Study of TOA Global Component Aerosol Direct Radiative Effect

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References: Zhao et al., *JQSRT*, doi:10.1016/jqsrt, 2007
Zhao et al., JGR, 2009 (submitted)

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Outline

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Introduction

- Tropospheric aerosols, due to their regional nature, cause the largest uncertainties in assessing the climate forcing of atmospheric constituents due to anthropogenic activities.

- Excessive amount of trace gases and aerosol particles have been released into the atmosphere due to human activities. This has caused irreversible changes/damages to air quality and climate.

- Due to the advance of satellite aerosol measurement in recent years, satellite aerosol observations have been actively used to estimate global aerosol direct radiative effect (ADRE) for the ensemble anthropogenic aerosols.

- It is still difficult using satellite observations alone to further derive ADRE for more detailed aerosol components, such as sea salt (SS), dust (DU), sulfate (SU), organic carbon (OC) and black carbon (BC), over the globe.

Objective

- Combining the Satellite CERES/MODIS-SSF data and the GSFC/ GOCART 3D aerosol model simulation to:
  - Derive top-of-atmosphere (TOA) component ADRE in clear-sky conditions over the globe for Sea Salt (SS), Dust (DU), Sulfate (SU), Organic Carbon (BC), and Black Carbon (BC), Anthropogenic Component (AN), and Natural Component (NA).
  - Narrow the large differences between model-based and observation-based estimates of ADRE.

[TOA ADRE is defined as the difference between the upward shortwave (SW) radiative fluxes in the absence and presence of aerosols in cloud-free conditions at the top of atmosphere.]

Satellite Data & Model Simulation

- **Satellite Observation**
  - CERES/MODIS-SSF aerosol optical thickness (AOT or τ) at 0.55μm
  - TOA CERES/MODIS-SSF clear-sky SW fluxes.
- **Model Simulation**
  - Aerosol classification: SS, DU, SU, OC, BC, AN=BC+(OC-OCn)+(SU-SUn) and NA=Total - AN.
  - Partitioning fractions of component AOT, $r_i=\tau_i/\tau_{TOT}$ ($\tau_i=\tau_{SS}$, τ_{DU}, τ_{SU}, τ_{OC}, τ_{BC}, τ_{AN}, τ_{NA} at 0.55μm).

$$\tau_i = r_i(\text{GOCART}) \times \tau_{TOT}(\text{CERES/MODIS-SSF})$$

[focus on year of 2001]

Methodology

(Two-Steps Approach)

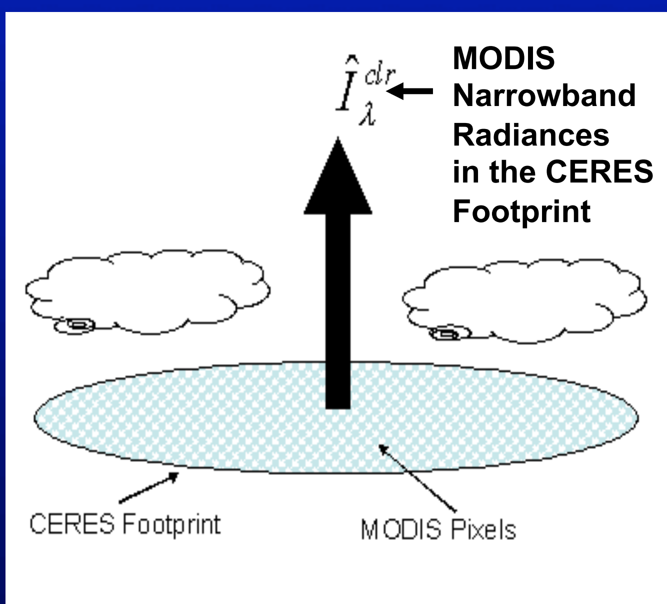
Step 1. Determine total TOA ADRE: $\Delta\overline{F}_{SW}^{clr}(d,\theta,\varphi)$

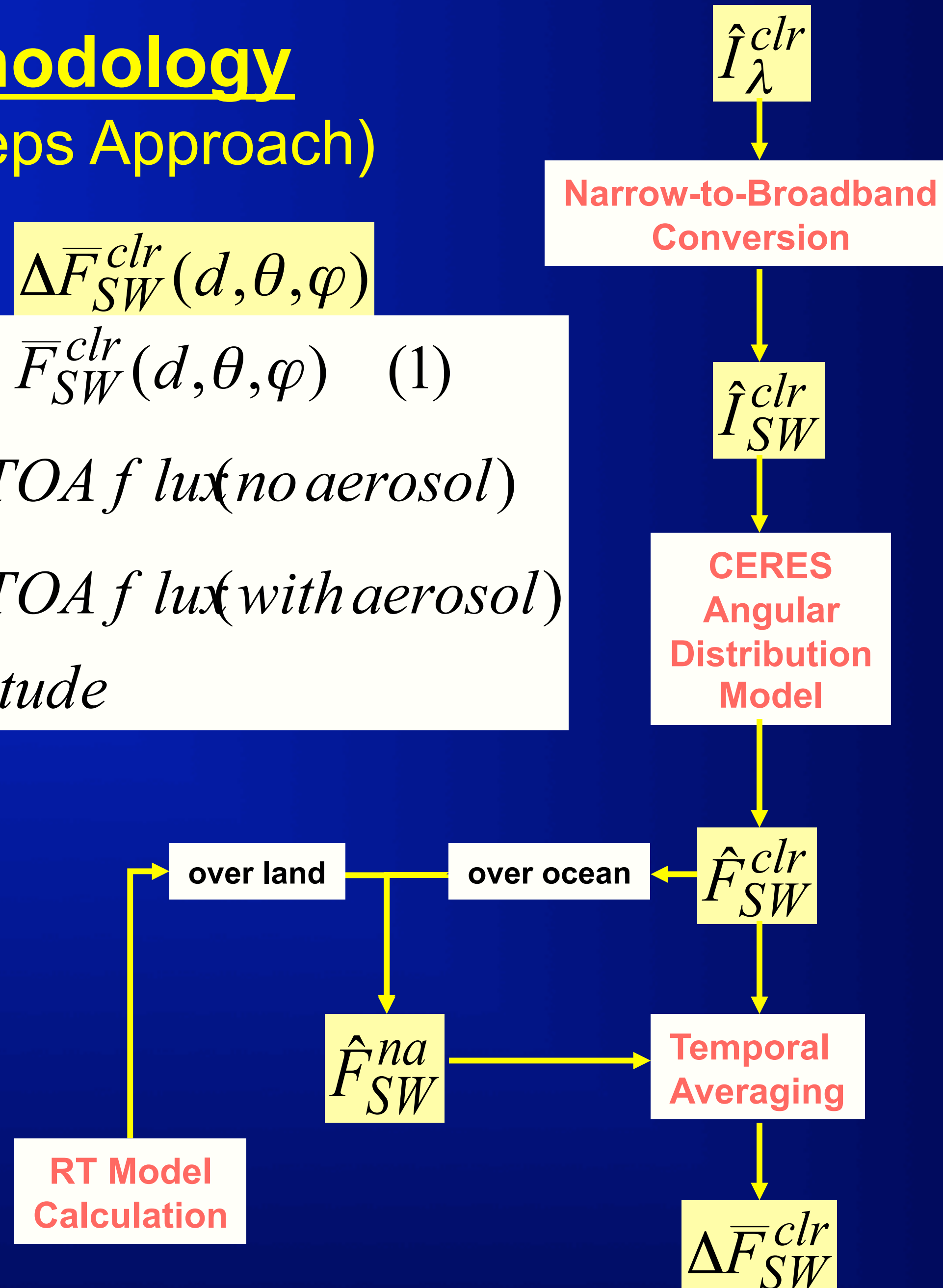
$$\Delta\overline{F}_{SW}^{clr}(d,\theta,\varphi) = \overline{F}_{SW}^{na}(d,\theta,\varphi) - \overline{F}_{SW}^{clr}(d,\theta,\varphi) \qquad (1)$$

$$\overline{F}_{SW}^{na}(d,\theta,\varphi) = clear-sky\ SW\ TOA\ flux(no\ aerosol)$$

$$\overline{F}_{SW}^{clr}(d,\theta,\varphi) = clear-sky\ SW\ TOA\ flux(with\ aerosol)$$

$$d = day,\ \theta = longitude,\ \varphi = latitude$$





Step 2. Partition total ADRE $\Delta\overline{F}_{SW}^{clr}$ into component ADRE $\Delta\overline{F}_{SW,i}^{clr}$:

(i = NA, AN, CR, FN, SS, SU, DU, OC, BC)

- **It is known** $\Delta\overline{F}_{SW,i}^{clr} \sim (e^{-\tau_i} - 1)$ **for non- or weakly- absorbing aerosols.**
- **We propose:** $\Delta\overline{F}_{SW,NAorCR}^{clr} = \Delta\overline{F}_{SW}^{clr} x(e^{-\tau_{NAorCR}} - 1)/(e^{-\tau_{TOT}} - 1)$

  \- assuming total ensemble aerosol radiative efficiency $(RE = \Delta\overline{F}_{SW}^{clr}/\tau)$ is close to that of weakly absorbing NA & CR. Then,

  $$\Delta\overline{F}_{SW,AN\ or\ FN}^{clr} = \Delta\overline{F}_{SW}^{clr} - \Delta\overline{F}_{SW,NA\ or\ CR}^{clr}$$

