Derivation of Component Aerosol Direct Radiative Forcing over Global Oceans and the Validation

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Reference: Zhao et al., *JQSRT*, doi:10.1016/j.jqsrt, 2007

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Outline

- Introduction & Objective
- Data & Methodology
- Comparison & Evaluation
- Results & Uncertainties
- Summary & Acknowledgement

Introduction

Global Annual Mean of Component Aerosol Direct Forcing (ADRF) at the TOA

Aerosol Components	$\Delta F(W/m^2)$	
	Recent Satellite Observations	Recent Models
Black Carbon (BC)	?	+0.15 — +0.58
Organic Carbon (OC)	?	-0.15 — -0.65
Sulfate (SU)	?	-0.21— -0.96
Dust (DU)	?	-0.14 — -1.06
Sea Salt (SS)	?	-0.3 — -1.1
Anthropogenic Aerosol (AN)	-0.5— -1.1	-0.60 – -0.64
Natural Aerosol (NA)	-4.7	-1.41
Total Aerosol (TOT)	-3.8— -6.5 (Mean: -5.5)	-2.3 — -4.7 (Mean: -3.2)

Objective

- Combining the Satellite CERES/MODIS-SSF data and the GSFC/GOCART model simulation to:
  - Derive component ADRF over clear-sky global oceans 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 global estimates of ADRF.

Data

- **Satellite Observation**
  - CERES/MODIS-SSF aerosol optical thickness (AOT or τ) at 0.55μm, TOA clear-sky SW fluxes, and CERES clear strong index (CSI) from the cloud screening scheme were used
- **Model Simulation**
  - The GOCART partitioning fractions of component AOT, $r_i=\tau_i/\tau_{TOT}$ ($\tau_i=\tau_{SS}$, τ_{DU}, τ_{SU}, τ_{OM}, τ_{BC}, τ_{AN}, τ_{NA} at 0.55μm) were used . AN=BC+(OC-OCn)+(SU-SUn) and NA=Total - AN.

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

2001, Oceanic Areas (60°S-60°N)

Methodology
(Two Step Approach)

✓ **Step 1. Derive total ADRF ΔF (see Loeb & Kato, 2002):**

- $\Delta F(d,\theta,\phi)=F^{na}(d,\theta,\phi) - F^{a}(d,\theta,\phi)$
- $F^{a}(d,\theta,\phi)$: daily averaged SSF SW fluxes in presence of aerosols for CSI ≥ 85%.
- $F^{na}(d,\theta,\phi)$: daily averaged SW fluxes in absence of aerosols derived for CSI ≥ 99% through a regression for CERES/MODIS $\tau_{0.55}$ versus SSF TOA clear-sky SW fluxes in 1° solar zenith angle (SZA) increments and extrapolated to zero AOT.

✓ **Step 2. Partition ΔF into ΔF_i (i=NA, AN, SS, DU, SU, OC, BC):**

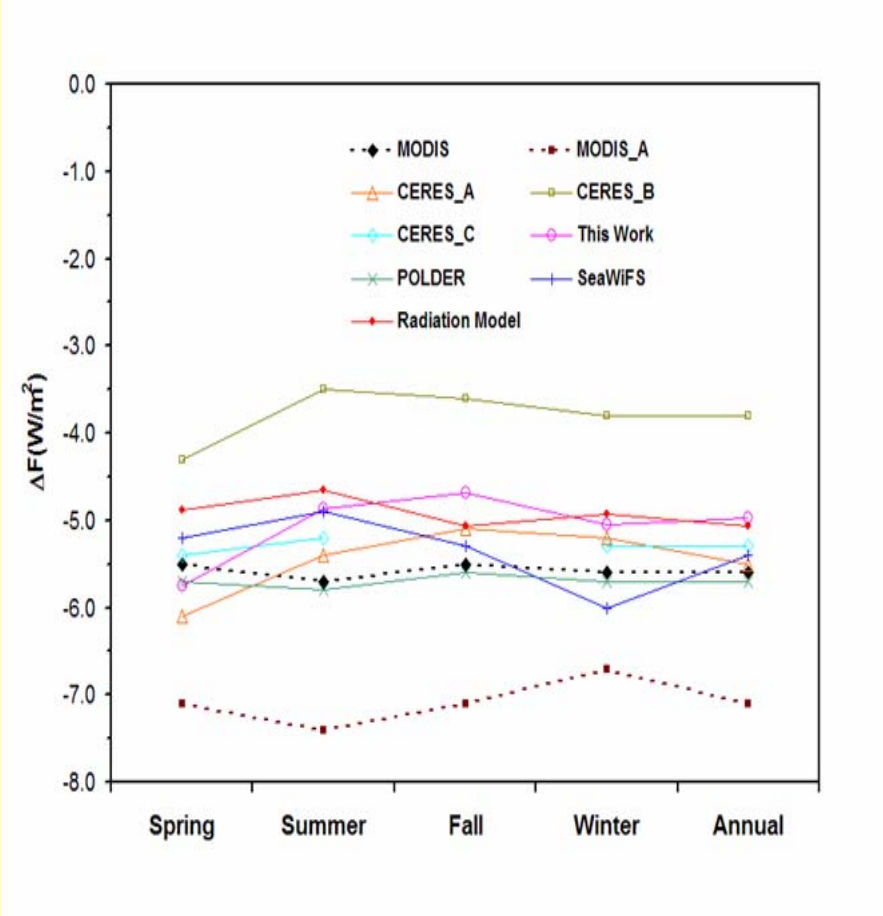
- It is known $\Delta F \sim (e^{-\tau} - 1)$ for non- or weak absorbing aerosols.
- We propose: $\Delta F_{NA}=\Delta F \times (e^{-\tau NA} - 1)/(e^{-\tau TOT} - 1)$ (assuming total ensemble aerosol radiative efficiency ($RE=\Delta F/\tau$) is close to that of non- or weak absorbing aerosols). → $\Delta F_{AN}=\Delta F - \Delta F_{NA}$
- Similarly, we obtain $\Delta F_i=\Delta F \times (e^{-\tau i} - 1)/(e^{-\tau TOT} - 1)$ (i=SS, DU, SU, OC).
- At last, $\Delta F_{BC}=\Delta F - (\Delta F_{SS} + \Delta F_{DU} + \Delta F_{SU} + \Delta F_{OC})$.

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

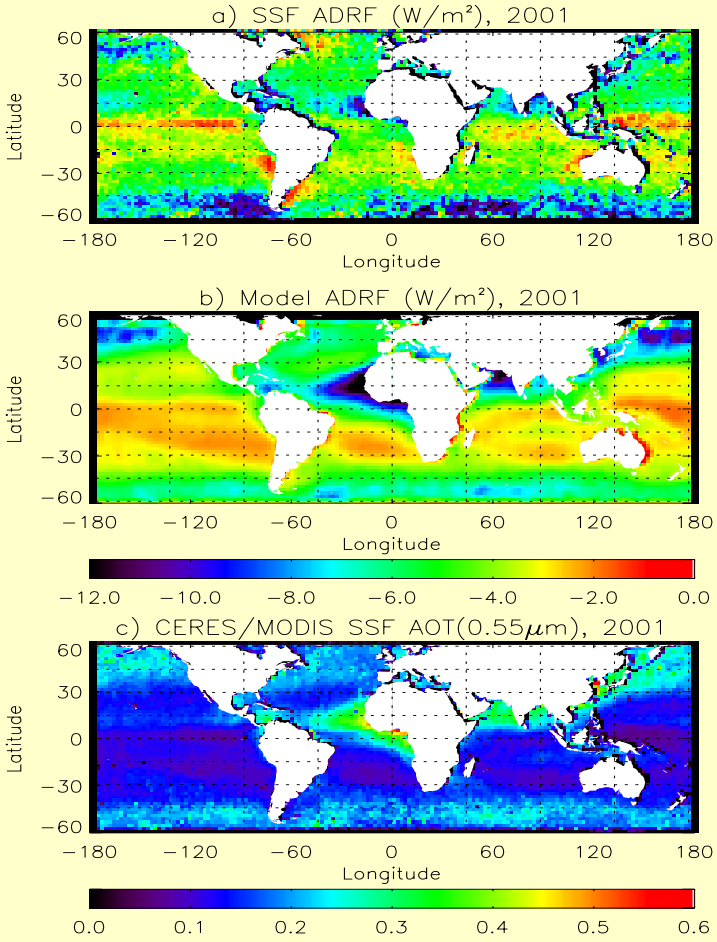
Comparison and Evaluation

(Global Ocean)

