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5 Aerosol optical depth derived from AVHRR satellite analysis following Higurashi et al. (2000) and Nakajima and Higurashi (1998) (labeled result: 1 and result: 2), Mishchenko et al. (1999) and Stowe et al. (1997) for January, April, July, and October. The results from Nakajima refer to 1990, while those from Mishchenko and Stowe refer to an average over the years 1985 to 1988. The results derived from the models which participated in the IPCC-sponsored workshop are also shown. The case labeled summed sensitivity study shows the derived optical depth for the ECHAM/GRANTOUR model using a factor of two increase in the DMS flux, the monthly average sea salt fluxes derived using the SSM/I wind fields, and the extinction coefficients for OC, BC, and SO_4^{2-} from the sensitivity case shown in Table 2.

6 Difference between the ECHAM/GRANTOUR computation of optical depth and the satellite-retrieved optical depths from Mishchenko et al. (1999). The left column shows the optical depths derived for the standard set of sources, while the right panel shows the derived optical depths for the sensitivity study using a factor of two increase in the DMS flux and the monthly average sea salt fluxes derived using the SSM/I wind fields and high optical extinction coefficients for SO_2^{2-} and carbon aerosols (see text). Note that the anthropogenic sulfate sources were for the year 2000 while the satellite analysis covers the time period 1985

to 1988. This may explain the systematic overestimate of optical depth off the coast of Asia in July.

- 7 Difference between GCM computations and ERBE satellite observations of the annual-mean solar irradiance reflected at the top of the atmosphere in clear skies over oceans for different models which participated in the IPCC model intercomparison. (a) GOCART, (b) GISS, (c) CCM1/GRANTOUR, (d) MPI/Dalhousie, (e) ULAQ, and (f) ECHAM/GRANTOUR models.
- 8 Difference between the mean of the model predicted clear sky shortwave flux and that from ERBE and from each of the AVHRR analyses.

Table 1: Aerosol models participating in optical depth intercomparison.

Cod e	Model	Contributor	Reference
1	ULAQ	Pitari	Pitari et al. (2000); Pitari and Mancini (2000)
2	GISS	Koch, Tegen	Koch et al. (1999); Tegen and Miller (1998)
3	GOCART (Georgia Tech./GSFC)	Chin, Ginoux	Chin et al. (2000); Ginoux et al. (2000)
4	CCM1/ GRANTOUR (LLNL/U. Mich.)	Chuang Penner Zhang	Chuang et al. (1997); Chuang et al. (2000)
5	Max Planck/ Dalhousie U. (ECHAM4.0)	Feichter Land Lohmann	Feichter et al. (1996); Lohmann et al. (1999)
6	ECHAM3.6/ GRANTOUR (U. Michigan)	Herzog, Penner Zhang	Penner et al. (2001b)

Table 2: Extinction coefficients at 0.55 μm and 80% relative humidity used in this analysis and in each models' in-line calculation of optical depth.

Model	Sulfate	Organic carbon	Black carbon	Dust r=(0.1- 1.0 μm)	Dust r=(1.0- 10 μm)	Sea salt r=(0.1- 1.0 μm)	Sea salt r=(1.0- 4.0 μm)	Sea salt r=(4-10 μm)
This analysis, base case	9.94 ¹	8.04	9.26	1.5	0.3	3.45 ^{1,2}	0.69 ^{1,2}	0.20 ^{1,2}
Values at 80% RH used for reflectivity	9.74	8.04	9.26	*	*			2.5
ECHAM/ GRANTOUR	12.2	7.4	9.6	1.13	0.45	2.83 ¹		1.27 ¹
ULAQ	7.35 ¹	3.67	8.90	1.23	0.49	1.45	0.48	0.12
GISS	8.56 ¹	8	9	*	*			2.0
GOCART	10	8	10	*	*			0.4

¹Indicates that these were included in the analysis with a humidity-dependence.

