GLOBAL AEROSOL MODELLING AND OBSERVATIONS: TOWARDS IPCC FAR

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Aerocom Second Meeting

10-12 March 2004

Acknowledgements to
Y. Balkanski, M. Schultz, C. Textor

Outline

0/ Background information on IPCC

1/ Estimation of the direct aerosol radiative perturbation from POLDER-1 / MODIS and AERONET

Bellouin et al., GRL, 2003
Bellouin, PhD, 2003
Bellouin et al., in preparation, 2004

2/ Estimation of the direct aerosol radiative forcing and perturbation from the LDMZT-aerosol model

Reddy et al., JGR, for submission, 2004
Reddy et al., GRL, for submission, 2004

3/ Discussion

Presentation of IPCC 4th assessment report
Outline

Chapter	Title	Pages
	Summary for Policymakers	15
	Technical Summary	60
1	Historical Overview of Climate Change Science	15
2	Changes in Atmospheric Constituents and in Radiative Forcing	60
3	Observations: Atmospheric and Surface Climate Change	60
4	Observations: Changes in Snow, Ice and Frozen Ground	25
5	Observations: Oceanic Climate Change and Sea Level	35
6	Paleoclimate	30
7	Couplings Between Changes in the Climate System and Biogeochemistry	50
8	Climate Models and their Evaluation	50
9	Understanding and Attributing Climate Change	50
10	Global Climate Projections	50
11	Regional Climate Projections	60
	(total)	560

Sulfate fields for 6 SRES scenarios (A1B, A1, A2, A1FI, B1, B2) available every 10 years from www-loa.univ-lille1.fr/~boucher/sres

Presentation of IPCC 4th assessment report Outline

2. Changes in Atmospheric Constituents and in Radiative Forcing

Executive Summary

- Introduction
- Definition and Utility of Radiative Forcing
- Recent Changes in Greenhouse Gases
- Aerosols – Direct and Indirect Radiative Forcing
- Radiative Forcing due to Land Use Changes
- Contrails and Aircraft-Induced Cirrus
- Variability in Solar and Volcanic Radiative Forcing
- Synthesis of Radiative Forcing Factors
- GWPs and Other Metrics for Comparing Different Emissions

Appendix: Techniques, Error Estimation, and Measurement Systems

7. Couplings Between Changes in the Climate System and Biogeochemistry

Executive Summary

- Introduction to Biogeochemical Cycles
- The Carbon Cycle and the Climate System
- Global Atmospheric Chemistry and Climate Change
- Air Quality and Climate Change
- Aerosols and Climate Change
- The Changing Land Surface and Climate
- Synthesis: Interactions Among Cycles and Processes

Presentation of IPCC 4th assessment report Timeline

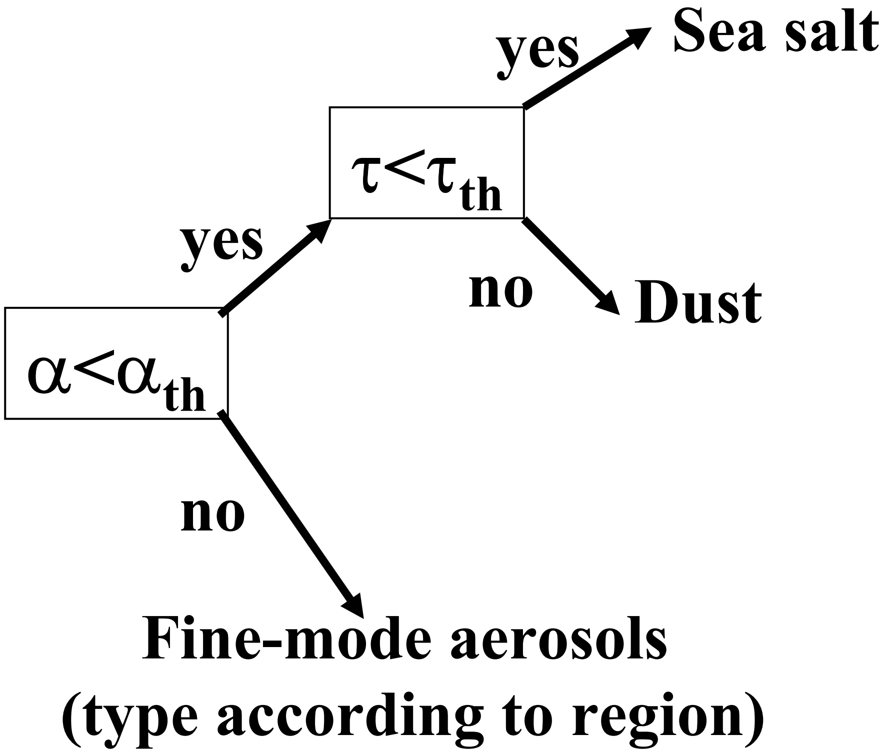
2003	
Apr	1st Scoping Meeting
Sep	2nd Scoping Meeting
Nov	WG1 AR4 Outline approved
Nov	Call for LA Nominations
2004	
Jan 20	Deadline for LA Nominations
Feb - Apr	Selection of LAs
Sep	1st LA Meeting (Italy)
2005	
Feb–Apr	Informal Review of Zero-Order Draft
May	2nd LA Meeting (China)
	Note that literature to be cited will need to be published or available in draft form by this time
Sep–Nov	Expert Review of First-Order Draft
Nov	3rd LA Meeting (New Zealand)
	Note that literature to be cited will need to be published or in press by this time
2006	
Apr–May	Government/Expert Review of Second-Order Draft
June	4th LA Meeting
Oct–Nov	Government Review of Summary for Policy Makers
2007	
Jan	IPCC Approval of WG1 AR4

