Modeling the effects of Black Carbon on Climate

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with contributions from

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Outline

- Modeling the distribution of the black carbon aerosols in GCMs.
- Modeling the optical characteristics of the aerosols.
- Model versus observations.
- Time evolution of BC's role in forcing.

Simulated BC concentrations

* *SKYHI* model

(Cooke, Ramaswamy, Kasibhatla, JGR 2002)

* GFDL *MOZART* model

Figures

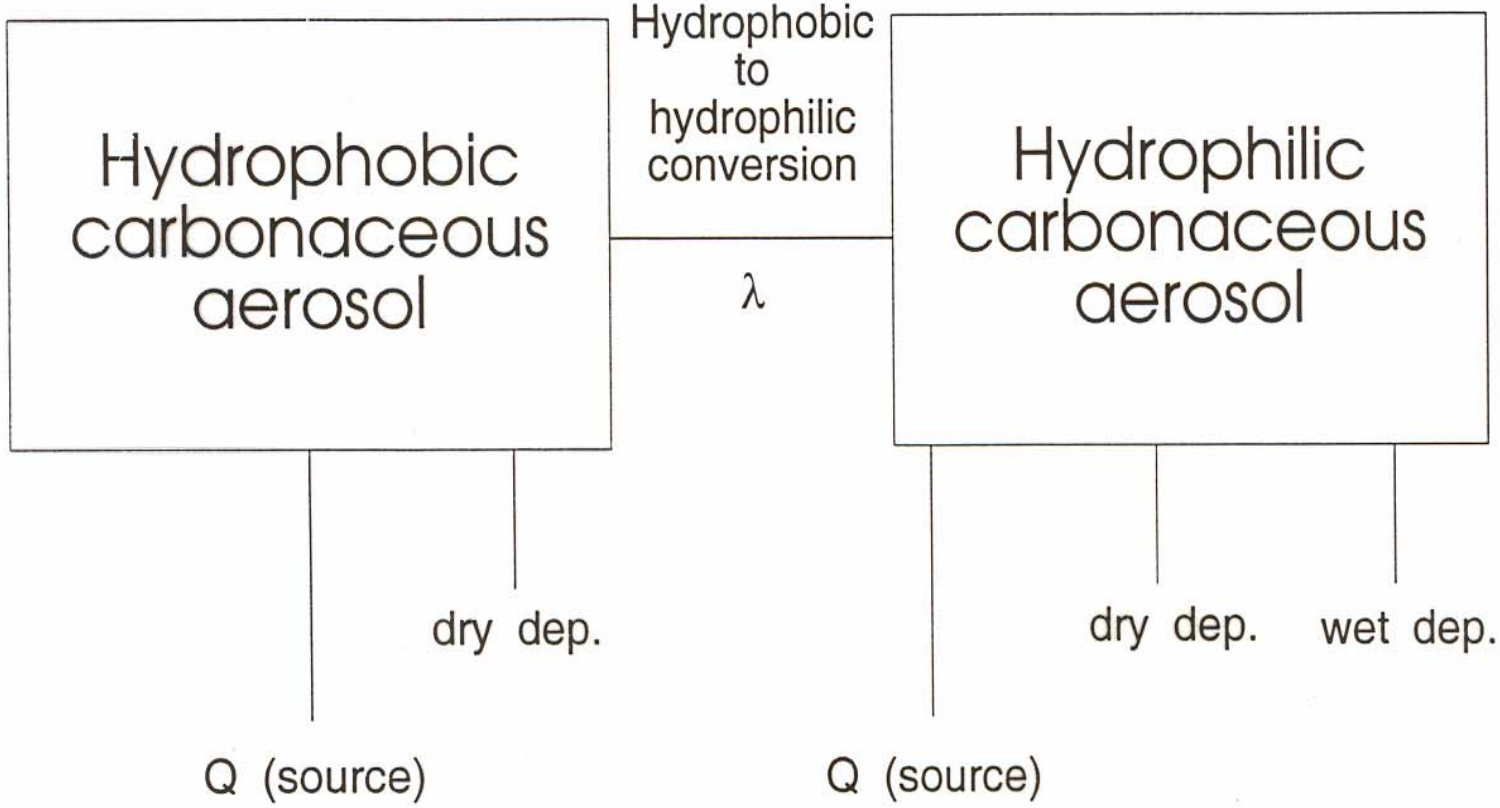


Figure 1. Emission and transformation scheme for carbonaceous aerosol as implemented in the GCM.

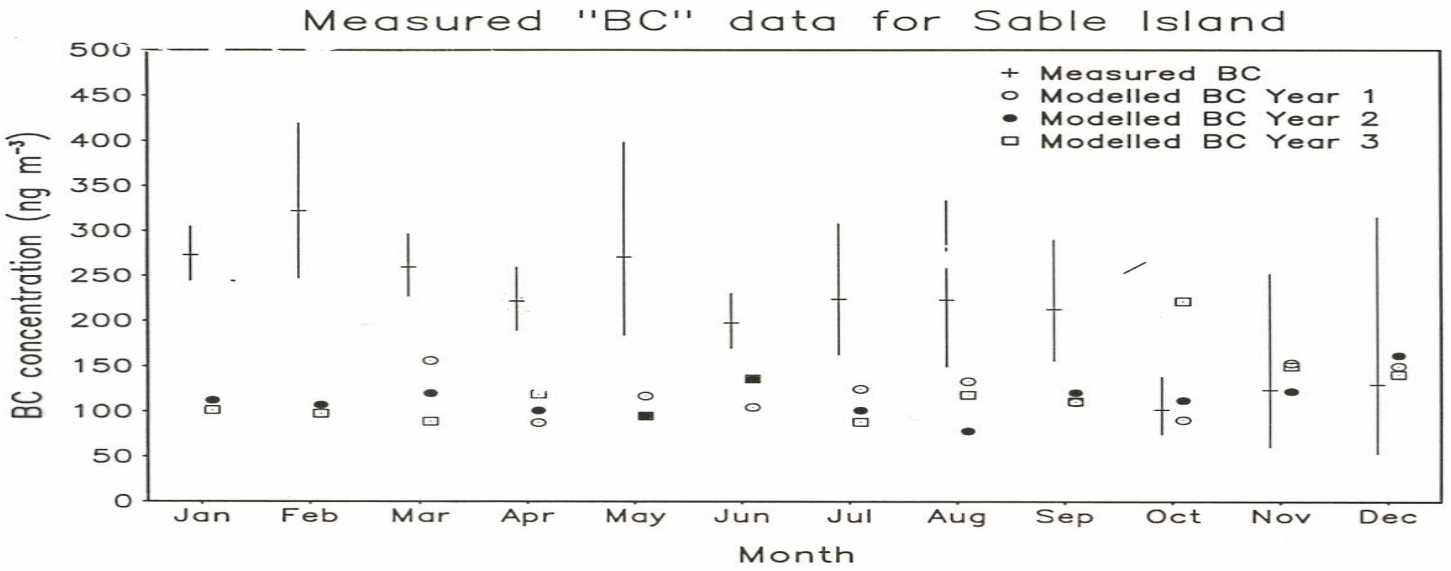


Figure 2. Comparison of modeled (3 years of data) and measured black carbon at Sable Island (60°W, 43.9°N). The mean and geometric deviation of the observations is shown, while , for the model, the values for each of the 3 years of simulation are plotted.

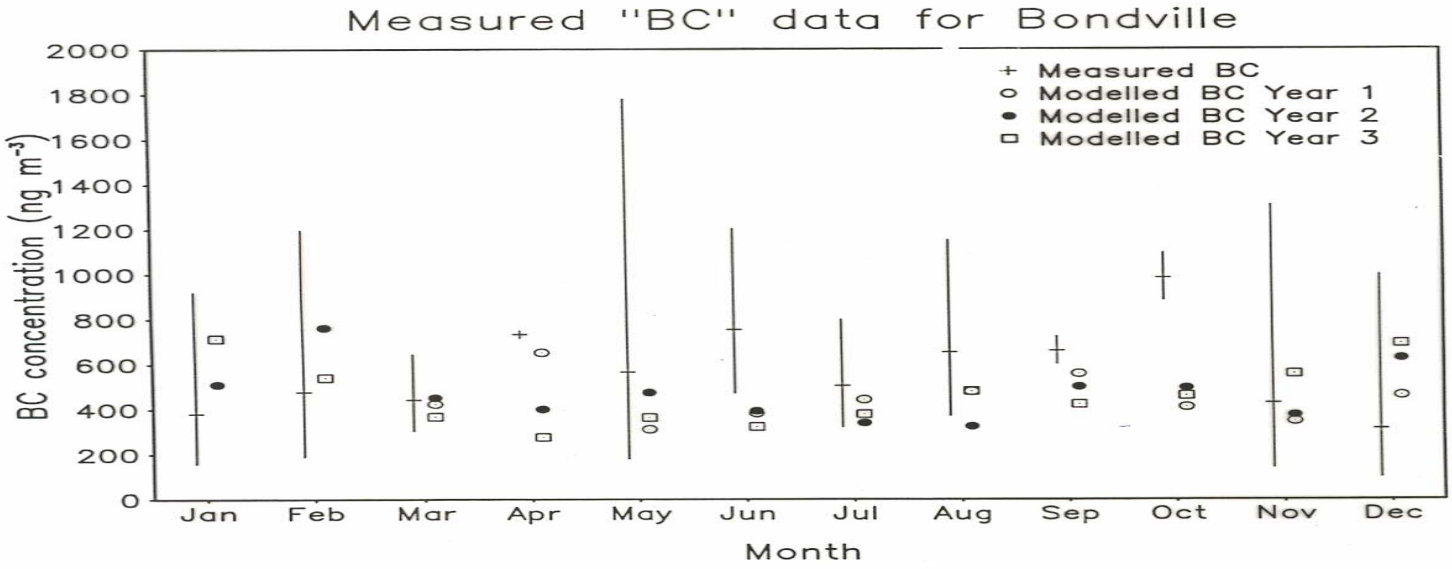
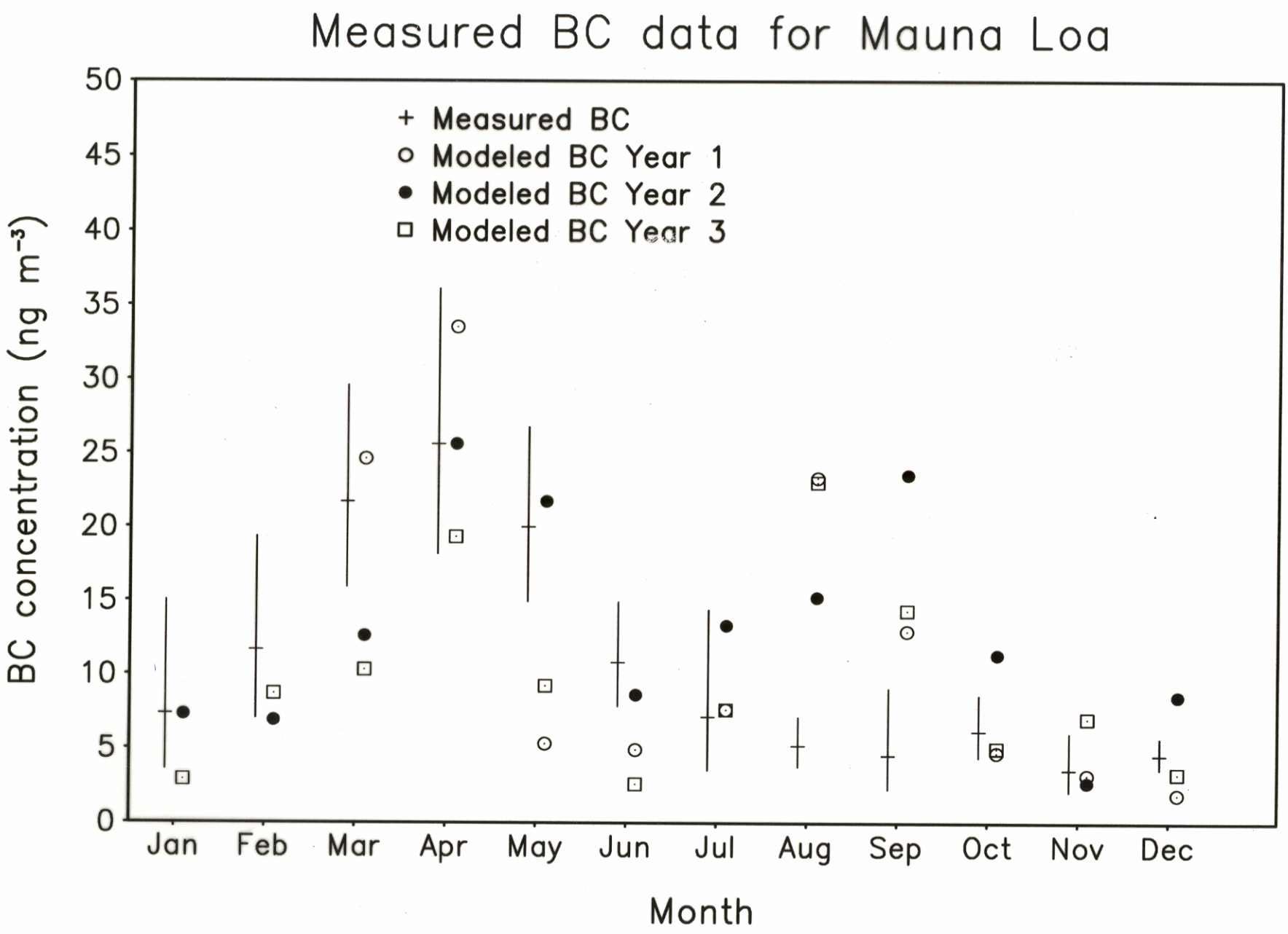
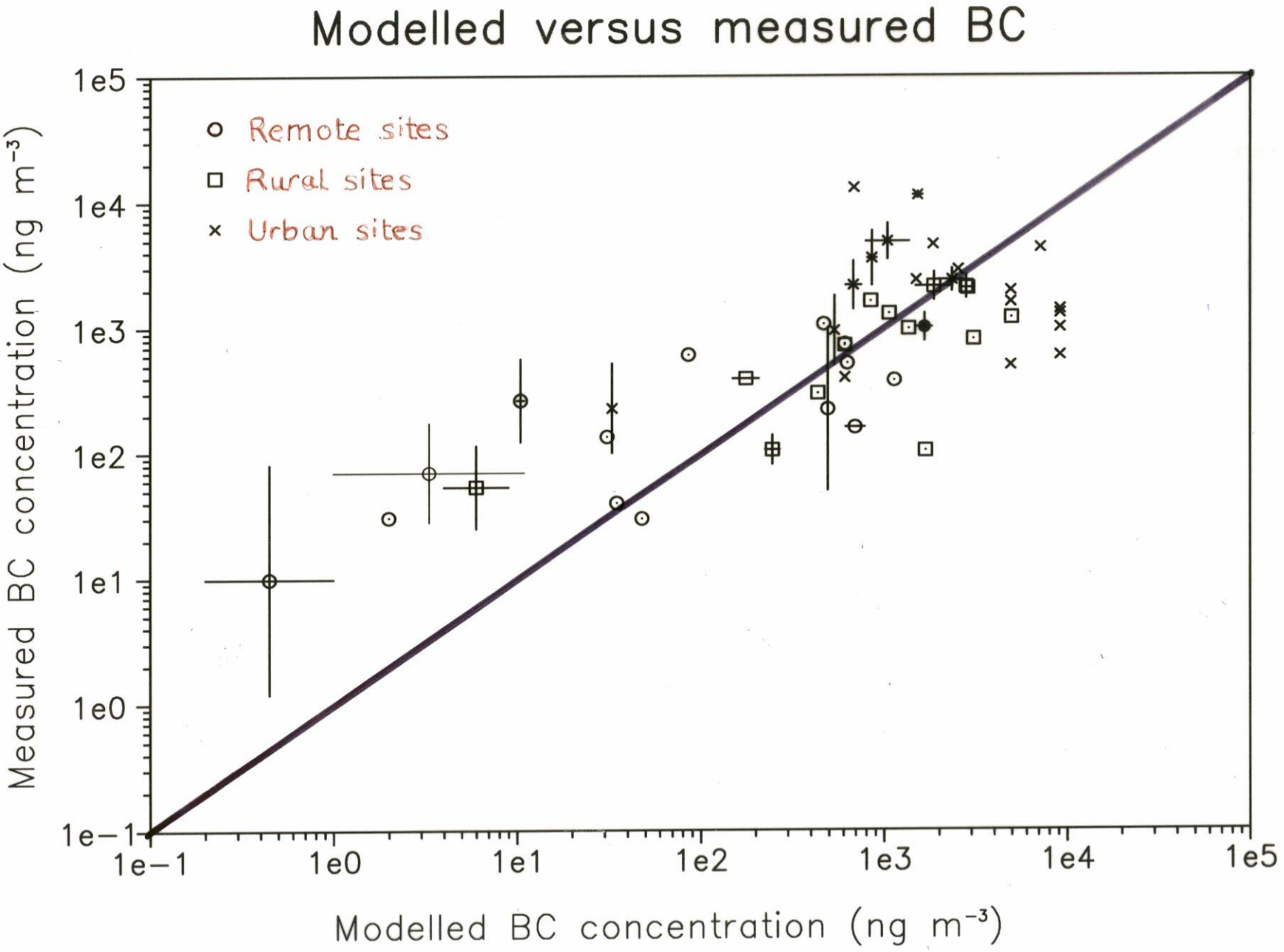


Figure 3. Same as Figure 2 except at Bondville (88.4°W, 40.1°N).