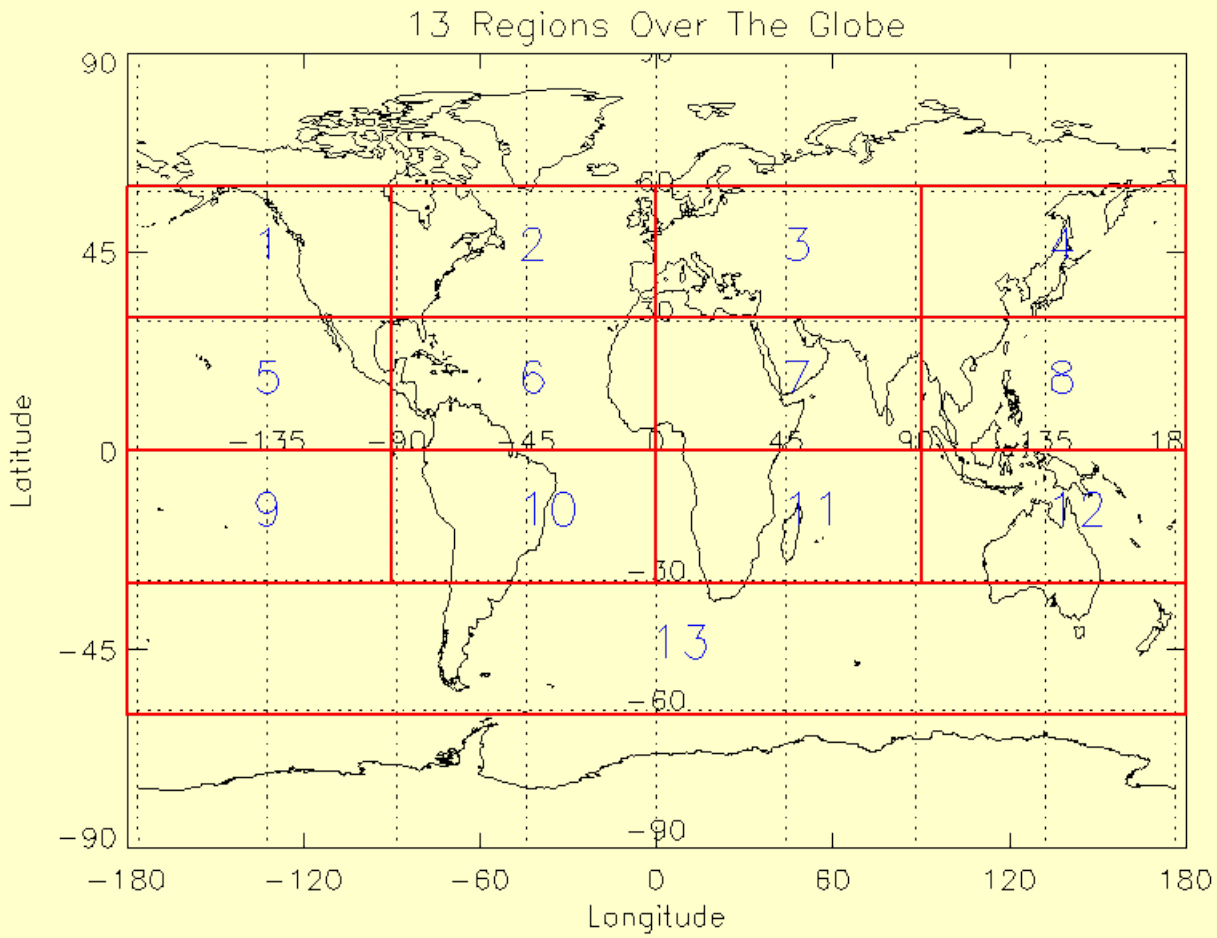
Seasonal & Annual Mean ADRF



Global Distribution of Annual Mean ADRF and AOT



13 Regions Selected for Comparison



Comparison in Selected Regions

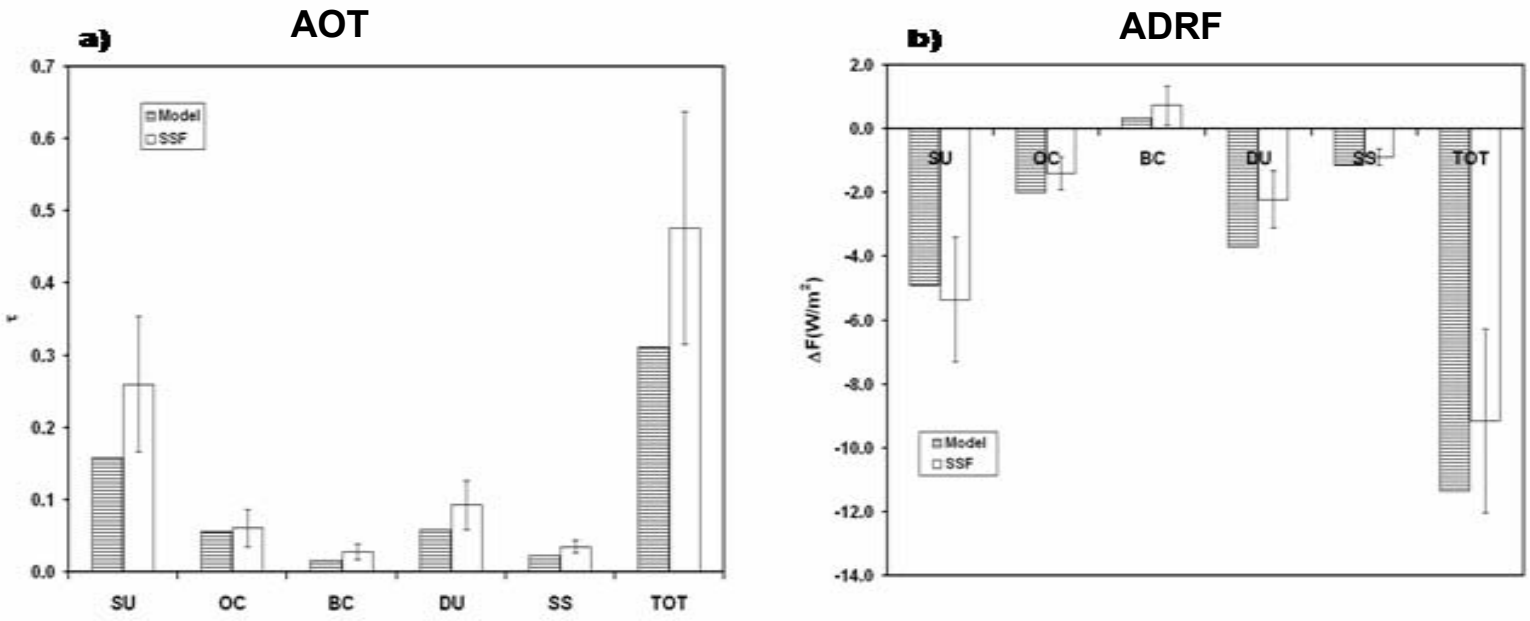
Number of Regions	[b]Other Observations		SSF		Difference	Model		Difference
	ΔF_O (W/m^2)	STD	ΔF_S (W/m^2)	ε	ΔF_S-ΔF_O	ΔF_M (W/m^2)	ε	ΔF_M-ΔF_O
1	-6.8	0.16	-5.0	1.7	1.8	-6.3	2.9	0.5
2	-6.5	0.16	-4.4	1.5	2.1	-5.6	2.1	0.9
3	-8.0	0.22	-8.5	8.8	-0.5	-4.2	3.6	3.8
4	-9.7	0.18	-5.7	3.4	4.0	-8.4	3.2	1.3
5	-4.4	0.19	-4.2	1.4	0.2	-4.2	1.1	0.2
6	-7.9	0.20	-5.7	2.5	2.2	-7.6	3.1	0.3
7	-9.3	0.24	-6.3	3.5	3.0	-5.7	4.4	3.6
8	-4.9	0.15	-4.8	2.2	0.1	-4.5	1.9	0.4
9	-3.5	0.21	-3.5	0.7	0.0	-3.0	0.3	0.5
10	-4.6	0.21	-3.9	2.1	0.7	-3.6	1.9	1.0
11	-4.7	0.16	-3.7	1.5	1.0	-3.7	1.8	1.0
12	-4.3	0.19	-3.7	3.1	0.6	-3.2	1.1	1.1
13	-5.6	0.16	-5.5	2.1	0.1	-5.6	1.7	0.0
[a]14	-5.4	0.18	-5.0	2.8	0.4	-4.5	3.1	0.9