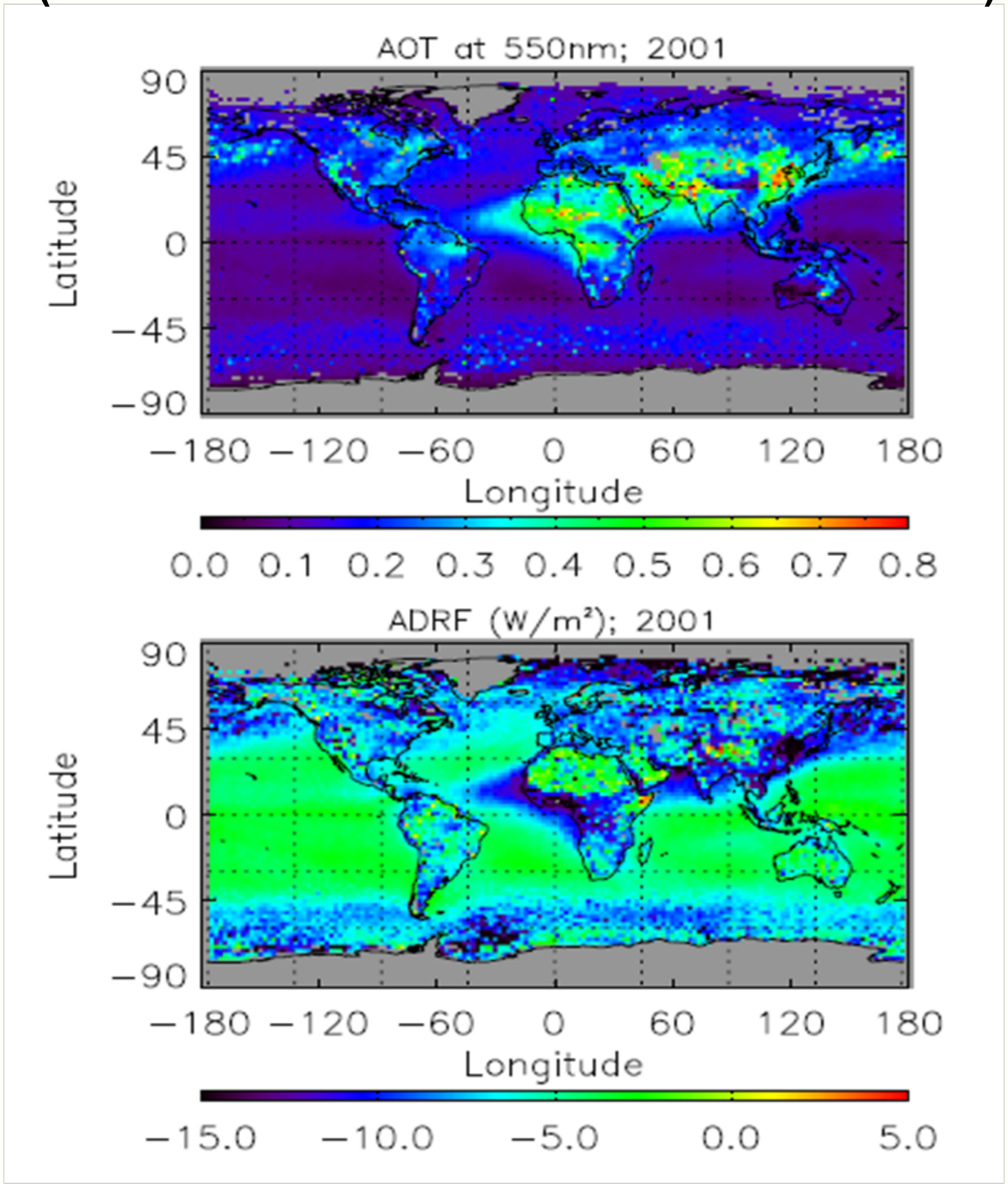
- **Similar to NA & CR, we have** $\Delta\overline{F}_{SW,i}^{clr} = \Delta\overline{F}_{SW}^{clr} x\,(e^{-\tau_i} - 1)/(e^{-\tau_{TOT}} - 1)\ (i = SS, DU, SU, OC)$

- **At last, we have** $\Delta\overline{F}_{SW,BC}^{clr} = \Delta\overline{F}_{SW}^{clr} - \sum_i \Delta\overline{F}_{SW,i}^{clr}\ (i = SS, DU, SU, OC)$

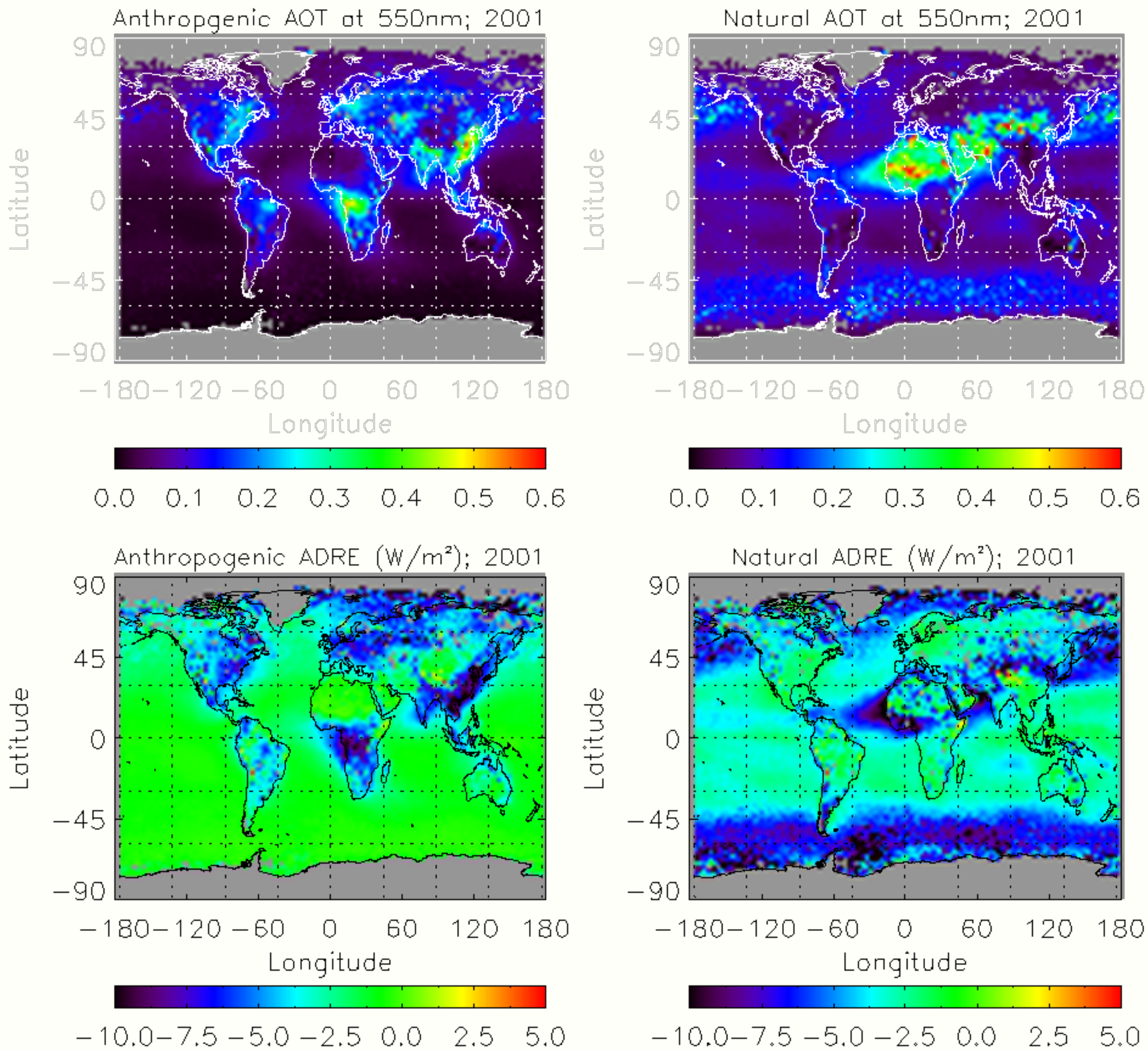
(Focus on the Study of Seasonal and Annual Mean Features)