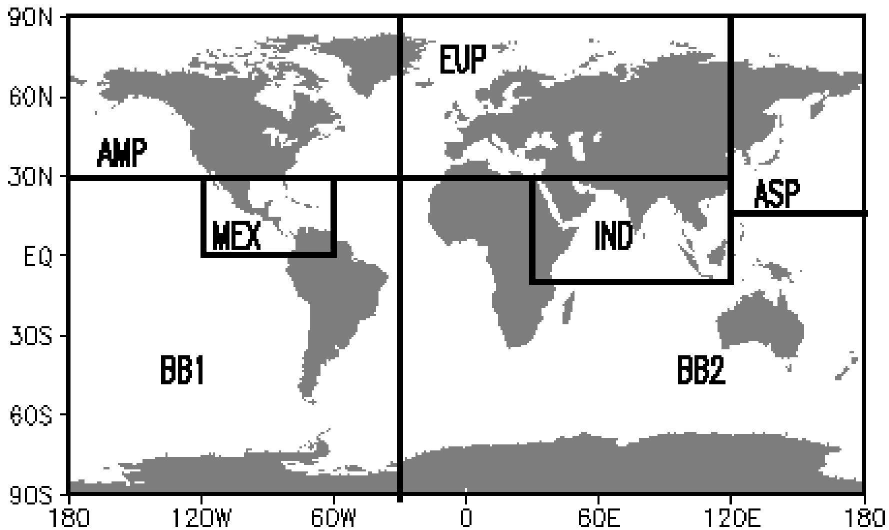
Boucher and Tanré, GRL, 2000

Bellouin *et al.*, GRL, 2003

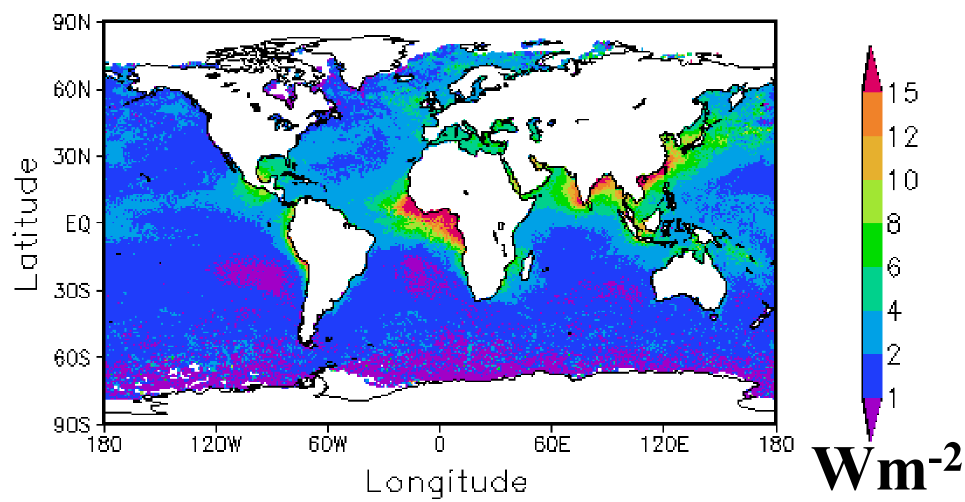
Bellouin, PhD, 2003.

Estimation of TOA, BOA, and atmospheric DARP from synergenetic use of POLDER-1 and AERONET