STD: Standard deviation of seven estimates. ε: Spatial standard deviation.
Region 14: Global oceans.

Comparison and Evaluation

(Regional Ocean: ACE-Asia Case)

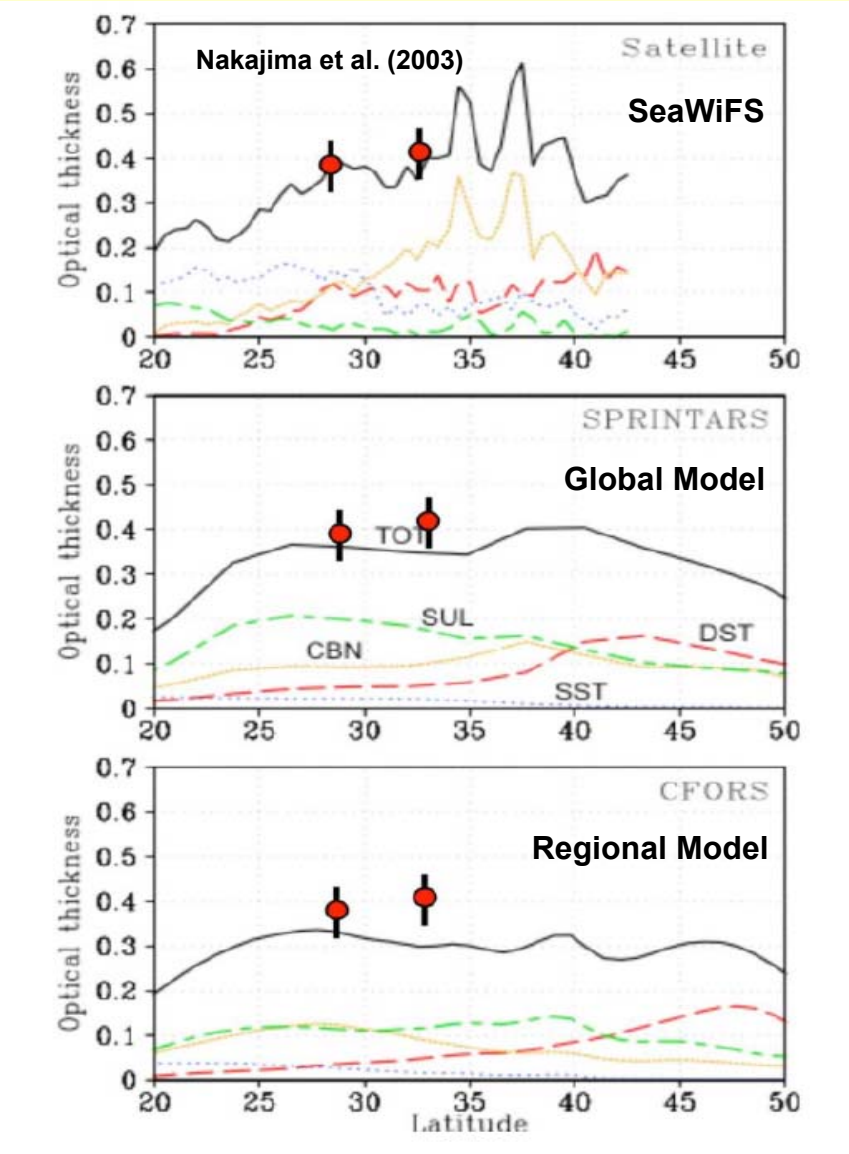
SSF/GOCART VS. MCR Model/CFORS Model **(Conant et al., 2003)**

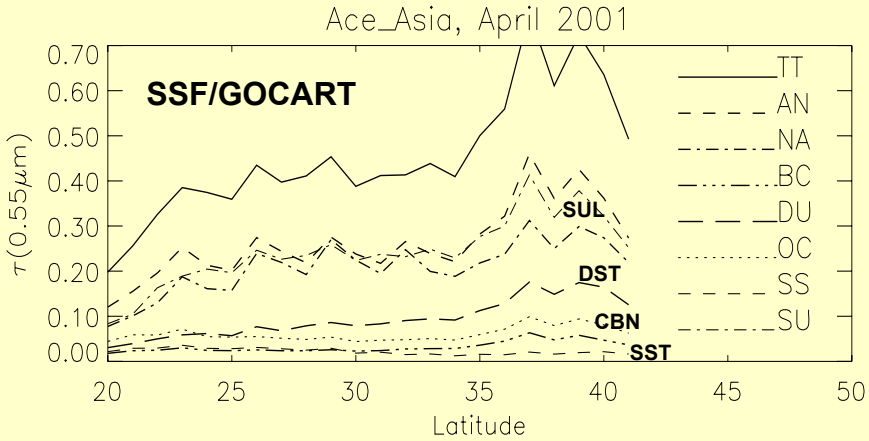


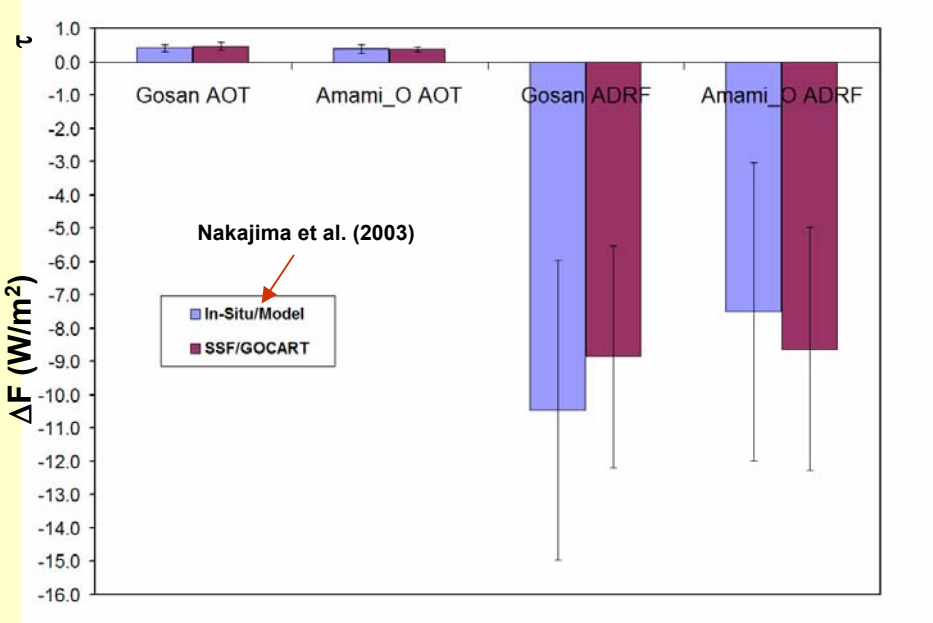
April 5-15, 2001
100°E-150°E; 20°N-50°N

APEX/ACE-Asia Case
(April 2001)