Results

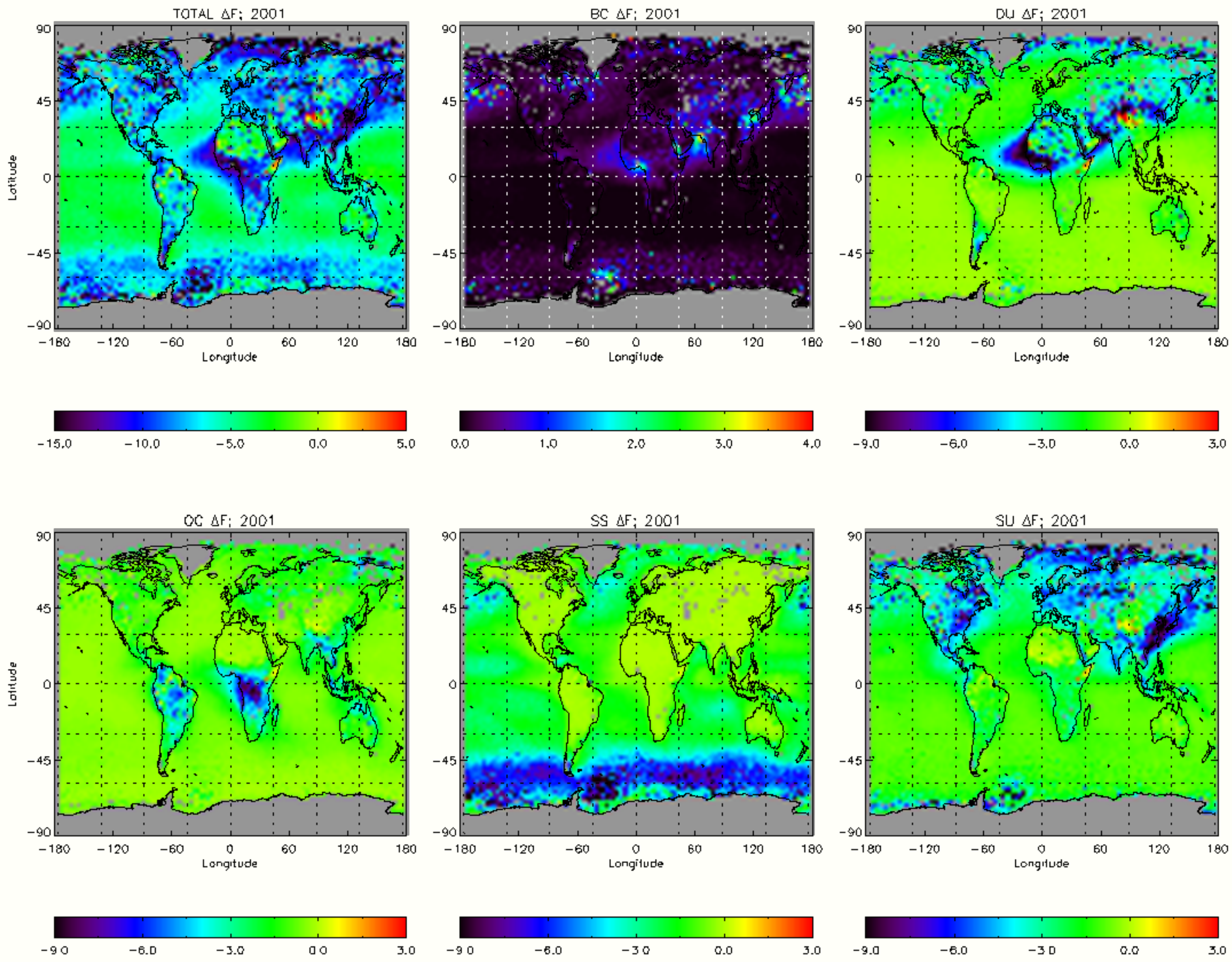
(Distribution of Annual Mean AOT and ADRE)



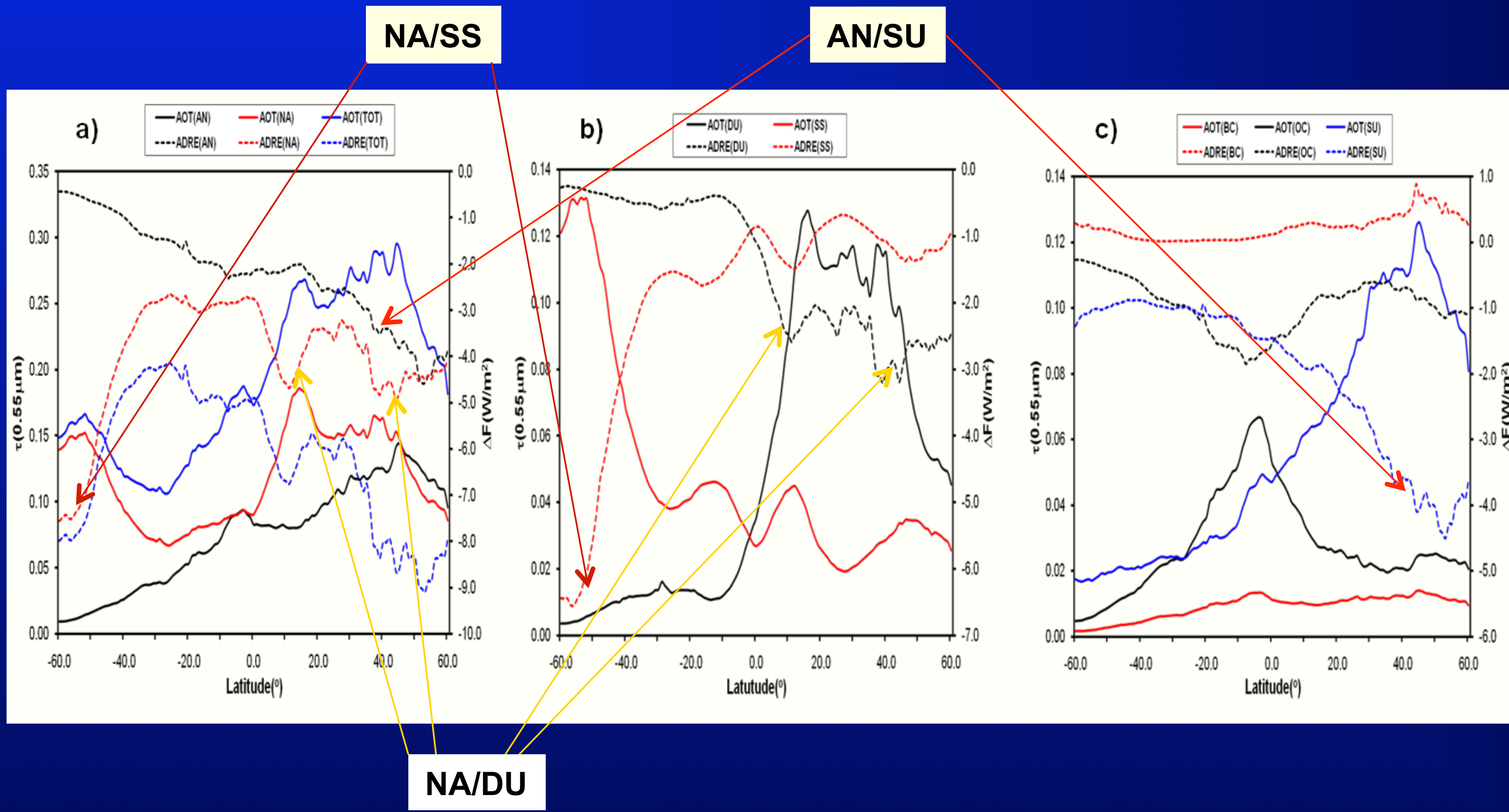
Distribution of AN & NA Annual Mean AOT and ADRE



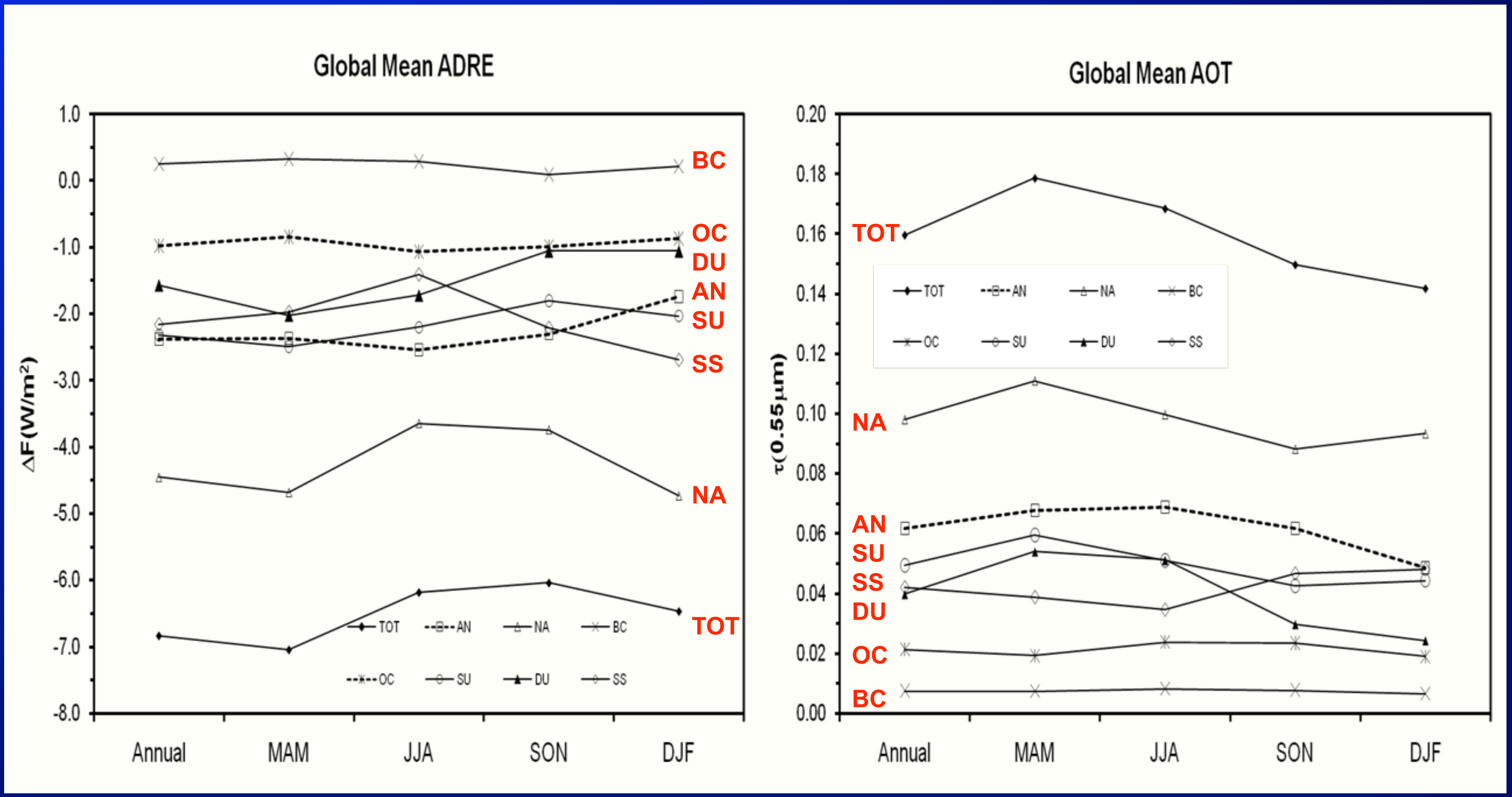
Distribution of Annual Mean Component ADRE



