$, (middle) cloud optical depths $\Delta\tau$, and (right) liquid water paths $\Delta LWP$ between the polluted and unpolluted clouds. The ensemble consists of 128 observations in which ship tracks were identified in a closed cell regime (solid red line) and 34 observations for which they were identified in an open cell regime (blue dashed line). Means and standard errors of the means are given.

**known phenomena since 1980s Coakley et al. (Science 87)**

**M. Christensen et al. (JGR 2011)**

# Deep clouds over land area



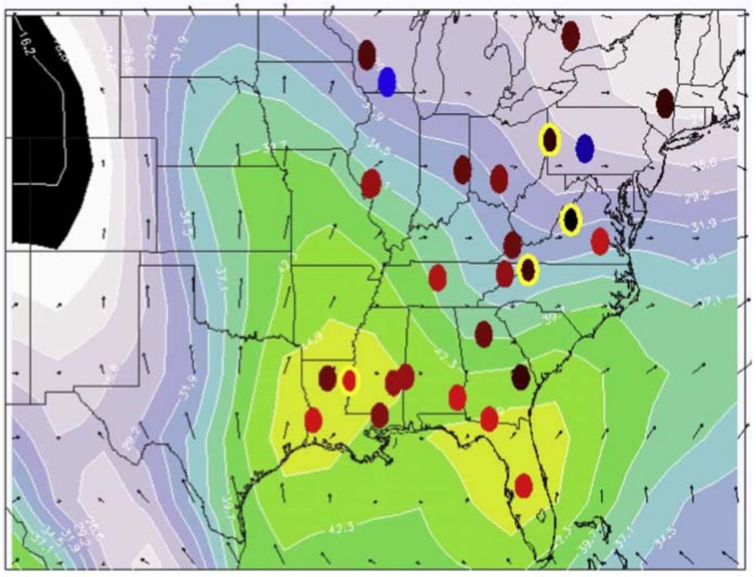


**Figure 4.** Distribution of the locations for the scenes selected in the study. Bright red dots denote large slopes, darker red for smaller slopes and blue for negative slopes. Monthly mean precipitable water and wind vectors from the NCEP-NCAR reanalysis are superimposed. The yellow circles are the four cases presented in Figure 2.

## RE=a+b AOT

- **Anti-Towmey effect**
- **Much unstable condition to activate clouds with CCN input**