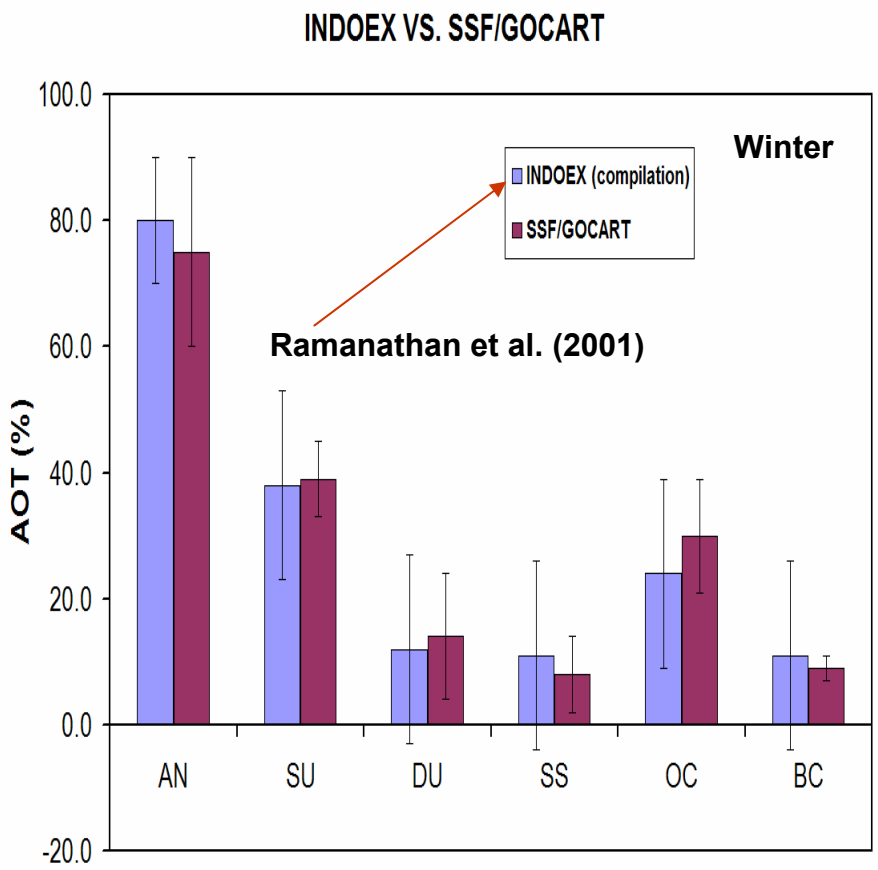
125.5°E-130.5°E, 20°N-42°N

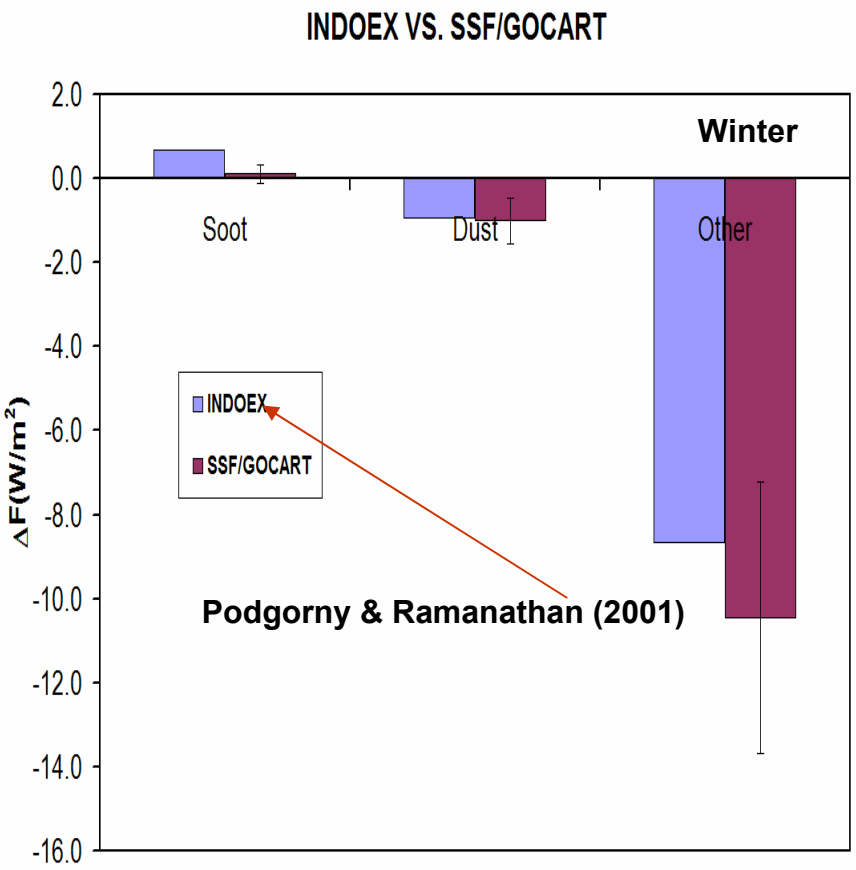




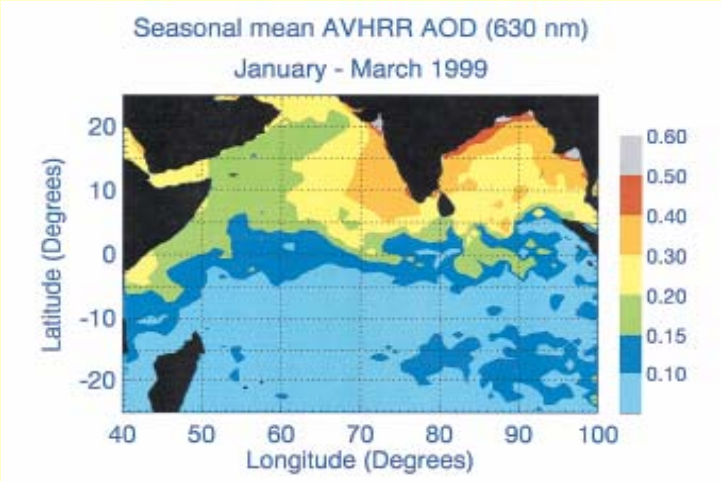


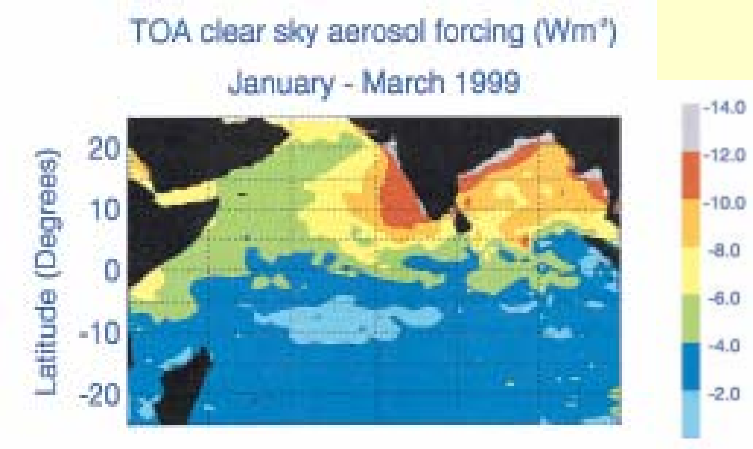
INDOEX Case
(5ºN-25ºN; 40ºE-100ºE)