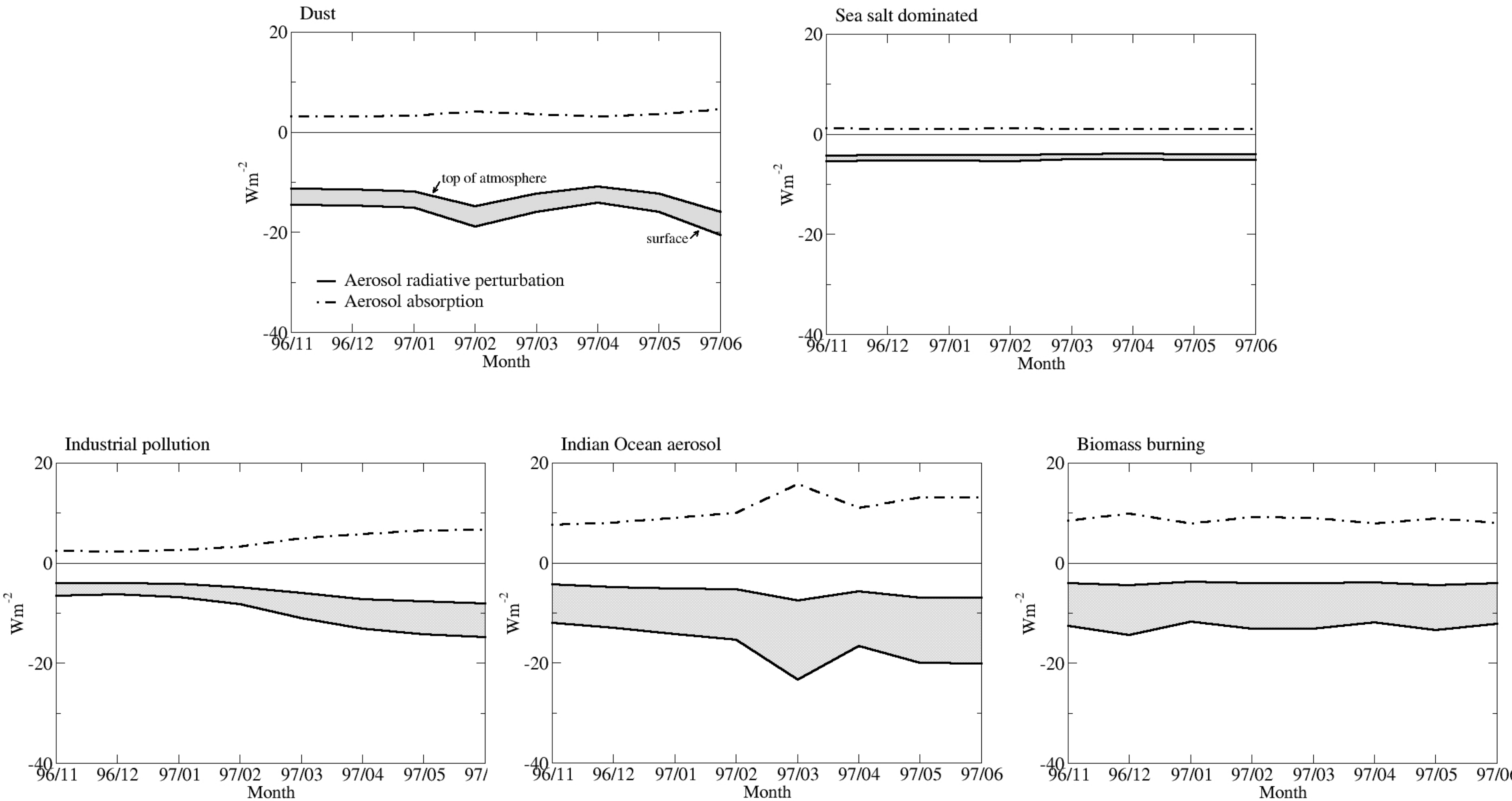


Atmospheric DARP=absorption



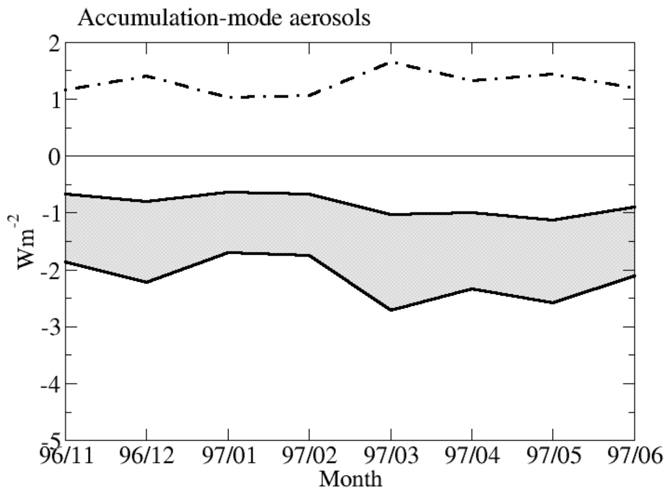
Average: 2.5 Wm^{-2}

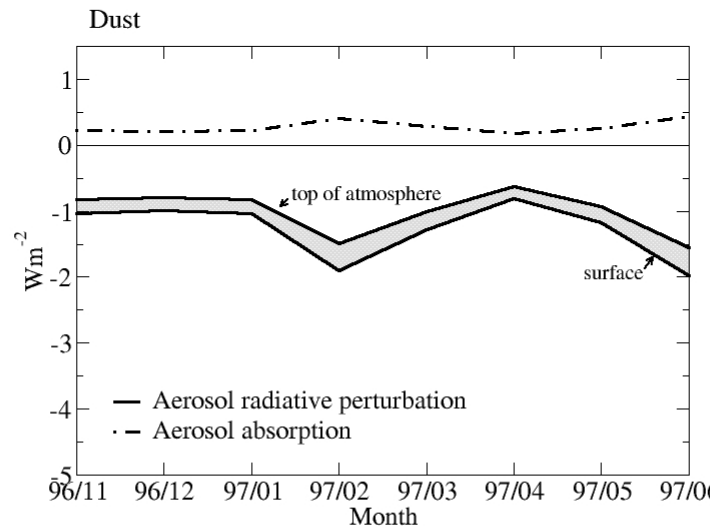
TOA, BOA, and atmospheric DARP over the clear-sky ocean by aerosol type

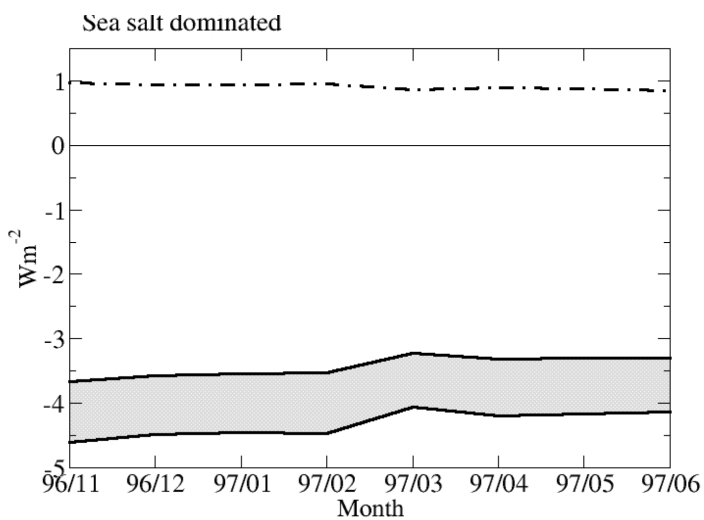


Bellouin *et al.*, GRL, 2003
Bellouin, PhD, 2003

TOA, BOA, and atmospheric DARP over the clear-sky ocean by aerosol type and weighted by plume extent