²The total mass- and size-weighted average extinction coefficient for sea salt from our analysis assuming the size distribution from Quinn et al. (1998) is $2.4 \text{ m}^2 \text{ g}^{-1}$.

*The analysis of optical depth in our study of reflectivity scaled the total mass of dust from each model to the vertical profile used in the study of Haywood et al. (1999). The following values for Ke for dust were used:

re (μm)	Ke ($\text{m}^2 \text{g}^{-1}$)
0.1	1.7
0.2	3.2
0.4	2.4

0.8	0.91
1.0	0.74
2.0	0.34
4.0	0.16
8.0	0.08

The GISS model used the following values for dust:

re (μm)	Ke (m^2g^{-1})
0.1	4.77
0.2	4.22
0.4	2.32
0.8	0.97
1.5	0.47
2.5	0.27
4.0	0.09

The GOCART model used the following values for dust:

re (μm)	Ke (m^2g^{-1})
0.14	3.29
0.24	3.52
0.45	2.06
0.8	0.97
1.4	0.47
2.4	0.26

4.5

0.14

Table 3. Difference between model-derived optical depth and that for each satellite-retrieved optical depth for January, April, July and October. The difference between the model 4-month average and the satellite retrieval is also shown. The results for Nakajima are those for “result 2” in Figures 4 and 5. The result labeled “model mean” used the average value from all the models.

January	Nakajima		Michchenko		Stowe	
	Absolute Error	Overall Bias	Absolute Error	Overall Bias	Absolute Error	Overall Bias
CCM1/GRANTOUR	0.05	-0.03	0.08	-0.08	0.03	0.00
ULAQ	0.06	-0.02	0.09	-0.07	0.05	0.01
MPI/Dalhousie	0.07	-0.05	0.10	-0.09	0.06	-0.01
GISS	0.06	-0.06	0.11	-0.11	0.04	-0.03
ECHAM/GRANTOU	0.05	-0.05	0.10	-0.10	0.03	-0.02
R						
GOCART	0.05	0.01	0.07	-0.03	0.06	0.04
Model Mean	0.04	-0.03	0.09	-0.08	0.04	0.00

April	Nakajima		Michchenko		Stowe	
	Absolute Error	Overall Bias	Absolute Error	Overall Bias	Absolute Error	Overall Bias
CCM1/GRANTOUR	0.06	-0.05	0.07	-0.07	0.05	-0.04
ULAQ	0.07	-0.03	0.08	-0.05	0.05	-0.03
MPI/Dalhousie	0.08	-0.06	0.09	-0.08	0.06	-0.05
GISS	0.08	-0.06	0.09	-0.08	0.05	-0.05
ECHAM/GRANTOU	0.07	-0.07	0.09	-0.09	0.06	-0.06
R						
GOCART	0.07	-0.01	0.07	-0.03	0.05	0.00
Model Mean	0.06	-0.05	0.07	-0.07	0.04	-0.04

July	Nakajima		Michchenko		Stowe	
	Absolute Error	Overall Bias	Absolute Error	Overall Bias	Absolute Error	Overall Bias
CCM1/GRANTOUR	0.05	-0.04	0.05	-0.03	0.03	-0.01
ULAQ	0.08	-0.01	0.08	0.00	0.06	0.02
MPI/Dalhousie	0.09	-0.07	0.08	-0.06	0.07	-0.04

GISS	0.08	-0.05	0.08	-0.04	0.06	-0.02
ECHAM/GRANTOU	0.07	-0.05	0.06	-0.04	0.04	-0.02
R						
GOCART	0.07	0.01	0.07	0.01	0.06	0.03
Model Mean	0.06	-0.03	0.06	-0.03	0.04	-0.01

Table 3 (continued).

October	Nakajima		Michchenko		Stowe	
	Absolute Error	Overall Bias	Absolute Error	Overall Bias	Absolute Error	Overall Bias
CCM1/GRANTOUR	0.04	-0.03	0.06	-0.05	0.03	0.01
ULAQ	0.06	-0.02	0.07	-0.04	0.05	0.02
MPI/Dalhousie	0.07	-0.06	0.09	-0.08	0.04	-0.02
GISS	0.07	-0.05	0.09	-0.08	0.04	-0.01
ECHAM/GRANTOU	0.06	-0.06	0.09	-0.09	0.03	-0.02
R						
GOCART	0.06	0.03	0.06	0.01	0.09	0.08
Model Mean	0.05	-0.03	0.06	-0.05	0.03	0.01

4-Month Average	Nakajima		Michchenko		Stowe	
	Absolute Error	Overall Bias	Absolute Error	Overall Bias	Absolute Error	Overall Bias
CCM1/GRANTOUR	0.05	-0.04	0.07	-0.06	0.04	-0.01
ULAQ	0.07	-0.02	0.08	-0.04	0.05	0.00
MPI/Dalhousie	0.08	-0.06	0.09	-0.08	0.06	-0.03
GISS	0.07	-0.05	0.09	-0.07	0.05	-0.03
ECHAM/GRANTOU	0.06	-0.06	0.09	-0.08	0.04	-0.03
R						
GOCART	0.06	0.01	0.07	-0.01	0.07	0.04
Model Mean	0.05	-0.04	0.07	-0.06	0.04	-0.01

Table 4. Overall bias between the four-month average model-derived optical depth and that for each satellite-retrieved optical depth (labeled O.D.) as a function of latitude. The calculated clear sky shortwave flux (in W/m⁻²) is also given (labeled flux). The results for Nakajima are those for “result 2” in Figures 4 and 5.

Table 4a. Comparison with satellite retrieval of Mishchenko et al. (1999).

Latitude	CCM1/ GRANTOUR		ULAQ		MPI/ Dalhousie		GISS		ECHAM/ GRANTOUR		GOCART		Mean of Models	
	O.D.	Flux	O.D.	Flux	O.D.	Flux	O.D.	Flux	O.D.	Flux	O.D.	Flux	O.D.	Flux
-55.00	-0.06	-4.37	0.00	-1.18	-0.08	-6.07	-0.10	-7.89	-0.13	-10.84	0.04	1.93	-0.06	-4.91
-45.00	-0.06	-3.43	-0.08	-5.16	-0.09	-6.52	-0.11	-7.08	-0.11	-5.76	0.01	0.44	-0.07	-4.70
-35.00	-0.04	-2.06	-0.05	-3.01	-0.07	-4.54	-0.07	-4.25	-0.07	-3.46	0.01	0.17	-0.05	-2.89
-25.00	-0.04	-2.66	-0.03	-1.93	-0.07	-4.16	-0.07	-4.00	-0.07	-3.57	-0.01	-1.27	-0.05	-2.92
-15.00	-0.07	-4.41	-0.05	-3.07	-0.10	-5.91	-0.10	-5.85	-0.09	-4.83	-0.05	-3.48	-0.07	-4.55
-5.00	-0.08	-5.86	-0.09	-5.58	-0.11	-6.96	-0.12	-8.92	-0.08	-5.26	-0.08	-5.98	-0.09	-6.29
5.00	-0.11	-8.09	-0.13	-7.20	-0.14	-9.54	-0.13	-7.31	-0.09	-6.36	-0.11	-7.37	-0.12	-7.48
15.00	-0.08	-4.55	-0.03	-1.74	-0.12	-6.83	-0.07	-3.39	-0.07	-2.87	-0.05	-2.33	-0.07	-3.47
25.00	-0.03	-1.63	0.05	2.59	-0.04	-2.36	-0.03	-1.93	-0.03	-1.75	0.02	1.32	-0.01	-0.63
35.00	-0.04	-2.18	0.03	1.63	0.00	-0.20	-0.01	-0.76	-0.06	-3.05	0.05	2.96	0.00	-0.26
45.00	-0.03	-1.35	0.04	2.25	0.02	1.18	0.02	1.37	-0.07	-3.84	0.11	6.64	0.01	0.91
55.00	-0.05	-2.75	0.02	1.28	0.00	-0.45	0.00	0.33	-0.09	-6.83	0.08	4.82	-0.01	-0.47
global														
average	-0.06	-3.76	-0.03	-2.00	-0.07	-4.64	-0.07	-4.32	-0.08	-4.64	0.00	-0.75	-0.05	-3.32