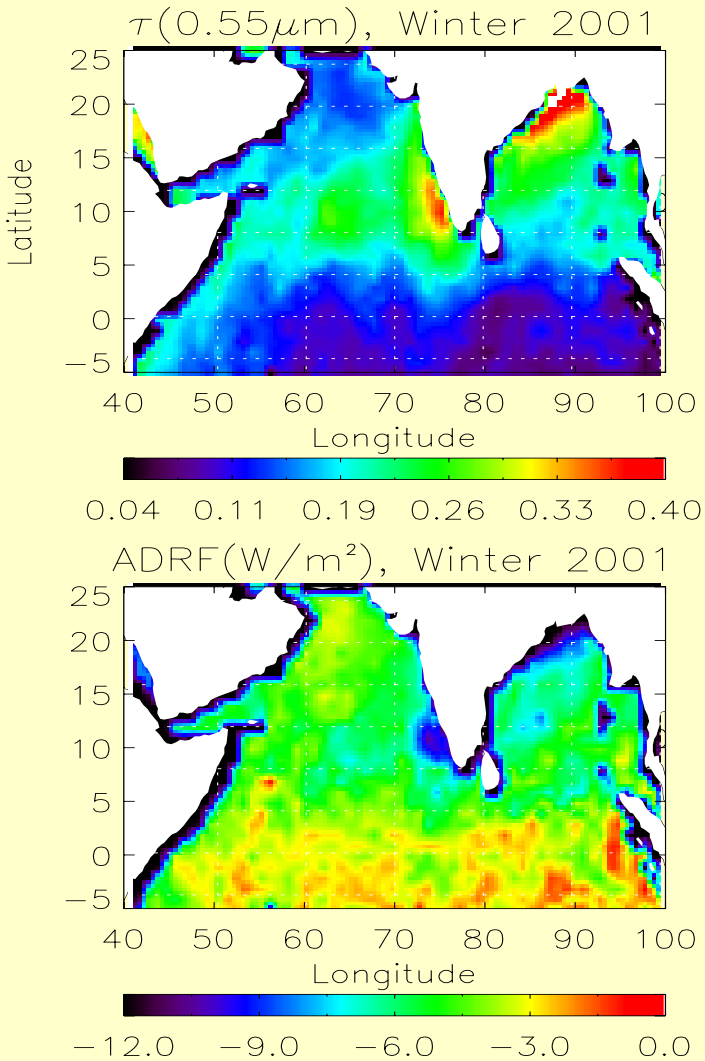


Regional Maps of AOT and ADRF in the INDOEX Region

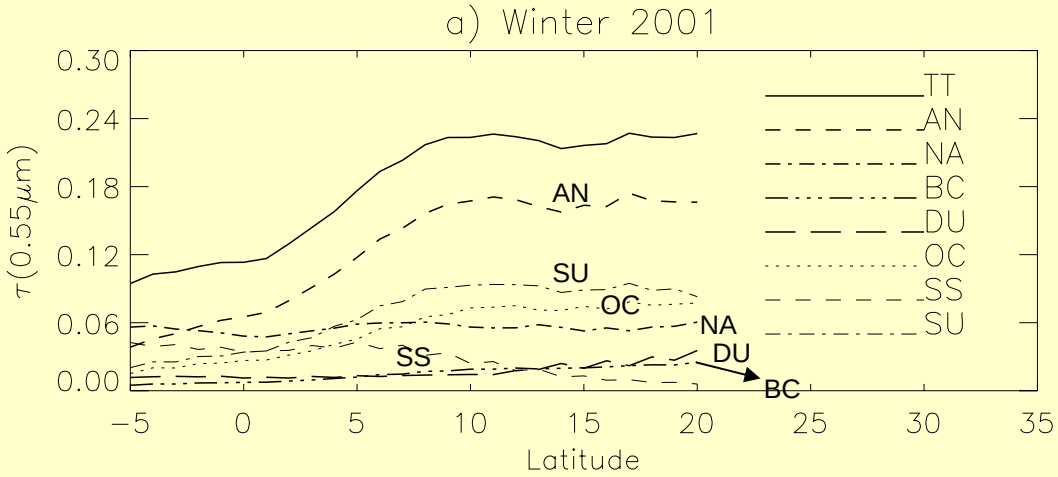


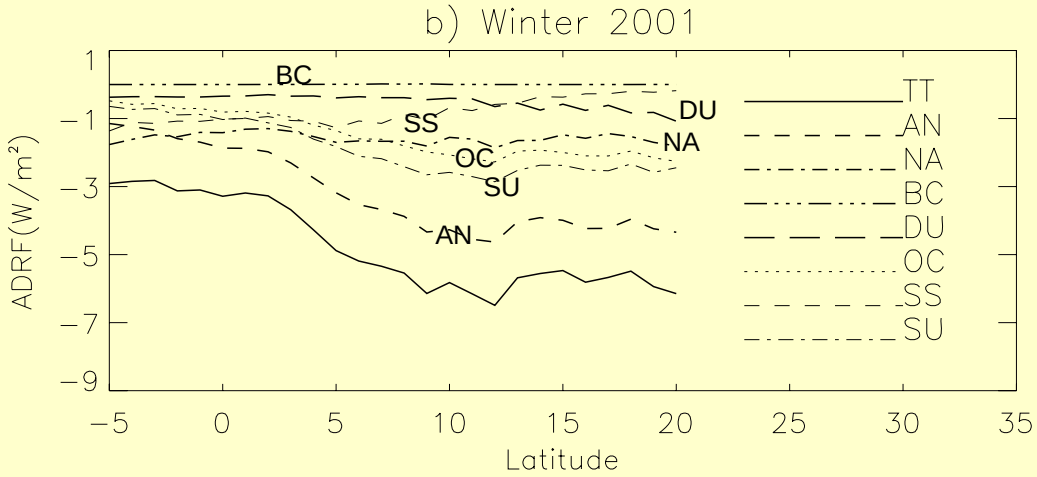


Rajeev and Ramanathan (2001)