Bellouin *et al*., GRL, 2003
Bellouin, PhD, 2003

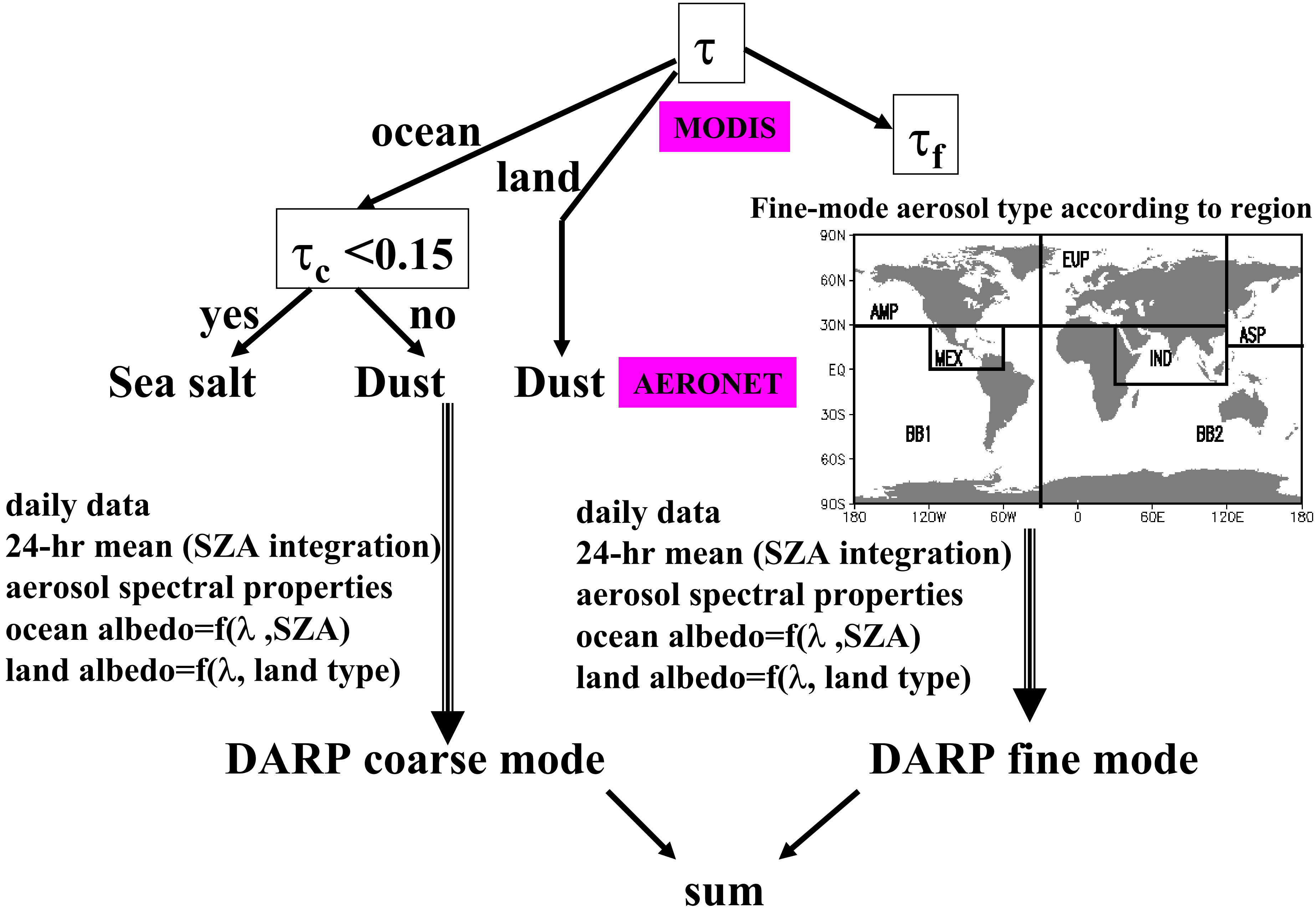
POLDER-1 AEROSOL RADIATIVE FORCING RESULTS

Boucher et Tanre (2000)
Non-absorbing aerosols - aerosol optical thickness (AOT) for scattering only.

Date	AOT @ 550 nm	TOA forcing	Surface forcing	RFE
Nov. 1996	0,122	-5,49	-5,69	-45
Dec. 1996	0,119	-5,47	-5,67	-46
Jan.1997	0,116	-5,33	-5,53	-46
Feb. 1997	0,142	-6,01	-6,23	-42
Mar. 1997	0,139	-5,69	-5,9	-41
Apr. 1997	0,124	-5,45	-5,65	-44
May. 1997	0,136	-5,93	-6,15	-44
Jun. 1997	0,139	-6,09	-6,31	-44
8-month average	**0,123**	**-5,58**	**-5,78**	-45

Bellouin et al. (2003)
Absorbing aerosols - AOT for extinction.

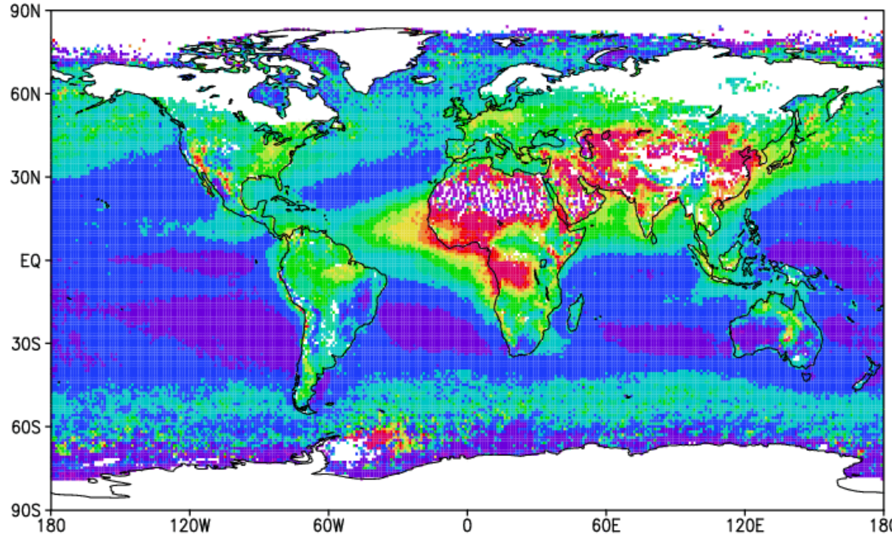
Date	AOT @ 550 nm	TOA forcing	Surface forcing	RFE
Nov. 1996	0,124	-5,06	-7,15	-41
Dec. 1996	0,121	-5,02	-7,23	-41
Jan.1997	0,118	-4,96	-6,84	-42
Feb. 1997	0,145	-5,59	-7,68	-39
Mar. 1997	0,141	-5,21	-7,53	-37
Apr. 1997	0,126	-4,99	-7,2	-40
May. 1997	0,138	-5,42	-7,88	-39
Jun. 1997	0,141	-5,63	-7,86	-40
8-month average	**0,125**	**-5,14**	**-7,26**	-41