Zonal Distribution of Annual Mean Component AOT & ADRE

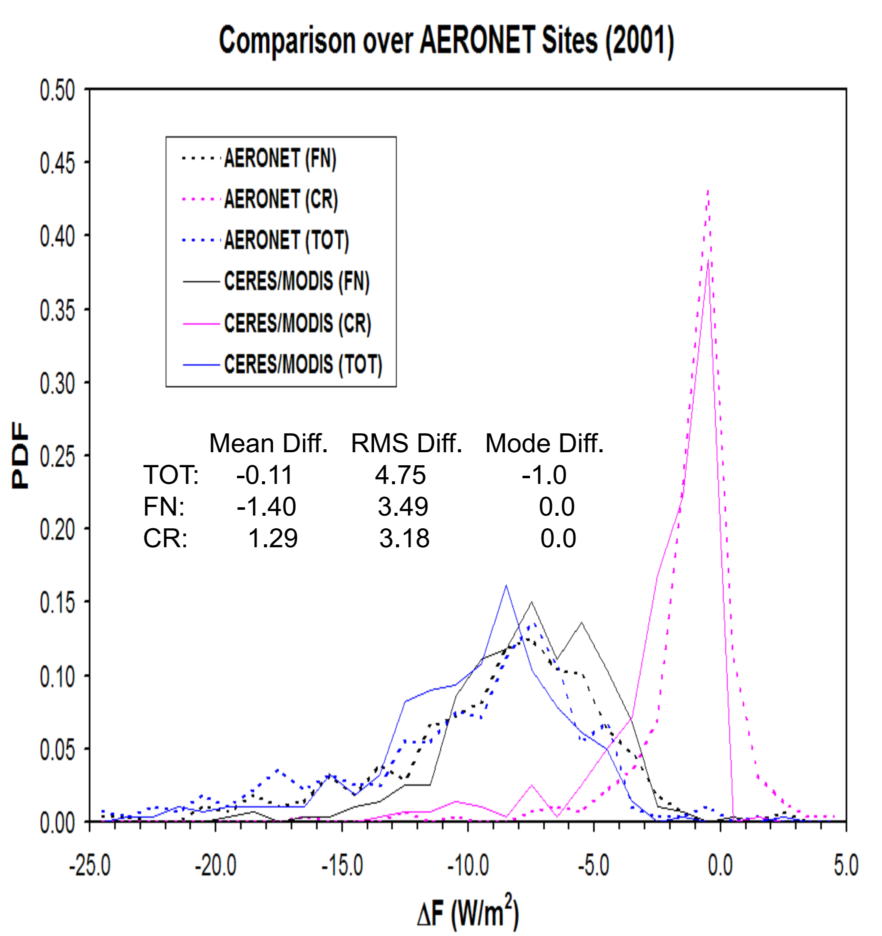


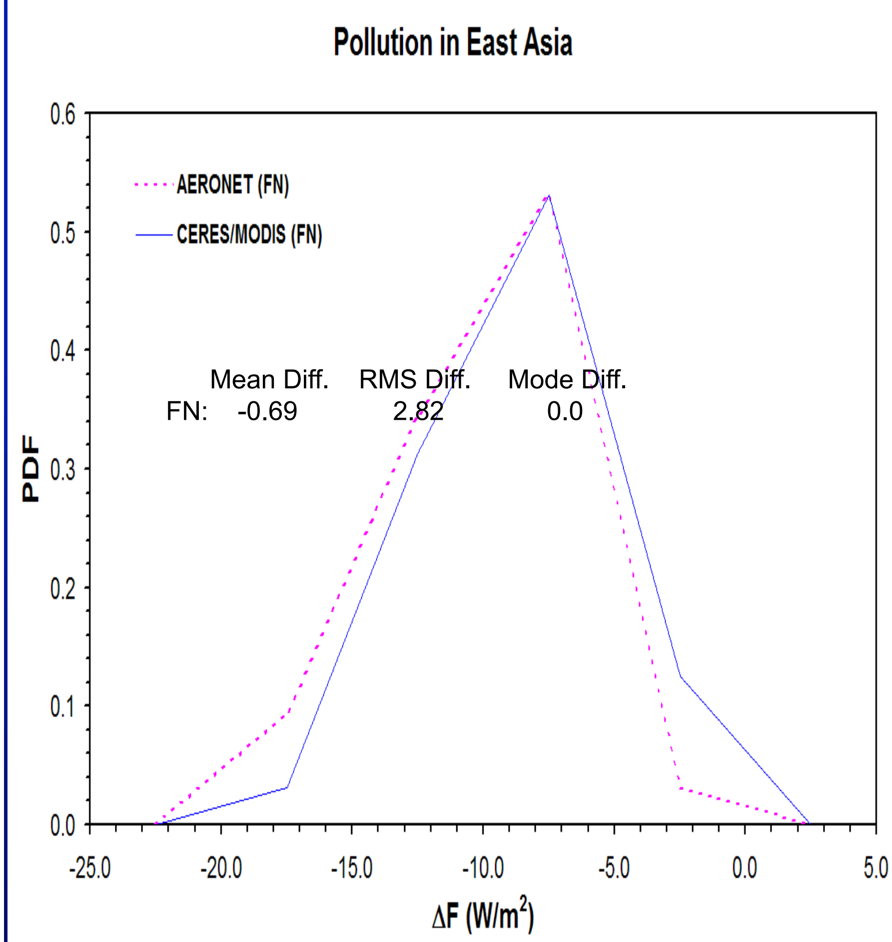
Seasonal Variations of Component ADRE and AOT



Validation– AERONET Measurement

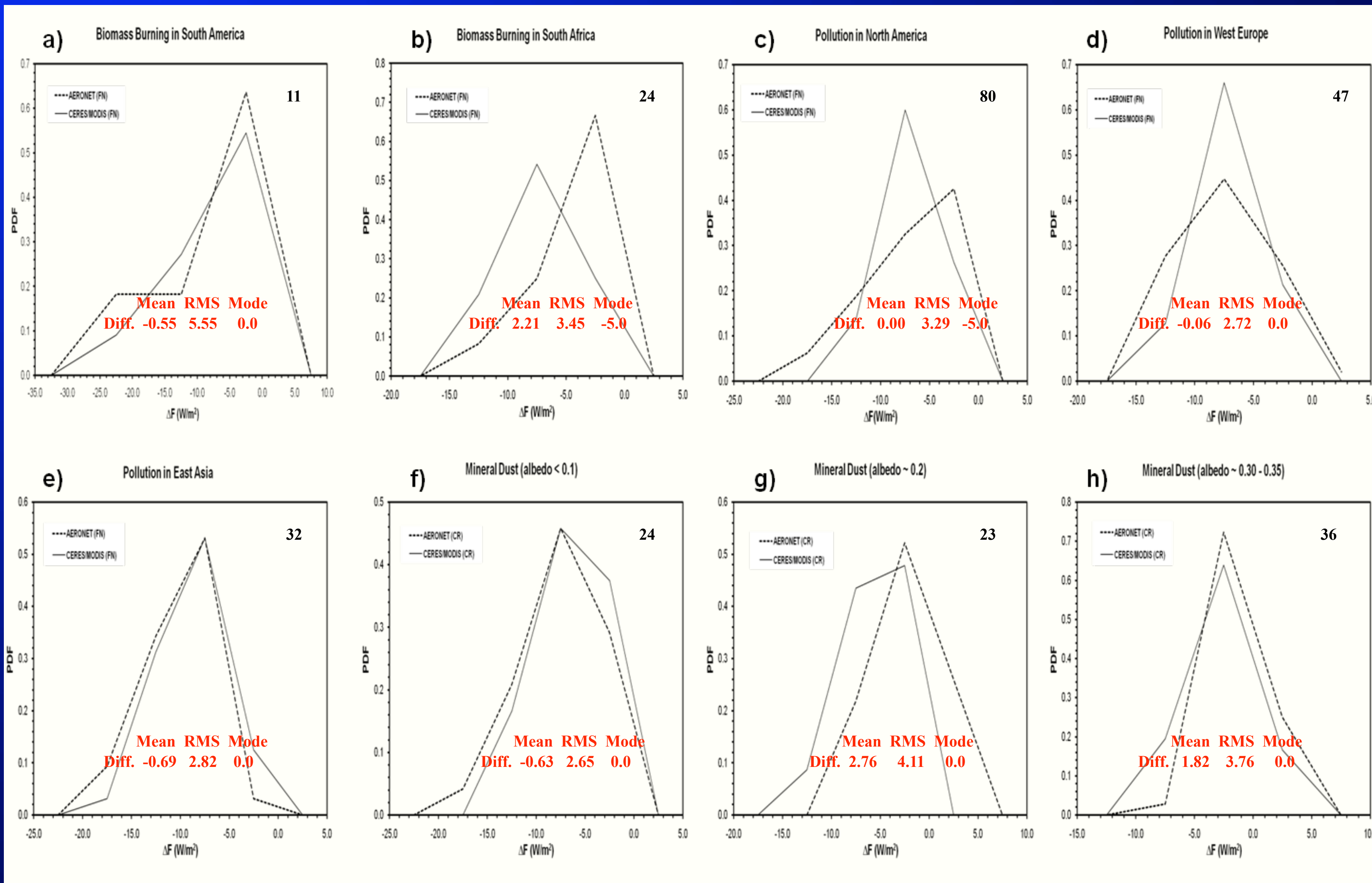
(Comparison of the PDF of ADRE between AERONET and CERES/MODIS-SSF)
2001