Table 4b. Comparison with satellite retrieval of Higurashi et al. (2000) and Nakajima and Higurashi (1998).

Latitude	CCM1/ GRANTOUR		ULAQ		MPI/ Dalhousie		GISS		ECHAM/ GRANTOUR		GOCART		Mean of Models	
	O.D.	Flux	O.D.	Flux	O.D.	Flux	O.D.	Flux	O.D.	Flux	O.D.	Flux	O.D.	Flux
-55.00	-0.01	-0.50	0.00	-0.13	0.04	3.81	-0.03	-3.17	-0.06	-6.75	0.10	10.70	0.01	0.54
-45.00	-0.01	-0.79	-0.03	-2.00	-0.05	-3.20	-0.07	-4.01	-0.06	-3.51	0.06	3.64	-0.03	-1.69
-35.00	-0.02	-1.35	-0.04	-2.02	-0.06	-3.63	-0.06	-3.27	-0.06	-2.81	0.02	1.29	-0.03	-1.96
-25.00	-0.04	-2.22	-0.03	-1.46	-0.07	-3.65	-0.07	-3.38	-0.06	-3.18	-0.01	-0.52	-0.04	-2.38
-15.00	-0.06	-3.40	-0.04	-2.30	-0.10	-4.97	-0.09	-4.51	-0.08	-4.00	-0.04	-2.12	-0.07	-3.50
-5.00	-0.05	-3.14	-0.07	-3.62	-0.09	-4.84	-0.09	-5.65	-0.06	-2.91	-0.05	-3.14	-0.07	-3.78
5.00	-0.06	-4.61	-0.08	-4.51	-0.10	-6.32	-0.08	-4.49	-0.04	-2.92	-0.06	-4.10	-0.07	-4.39
15.00	-0.06	-3.74	-0.01	-0.83	-0.11	-5.86	-0.05	-2.75	-0.05	-2.09	-0.03	-1.62	-0.05	-2.67
25.00	-0.03	-1.82	0.04	2.22	-0.04	-2.25	-0.04	-2.17	-0.04	-1.81	0.02	1.11	-0.01	-0.76
35.00	-0.02	-1.27	0.05	2.57	0.01	0.75	0.01	0.18	-0.04	-2.14	0.07	3.84	0.01	0.68
45.00	-0.03	-1.37	0.04	2.26	0.02	1.27	0.01	0.73	-0.06	-3.62	0.10	6.02	0.01	0.77
55.00	-0.02	-1.80	0.04	2.28	0.01	0.43	0.02	1.39	-0.06	-4.60	0.11	5.99	0.02	0.83
global														
average	-0.04	-2.34	-0.02	-0.86	-0.06	-2.84	-0.05	-2.82	-0.06	-3.20	0.01	1.04	-0.04	-1.80

Table 4c. Comparison with satellite retrieval of Stowe et al. (1997).

Latitude	CCM1/ GRANTOUR		ULAQ		MPI/ Dalhousie		GISS		ECHAM/ GRANTOUR		GOCART		Mean of Models	
	O.D.	Flux	O.D.	Flux	O.D.	Flux	O.D.	Flux	O.D.	Flux	O.D.	Flux	O.D.	Flux
-55.00	0.05	2.73	0.08	5.71	0.06	4.55	0.01	1.02	-0.02	-2.06	0.18	13.42	0.06	4.35
-45.00	0.02	1.17	0.00	0.09	-0.01	-0.64	-0.03	-1.99	-0.03	-1.65	0.09	5.90	0.01	0.45
-35.00	0.01	0.33	0.00	-0.43	-0.02	-1.81	-0.03	-1.87	-0.03	-1.39	0.06	2.66	-0.01	-0.42
-25.00	0.00	-0.19	0.01	0.53	-0.03	-1.86	-0.03	-1.61	-0.02	-1.40	0.04	1.10	-0.01	-0.58
-15.00	-0.02	-1.44	0.00	-0.41	-0.05	-3.22	-0.05	-3.00	-0.04	-2.29	0.01	-0.70	-0.03	-1.83
-5.00	-0.03	-2.18	-0.04	-2.60	-0.06	-3.94	-0.07	-5.06	-0.04	-2.19	-0.03	-2.43	-0.05	-2.99
5.00	-0.03	-4.24	-0.05	-4.04	-0.07	-6.11	-0.06	-3.94	-0.02	-3.18	-0.03	-3.59	-0.06	-4.09
15.00	-0.04	-2.40	-0.02	-0.09	-0.09	-4.75	-0.04	-1.63	-0.03	-1.40	-0.02	-0.39	-0.04	-1.67
25.00	-0.02	0.08	0.05	3.42	-0.04	-0.91	-0.02	-0.64	-0.02	-0.62	0.02	2.71	0.01	0.62

35.00	-0.01	-0.20	0.05	2.06	0.02	2.03	0.01	0.69	-0.02	-1.48	0.07	4.28	0.02	1.17
45.00	-0.02	-0.76	0.03	2.10	0.04	3.27	0.04	3.03	-0.04	-3.20	0.09	5.37	0.02	1.52
55.00	-0.02	-0.22	0.06	3.57	0.04	2.87	0.04	3.02	-0.06	-4.39	0.11	7.02	0.03	2.13
global														
average	-0.01	-0.84	0.01	0.47	0.00	-1.40	-0.02	-1.35	-0.04	-2.04	0.06	2.19	-0.01	-0.47

Table 5. Difference between model-predicted clear sky shortwave radiative flux and ERBE satellite measured clear sky fluxes. Last column is the difference between the model mean flux and that inferred from the average of the three AVHRR analyses.

Latitude	CCM1/	ULAQ	MPI/	GISS	ECHAM/		Mean of Models	
	GRANTOUR				GRANTOUR	GOCART	ERBE	AVHRR
-55.00	7.84	8.84	2.39	6.52	2.59	8.56	6.12	-1.58
-45.00	5.47	3.90	1.53	4.11	1.50	7.83	4.06	-2.13
-35.00	0.72	0.06	-2.17	-0.44	-1.90	3.22	-0.08	-1.69
-25.00	-2.22	-1.43	-4.68	-3.22	-3.88	-0.66	-2.68	-1.77
-15.00	-2.93	-2.38	-5.99	-4.57	-4.82	-2.30	-3.83	-2.67
-5.00	0.78	-1.31	-3.05	-1.42	-0.91	0.64	-0.88	-3.34
5.00	1.39	-0.97	-2.27	0.86	0.29	1.60	0.15	-3.88
15.00	0.23	1.59	-3.87	1.13	-1.82	1.60	-0.19	-2.02
25.00	1.92	6.82	-0.18	4.40	0.81	6.10	3.31	-0.47
35.00	5.43	9.22	3.46	9.43	1.78	9.61	6.49	0.14
45.00	3.54	9.04	4.38	9.92	1.75	12.05	6.78	0.71
55.00	3.99	6.30	3.10	8.79	1.66	12.31	6.02	0.07
global								
average	1.76	2.74	-1.09	2.34	-0.52	4.33	1.59	-1.70