Bellouin *et al.*, 2004

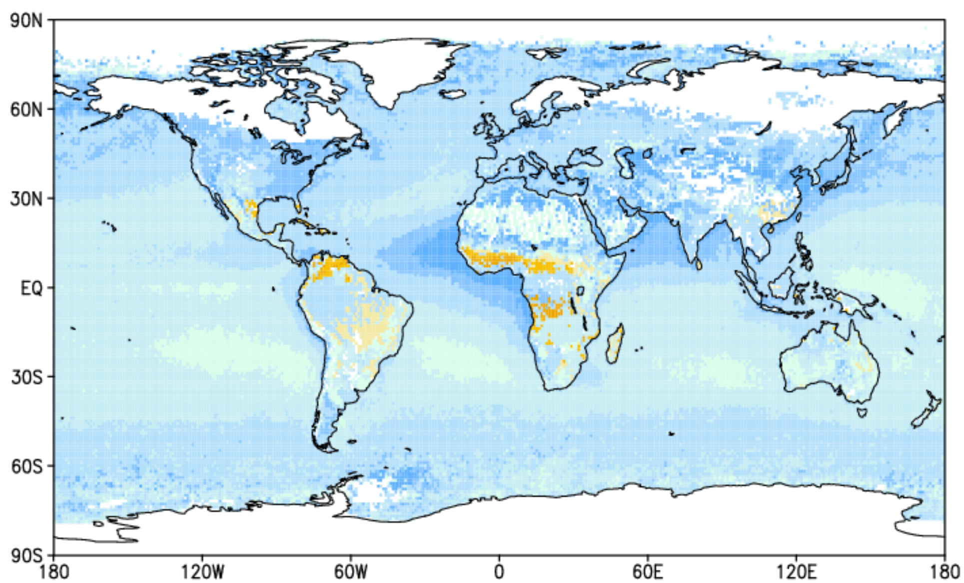
MODIS AOD=0.19

Clear-sky

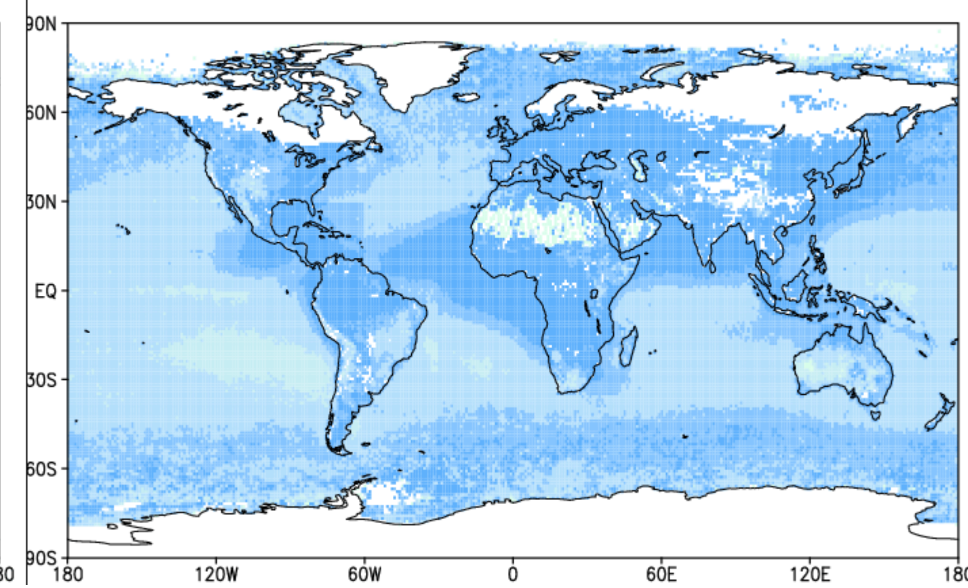


July 2000-
August 2001

TOA DARP= -4.9 Wm^{-2}



BOA DARP= -10.3 Wm^{-2}

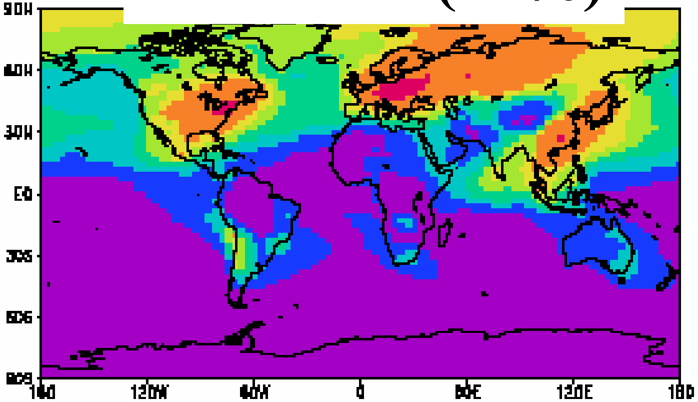


LMDZT-aerosol model (LOA version)

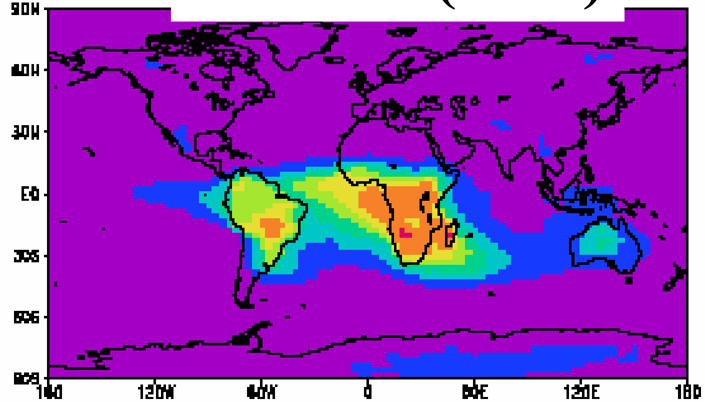
- Sulfate, BC, POM, dust, sea-salt
- same as in AEROCOM A runs
  (sulfate overestimated, BC/POM underestimated)
- External mixture
- Evaluation done with EMEP, IMPROVE, and other
  surface mass concentrations, and AERONET
  extinction and absorption AOD ==>
  small underestimation of extinction and absorption AOD

AOD by source type

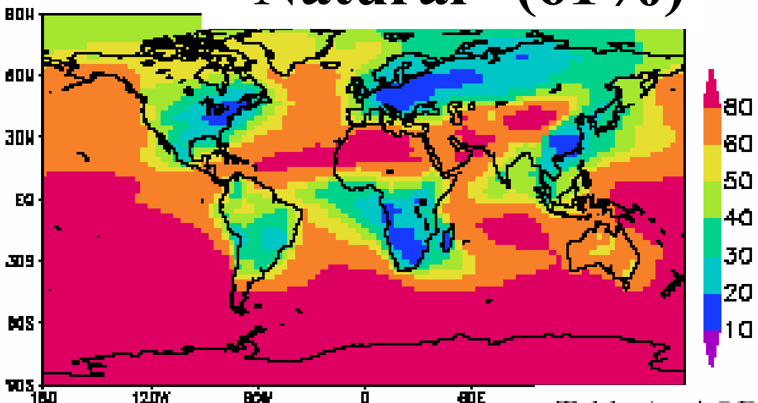
Fossil fuel (26%)



Biomass (13%)