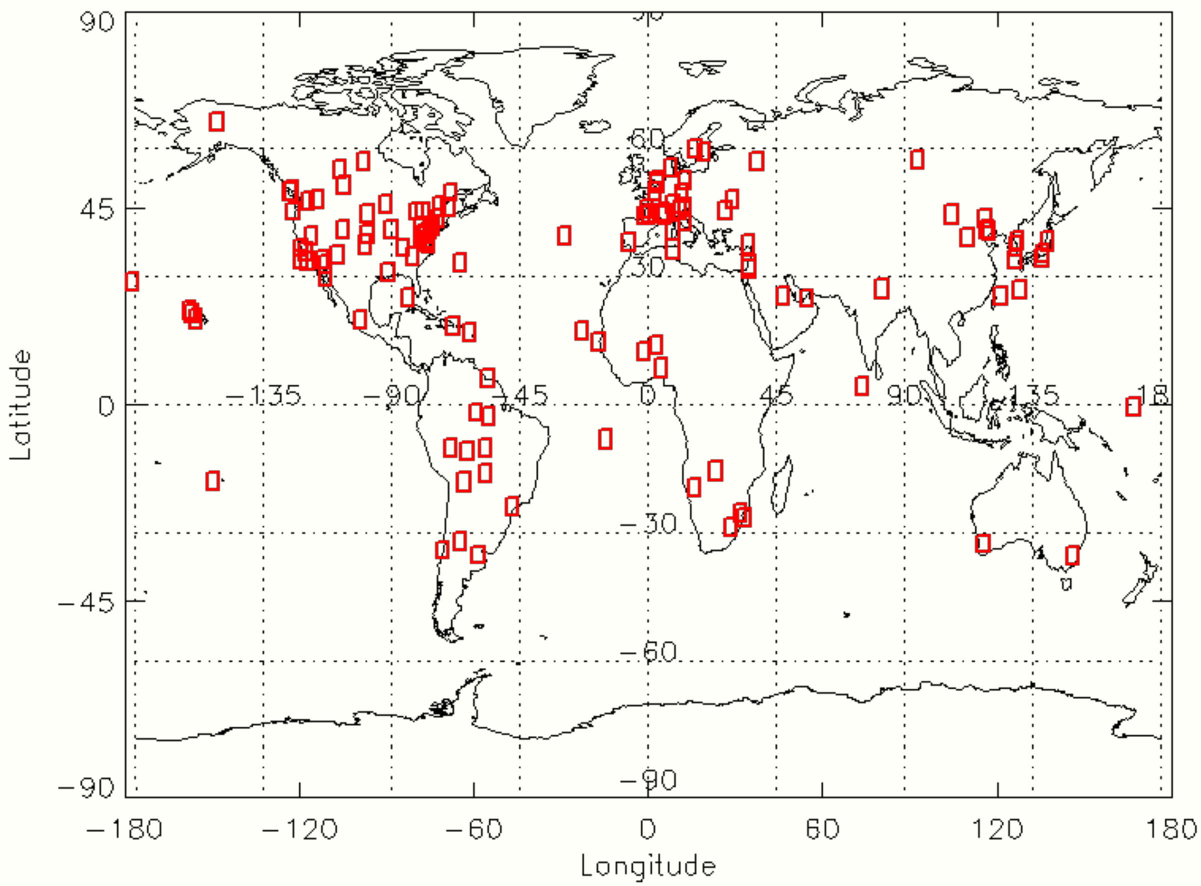


(Zhou et al., 2006 for AERONET Calculation)

More Regional AERONET Validation



AERONET Sites Used for Validation



Total 128 Sites

Summary and Conclusions

- A two-step approach by combining satellite observations with a 3-D aerosol model simulation has be proposed to derive global TOA component ADRE for clear-sky condition.
- Validation based on computation from AERONET observations has been performed and results are promising.
- The annual mean values of component ADRE over the global is summarized in Table 1 along with the estimated uncertainties.
- The final uncertainties in the component ADRE might be larger than our current estimates since our analysis is limited by the current aerosol modeling capability, which will be improved continuously.

Table 1. Summary of 2001 annual mean TOA component ADRE (ΔF, W/m^2) and its uncertainty (σ, W/m^2) for clear-sky condition over the globe and the corresponding AOT(τ) at 0.55μm.

	BC	OC	SU	DU	SS	AN	NA	TOT
$\tau_{0.55}$	(.018) .007	(.039) .021	(.130) .049	(.137) .040	(.019) .042	(.165) .062	(.177) .098	(.343) .160
ΔF	(+0.6) +0.3	(-1.2) -1.0	(-3.8) -2.3	(-3.2) -1.6	(-0.6) -2.2	(-4.0) -2.4	(-4.4) -4.5	(-8.4) -6.8
σ	(±0.2) ±0.1	(±0.3) ±0.4	(±0.9) ±0.7	(±0.7) ±0.5	(±0.5) ±0.6	(±0.6) ±0.6	(±1.1) ±1.1	(±2.1) ±1.7

Notes: numbers in the parenthesis are the values in the Asian region [50°E-150°E, 10°N-60°N] for a comparison. ADRE in the Asian region is much larger than the global mean, especially for anthropogenic components and dust.

Acknowledgement

- The CERES/MODIS-SSF data provided by Dr. Norman G. Loeb through the NASA CERES Project and the DAAC of the NASA Langley.
- GOCART model output provided by the Dr. Mian Chin at GSFC and AERONET validation data provided by Dr. Mi Zhou at I. M. System Group, Inc.
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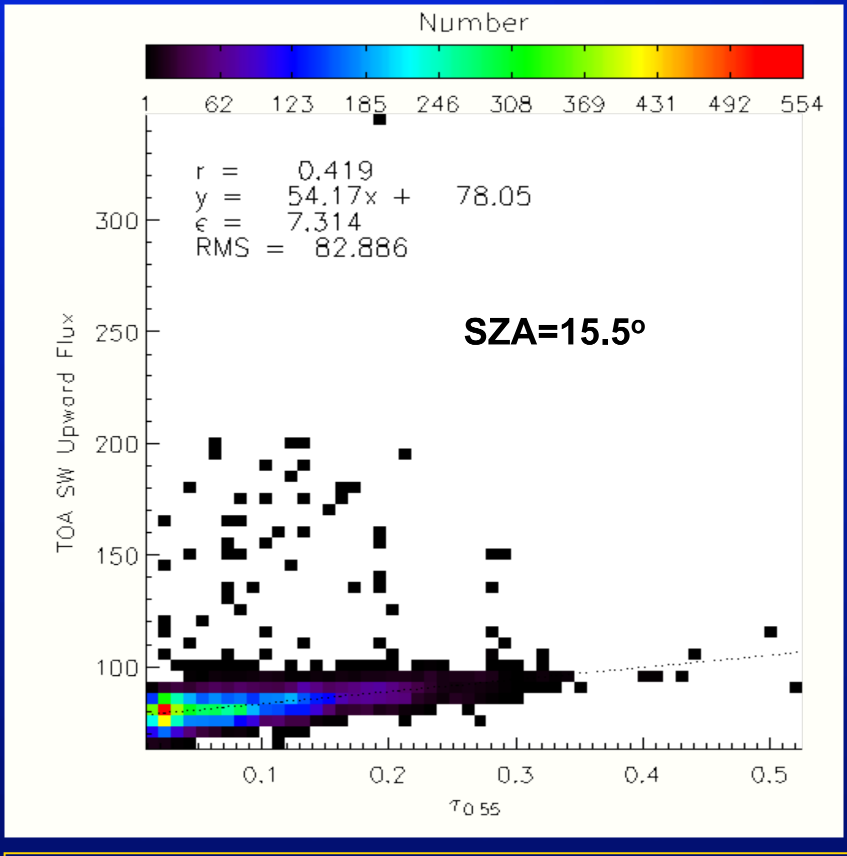
Thank You!

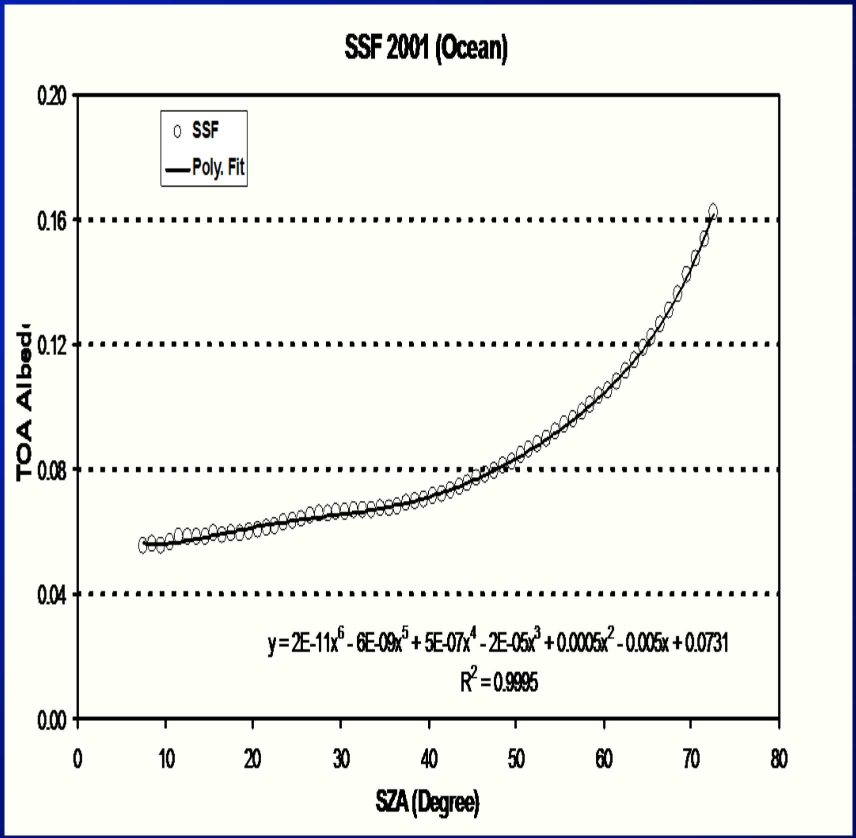
Backup Slides

Derivation of $\overline{F}_{SW}^{na}$ over Ocean

Daily averaged SW fluxes in absence of aerosols is derived through a regression for CERES/MODIS $\tau_{0.55}$ versus SSF TOA clear-sky SW fluxes in 1° solar zenith angle (SZA) increment. Then extrapolate to zero AOT.