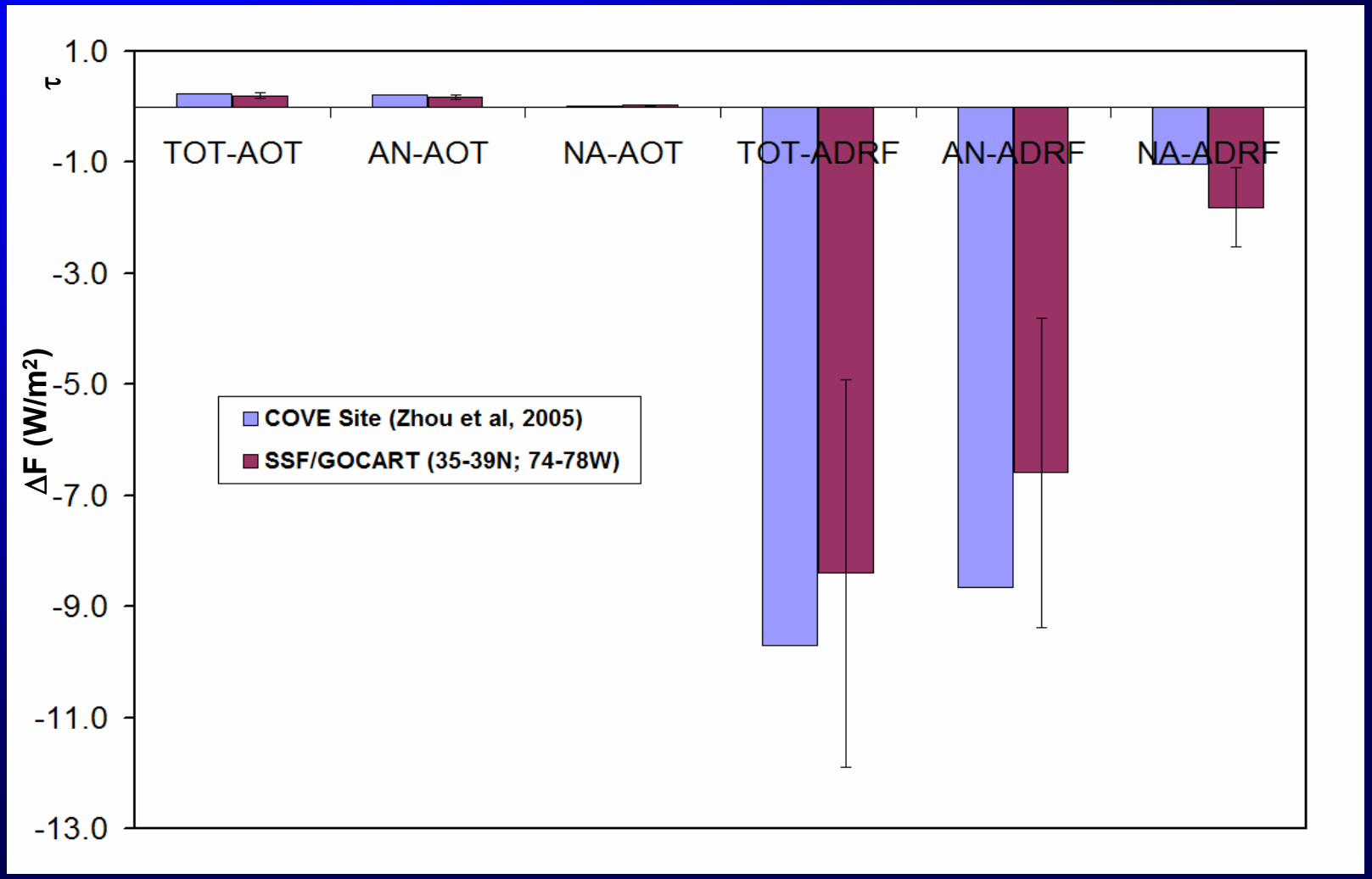


Latitudinal Variations
(INDOEX;5°E-100°E)





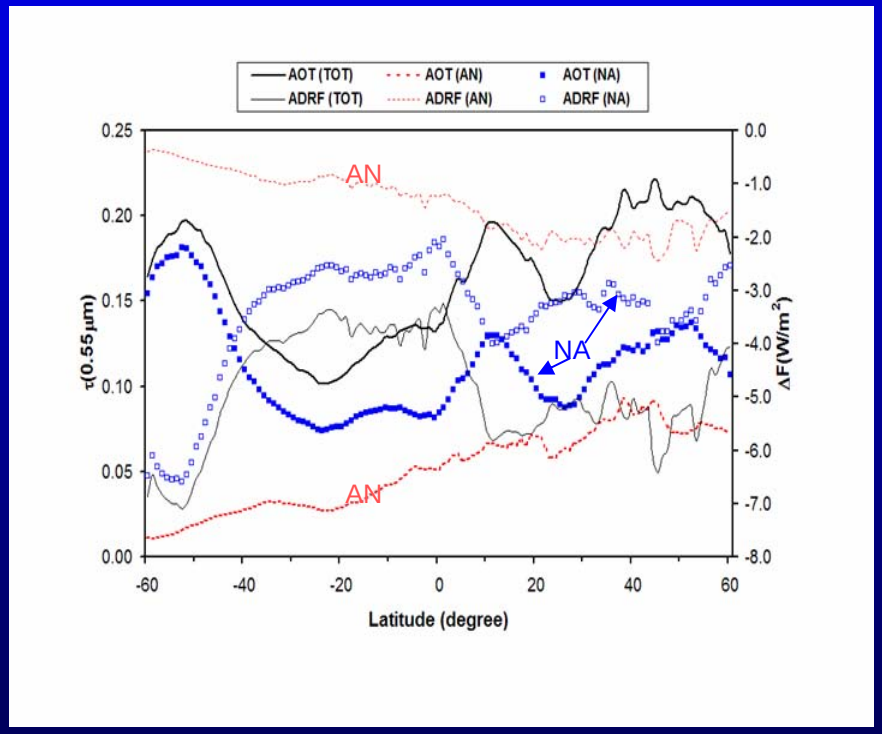
CLAMS CASE
(July 2001)

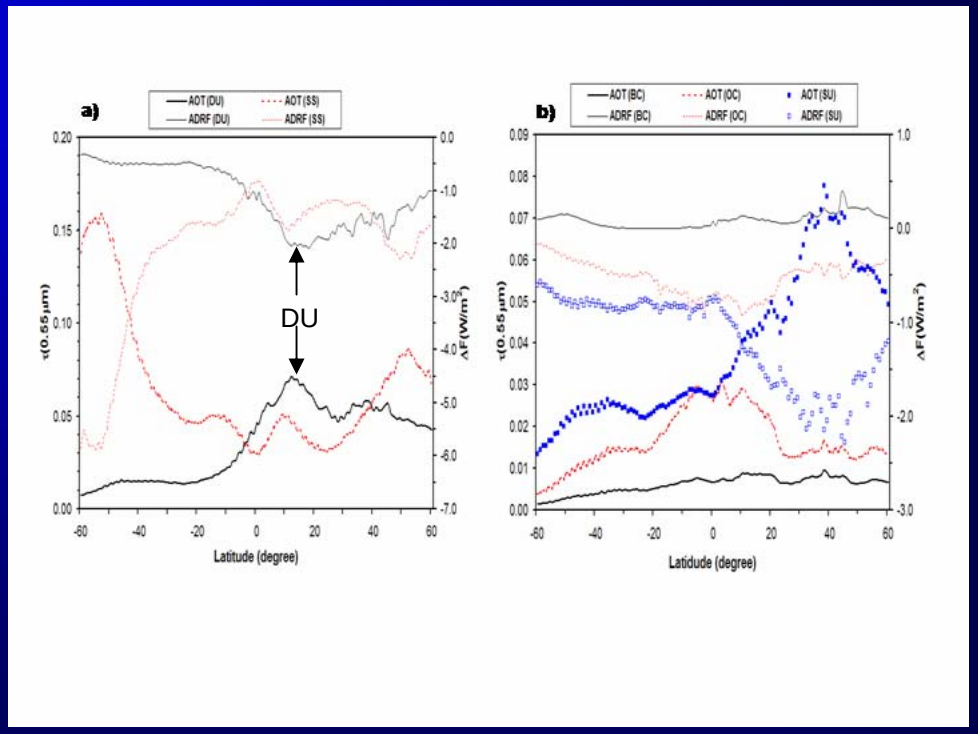


Results

Zonal Distribution of Annual Mean AOT and ADRF

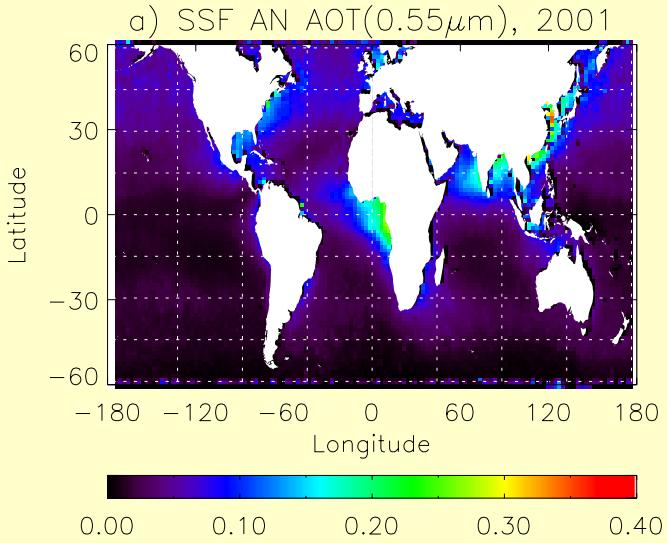
(2001)