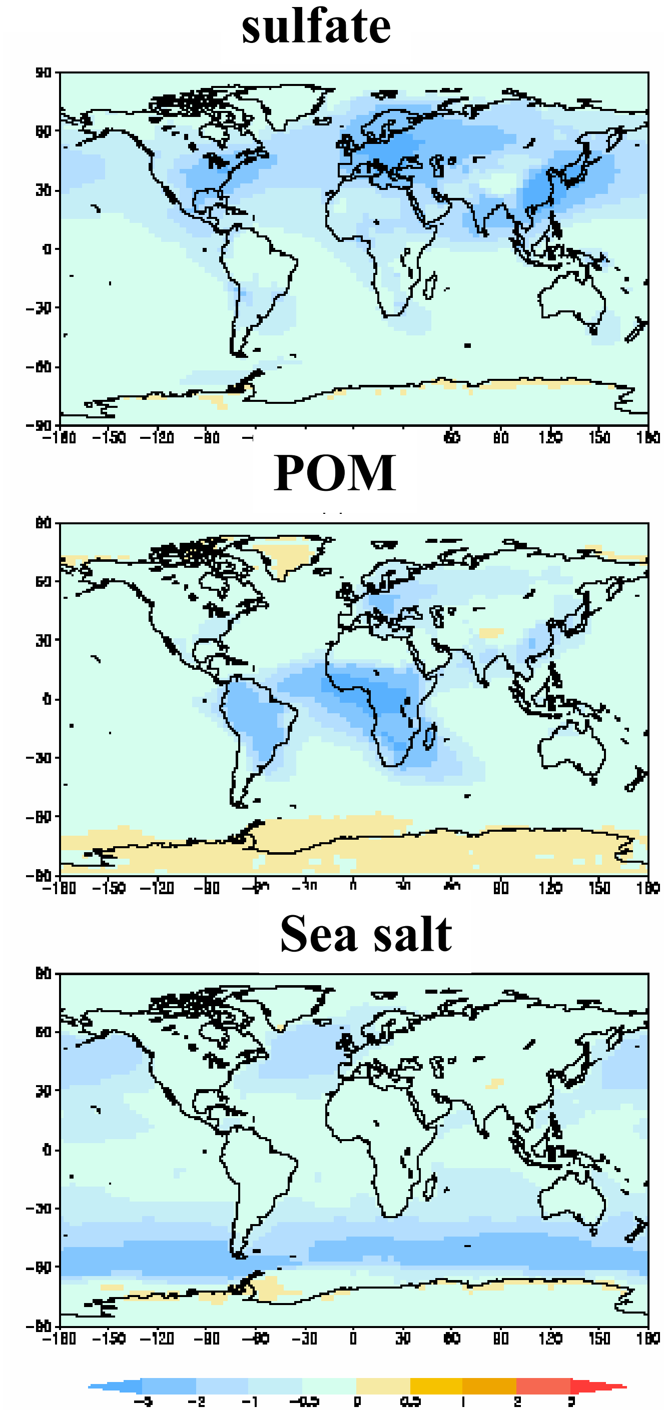
"Natural" (61%)

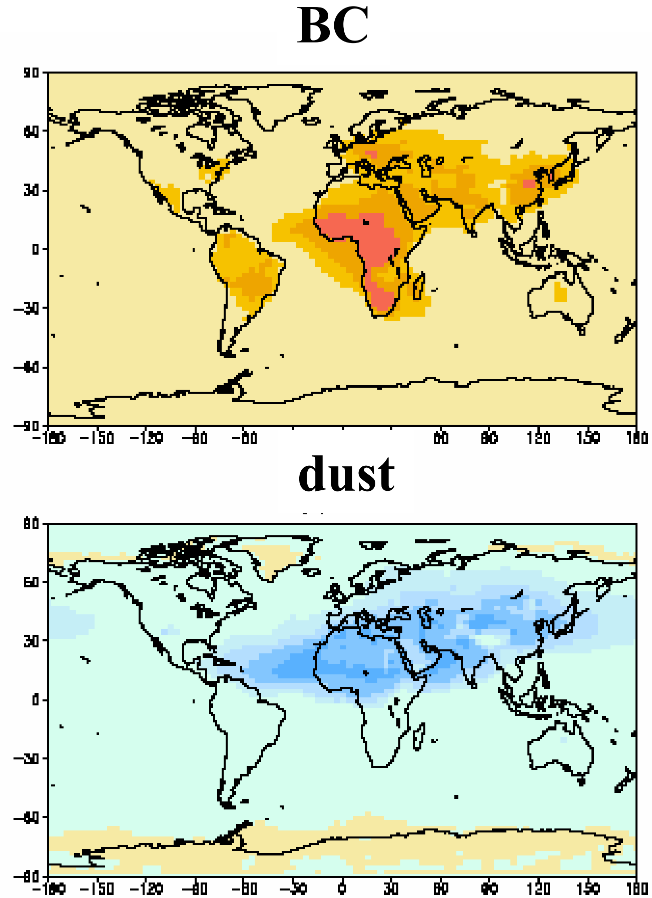


all dust and sea-salt

Table 1: AOD ×100 (at 550 nm) by Different Aerosol and Source Types for Year 2001