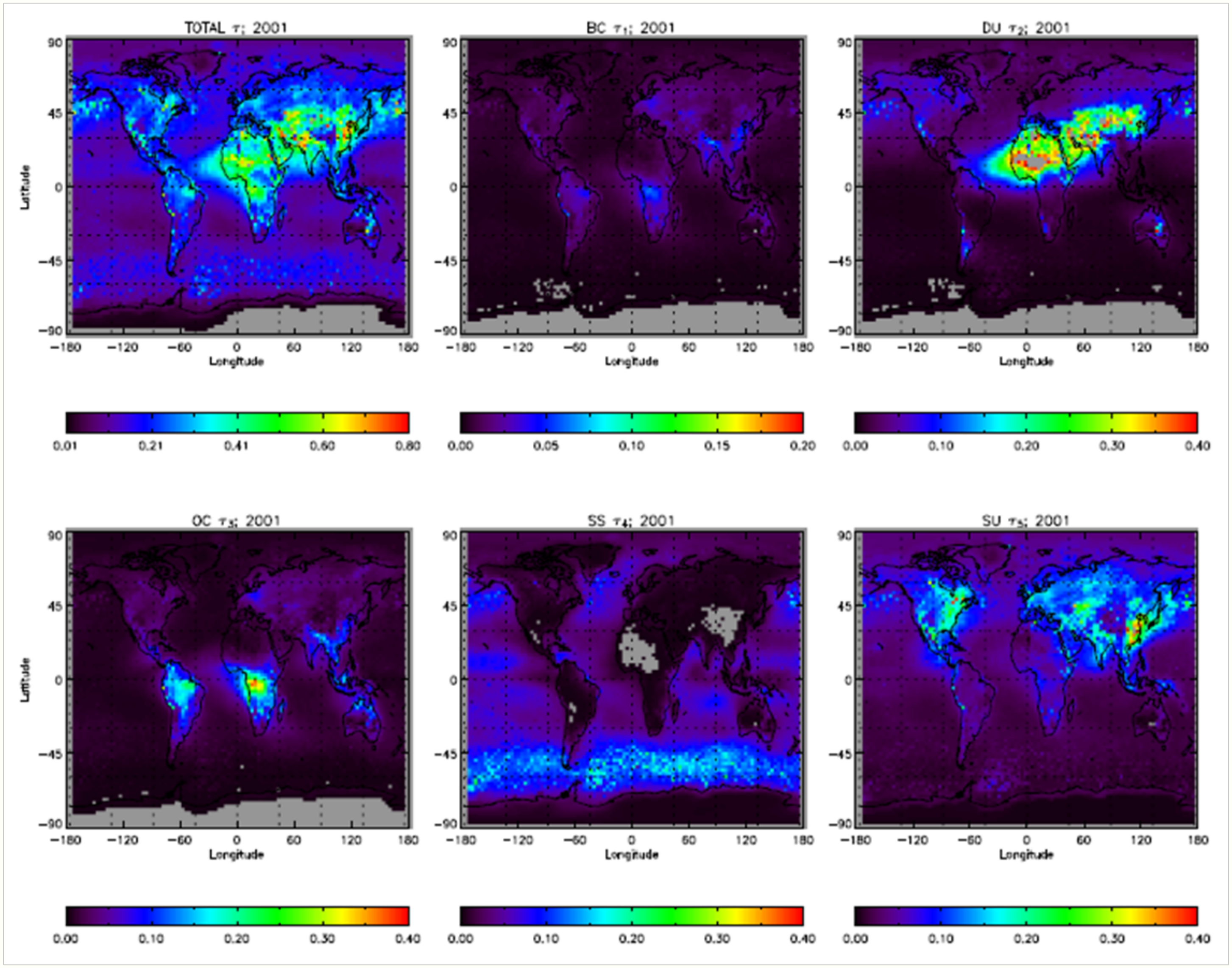


Fit daily averaged SW fluxes (or albedos) in absence of aerosols with a polynomial formula according to SZA.



Over land, TOA SW fluxes in absence of aerosols are calculated from the Fu-Liou radiation model for a molecular atmosphere with input surface spectral albedos from MODIS Filled Land Surface Albedo (FLSA) product (Moody et al., 2005).

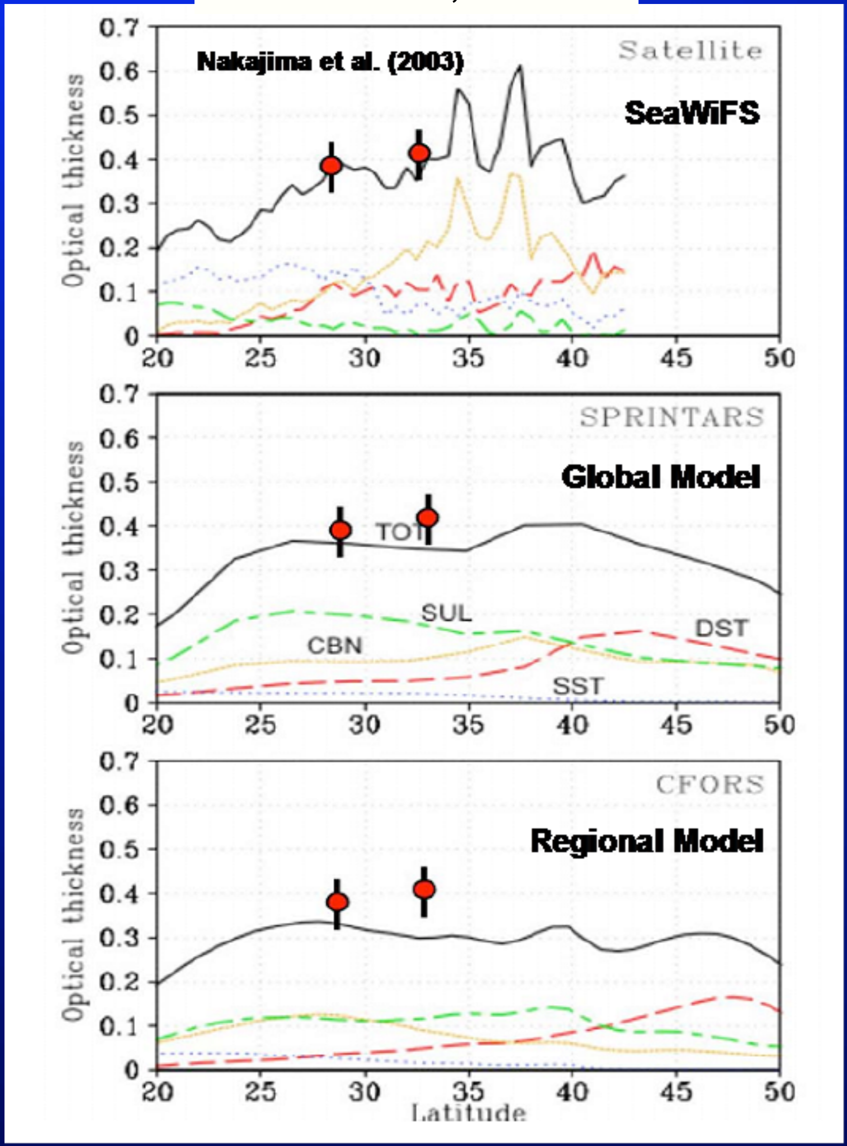
Distribution of Annual Mean Component AOT

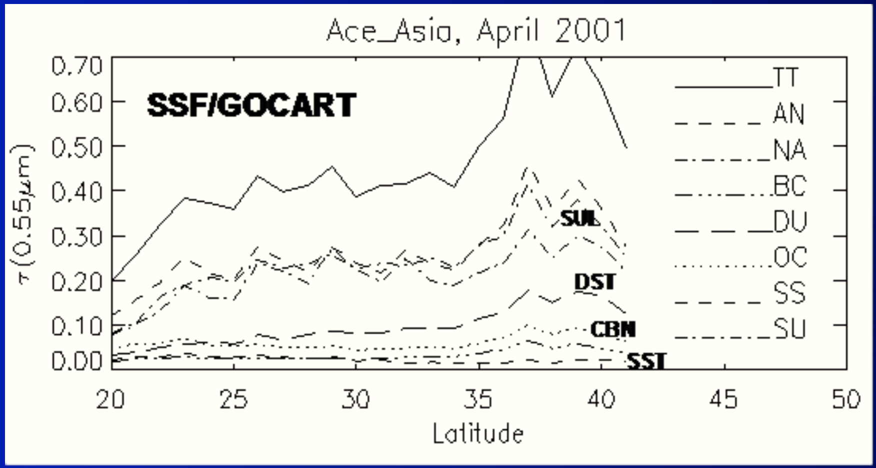


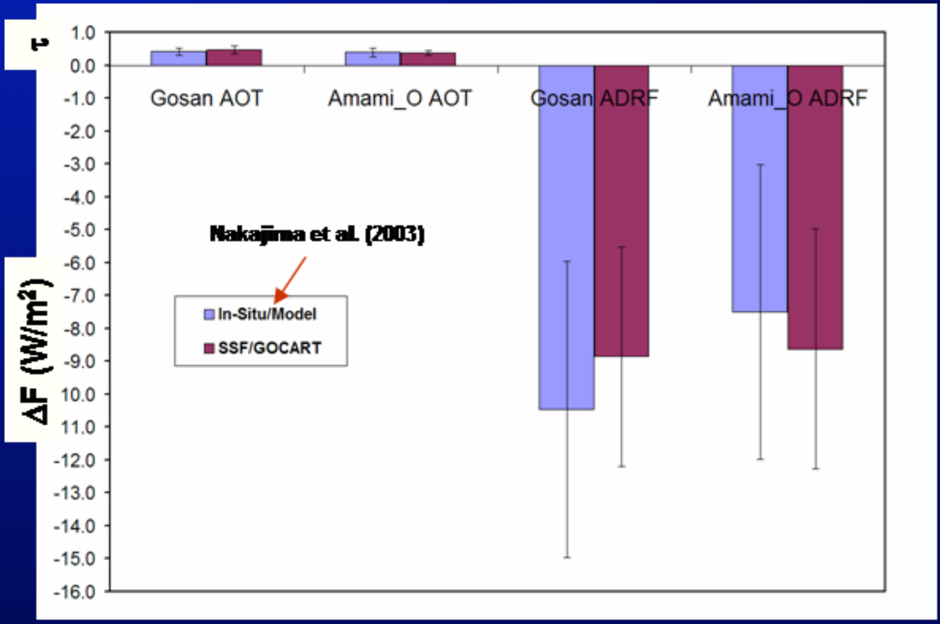
Validation— Field Campaigns

(APES/ACS-Asia Campaign, April 2001)

125.5°E-130.5°E, 20°N-42°N



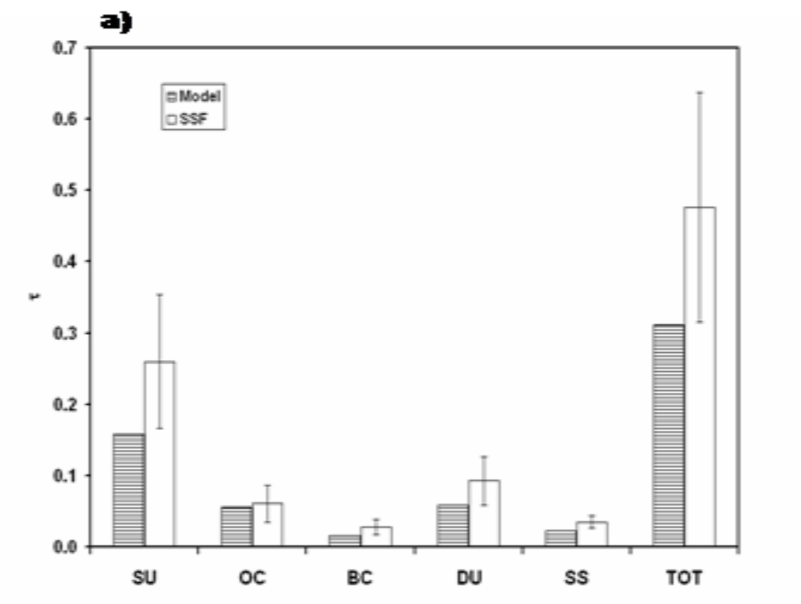


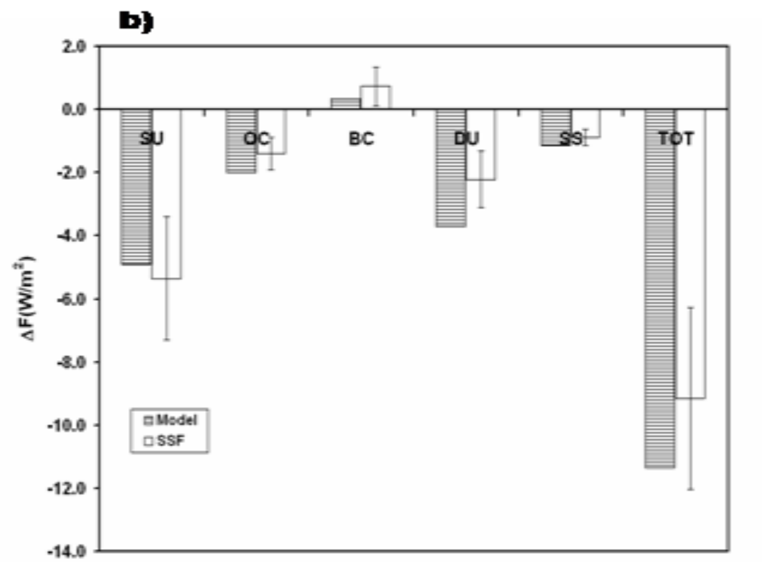


ACE-Asia Campaign

April 5-15, 2001
100°E-150°E; 20°N-50°N

SSF/GOCART VS. MCR Model/CFORS Model (Conant et al., 2003)

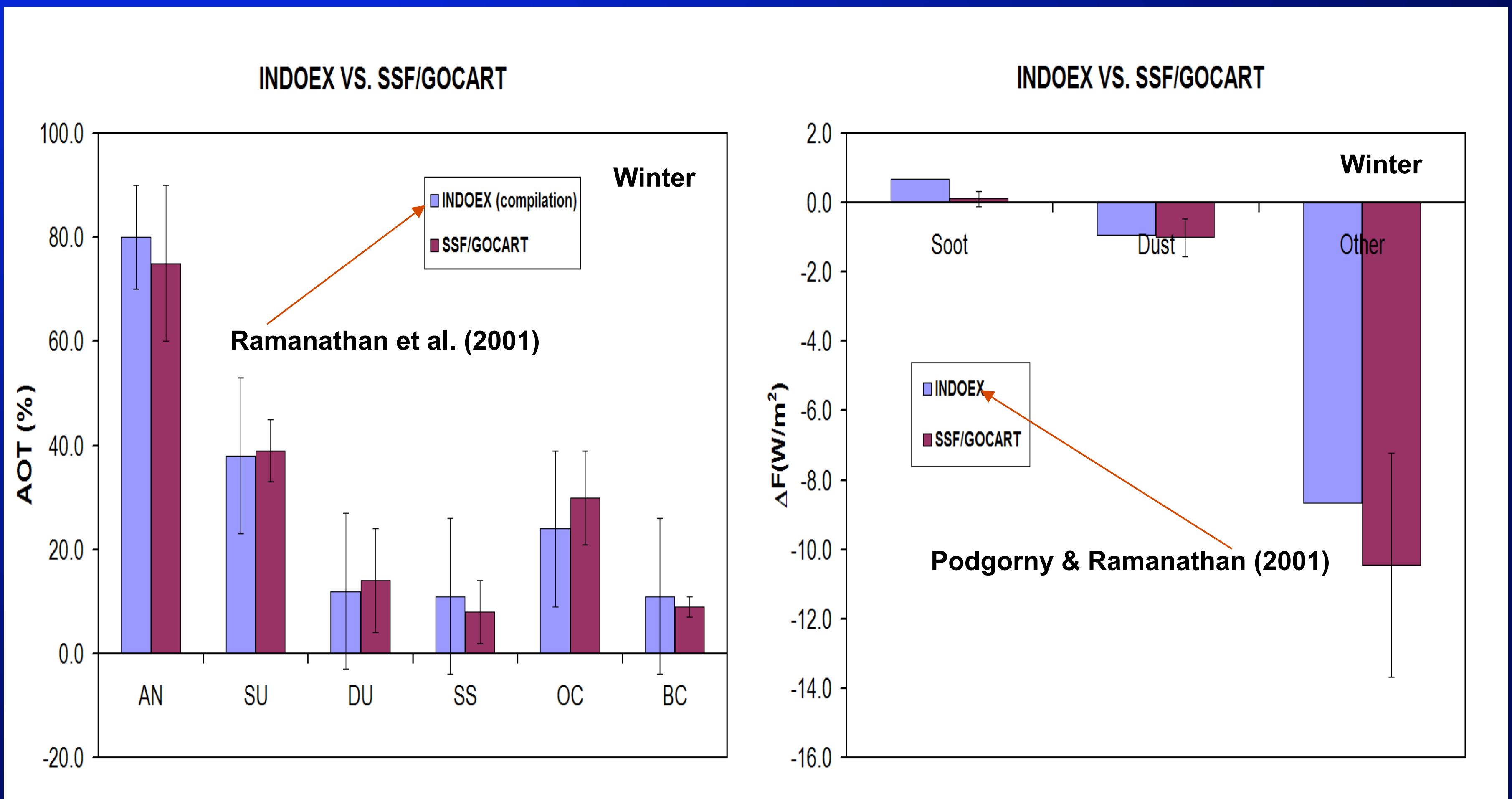




INDOEX Campaigns

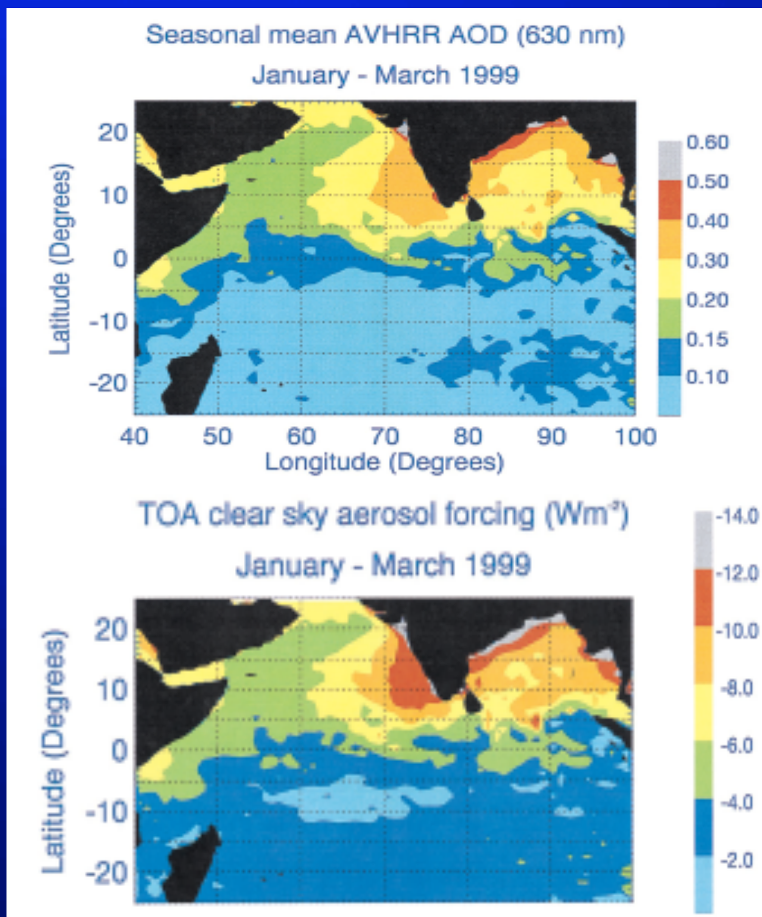
(1997, 1998, 1999)

(5°N-25°N; 40°E-100°E)

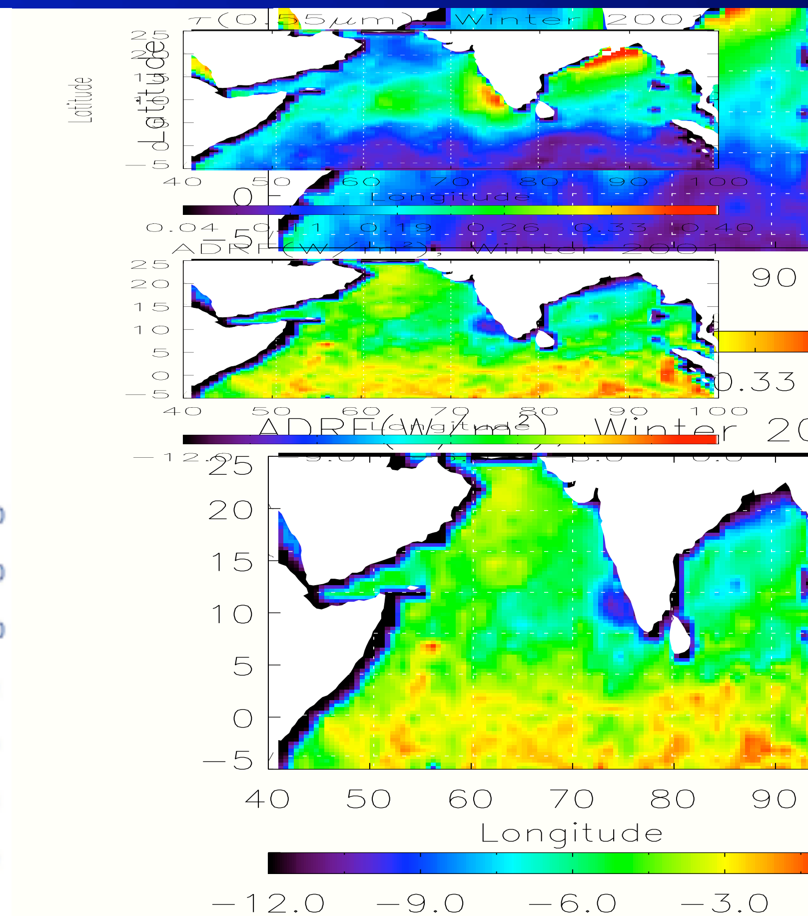


Regional Maps of AOT and ADRE in the INDOEX Region

Rajeev and Ramanathan (2001)



SSF/GOCART



Summary of the Uncertainties

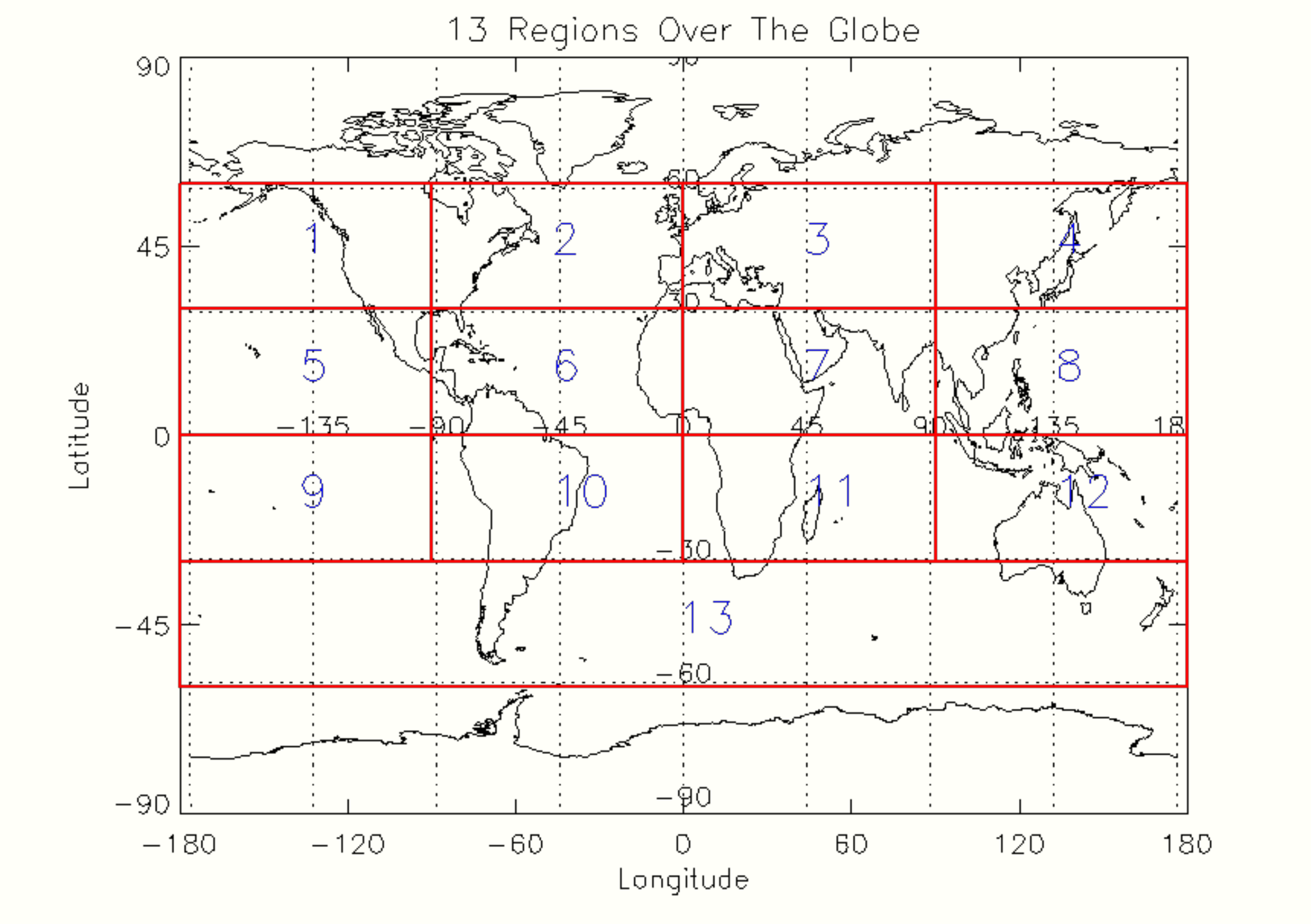
➢ **For Total ADRE (W/m^2):**

- Uncertainty in F^{na}: 1.0
- Instrument Related Uncertainties:
  - Narrow to broadband conversion: 1.0
  - ADM radiance to flux conversion: 0.2
  - Cloud contamination: 0.9
  - Summation: $(1.0^2+0.2^2+0.9^2)^{1/2}=1.36$
- Total: $(1.0^2+1.36^2)^{1/2}=1.69$ or 24.7% of total TOA ADRE

➢ **For Component ADRE (W/m2):**

- Inherited from TOT ADRE (24.7%):
  - BC, OC, SU, DU, SS, AN, NA
  - 0.062, 0.240, 0.574,0.388, 0.533, 0.563,1.102
- Uncertainties in the Partitioning:
  - BC, OC, SU, DU, SS, AN, NA
  - 0.08, 0.31, 0.41, 0.23, 0.14, 0.06, 0.11
- Total:
  - $(\text{inherited}^2+\text{partitioning}^2)^{1/2}$
  - BC, OC, SU, DU, SS, AN, NA
  - 0.10, 0.39, 0.71, 0.45, 0.55, 0.57, 1.11

13 Regions Selected for the Uncertainty Estimation of Partitioning



How to Estimate the Uncertainties of Partitioning?

Step1:

Find location & season that dominated by different component aerosols and compute radiative efficiency ($RE_i=\Delta F_i/\tau_\iota$) for each component:

- RE_{TOT}(Globe); RE_{SS} (Regions 9, 13); RE_{DU}(Region 6)
- RE_{NA} $(\tau_{SS} x RE_{SS} + \tau_{DU} x RE_{DU})/(\tau_{SS}+\tau_{DU})$
- RE_{SU}(Region 3, Winter); RE_{smoke}(Left Half of Region 11, Summer)

Step2:

Estimate uncertainties: $\delta_i=|RE_{TOT} - RE_i| \times \tau_i$ (i=DU, SS, SU, NA)

- $\delta_{AN} \sim \delta_{NA}$; $\delta_{OC} \sim | RE_{TOT} - RE_{smoke}|\tau_{smoke}$; $\delta_{BC} \geq | RE_{TOT} - RE_{smoke}|\tau_{smoke}$

$(\tau_{smoke}=\tau_{BC} + \tau_{OC})$