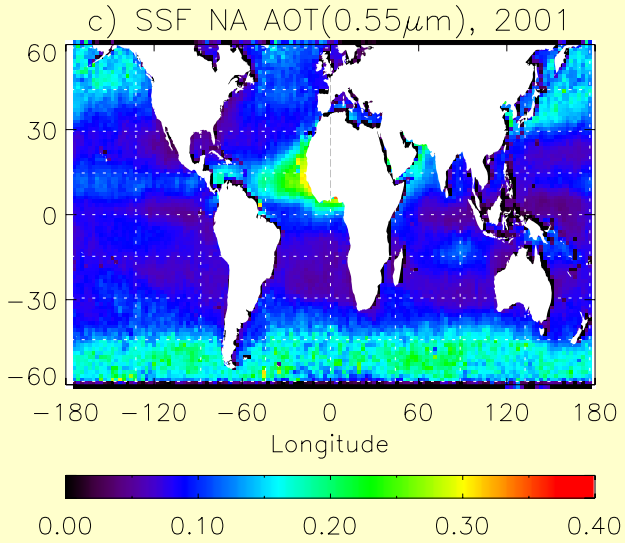




Global Distribution of Annual Mean AOT and ADRF for AN and NA

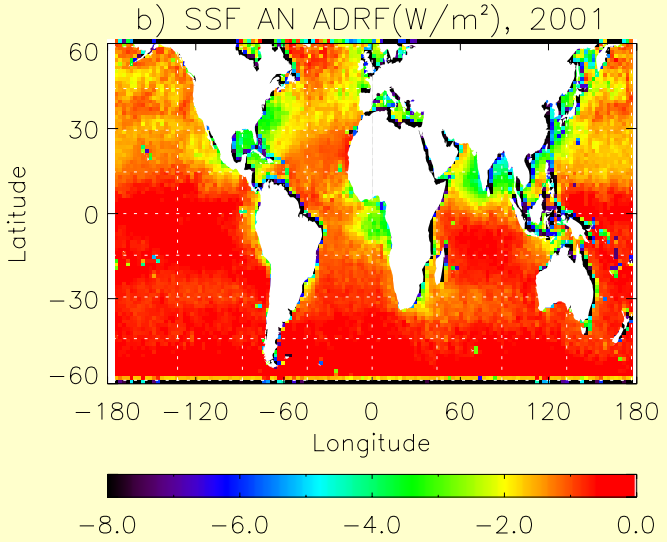
0.046

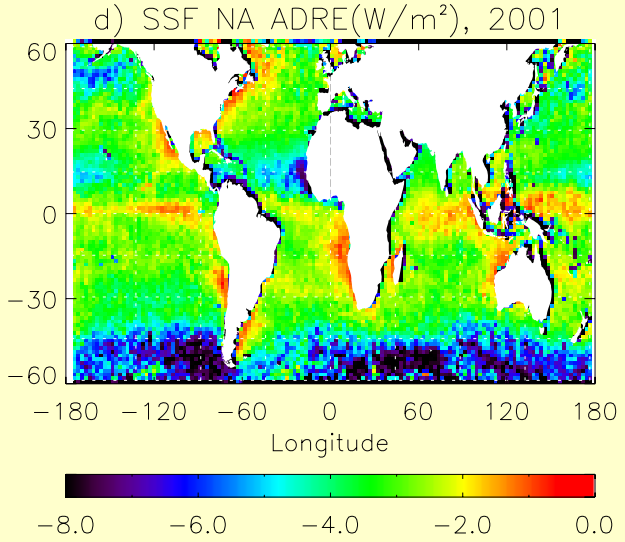




0.112

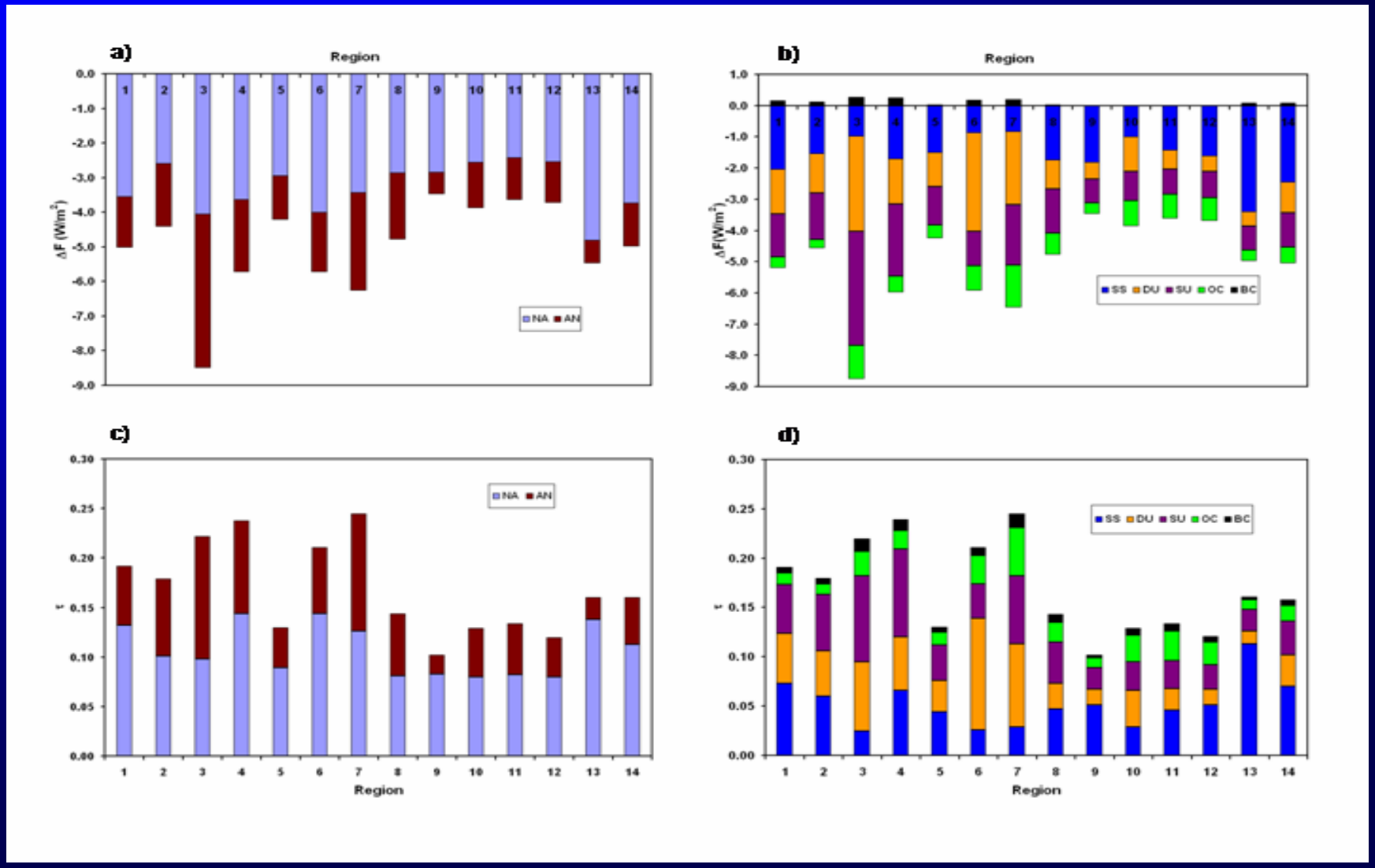
-1.25W/m²





-3.73W/m²

Regional and Global Annual Means of Component AOT and ADRF



Estimate the Uncertainties of the Partitioning

Step1

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

- RE_{TOT}=-5.0/0.158 = -31.6 (Wm^{-2}/τ)
- RE_{SS} =-8.95/0.264 = -33.8 (Wm^{-2}/τ) (Regions 9, 13)
- RE_{DU} =-5.7/0.211 = -27.0 (Wm^{-2}/τ) (Region 6)
- $RE_{NA} = (\tau_{SS} x RE_{SS} + \tau_{DU} x RE_{DU})/(\tau_{SS}+\tau_{DU})$ = -30.8 (Wm^{-2}/τ)
- RE_{SU}=-2.20/0.059= -37.3 (Wm^{-2}/τ) (Region 3, Winter)
- RE_{smoke}=-5.45/0.227=-24.0 (Wm^{-2}/τ) (Left Half of Region 11, Summer)

Step2

Estimate uncertainties:

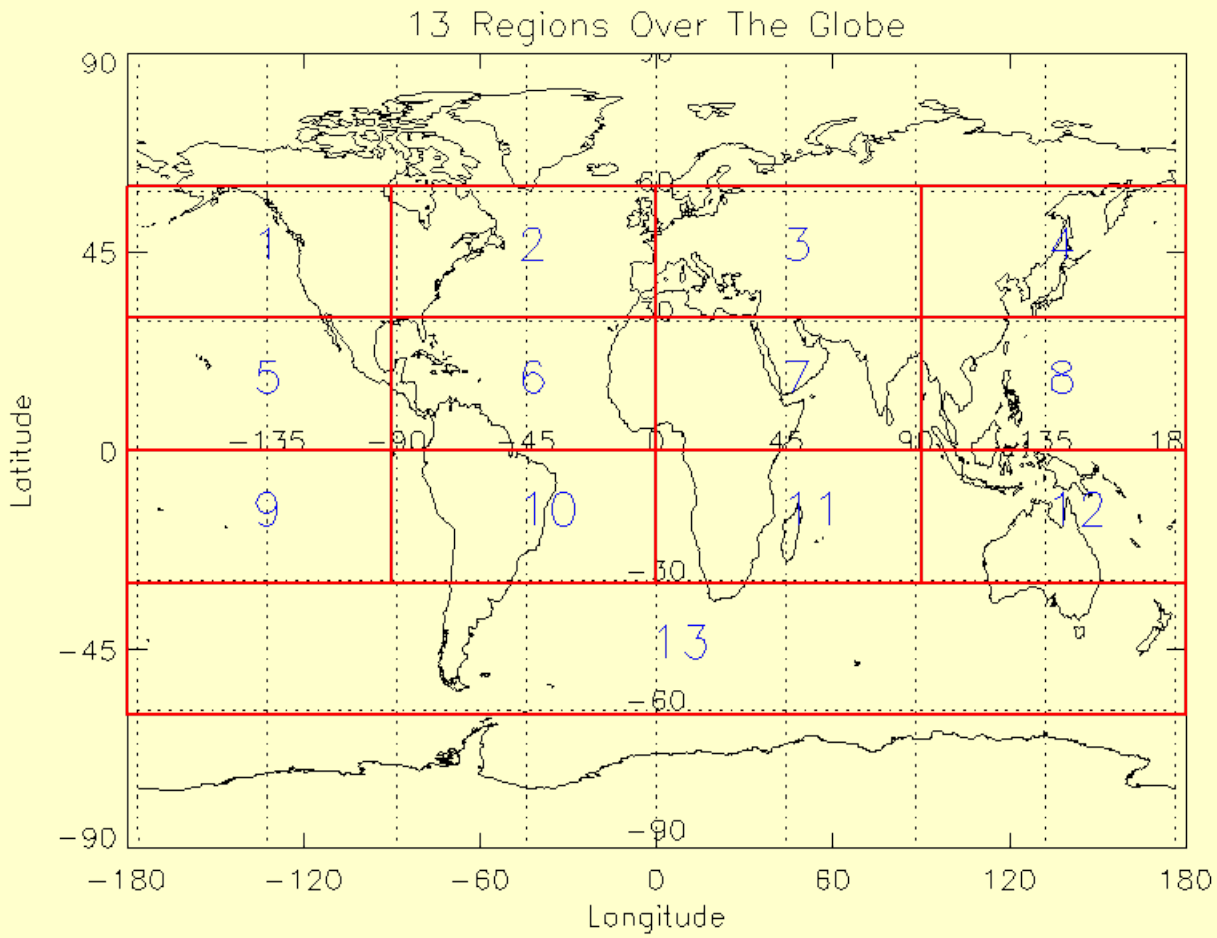
$$\delta_i=|RE_{TOT} - RE_i| \times \tau_i$$

- δ_{NA} = |-31.6+30.8|τ_{NA} =0.8x0.112= 0.09 (W/m^2)
- $\delta_{AN} \sim \delta_{NA}$ = 0.09 (W/m^2)
- δ_{SS} = |-31.6+33.8|τ_{SS} =2.2x0.07 = 0.154 (W/m^2)
- δ_{DU} = |-31.6+27.0|τ_{DU} =4.6x0.032 = 0.147 (W/m^2)
- δ_{SU} = |-31.6+37.3|τ_{SU} = 5.7x0.034 = 0.194 (W/m^2)
- $\delta_{OC} \leq$ |-31.6+24.0|τ_{smoke} =7.6x0.022 = 0.167 (W/m^2)

($\tau_{smoke}=\tau_{BC} + \tau_{OC}$=0.006+0.016=0.022)

$\delta_{BC} \geq$ |-31.6+24.0|τ_{smoke} =7.6x0.022 = 0.167 (W/m2)

13 Regions Selected for Comparison



Summary of the Uncertainties

➢ **For Total ADRF (W/m^2):**

- Uncertainty in F^o: 1.2
- Uncertainty in Averaging: 0.25
- Uncertainty in F^a: 0.9
- Instrument Related Uncertainties:
  - Calibration: 0.4
  - Filtered to unfiltered Radiance: 0.4
  - ADM: 0.2
  - Aerosol Effect in ADM: 0.32
  - Summation:

  $(0.4^2+0.4^2+0.2^2+0.32^2)^{1/2}=0.68$
- Total:

  $(1.2^2+0.25^2+0.9^2+0.68^2)^{1/2}=1.67$

➢ **FOR Component ADRF (W/m2):**

- Inherited from TOT ADRF (34%):
  - BC, OC, SU, DU, SS, AN, NA
  - 0.027, 0.177, 0.374,0.337, 0.830, 0.425,1.268
- Uncertainties in the Partitioning:
  - BC, OC, SU, DU, SS, AN, NA
  - 0.167, 0.167, 0.194, 0.147, 0.154, 0.09, 0.09
- Total:
  - $(\text{inherited}^2+\text{partitioning}^2)^{1/2}$
  - BC, OC, SU, DU, SS, AN, NA
  - 0.027, 0.177, 0.374, 0.337,0.830, 0.425, 1.268

Summary

Aerosol Component	Global Annual Mean of Component ADRF (W/m^2)			
	Our Estimation		Recent Observations[2] ΔF_i	Recent Models[3] ΔF_i
	ΔF_i	uncertainty		
BC	+0.08	±0.17	?	+0.15 — +0.58
OC	-0.52	±0.24	?	-0.15 — -0.65
SU	-1.10	±0.42	?	-0.21 — -0.96
DU	-0.99	±0.37	?	-0.14 — -1.06[5]
SS	-2.44	±0.84	?	-0.3 — -1.1[5]
AN	-1.25	±0.43	-0.5 — -1.1[4]	-0.60 — -0.64[6]
NA	-3.73	±1.27	-4.7	-1.41[6]
Total	-4.98	±1.67 (33.5%)	-3.8 — -6.5 (-5.5)	-2.3 — -4.7 (-3.2)

Acknowledgements

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- ✓ Founding support from the NASA Radiation Program and the Cooperative Institute Program of NOAA/NESDIS/STAR.

Thank You!