Measured BC data for Mauna Loa
+ Measured BC
o Modeled BC Year 1
• Modeled BC Year 2
□ Modeled BC Year 3
BC concentration (ng m⁻³)
0
5
10
15
20
25
30
35
40
45
50
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month


Modelled versus measured BC
Remote sites
Rural sites
Urban sites
Measured BC concentration (ng m⁻³)
Modelled BC concentration (ng m⁻³)
1e5
1e4
1e3
1e2
1e1
1e0
1e−1
1e−1
1e0
1e1
1e2
1e3
1e4
1e5

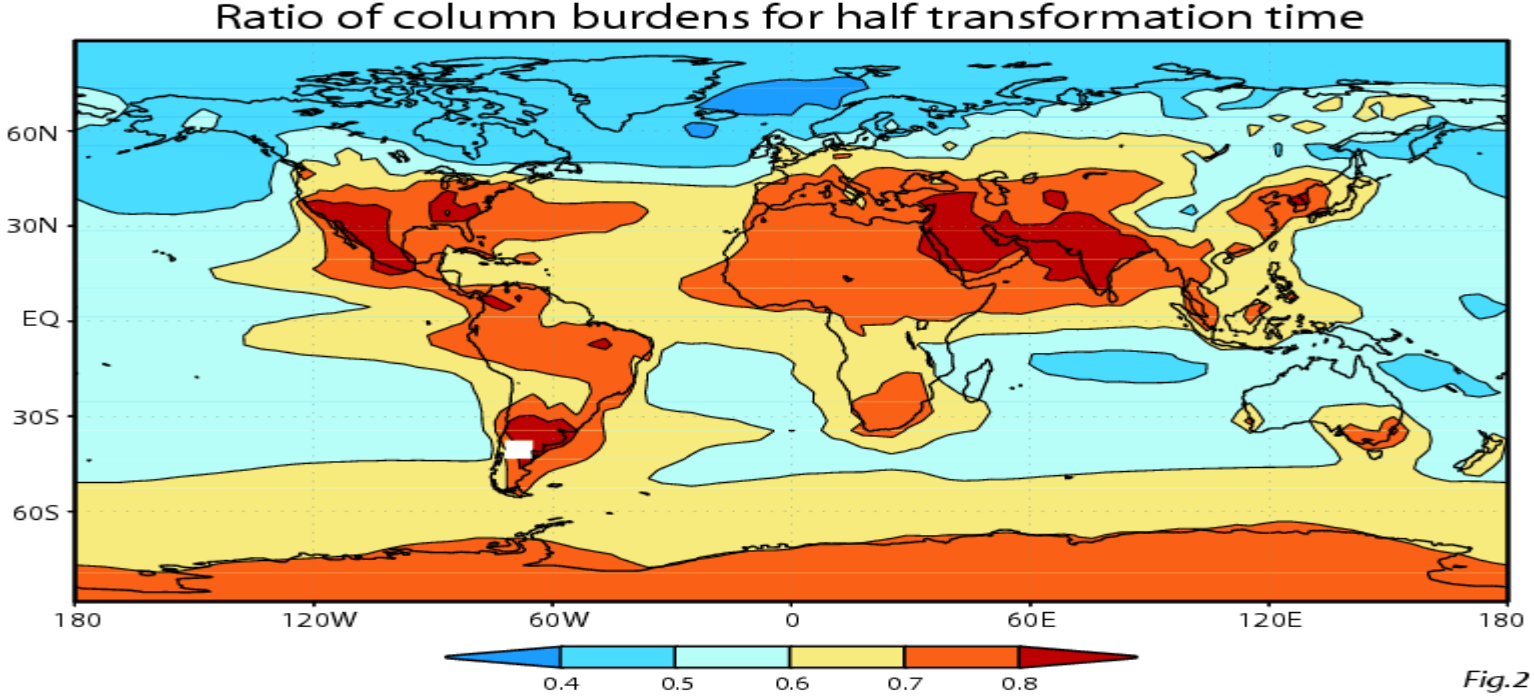

Ratio of column burdens for half transformation time
60N
30N
EQ
30S
60S
180
120W
60W
0
60E
120E
180
0.4
0.5
0.6
0.7
0.8

Fig.2

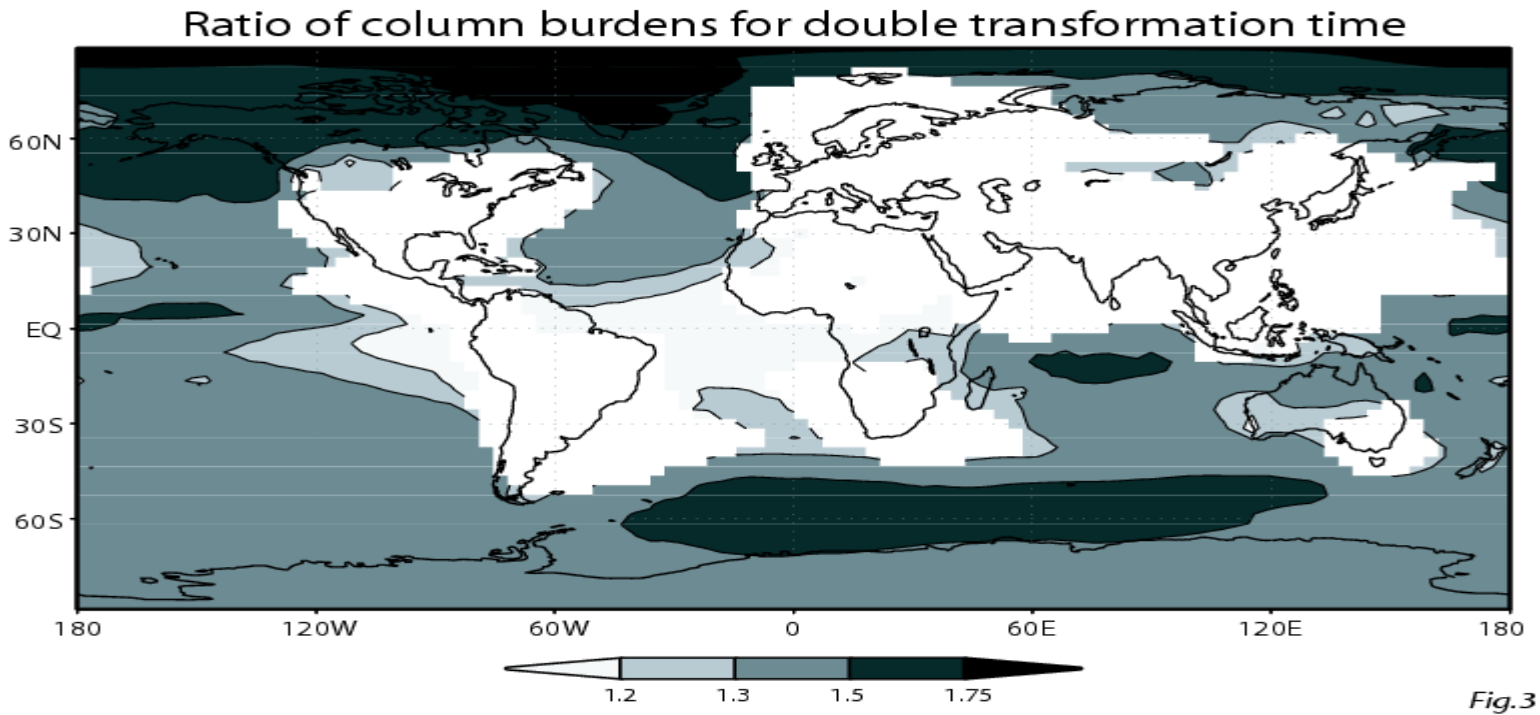

Ratio of column burdens for double transformation time
60N
30N
EQ
30S
60S
180
120W
60W
0
60E
120E
180
1.2
1.3
1.5
1.75

Fig.3

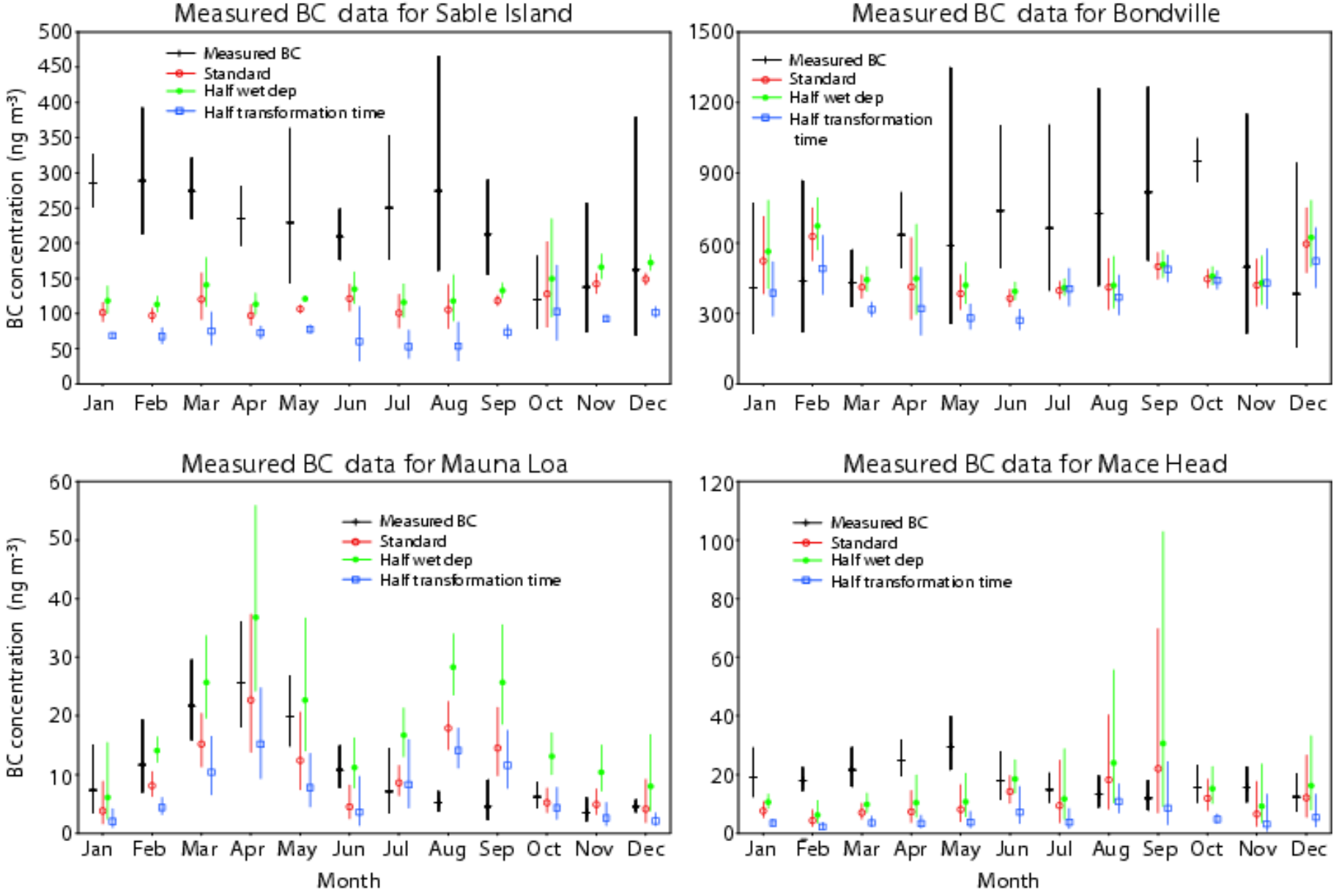

Measured BC data for Sable Island
Measured BC data for Bondville
Measured BC data for Mauna Loa
Measured BC data for Mace Head
Measured BC
Standard
Half wet dep
Half transformation time
BC concentration (ng m-3)
Month
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

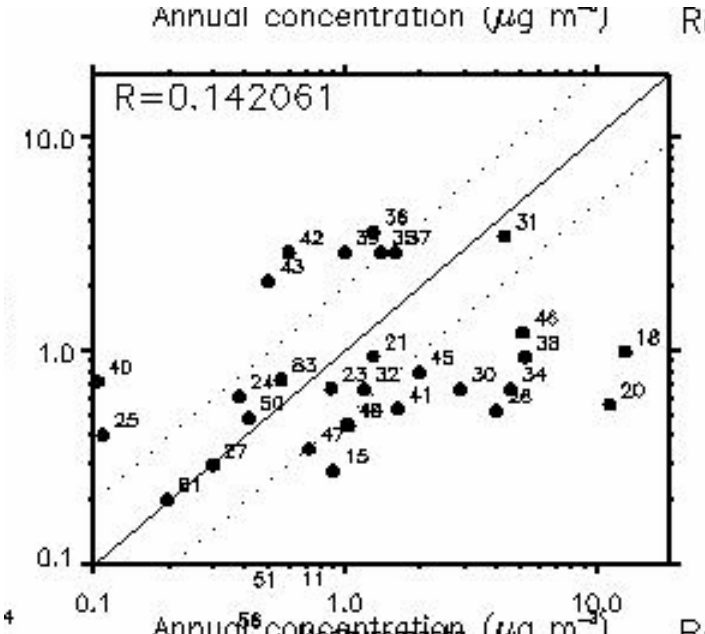
Fig.4

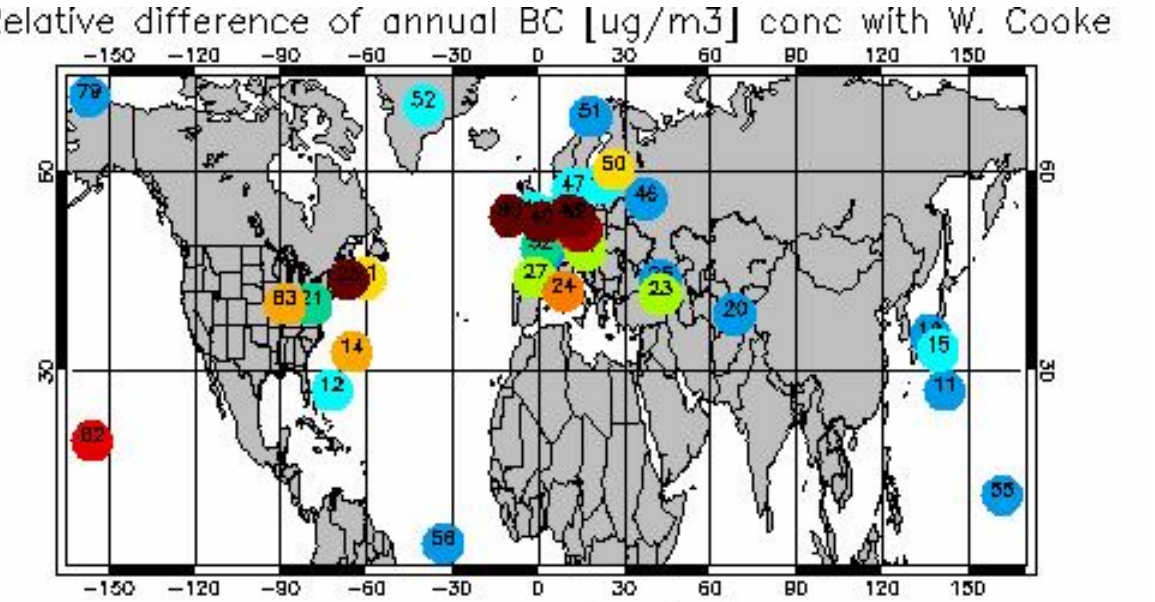
Sensitivity of global-mean forcing of black carbon aerosol from fossil-fuel combustion to aerosol microphysics.