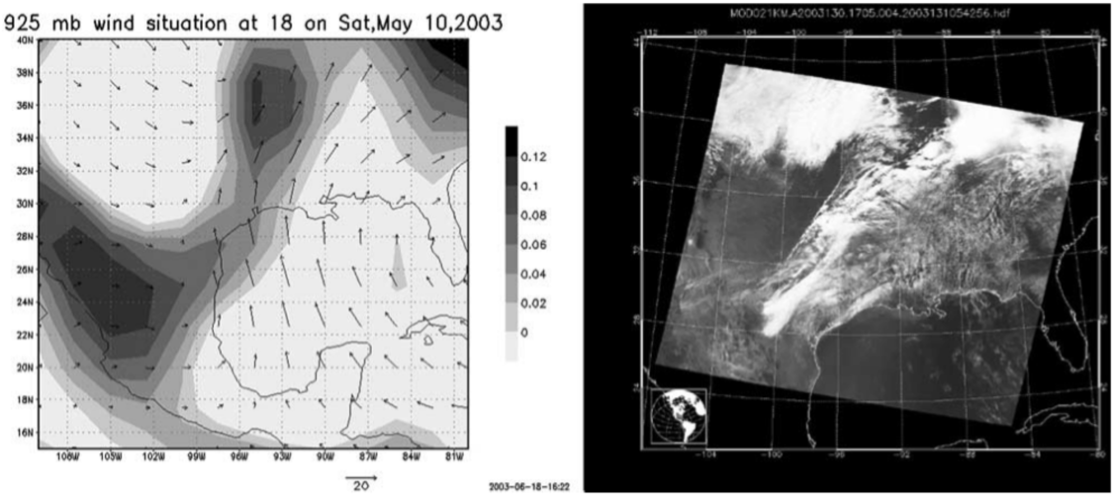
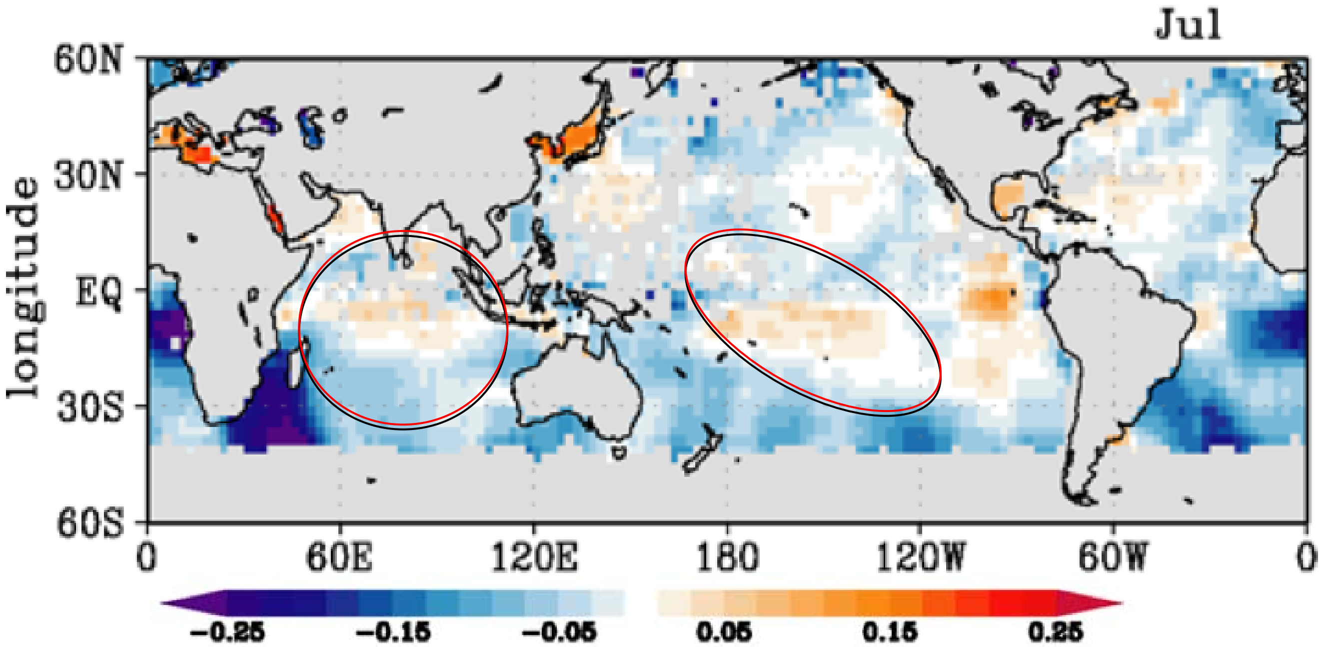


**Figure 1.** Right: MODIS cloud image at 17:05 UTC; Left: NCEP/NCAR reanalysis of wind vector (m/s) and vertical velocity (shaded area for updraft) at 18 UTC, both on 10 May 2003.

**Yuan et al. (JGR2007)**

$$b(RE)=\frac{d\ln r_e}{d\ln N_a}$$

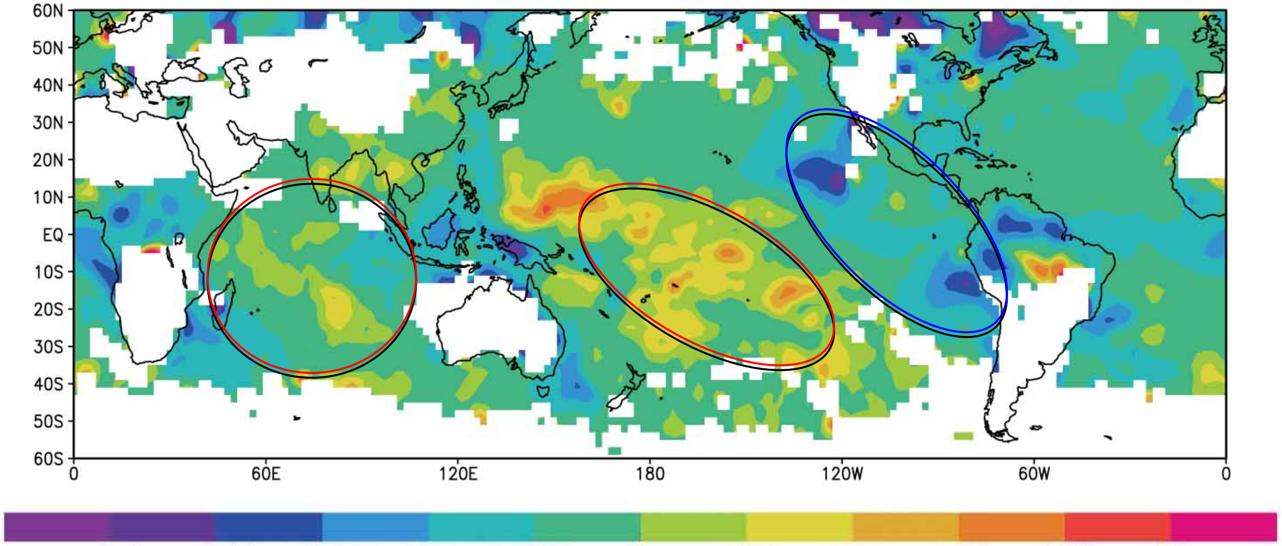
**Sekiguchi et al. (2003)**



**NICAM+SPRINTARS**

**1-8 July 2006**

dln(CDR)/dln(AI) NICAM−SPRINTARS

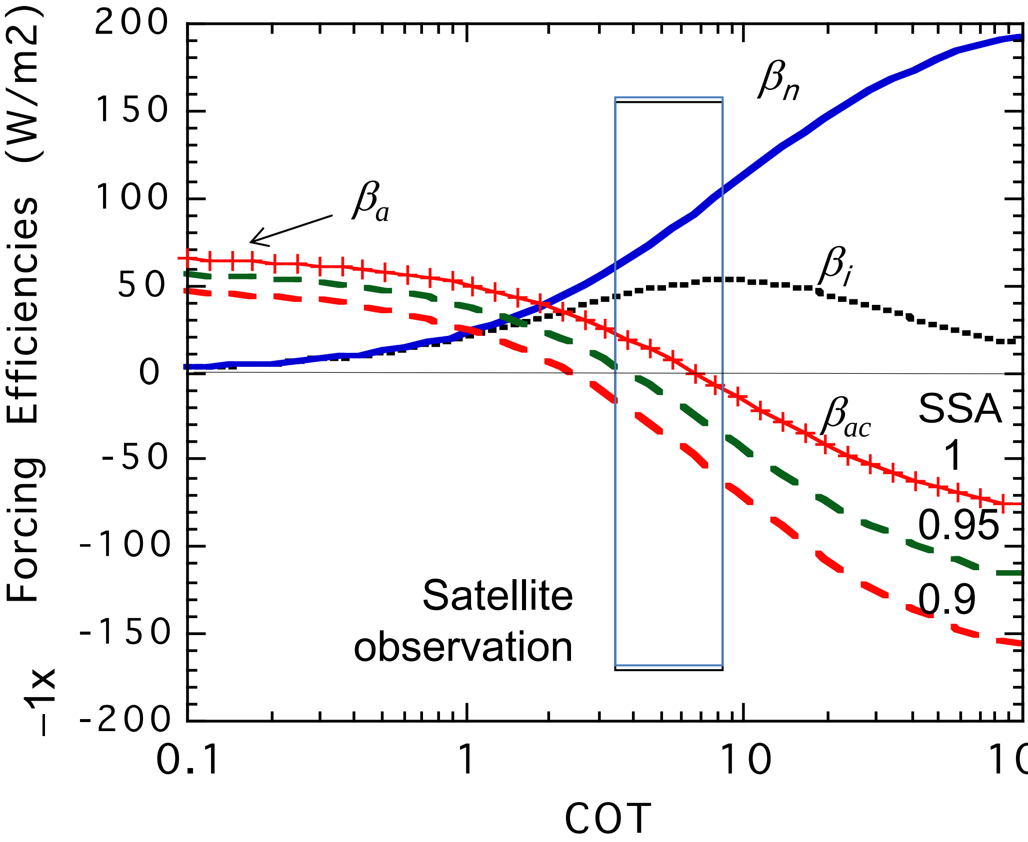


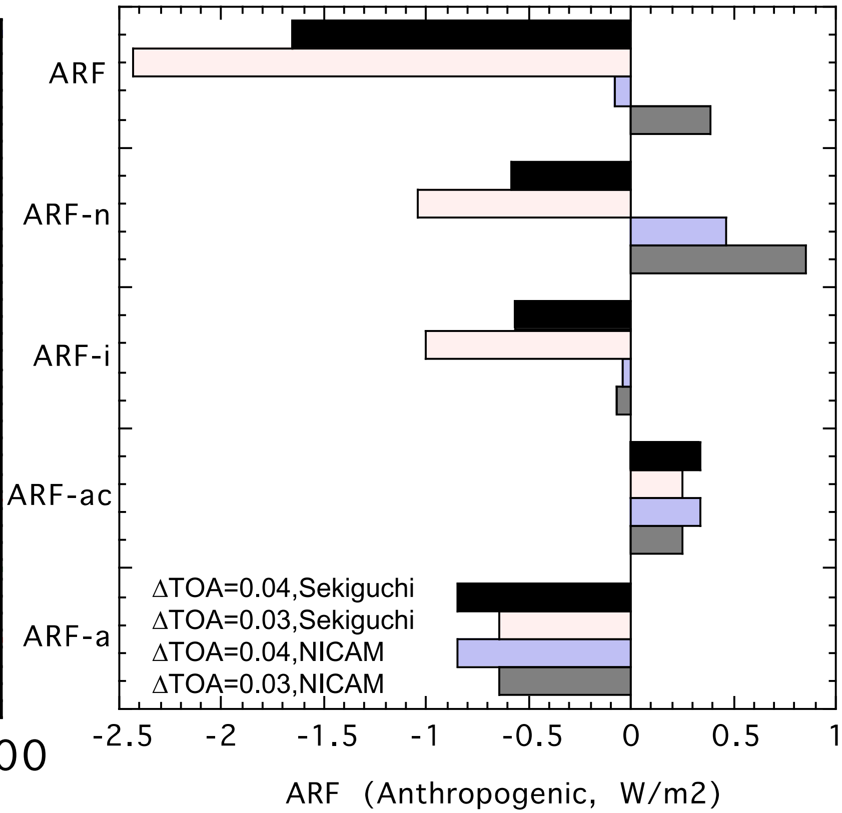
- **Sign correlation among *b*(COT), *b*(RE), and *b*(*n*)?**
- **Need to understand the cloud dynamics Matsui et al.(GRL 04)**
- **High reso. global**

# Anthropogenic forcings

$$ARF = (1-n)\beta_a \Delta\tau_a + n_L \beta_{ac} \eta \Delta\tau_a + n_L \beta_i b_{COT} \Delta \ln(N_a) + \beta_n b_n \Delta \ln(N_a)$$

- **AOT532: 0.082 to 0.11; ΔAOT532= 0.03 to 0.04**
- **ΔNa/Na: 1.6 to 1.4**
- **Other satellite slopes are even larger**





# Satellite remote sensing of cloud-aerosol interaction

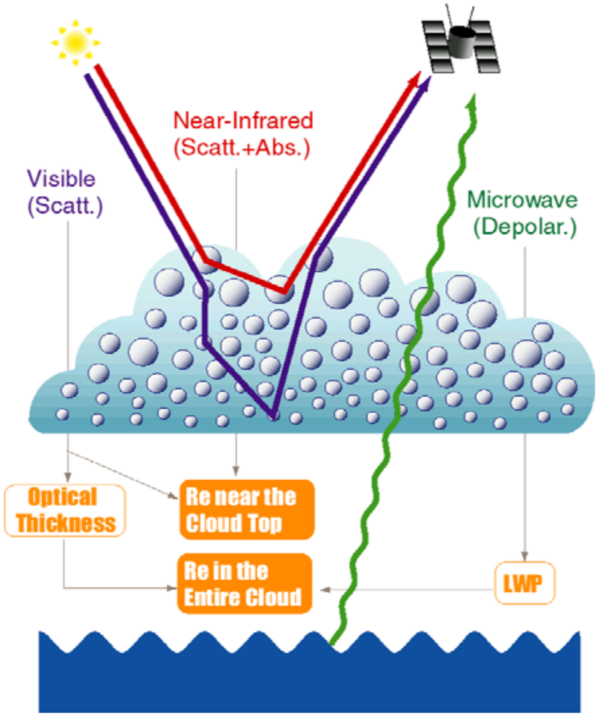
## 20th Century

Aerosol signature on cloud parameters:
$COT$ and $RE$ as function of $N_a$

**Nakajima & King (1990)**

$COT \propto r_e^{2}$ (visible)

$LWP \propto r_e^{3}$ (microwave)



$r_{top}$ (NIR)

$r_{mean}$

$T_{14}(r_e=14\mu m)$

**Rosenfeld (Science'00)**

Drizzle index= $r_{mean}/r_{top}$

**Masunaga et al. (JGR2002)**

## 21th Century

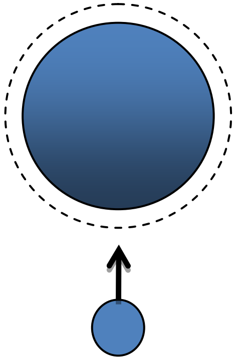
**Cloud radar and lidar**

**Suzuki and Stephens (GRL'08)**

Growth factor:
$\Delta r_e$, $\Delta dBZ$ $etc$

**Condensation Growth**

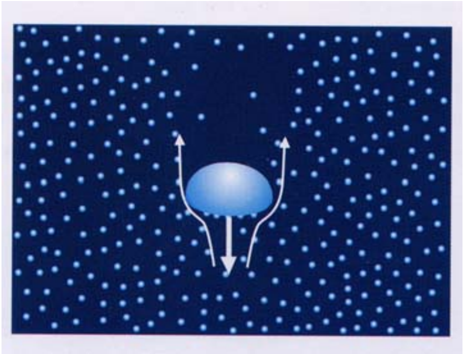
$Z_e \propto N r_e^{6}$



**Coalescence**

$$Z_e \propto N r_e^{6} \propto q r_e^{3}$$

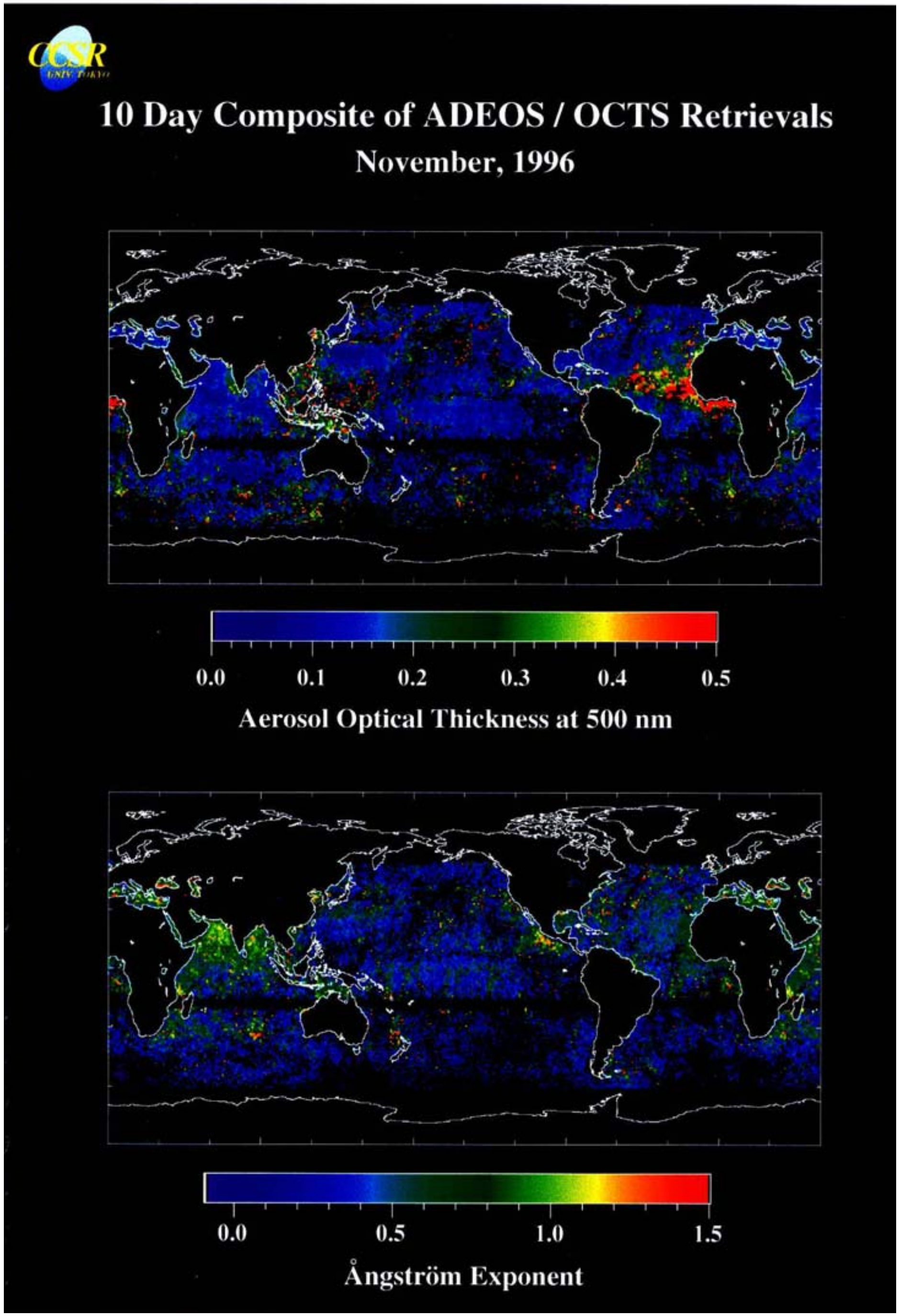
$$(q \propto N r_e^{3})$$



# Thanks for collaborators!

Hayasaka tackled me...
Dubovik, honest young man from Minsk...
Higurashi failed two exams...
TY. Nakajima tried me tree times...
Takemura threw papers to wall; went a
hospital right after Indonesian fire...
Campanelli almost gave up PHD...
K. Suzuki had no paper in 6 yrs..
Sekiguchi led a convoy...
Schutgens, lonely man in NICT ...

- Ask me for details in the party time...



10 Day Composite of ADEOS / OCTS Retrievals
November, 1996