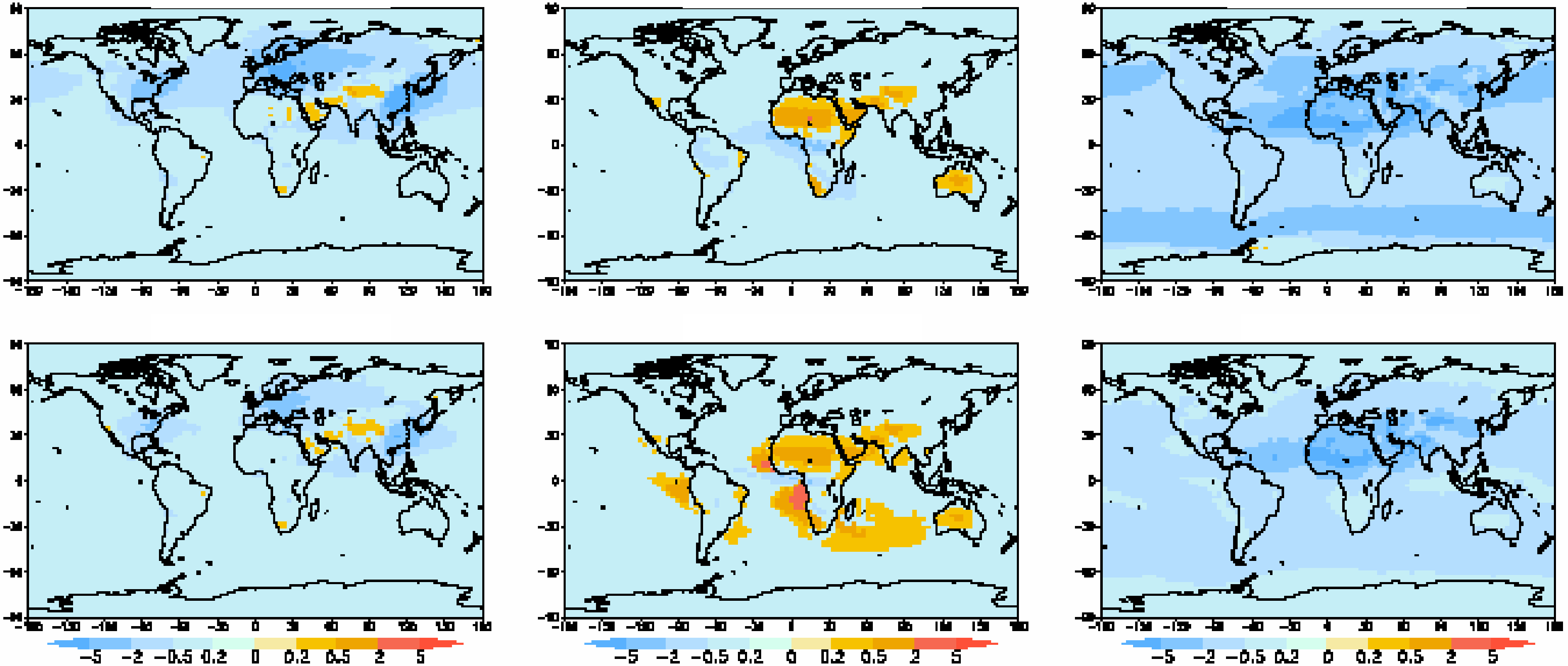
Source →	Fossil Fuels			Biomass			Natural			All sources		
Aerosols ↓	NH	SH	Global	NH	SH	Global	NH	SH	Global	NH	SH	Global
Sulfate	4.99	0.61	2.80	0.13	0.10	0.11	1.15	1.27	1.21	6.27	1.98	4.13
BC	0.20	0.02	0.11	0.18	0.18	0.18	–	–	–	0.38	0.20	0.29
OM	0.33	0.02	0.17	1.25	1.33	1.29	0.39	0.33	0.36	1.97	1.68	1.82
Dust	–	–	–	–	–	–	5.67	0.23	2.95	5.67	0.23	2.95
Sea Salt	–	–	–	–	–	–	1.85	3.58	2.71	1.85	3.58	2.71
(acc. mode)	–	–	–	–	–	–	0.89	1.57	1.23	0.89	1.57	1.23
(coarse mode)	–	–	–	–	–	–	0.96	2.01	1.48	0.96	2.01	1.48
All	*5.52*	*0.65*	*3.08*	*1.56*	*1.61*	*1.58*	*9.06*	*5.41*	*7.23*	*16.14*	*7.67*	*11.90*





TOA DARP by aerosol type

Fossil fuel **Biomass** **“Natural”**



TOA DARP by source type
clear-sky (top) - all-sky (bottom)

Table 2: Summary of Globally- and Annually- Averaged Aerosol Shortwave DRF (Wm^{-2}) by Different Aerosol and Source Types for Clear and All Sky Conditions for Year 2001

Sources →	Fossil Fuels			Biomass			Natural			All sources		
Aerosols ↓	NH	SH	Global	NH	SH	Global	NH	SH	Global	NH	SH	Global
Clear sky:												
Sulfate	–1.23	–0.12	–0.67	–0.02	–0.02	–0.02	–0.23	–0.25	–0.24	–1.48	–0.39	–0.93
BC	+0.25	+0.03	+0.14	+0.23	+0.21	+0.22	–	–	–	+0.48	+0.24	+0.36
OM	–0.13	–0.01	–0.07	–0.49	–0.54	–0.52	–0.07	–0.06	–0.07	–0.69	–0.61	–0.66
Dust	–	–	–	–	–	–	–1.23	–0.04	–0.63	–1.23	–0.04	–0.63
Sea salt (acc. mode)	–	–	–	–	–	–	–0.22	–0.44	–0.33	–0.22	–0.44	–0.33
Sea salt (coarse mode)	–	–	–	–	–	–	–0.16	–0.42	–0.29	–0.16	–0.42	–0.29
All	*–1.11*	*–0.10*	*–0.60*	*–0.28*	*–0.35*	*–0.32*	*–1.91*	*–1.21*	*–1.56*	*–3.30*	*–1.66*	*–2.48*
All sky:												
Sulfate	–0.76	–0.07	–0.42	–0.01	–0.01	–0.01	–0.14	–0.14	–0.14	–0.91	–0.22	–0.57
BC	+0.26	+0.03	+0.15	+0.26	+0.28	+0.27	–	–	–	+0.52	+0.31	+0.42
OM	–0.08	0.00	–0.04	–0.39	–0.38	–0.38	–0.04	–0.03	–0.04	–0.51	–0.41	–0.46
Dust	–	–	–	–	–	–	–0.90	–0.02	–0.46	–0.90	–0.02	–0.46
Sea salt (acc. mode)	–	–	–	–	–	–	–0.13	–0.22	–0.18	–0.13	–0.22	–0.18
Sea salt (coarse mode)	-	–	–	–	–	–	–0.08	–0.17	–0.12	–0.08	–0.17	–0.12
All	*–0.58*	*–0.04*	*–0.31*	*–0.14*	*–0.11*	*–0.12*	*–1.29*	*–0.58*	*–0.94*	*–2.01*	*–0.73*	*–1.37*

DARP=-2.5 Wm^{-2} ; AOD=0.119 ; RFE=-21 Wm^{-2}

RT, SSA, AOD, sampling ?

MODIS TOA DARP

DARP=-4.9 Wm^{-2} ; AOD=0.19 ; RFE=-26 Wm^{-2}

Reddy et al., JGR, for submission, 2004

Reddy et al., GRL, for submission, 2004

Compare various estimates of AOD, DARF, and Forcing Efficiency (TOA) over the ocean

i. Observational and modeling studies of aerosol over the global oceans

Study	notes	Region	AOD	---- local/instantaneous --- DARF W/m2	RFE W/m2/AOD	---------- clear-sky ---------- DARF W/m2	RFE W/m2/AOD
Haywood_99	1	global oceans	n/a			-6.7	n/a
Boucher_00	2	global oceans	n/a			-5.5	n/a
Takemura_02	3	global oceans	0.089			-1.9	-22
Chou_02	4	global oceans	0.104			-5.4	-52
Yu_04_GOCART	5	global oceans	0.106			-2.9	-27
Yu_04_GOCART+MODIS	5	global oceans	0.128			-4.6	-36
Christopher/Zhang_02	6	global oceans	0.15	-10.5	-70	-3.5	-23

ii. Observational and modeling studies of regional aerosols over the ocean

Study	notes	Region	AOD	---- local/instantaneous --- DARF W/m2	RFE W/m2/AOD	---------- clear-sky ---------- DARF W/m2	RFE W/m2/AOD
Christopher/Zhang_02	6	Australia	0.172	-13.37	-78	-4.46	-26
		East Asia	0.143	-12.43	-87	-4.14	-29
		North Africa	0.114	-12.56	-110	-4.19	-37
		North America	0.067	-8.02	-120	-2.67	-40
		South Africa	0.139	-12.66	-91	-4.22	-30
		Remote Ocean	0.039	-1.73	-44	-0.58	-15

iii. Studies of forcing efficiency using ground-based, in-situ measurements of aerosol optical properties and a simple formula