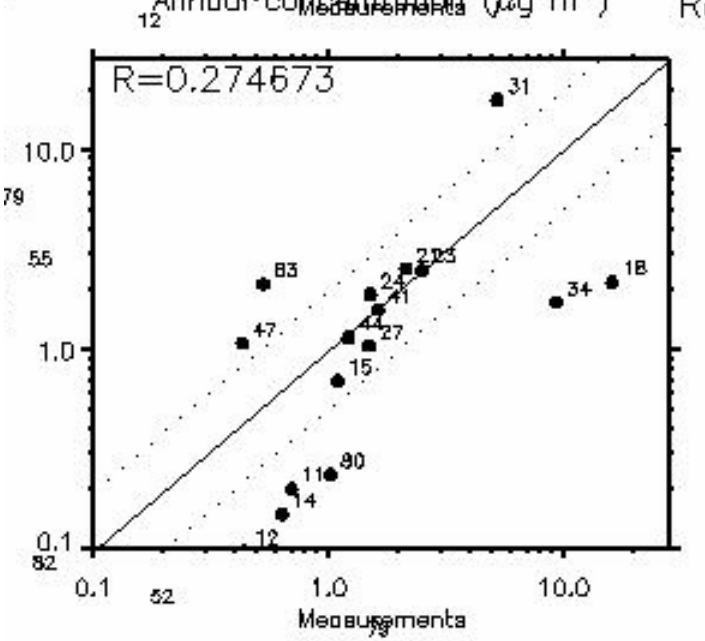
Parameter	FACTOR DIFFERENCE
STANDARD	1
Transformation time halved	0.8
Transformation time doubled	1.1
100% hydrophobic emission	1.2
100% soluble aerosol	0.6
Wet deposition rate halved	1.3

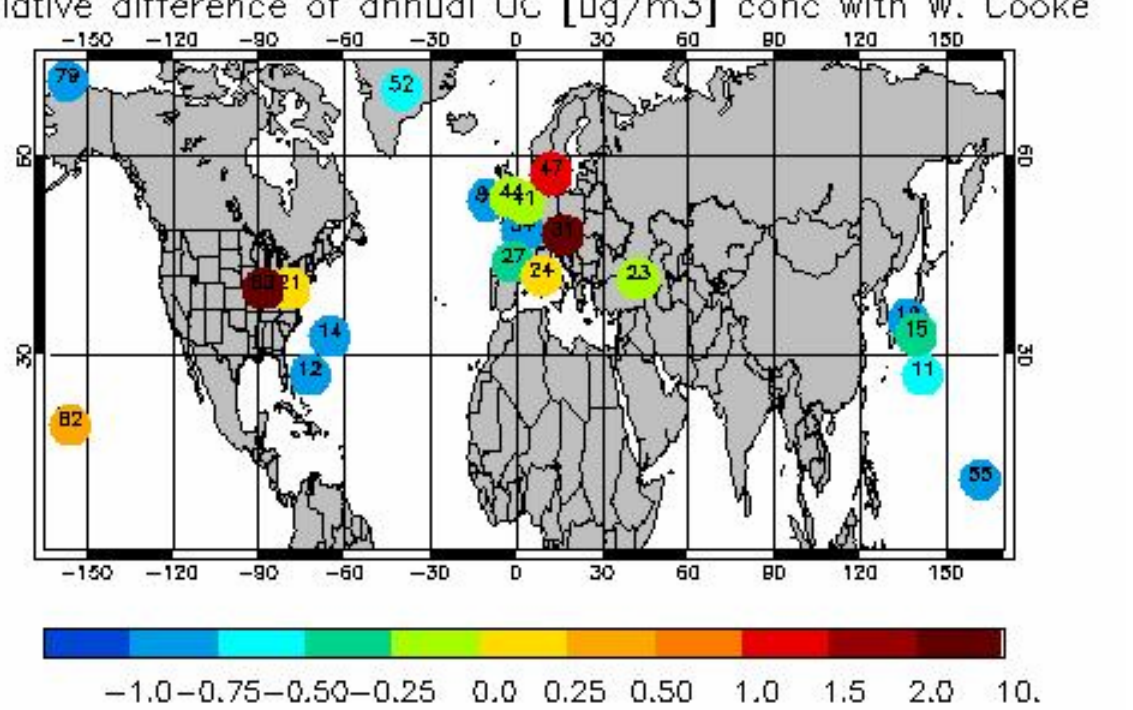
OVERALL SENSITIVITY

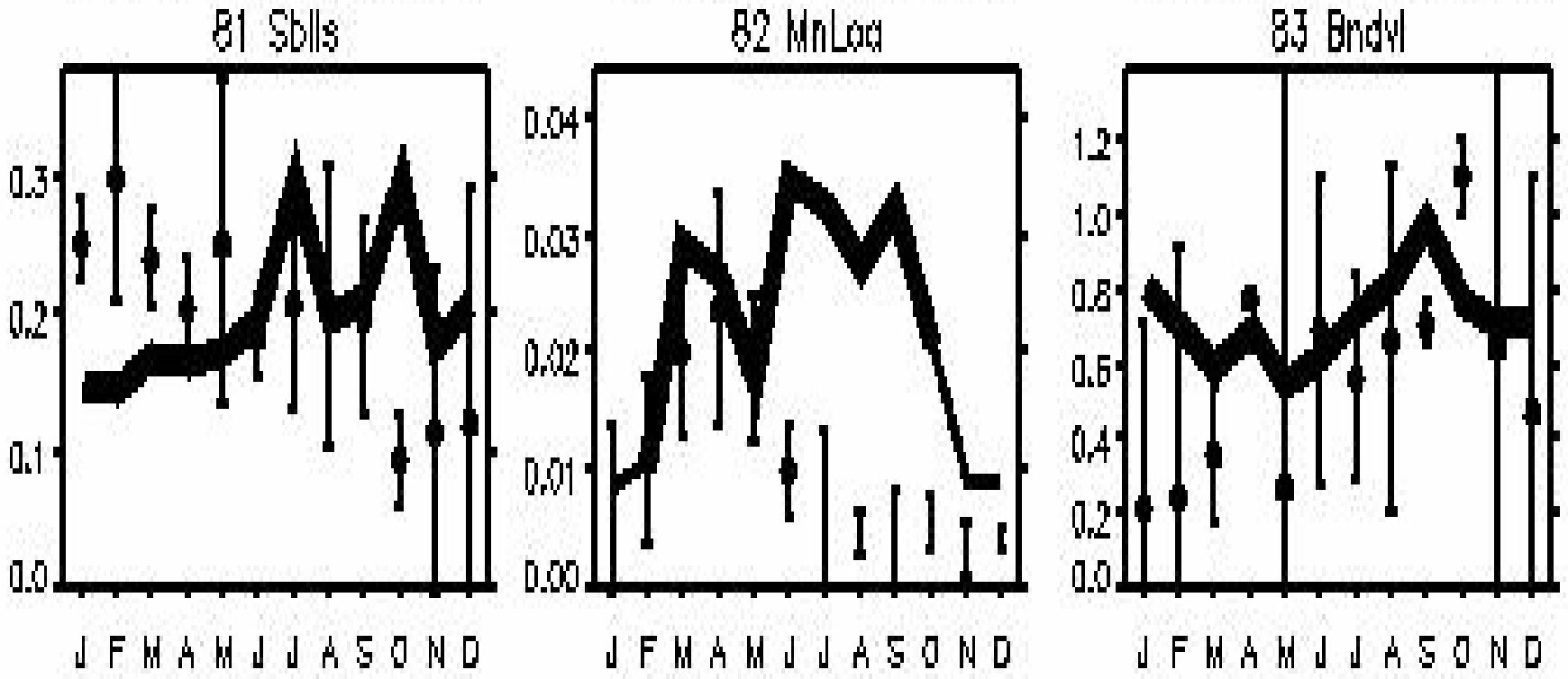
~2x


Annual concentration (μg m⁻³)
R=0.142061
10.0
1.0
0.1
0.1
1.0
10.0
Measurements


Relative difference of annual BC [ug/m3] conc with W. Cooke
−150 −120 −90 −60 −30 0 30 60 90 120 150
60
30


Annual concentration (μg m⁻³)
R=0.274673
10.0
1.0
0.1
0.1
1.0
10.0
Measurements


Relative difference of annual OC [ug/m3] conc with W. Cooke
−150 −120 −90 −60 −30 0 30 60 90 120 150
60
30
−1.0 −0.75 −0.50 −0.25 0.0 0.25 0.50 1.0 1.5 2.0 10.


B1 Sblls
B2 MnLoa
B3 Bndvl
0.3
0.2
0.1
0.0
0.04
0.03
0.02
0.01
0.00
1.2
1.0
0.8
0.6
0.4
0.2
0.0
J F M A M J J A S O N D
J F M A M J J A S O N D
J F M A M J J A S O N D

Optics concerning BC

- *Soot mixtures with other aerosols*
- *Soot mixtures in clouds*
- *Soot-snow mixture*

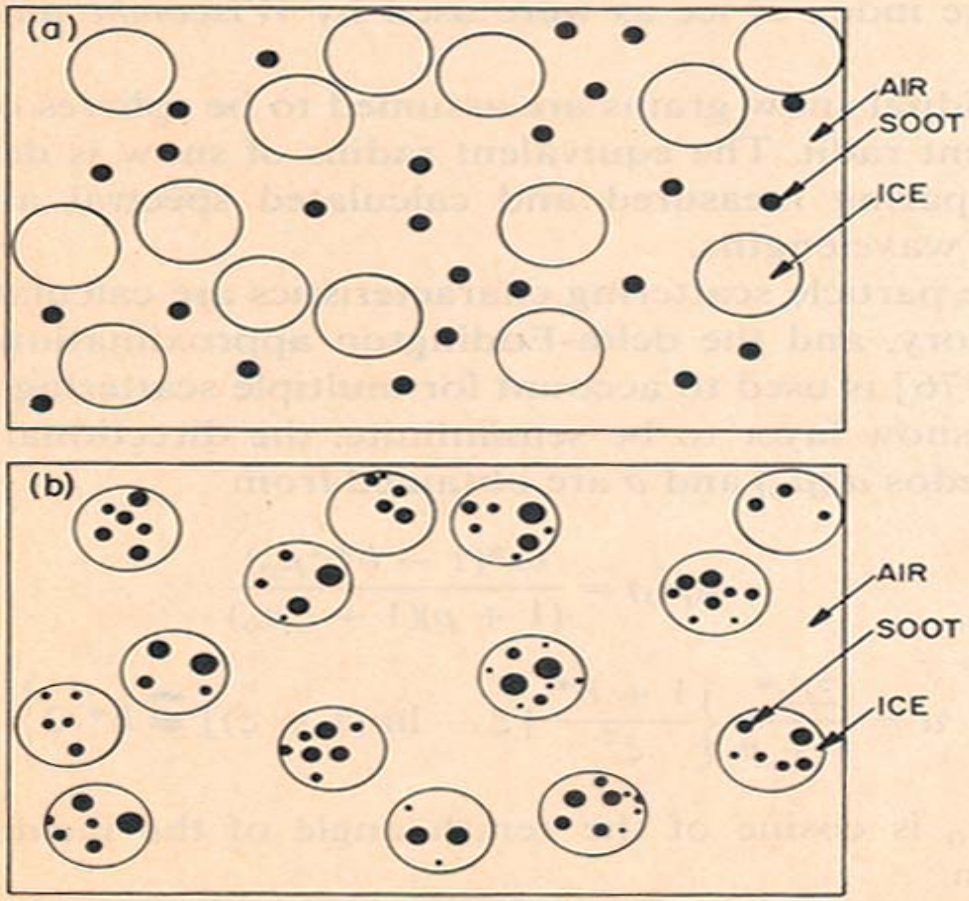


Fig. 1. In an external mixture model (*a*) graphitic carbon particles are supposed to stay outside of the snow grains. Model calculations always require concentrations of graphitic carbon that are too high compared with measured values. An internal mixture model with graphitic carbon particles distributed randomly throughout the volume of snow grains (*b*) leads to carbon content compatible with measured values.

Chylek et al. (1983)

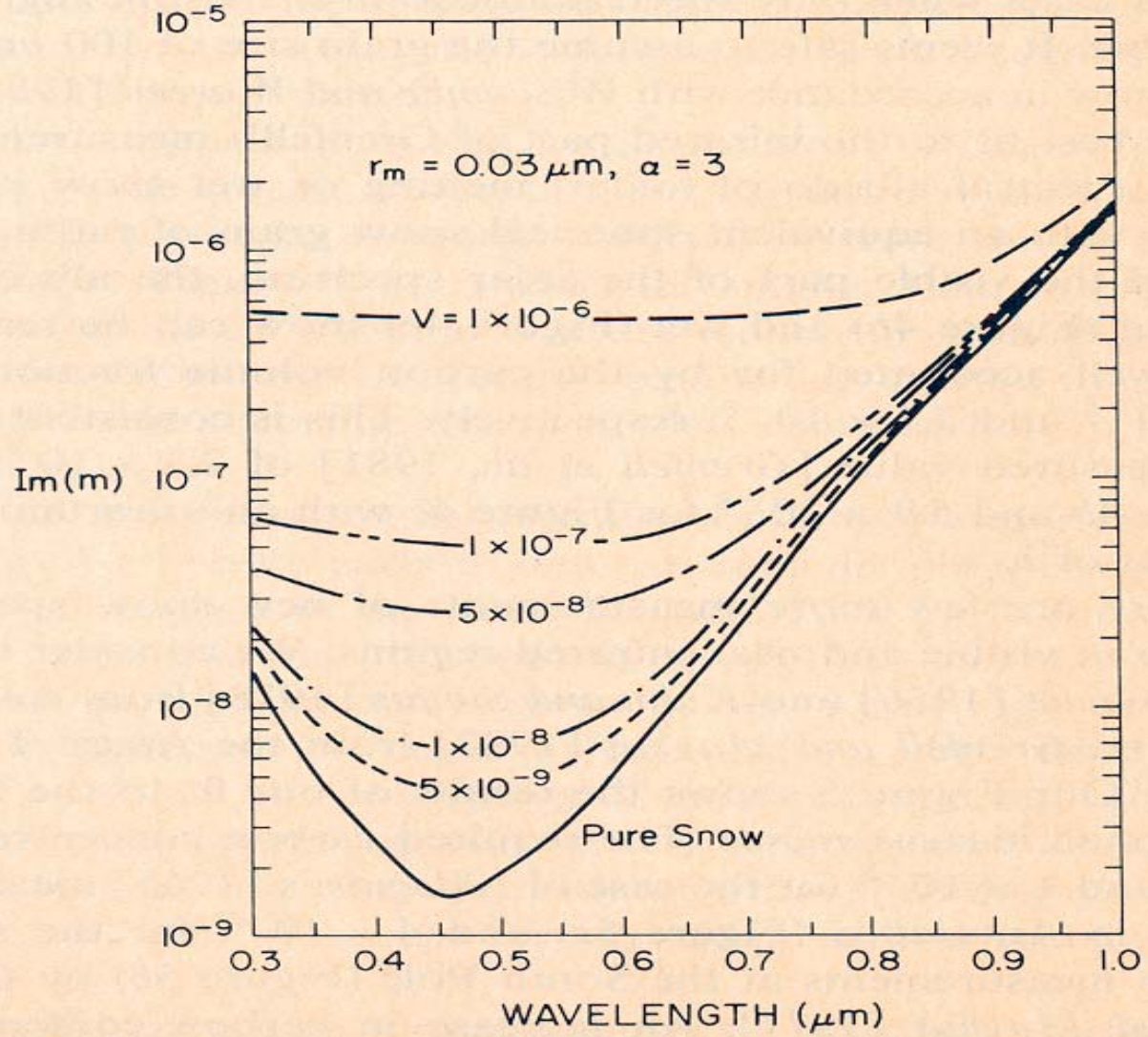
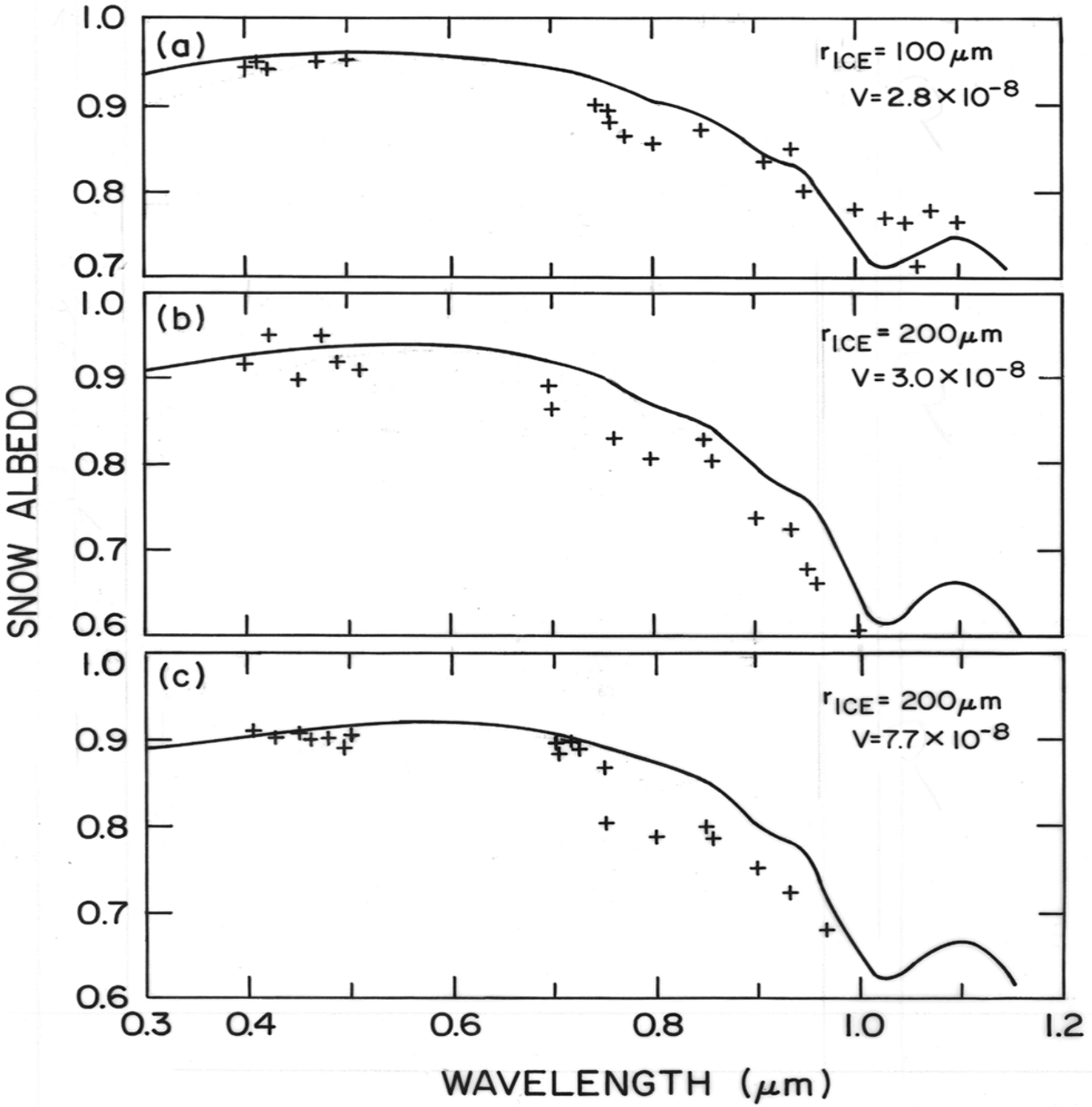
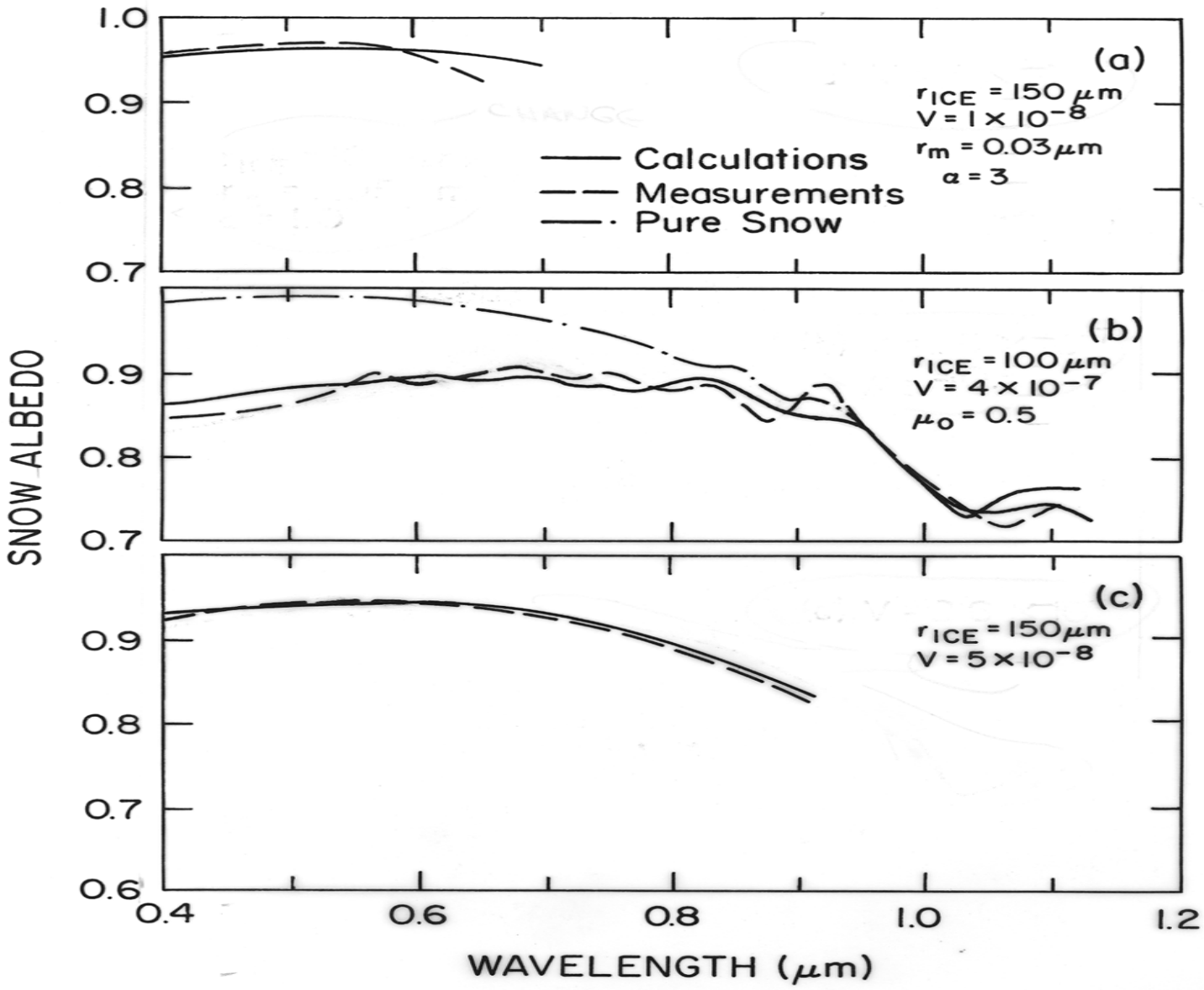
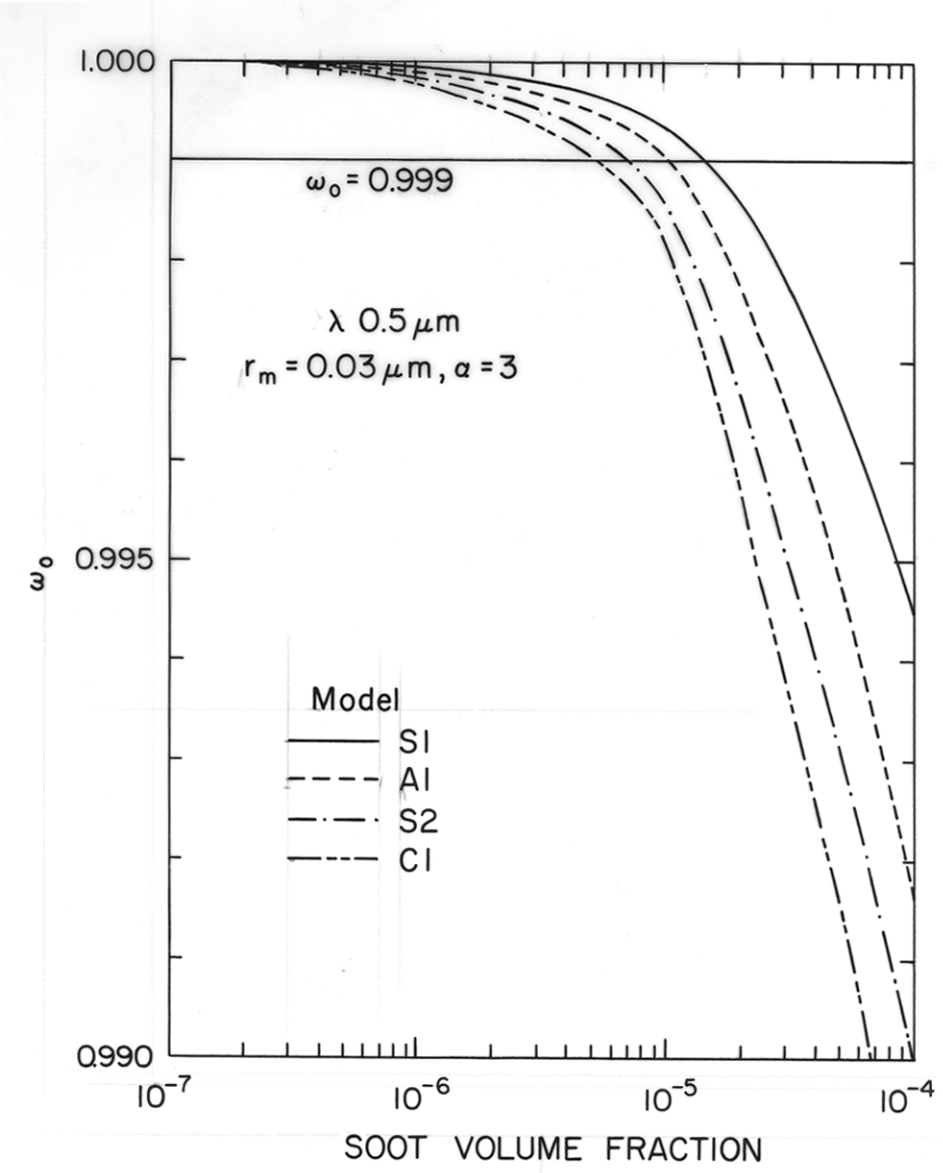
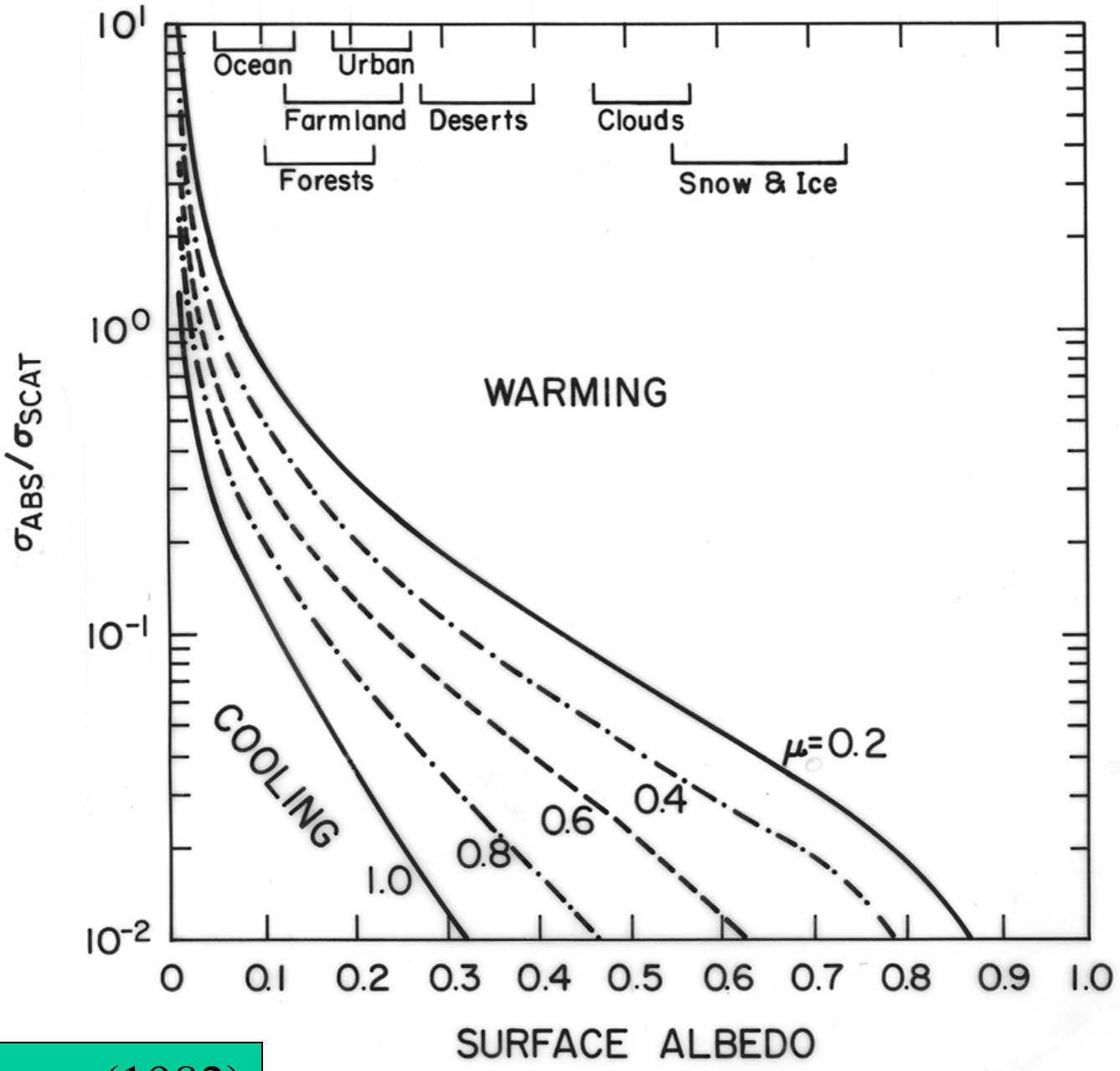


Fig. 2. The imaginary part of the refractive index of snow-soot composition is a very sensitive function of the soot volume fraction V. Around wavelength $\lambda = 0.5$ μm, an amount of soot of only 5×10^{-8} by volume increases the imaginary part of refractive index by almost a factor of 10. A fraction of 1×10^{-7} of carbon increases the imaginary part of the refractive index 50 times. In the near infrared, the refractive index is not affected by the amount of carbon present.


(a)
r_{ICE} = 100 μm
V = 2.8 × 10⁻⁸
(b)
r_{ICE} = 200 μm
V = 3.0 × 10⁻⁸
(c)
r_{ICE} = 200 μm
V = 7.7 × 10⁻⁸
SNOW ALBEDO
WAVELENGTH (μm)
1.0
0.9
0.8
0.7
0.6
0.3
0.4
0.6
0.8
1.0
1.2


SNOW ALBEDO
WAVELENGTH (μm)
1.0
0.9
0.8
0.7
0.6
0.4
0.6
0.8
1.0
1.2
(a)
r_{ICE} = 150 μm
V = 1 × 10⁻⁸
r_m = 0.03 μm
α = 3
Calculations
Measurements
Pure Snow
(b)
r_{ICE} = 100 μm
V = 4 × 10⁻⁷
μ_o = 0.5
(c)
r_{ICE} = 150 μm
V = 5 × 10⁻⁸

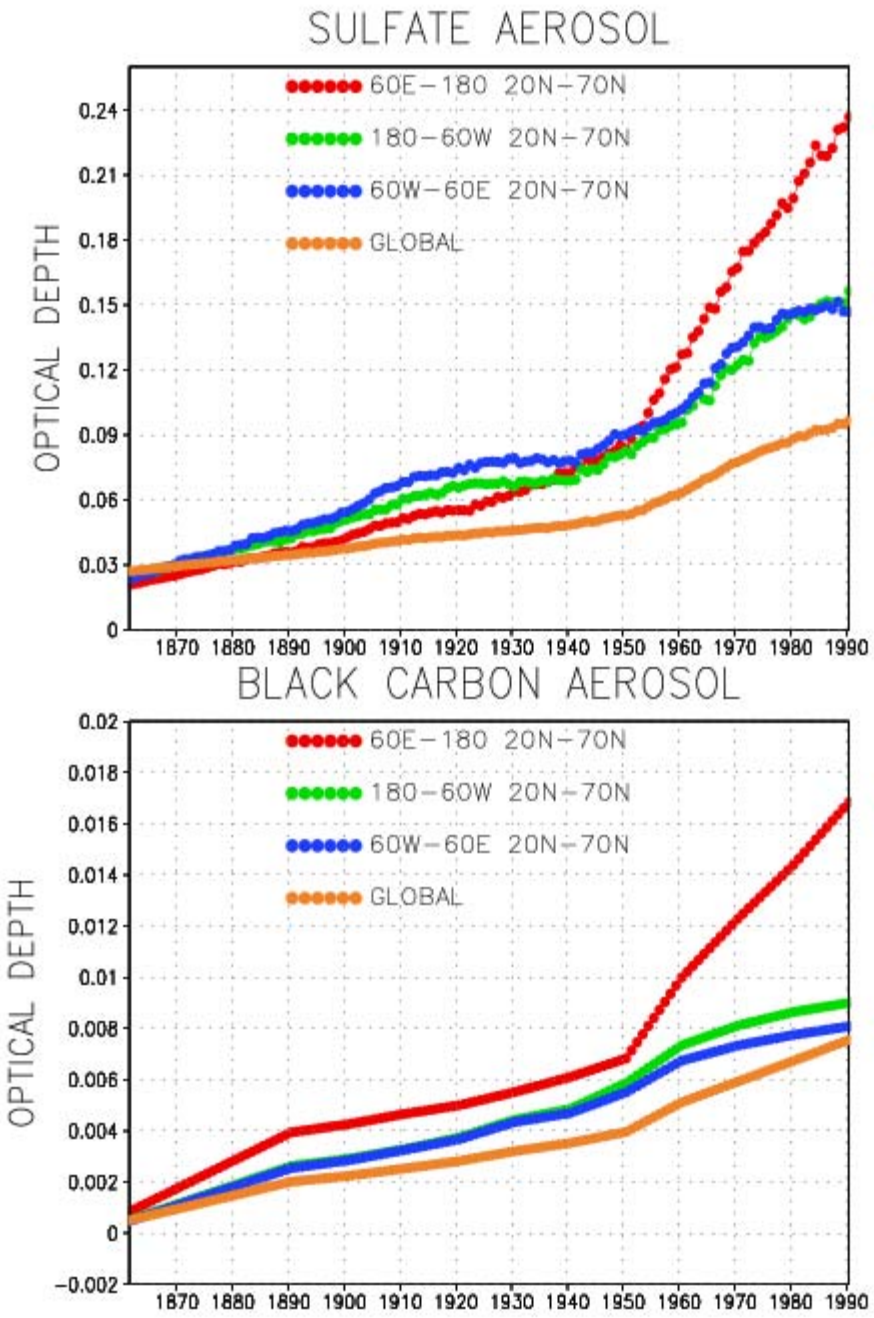

1.000
0.995
0.990
ω_o
$\omega_o = 0.999$
λ 0.5 μm
$r_m = 0.03\,\mu m, \alpha = 3$
Model
S1
A1
S2
C1
10^{-7}
10^{-6}
10^{-5}
10^{-4}
SOOT VOLUME FRACTION

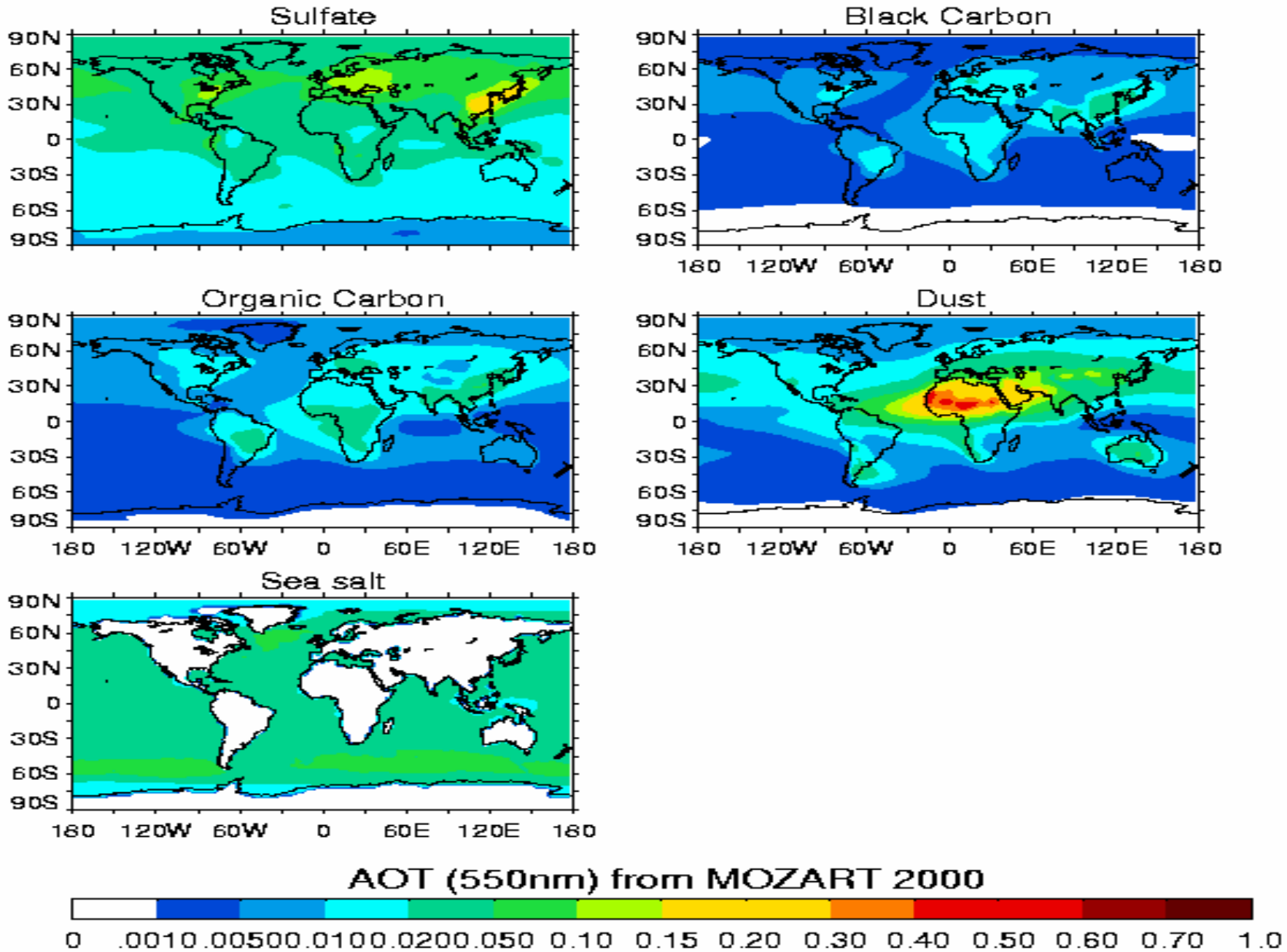


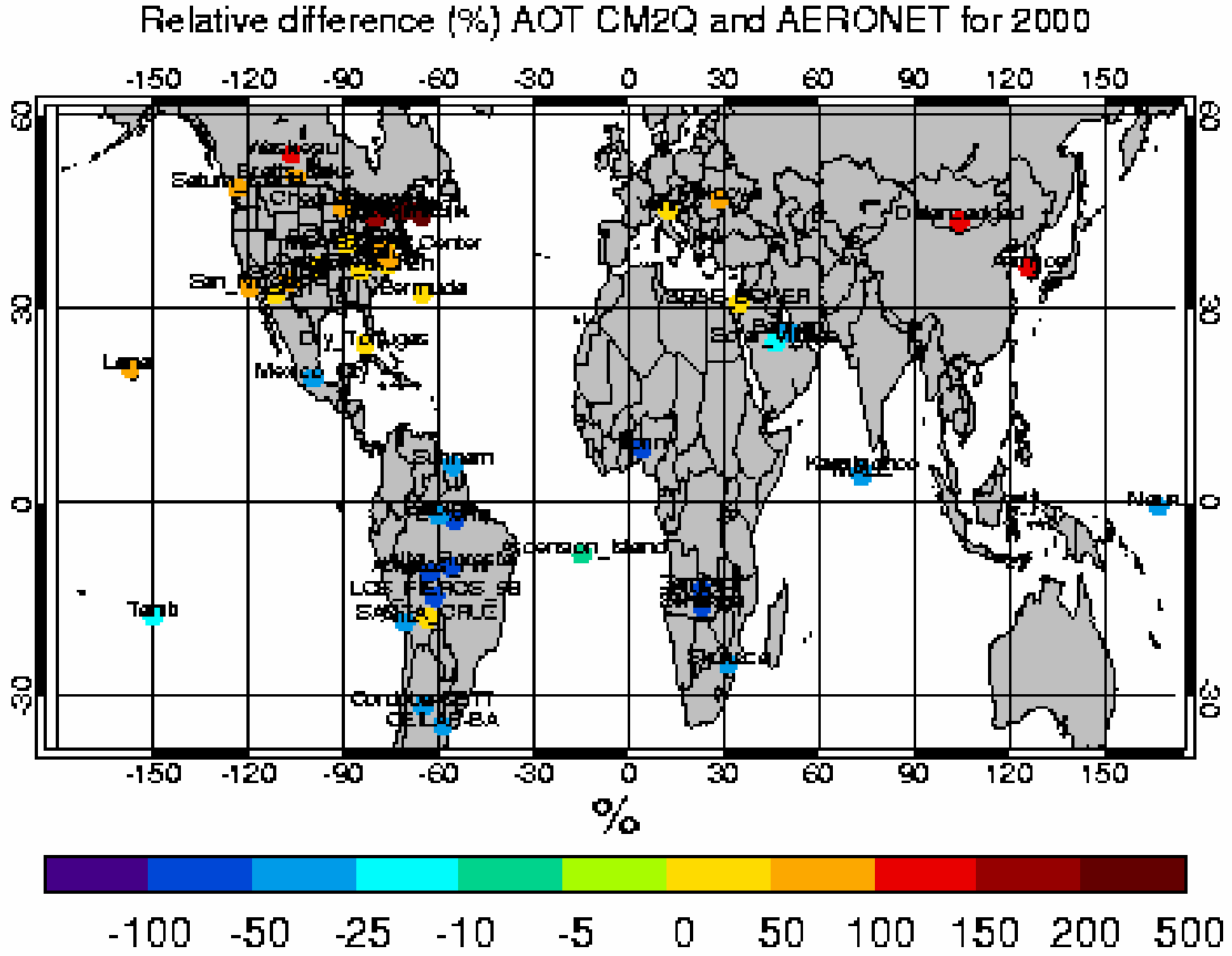
Ramaswamy (1982)

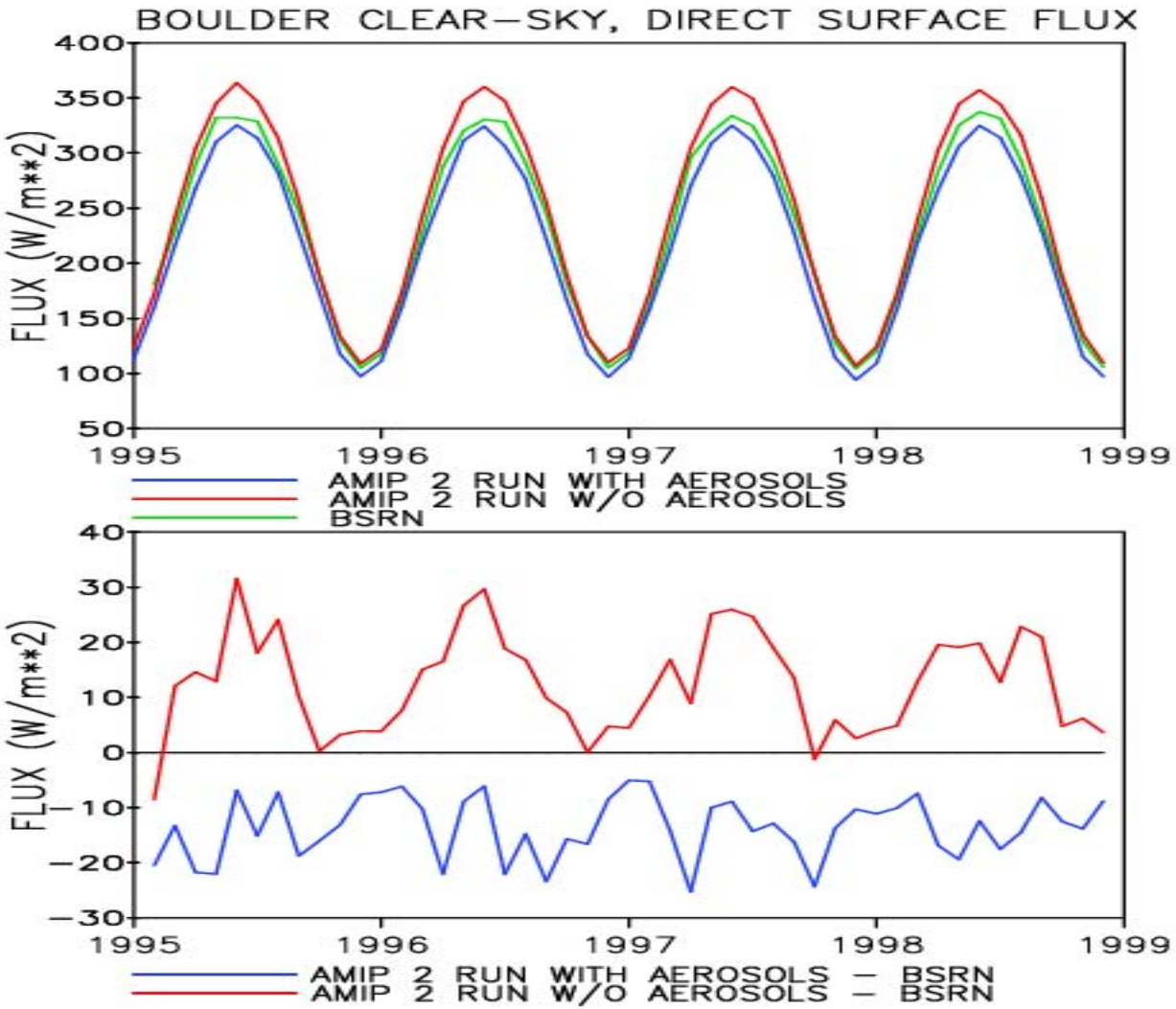
Time evolution of BC and other aerosols
[GFDL Climate Model]

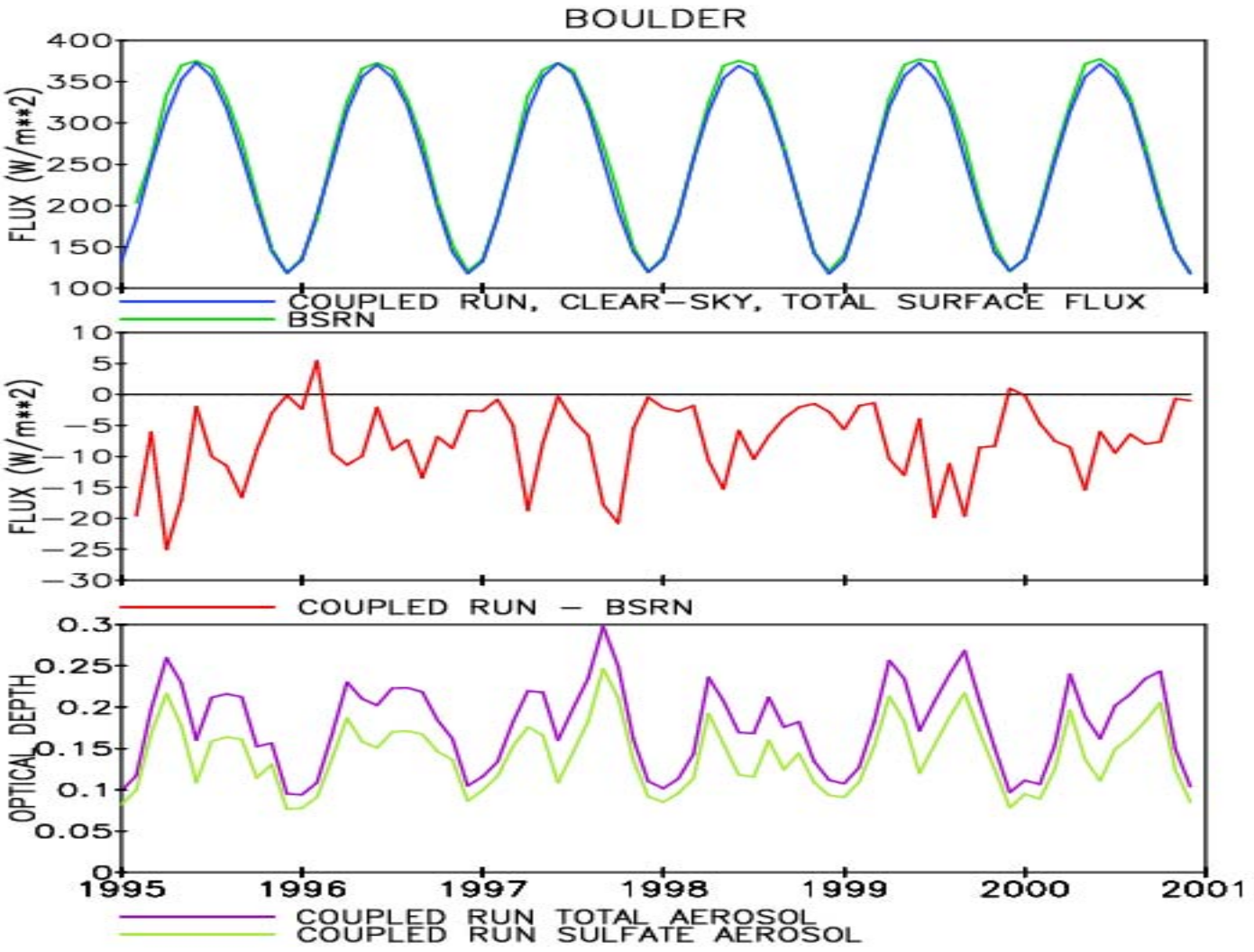
* *Optical depths*
* *Fluxes*

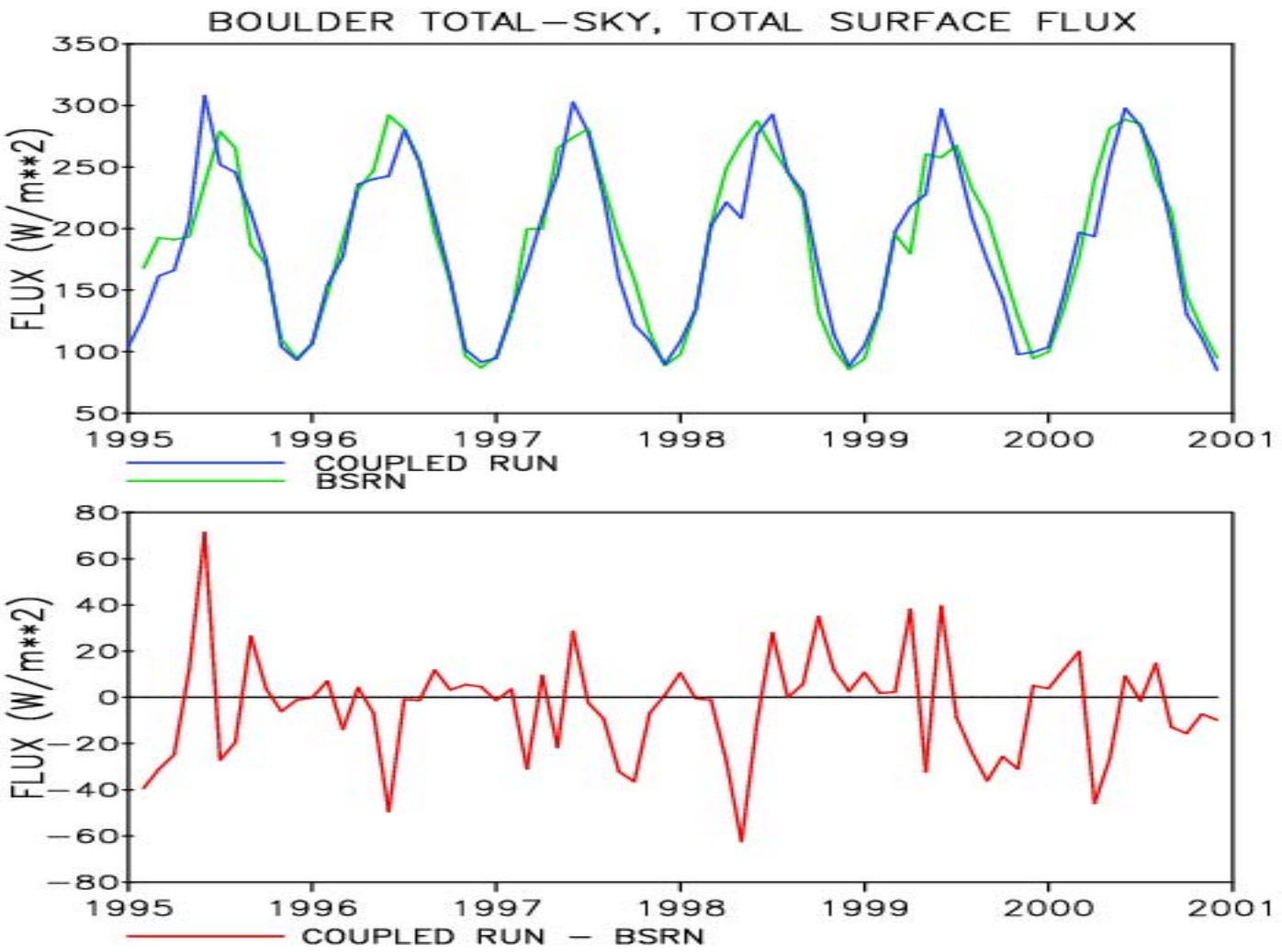

SULFATE AEROSOL
60E-180 20N-70N
180-60W 20N-70N
60W-60E 20N-70N
GLOBAL
OPTICAL DEPTH
0.24
0.21
0.18
0.15
0.12
0.09
0.06
0.03
0
1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990
BLACK CARBON AEROSOL
60E-180 20N-70N
180-60W 20N-70N
60W-60E 20N-70N
GLOBAL
OPTICAL DEPTH
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990

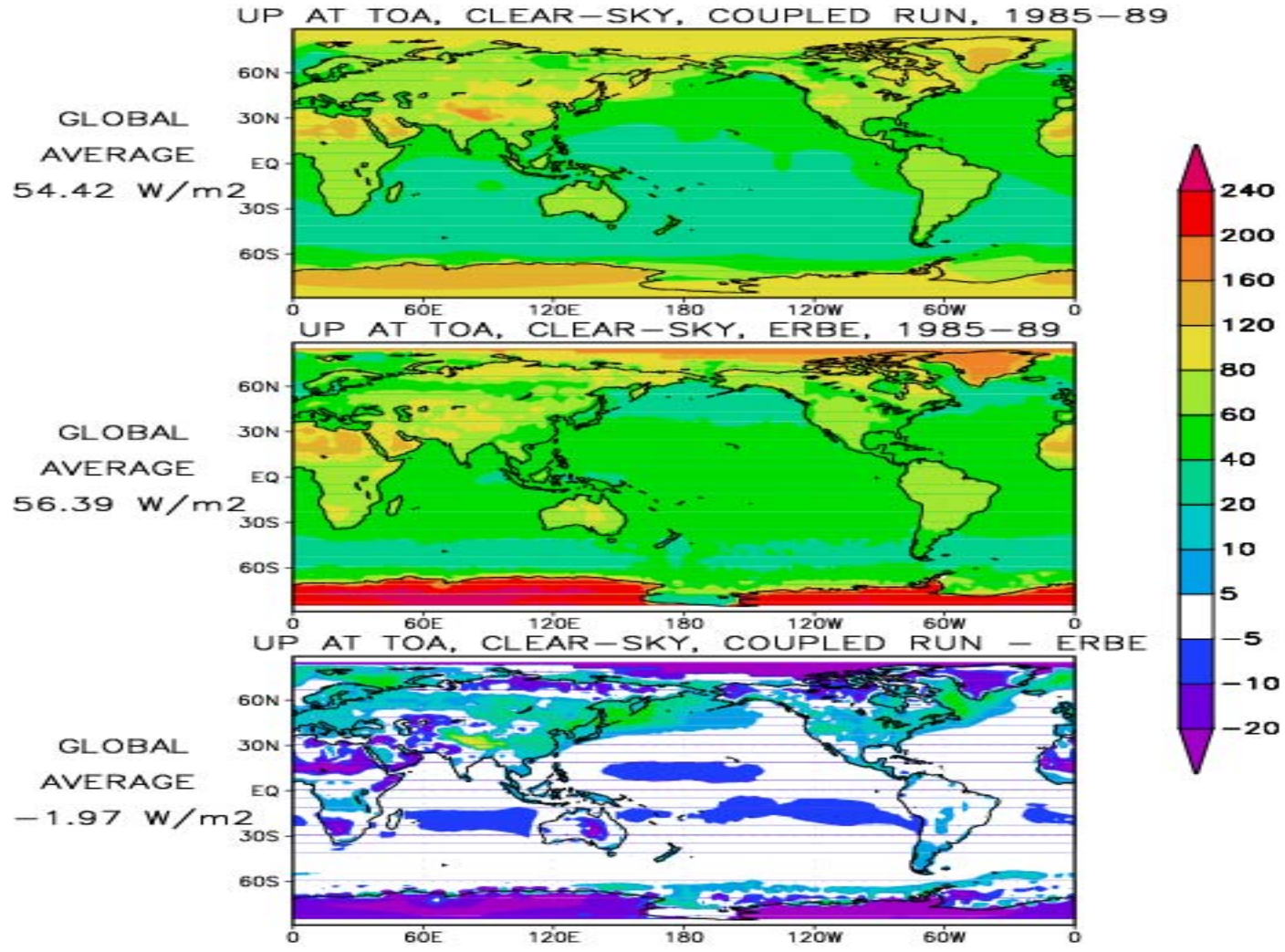

Sulfate
Black Carbon
Organic Carbon
Dust
Sea salt
90N
60N
30N
0
30S
60S
90S
180
120W
60W
0
60E
120E
180
AOT (550nm) from MOZART 2000
0
.0010
.00500
.0100
.0200
.050
0.10
0.15
0.20
0.30
0.40
0.50
0.60
0.70
1.0


Relative difference (%) AOT CM2Q and AERONET for 2000
-150 -120 -90 -60 -30 0 30 60 90 120 150
60
30
0
-30
Bermuda
Cape_Verde
Tamb
Ilorin
%
-100 -50 -25 -10 -5 0 50 100 150 200 500

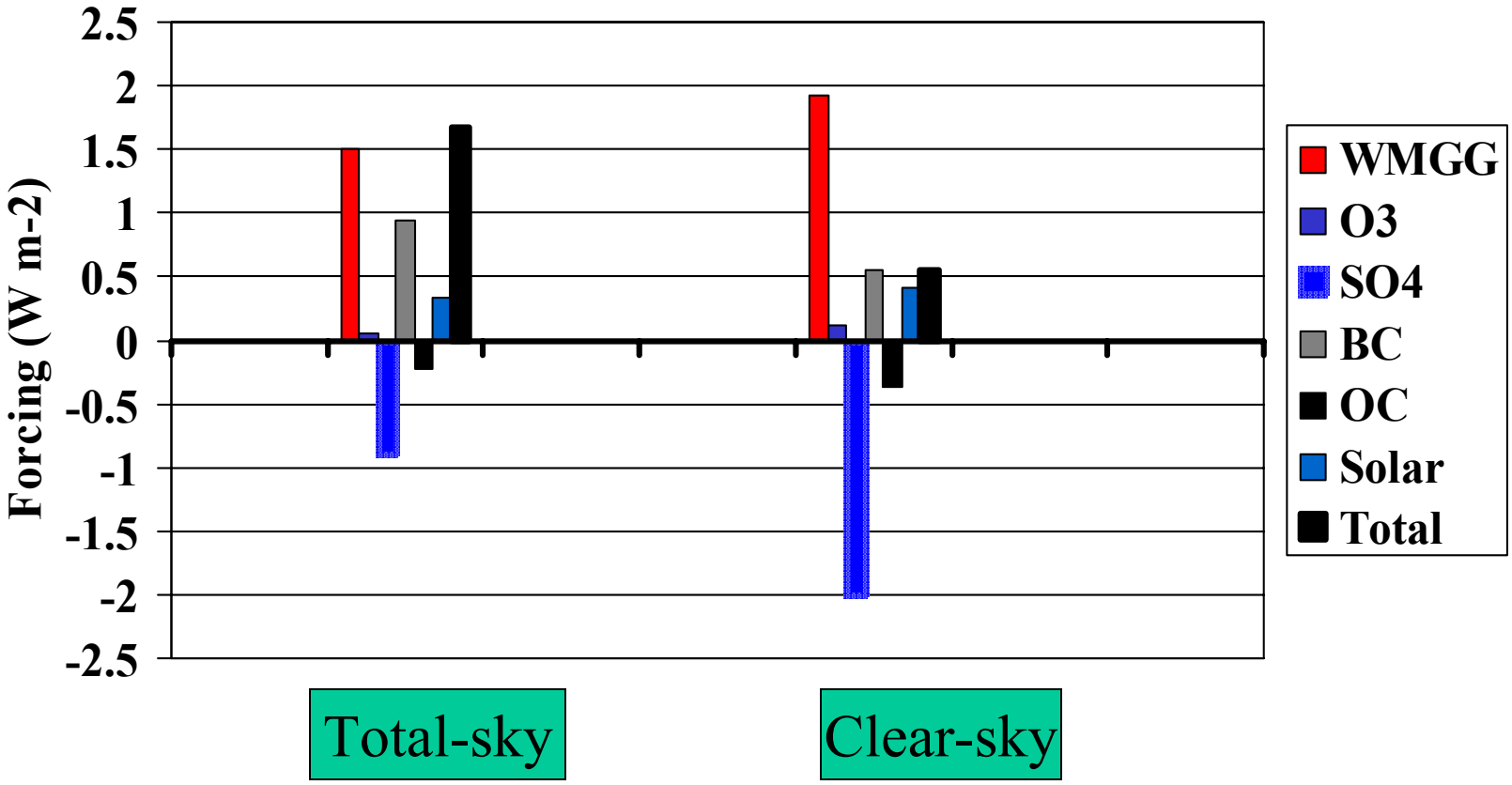

BOULDER CLEAR–SKY, DIRECT SURFACE FLUX
FLUX (W/m**2)
400
350
300
250
200
150
100
50
1995
1996
1997
1998
1999
AMIP 2 RUN WITH AEROSOLS
AMIP 2 RUN W/O AEROSOLS
BSRN
FLUX (W/m**2)
40
30
20
10
0
−10
−20
−30
1995
1996
1997
1998
1999
AMIP 2 RUN WITH AEROSOLS – BSRN
AMIP 2 RUN W/O AEROSOLS – BSRN

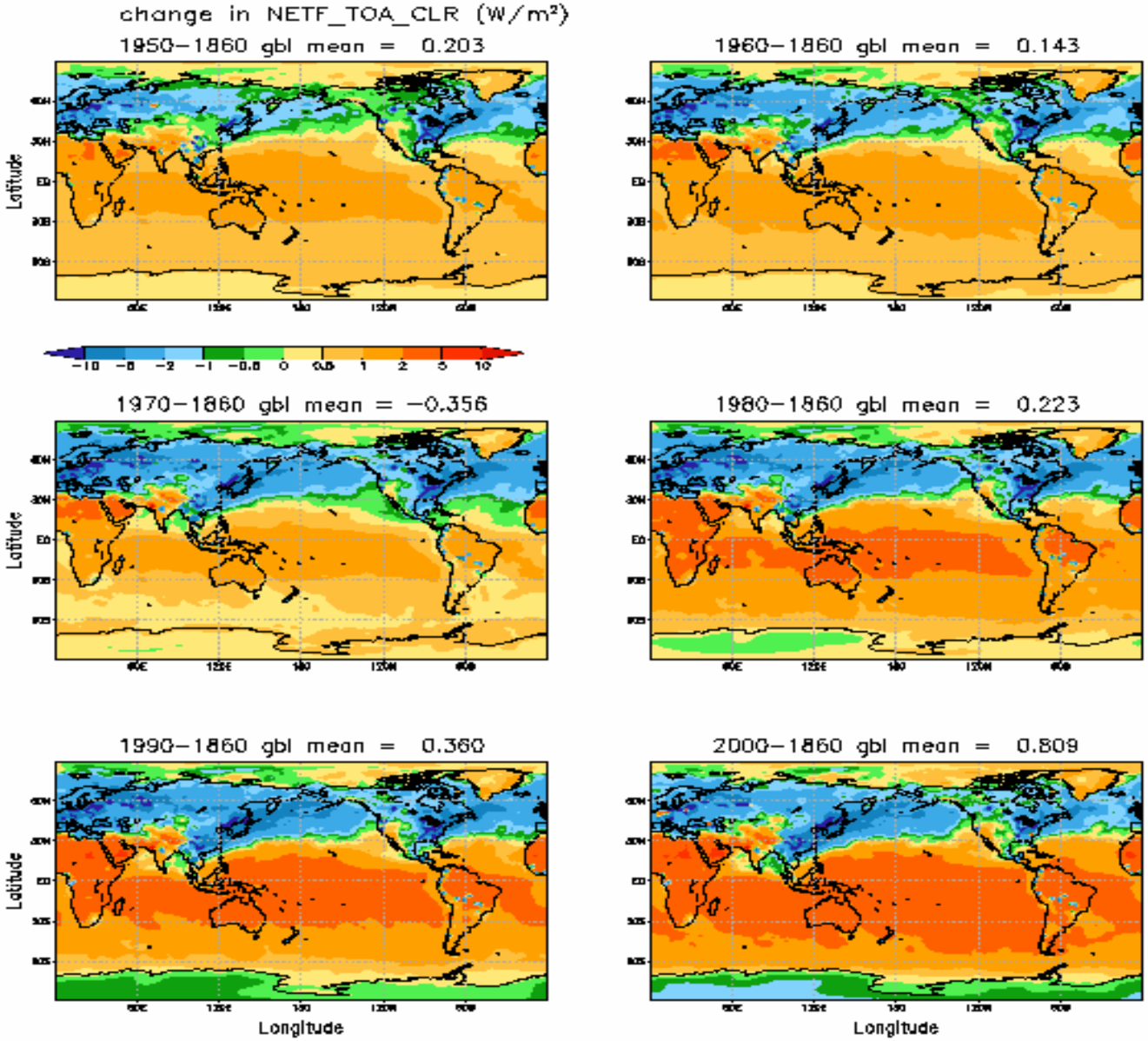

BOULDER
FLUX (W/m**2)
400
350
300
250
200
150
100
COUPLED RUN, CLEAR-SKY, TOTAL SURFACE FLUX
BSRN
FLUX (W/m**2)
10
5
0
-5
-10
-15
-20
-25
-30
COUPLED RUN - BSRN
OPTICAL DEPTH
0.3
0.25
0.2
0.15
0.1
0.05
0
1995
1996
1997
1998
1999
2000
2001
COUPLED RUN TOTAL AEROSOL
COUPLED RUN SULFATE AEROSOL

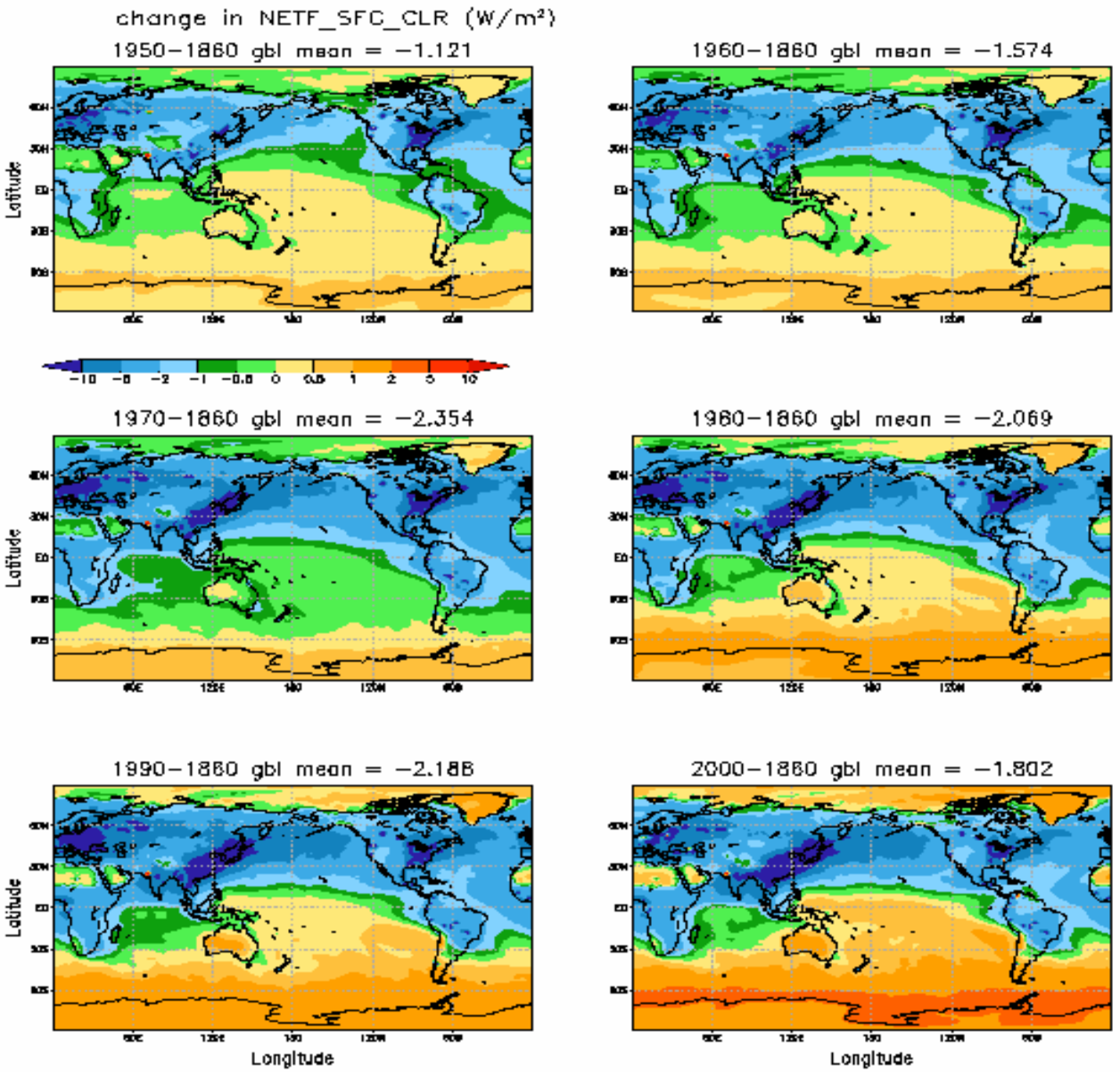

BOULDER TOTAL-SKY, TOTAL SURFACE FLUX
FLUX (W/m**2)
350
300
250
200
150
100
50
1995
1996
1997
1998
1999
2000
2001
COUPLED RUN
BSRN
FLUX (W/m**2)
80
60
40
20
0
-20
-40
-60
-80
1995
1996
1997
1998
1999
2000
2001
COUPLED RUN - BSRN

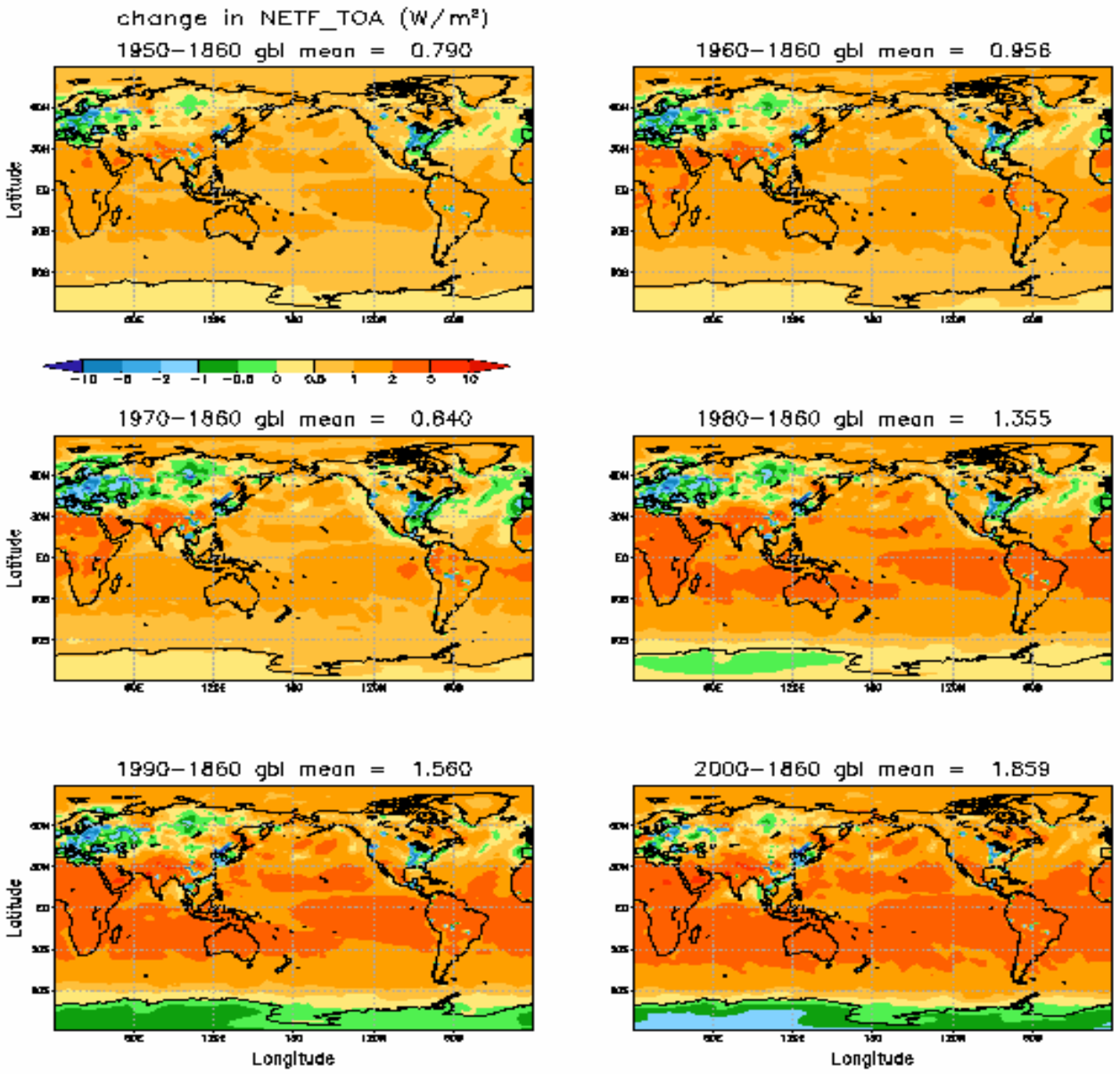

UP AT TOA, CLEAR-SKY, COUPLED RUN, 1985-89
GLOBAL AVERAGE 54.42 W/m2
UP AT TOA, CLEAR-SKY, ERBE, 1985-89
GLOBAL AVERAGE 56.39 W/m2
UP AT TOA, CLEAR-SKY, COUPLED RUN - ERBE
GLOBAL AVERAGE -1.97 W/m2
60N
30N
EQ
30S
60S
0
60E
120E
180
120W
60W
240
200
160
120
80
60
40
20
10
5
-5
-10
-20

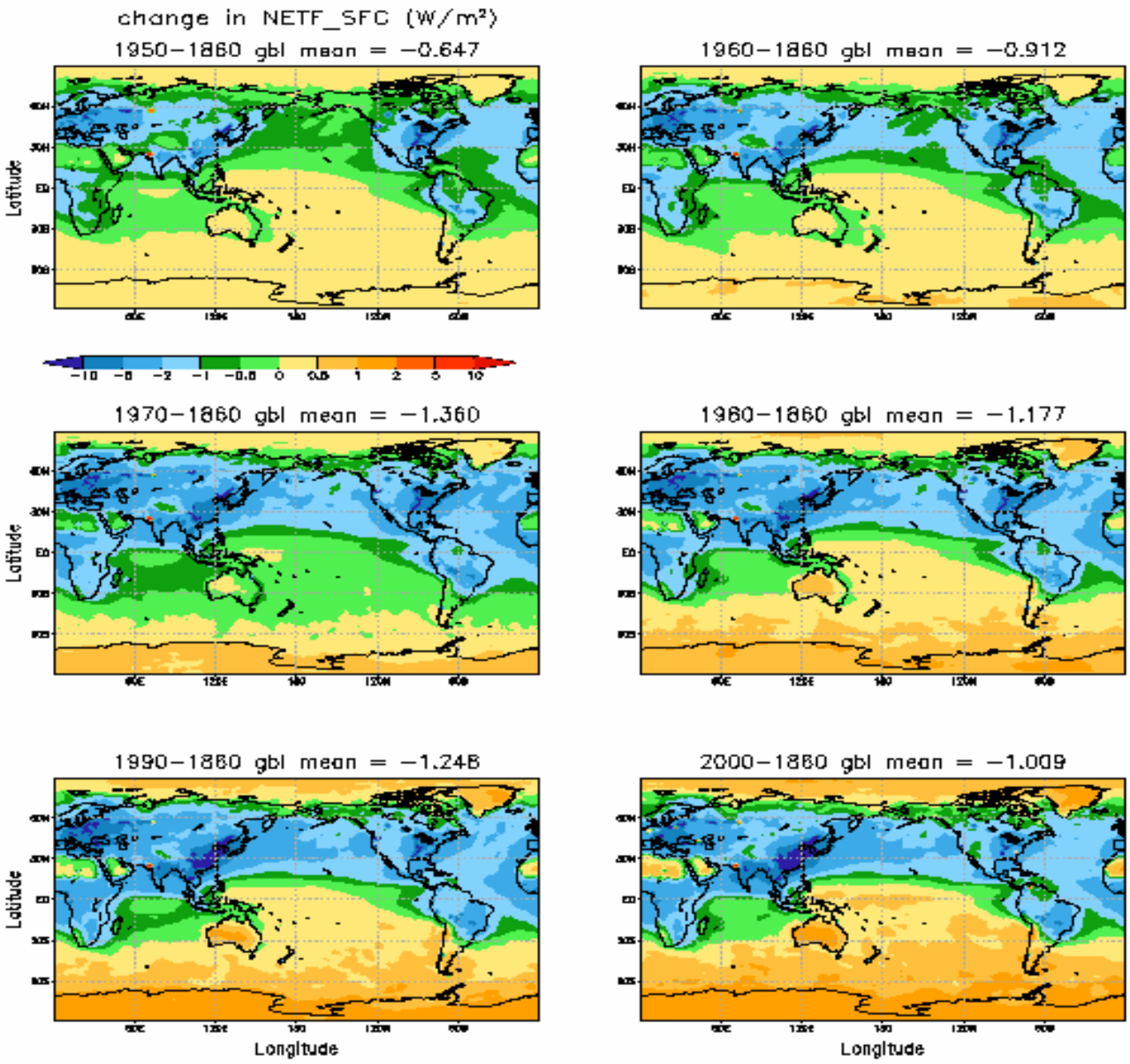
Global-annual-mean forcing TOA [1990 – 1860]




change in NETF_TOA_CLR (W/m²)
1950−1860 gbl mean = 0.203
1960−1860 gbl mean = 0.143
−10 −5 −2 −1 −0.5 0 0.5 1 2 5 10
1970−1860 gbl mean = −0.356
1980−1860 gbl mean = 0.223
1990−1860 gbl mean = 0.360
2000−1860 gbl mean = 0.809
Latitude
Longitude

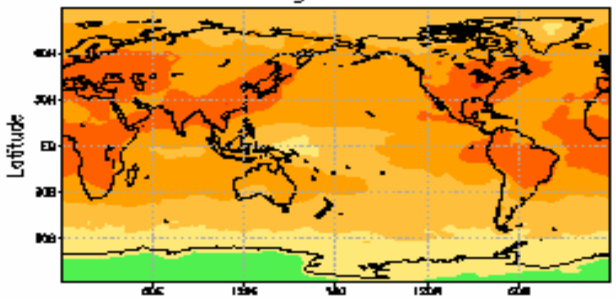

change in NETF_SFC_CLR (W/m²)
1950−1860 gbl mean = −1.121
1960−1860 gbl mean = −1.574
−10 −5 −2 −1 −0.5 0 0.5 1 2 5 10
1970−1860 gbl mean = −2.354
1980−1860 gbl mean = −2.069
1990−1860 gbl mean = −2.188
2000−1860 gbl mean = −1.802
Latitude
Longitude


change in NETF_TOA (W/m²)
1950−1860 gbl mean = 0.790
1960−1860 gbl mean = 0.956
1970−1860 gbl mean = 0.640
1980−1860 gbl mean = 1.355
1990−1860 gbl mean = 1.560
2000−1860 gbl mean = 1.859
Latitude
Longitude

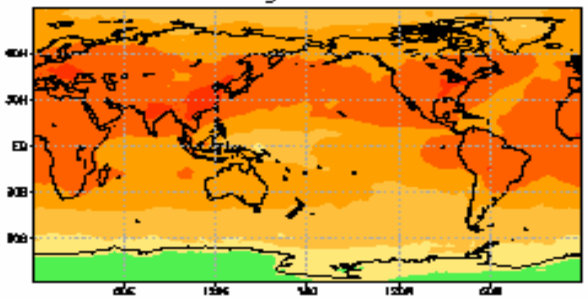

change in NETF_SFC (W/m²)
1950−1860 gbl mean = −0.647
1960−1860 gbl mean = −0.912
−10 −5 −2 −1 −0.5 0 0.5 1 2 5 10
1970−1860 gbl mean = −1.360
1980−1860 gbl mean = −1.177
1990−1860 gbl mean = −1.248
2000−1860 gbl mean = −1.009
Latitude
Longitude

change in NETF_ABS (W/m²)

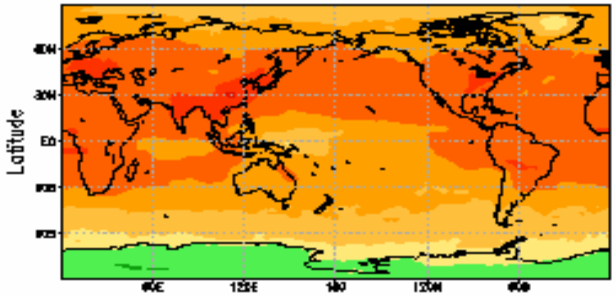
1950−1860 gbl mean = 1.437



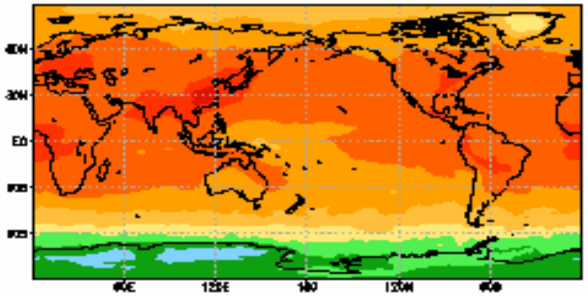
1960−1860 gbl mean = 1.868



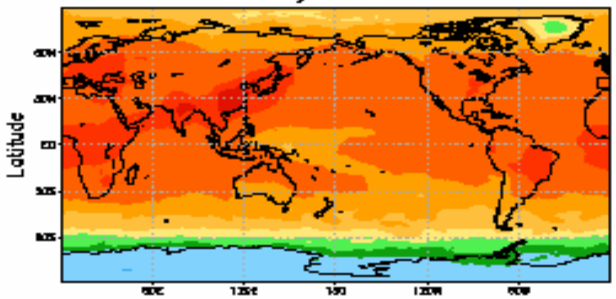
1970−1860 gbl mean = 2.201



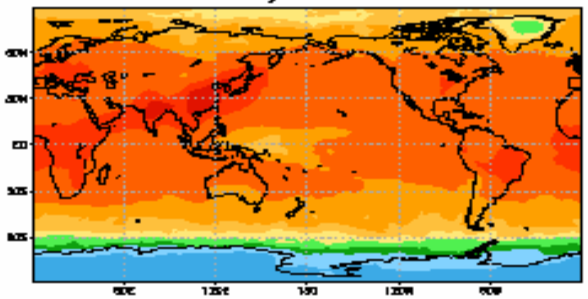
1980−1860 gbl mean = 2.533

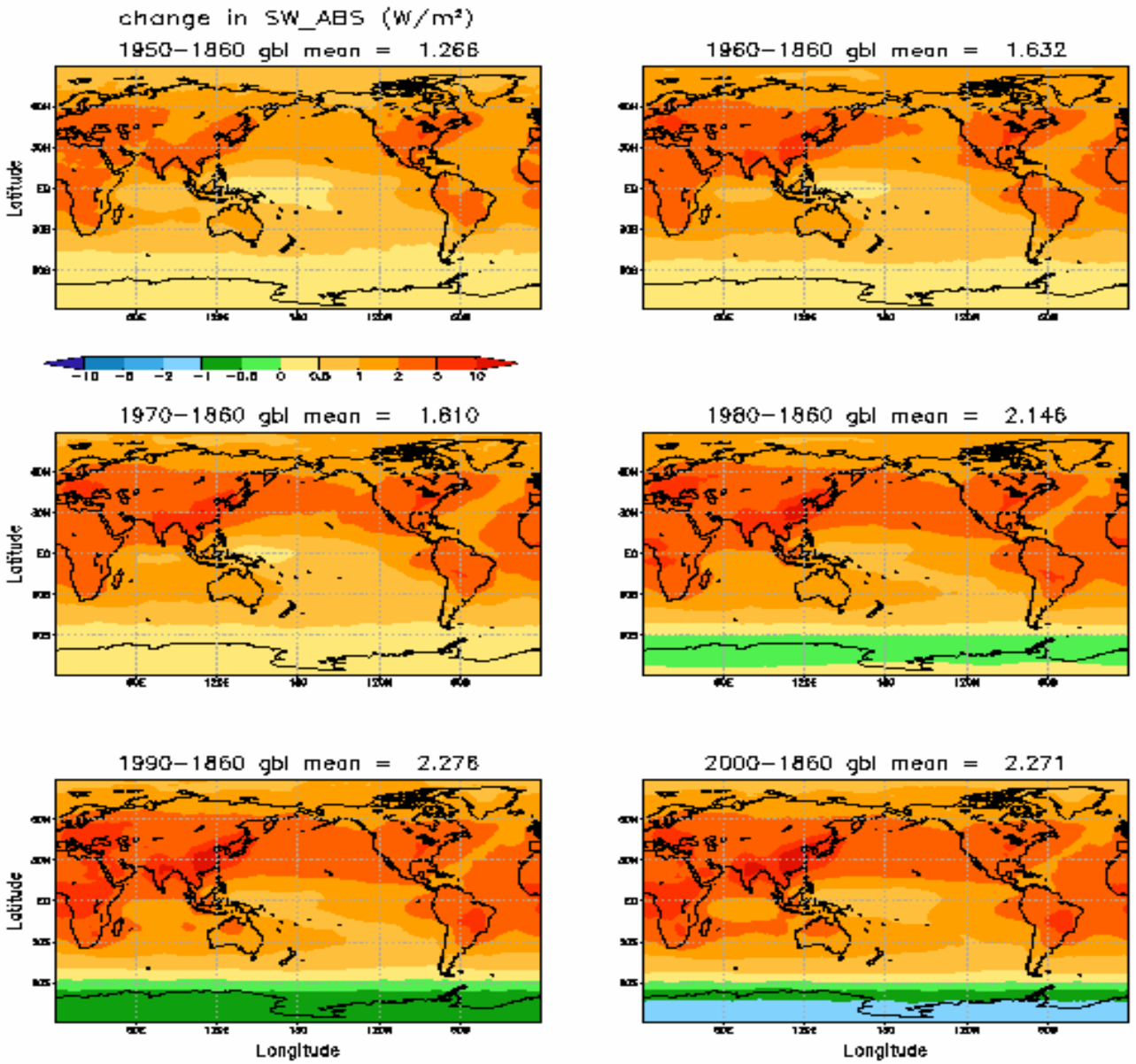


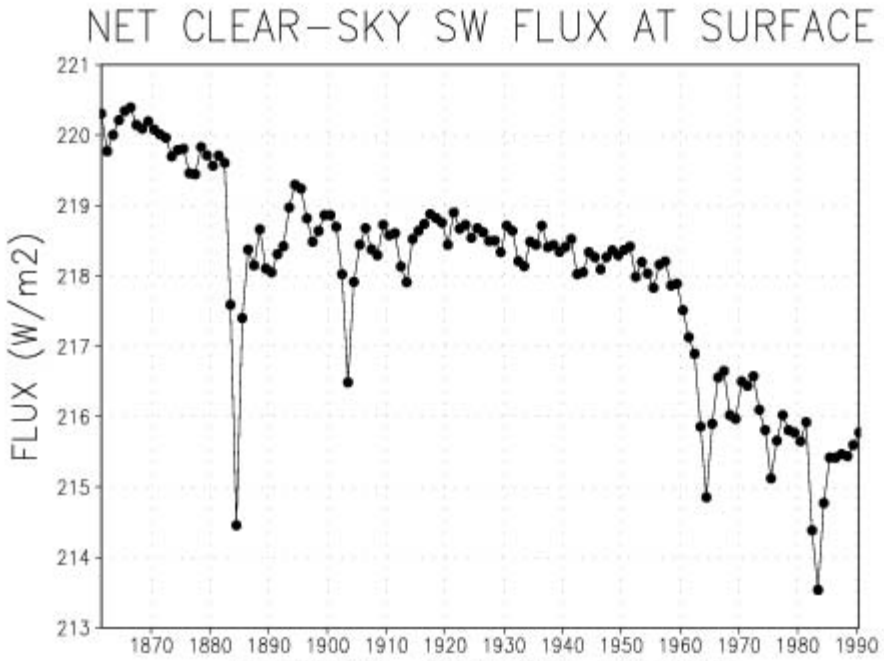
1990−1860 gbl mean = 2.808

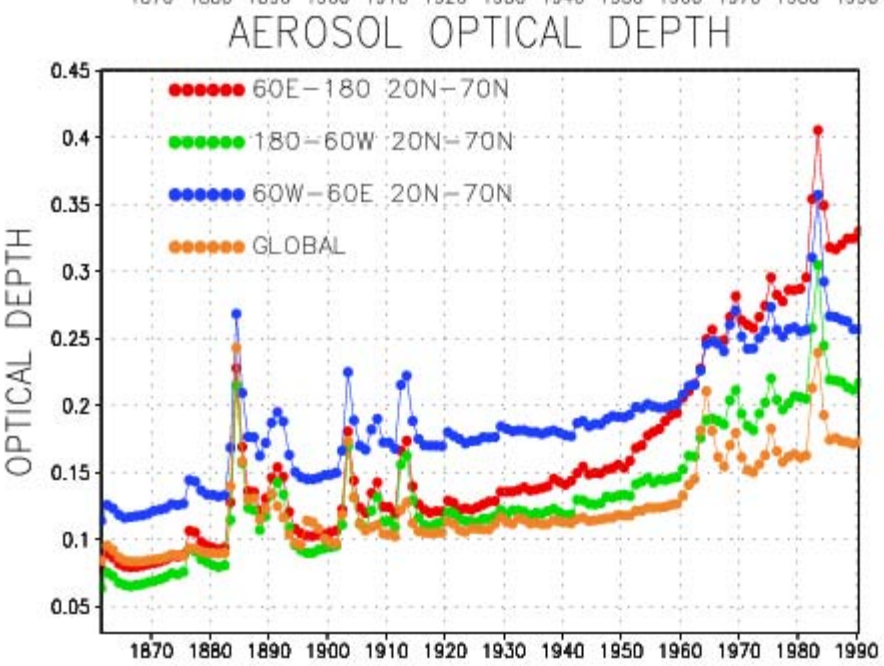


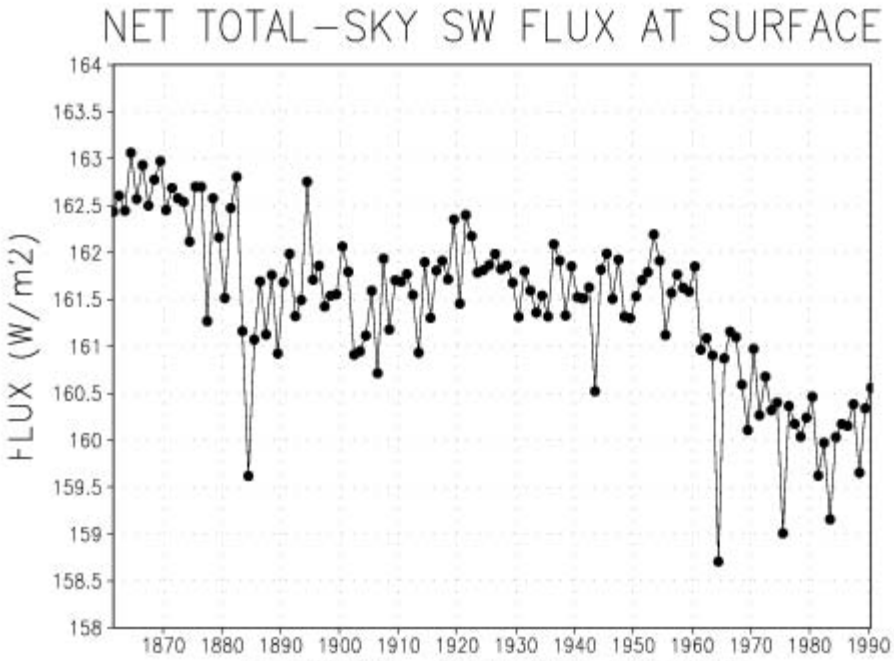
2000−1860 gbl mean = 2.868

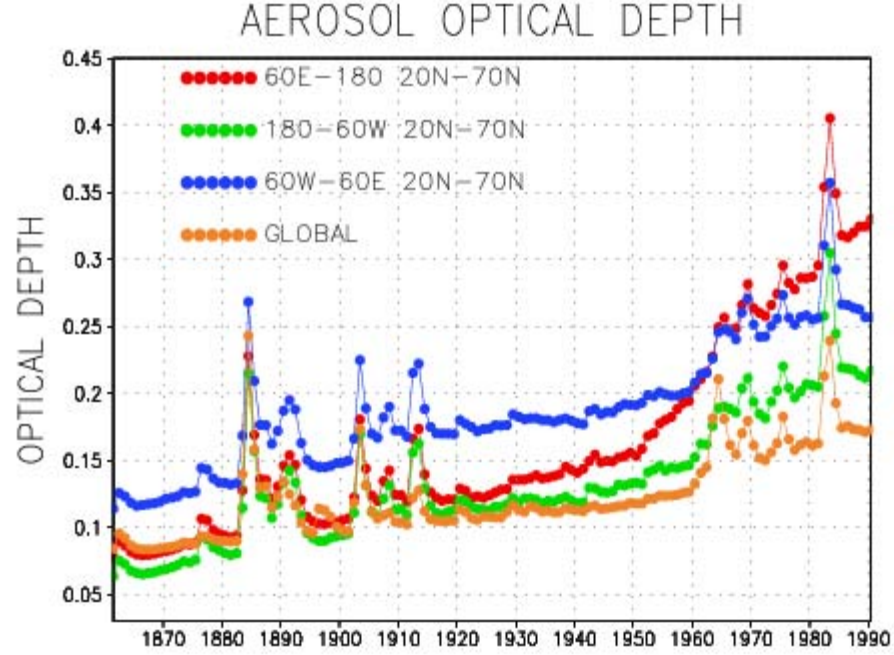


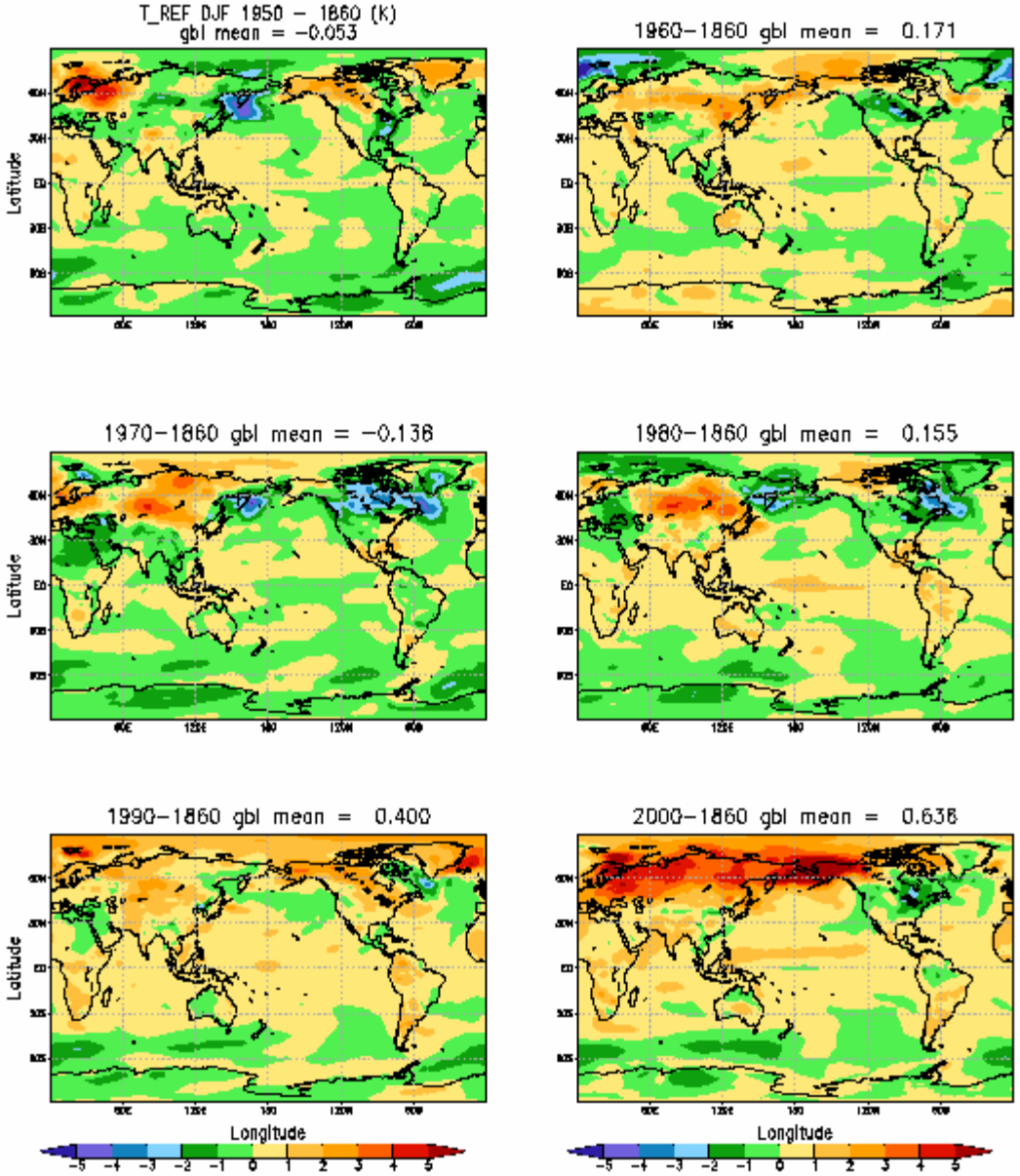

change in SW_ABS (W/m²)
1950−1860 gbl mean = 1.266
1960−1860 gbl mean = 1.632
−10 −5 −2 −1 −0.5 0 0.5 1 2 5 10
1970−1860 gbl mean = 1.810
1980−1860 gbl mean = 2.146
1990−1860 gbl mean = 2.276
2000−1860 gbl mean = 2.271
Latitude
Longitude


NET CLEAR-SKY SW FLUX AT SURFACE
FLUX (W/m2)
221
220
219
218
217
216
215
214
213
1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990


AEROSOL OPTICAL DEPTH
60E-180 20N-70N
180-60W 20N-70N
60W-60E 20N-70N
GLOBAL
OPTICAL DEPTH
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990


NET TOTAL-SKY SW FLUX AT SURFACE
FLUX (W/m2)
164
163.5
163
162.5
162
161.5
161
160.5
160
159.5
159
158.5
158
1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990


AEROSOL OPTICAL DEPTH
60E-180 20N-70N
180-60W 20N-70N
60W-60E 20N-70N
GLOBAL
OPTICAL DEPTH
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970 1980 1990


T_REF DJF 1950 - 1860 (K)
gbl mean = -0.053
1960-1860 gbl mean = 0.171
1970-1860 gbl mean = -0.136
1980-1860 gbl mean = 0.155
1990-1860 gbl mean = 0.400
2000-1860 gbl mean = 0.636
Latitude
Longitude
-5 -4 -3 -2 -1 0 1 2 3 4 5

CONCLUDING POINTS

- Meteorology may be **MORE** important than microphysical details in global free tropospheric distribution ➔
  esp. frequency of precipitation

- Temporal variations can be significant

- Internal mixtures of Carbonaceous aerosols with other aerosols, clouds and snow ➔
  need spectral measurements **AND** aerosol amount simultaneously

- **HOW MUCH OF "IT" IS UP THERE ???**

- **CRITICAL** to verify modeled time evolution of surface concentrations, vertical profile, optical depth and fluxes to construct an accurate picture of the forcing ➔ providing **CONSTRAINTS**