Study	notes	Region	Scat_550 Mm-1	b	β	ω	RFE W/m2/AOD
Anderson_99	7,8	CPO: Marine	11.91	0.102	0.239	0.986	-70
		CPO: NA-modifed marine	13.57	0.116	0.256	0.941	-70
		CPO: Continental	13.8	0.127	0.269	0.904	-69
		CPO: Asian-modified marine	43.75	0.104	0.242	0.955	-67
Delene/Ogren_02	7,9	BND	57.0	0.130	0.272	0.906	-70
		SGP	46.7	0.128	0.270	0.932	-72
		WSA	40.7	0.118	0.259	0.953	-72
		BRW	10.4	0.109	0.248	0.959	-70

iv. Studies of forcing efficiency using airborne in-situ measurements and full-blown radiative transfer modeling

Study	notes	Region	RFE W/m2/AOD
Conant_03	10	Asian_dust	-37
		Asian_pollution	-34

Tad Anderson, Univ. Washington, 2004

DEFINITIONS:

AOD: Aerosol optical depth at 550 nm averaged over the global oceans (or clear-sky portions thereof)

DARF: top-of-atmosphere, direct aerosol radiative forcing (shortwave energy perturbation by the total aerosol: natural plus anthropogenic)

local/instantaneous: forcing averaged over all times and locations where it was measured

clear-sky = average over all times (24-hour) but only over cloud-free regions of the ocean

all-sky = includes direct effect in cloudy regions; averaged over all times and places (clear and cloudy)

RFE: top-of-atmosphere radiative forcing efficiency or DARF divided by AOD.

Scat_550: Mean value of low-RH scattering at 550nm as measured by nephelometry.

b: ratio of hemispheric backscatter to total scatter at low-RH as measured by nephelometry.

β: ratio of upscatter to total scatter as calculated from b with polynomial fit based on the Henyey-Greenstein phase function

ω: single scattering albedo at low RH as measured by nephelometer and absorption photometer

Ground-based stations: CPO (Cheeka Peak, Washington coast), BND (Bondville, rural Illinois), SGP (Southern Great Plains, rural Oklahoma), WSA (Sable Island, Nova Scotia), BRW (Barrow, northern coast of Alaska)

NOTES:

1. Haywood et al. (1999) Science, 283, 1299-1303. ERBE measurement minus GCM calculation of reflected sunlight at TOA where GCM has zero aerosol. The difference is therefore the aerosol effect (but maybe some whitecap effect as well, as the paper admits).
2. Boucher and Tanre (2000) GRL, 27, 1103. Uses 8-months of data from POLDER-I. Assumptions carefully described; various sensitivity tests performed.
3. Takemura, Nakajima, Dubovik, Holben, Kinne (2002), J Clim. 15(4), 333-352. Global, 3-D model tied to various measurements. Paper reports forcing for shortwave plus longwave. Results here were obtained from the author (personal communication) and apply to shortwave only.
4. Chou et al. (2002), J. Atmos. Sci, 59, 748. Uses SeaWIFS satellite and radiative transfer modeling.
5. Yu et al. (2004), JGR, in press and also Yu et al. (2003), JGR, 108(D3), 4128, doi:10.1029/JD002717. Uses MODIS and GOCART model. Table 3 shows results for GOCART model only and for GOCART model after assimilation of MODIS data.
6. Christopher and Zhang (2002), Geophys. Res. Lett., 29 (18), 1859, doi:10.1029/2002GL014803. Solar flux from CERES divided by AOD from MODIS. Additional information from Christopher et al. (2004), draft manuscript on radiative forcing, available from author (sundar@nsstc.uah.edu) Cloud-cleared CERES pixels had mean AOD of 0.09, but this was only 5% of all CERES pixels; for all MODIS clear-sky ocean data mean AOD was 0.15. Paper reports 70 W/m2 per unit AOD as mean, instantaneous forcing efficiency; so here I just apply that number to the mean AOD of 0.15. For diurnal averaging - i.e. clear-sky DARF as opposed to instantaneous DARF - the paper says divide by 3.
7. Simple formula for RFE has been applied to aerosol optical properties measured at low RH. Forcing efficiency at ambient RH is somewhat lower due to aerosol hydration. To approximately correct for this effect, values reported here have been multiplied by a factor of 0.88, which is consistent with the hydration calculations of Anderson et al. (1999).
8. Anderson et al. (1999) J. Geophys. Res., 104, 26793. RFE recalculated here with assumed cloud-cover of zero to be consistent with the clear-sky definition of RFE.
9. Delene and Ogren (2002), J. Atmos. Sci, 59, 1135-1150. RFE recalculated from aerosol optical properties given in Table 3 and with assumed cloud-cover of zero (to be consistent with clear-sky definition of RFE) and assumed surface reflectivity appropriate to the ocean (0.07).
10. Conant et al. (2003), J. Geophys. Res., 108 (D23), 8661, doi:10.1029/2002JD003260.

Tad Anderson, Univ. Washington, 2004

Questions for discussion

* Should we add RF to the list of AEROCOM parameters?

* Can we produce our best estimate of aerosol RF?

* What about J. Hansen's paper on BC absorption?

* Can we give recommendations on how to group aerosol effects for the RF bar chart? i.e. FF, open BB, biofuels, dust?

* Estimation of uncertainties combing models and observations?
    - test Yoram's hypothesis of accumulation-mode being mostly anthropogenic
    - consider the fact that the constraints from satellite and ground-based observations decreases the uncertainty

We can propagate uncertainties

But some observational constraints: