CLIMATE:

Needs, Requirements, Applications:

GFDL Chemistry–Climate Model

NOAA/ Geophysical Fluid Dynamics Laboratory, Princeton NJ

- Modeling and verifying processes
- Understanding of the physico-chemical mechanisms
- Understanding of climate change due to chemistry
- Causal attribution to specific species
- Projections of climate change due to time history of emissions

Evolution at GFDL

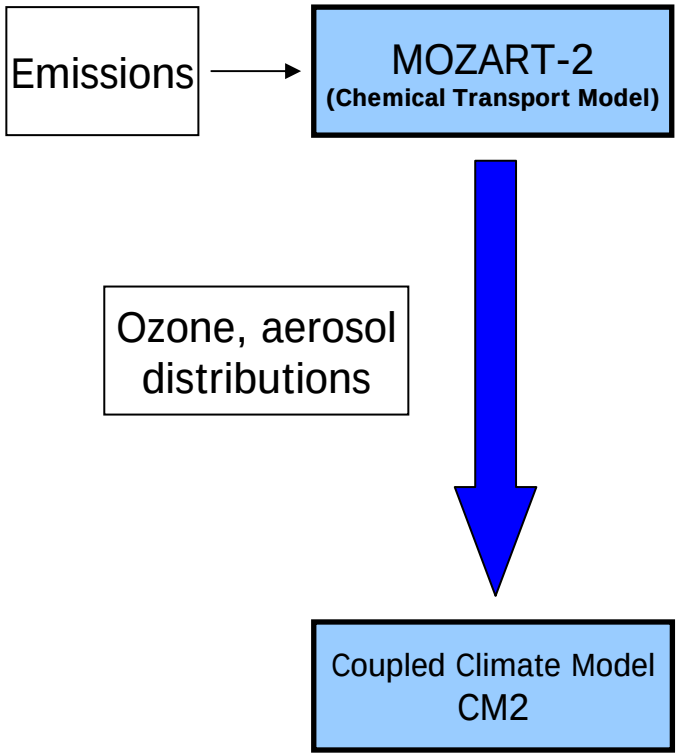
- Prior to 2001, and before AR4,

GFDL Climate Model simulations only with prescribed CO2, with ad hoc sulfate aerosol-like entity

- AR4:

Prescribed Chemical species calculated offline using MOZART CTM

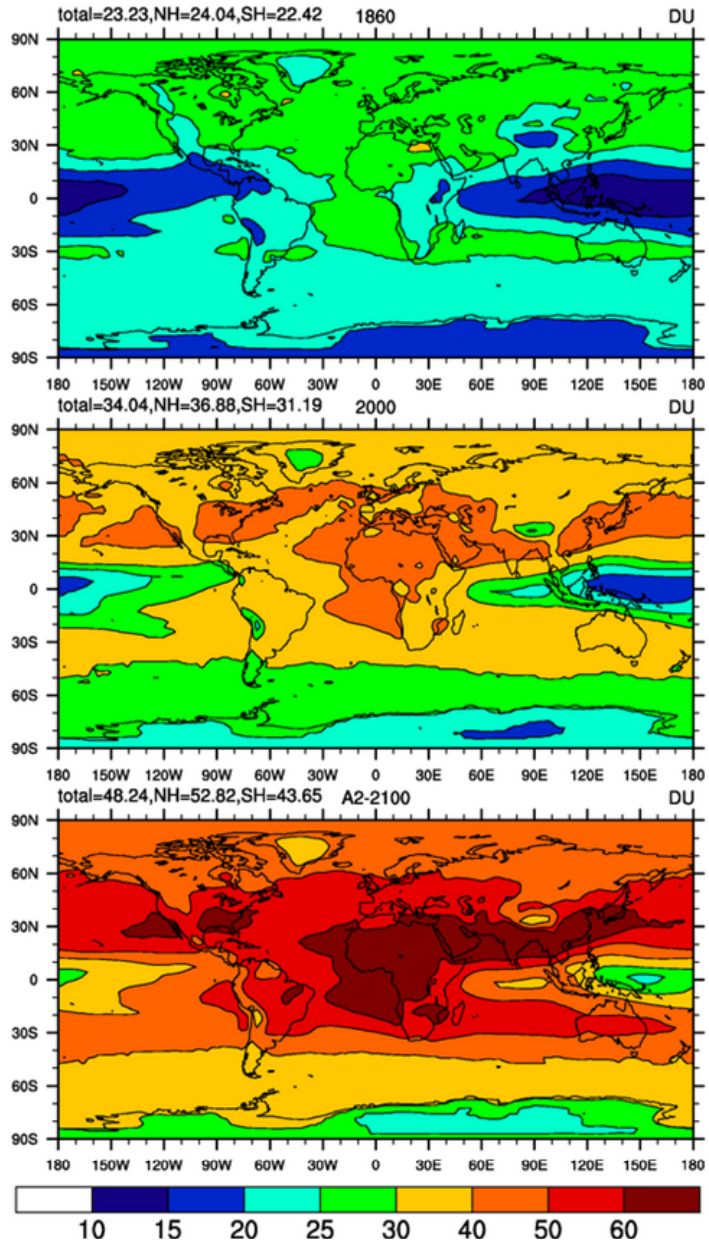
One-way Coupling (completed)



- **Used in GFDL simulations for IPCC/AR4, CCSP, AEROCOM**
- **Impact of changing emissions on climate**
- **Historical runs (1860-present, decadal)**
- **Future runs (present-2100, decadal) for A2, A1B, B1 scenarios**

Tropospheric Ozone Column

MOZART calculations [Horowitz, 2006], used in GFDL CM2.0 and CM2.1 simulations (IPCC AR4)



1860

2000

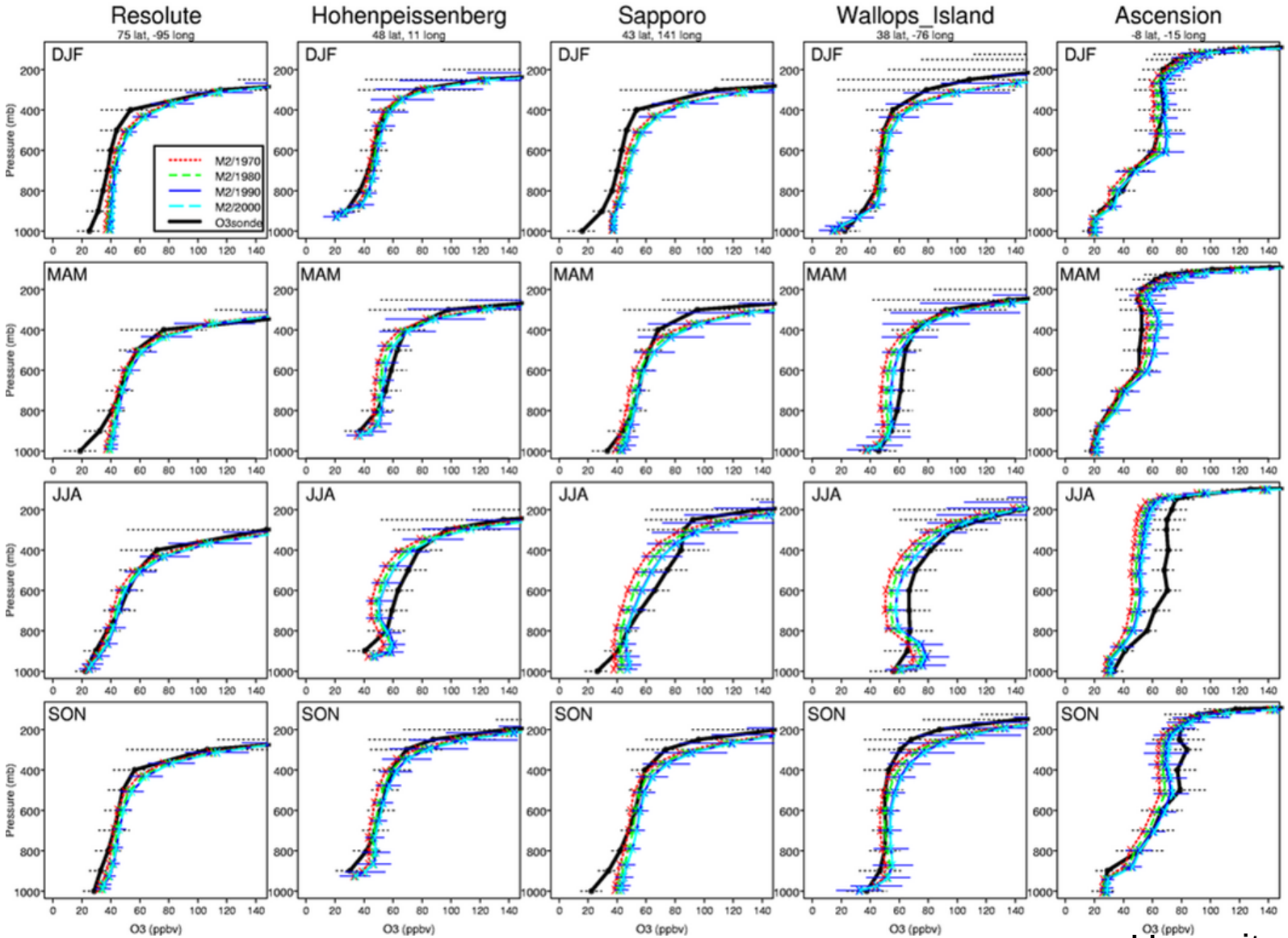
2100 (A2)

DU (Dobson units)

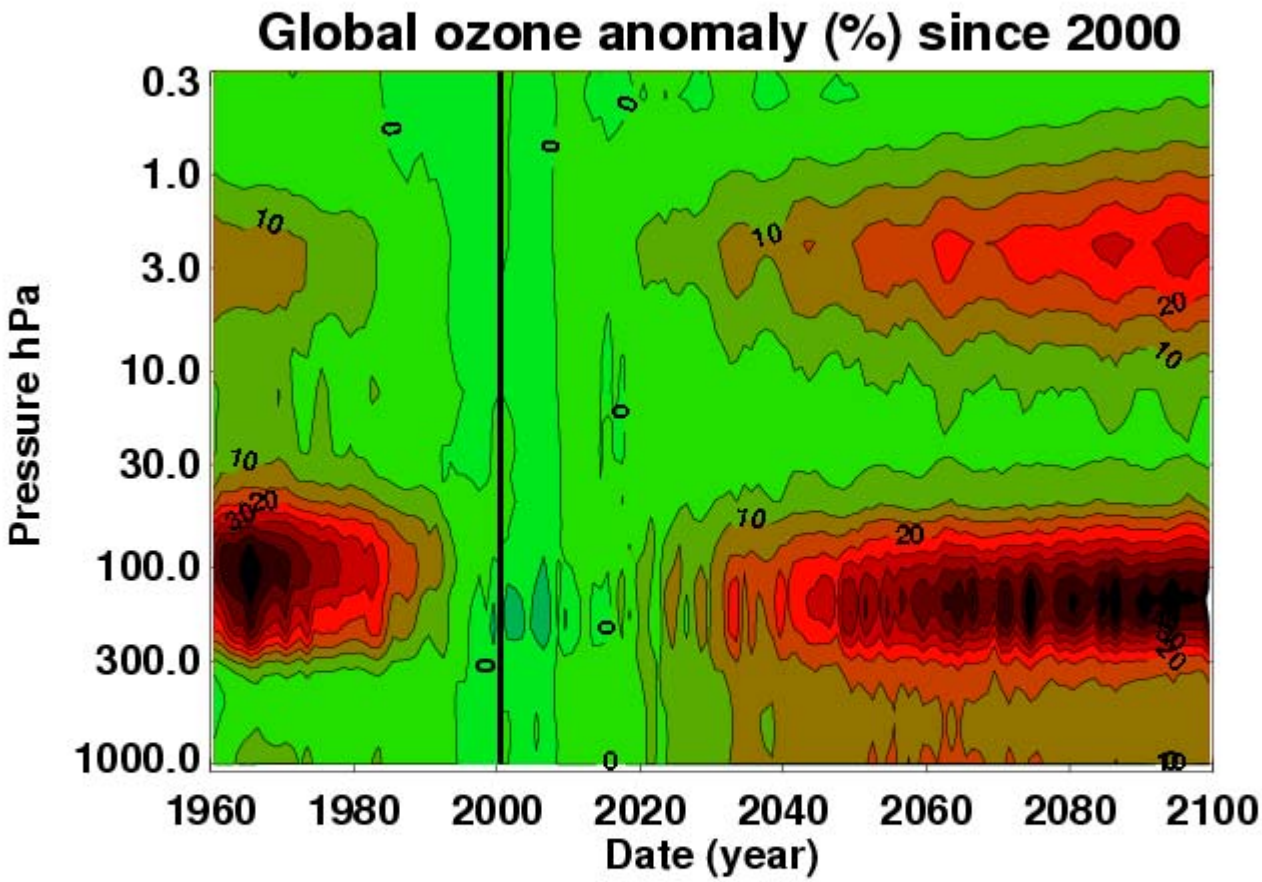
Horowitz [2006]

Model Evaluation

MOZART Ozone vs. Ozonesonde Observations

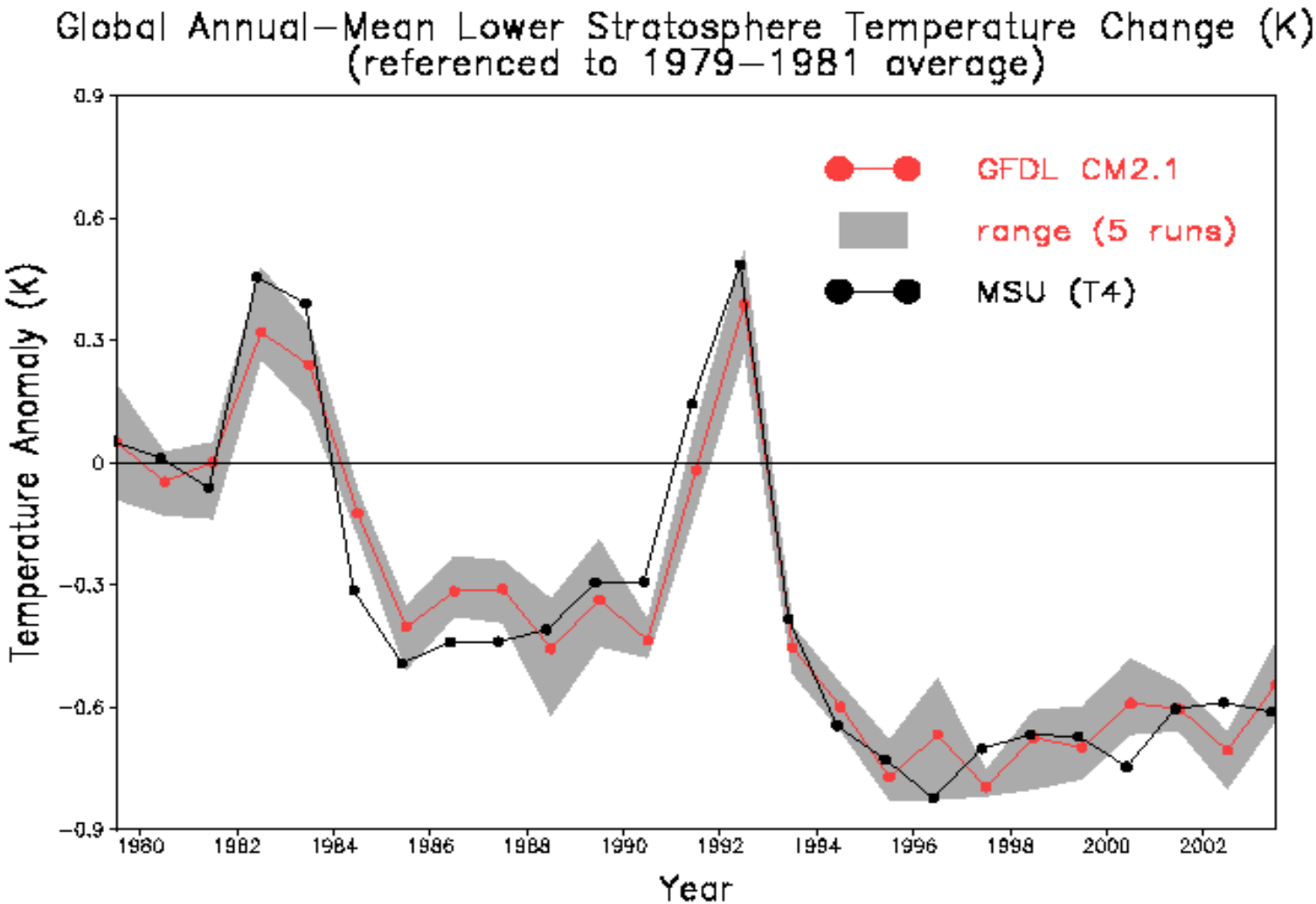


Horowitz [2006]

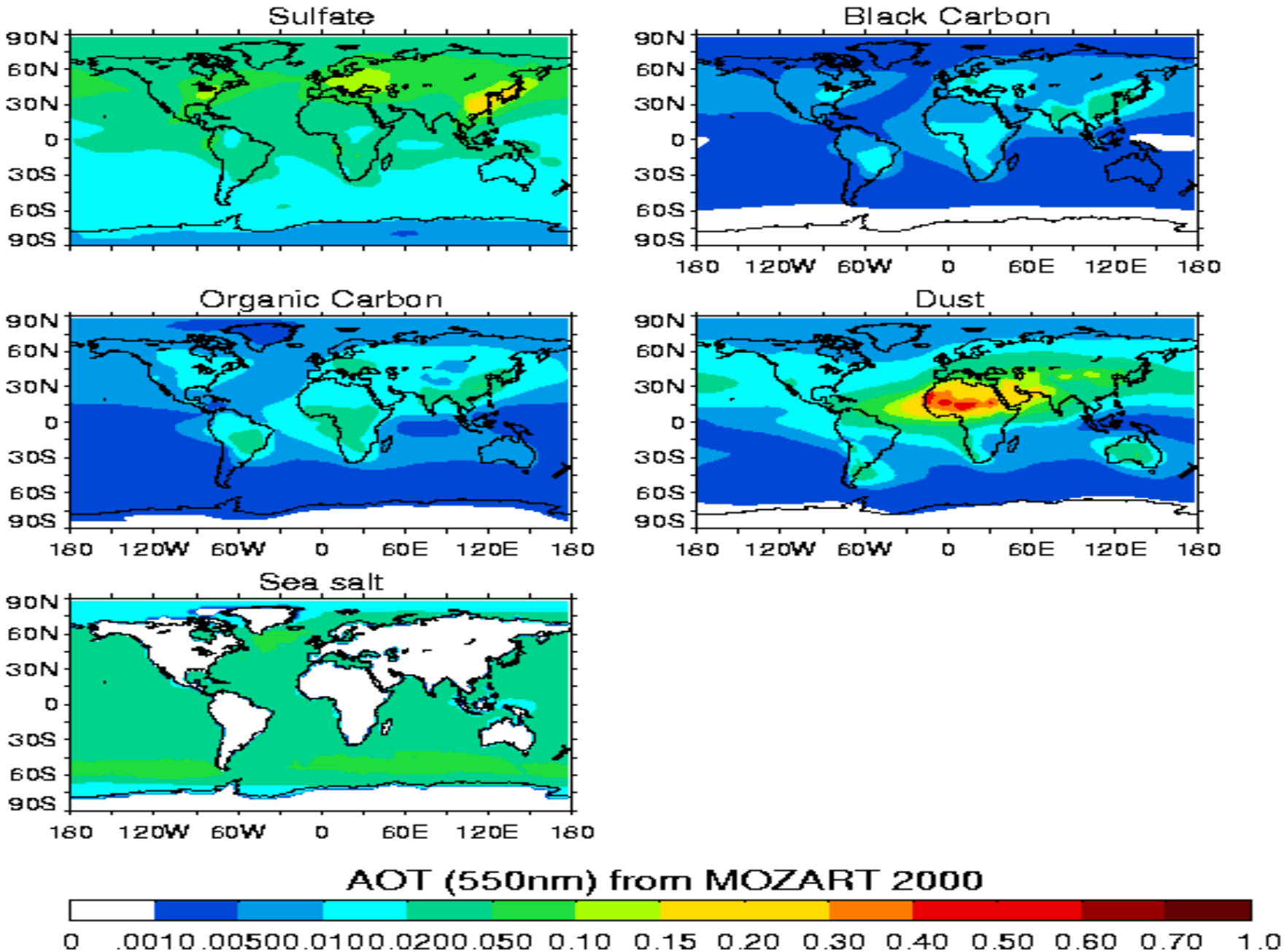


Results from interactive stratospheric ozone, dynamics, radiation simulation [48-layer model with ozone chemistry]

[GFDL simulation ➔ WMO/ UNEP 2007]

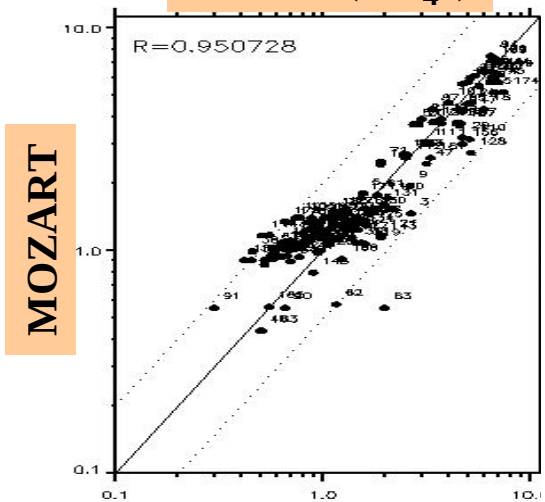


Explaining the satellite-observed stratospheric temperature evolution in terms of the Anthropogenic (ozone depletion, long-lived greenhouse gases and Natural (solar variations, major volcanos) forcings

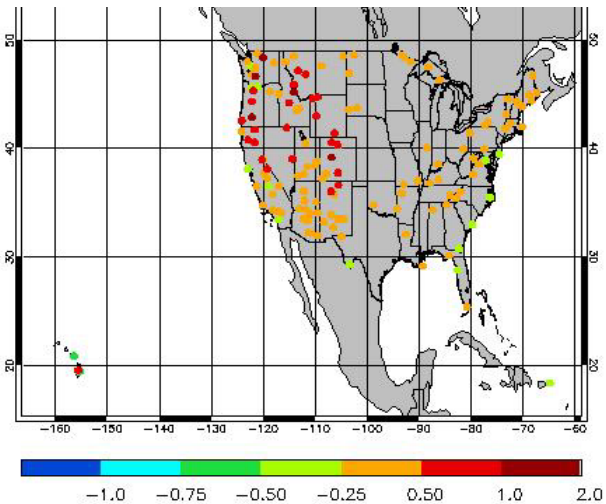

Sulfate
Black Carbon
Organic Carbon
Dust
Sea salt
90N
60N
30N
0
30S
60S
90S
180
120W
60W
0
60E
120E
180
AOT (550nm) from MOZART 2000
0
.0010
.00500
.0100
.0200
.050
0.10
0.15
0.20
0.30
0.40
0.50
0.60
0.70
1.0

Aerosol Model Evaluation

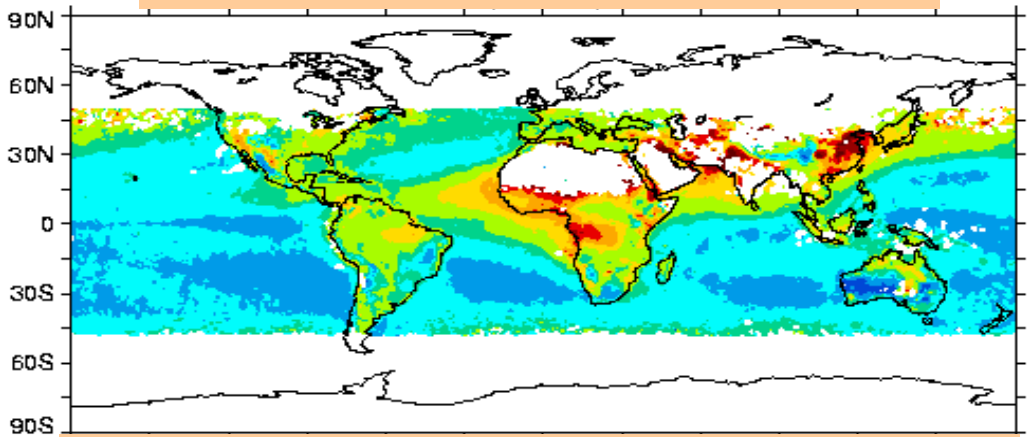
Sulfate ($SO_4^=$)



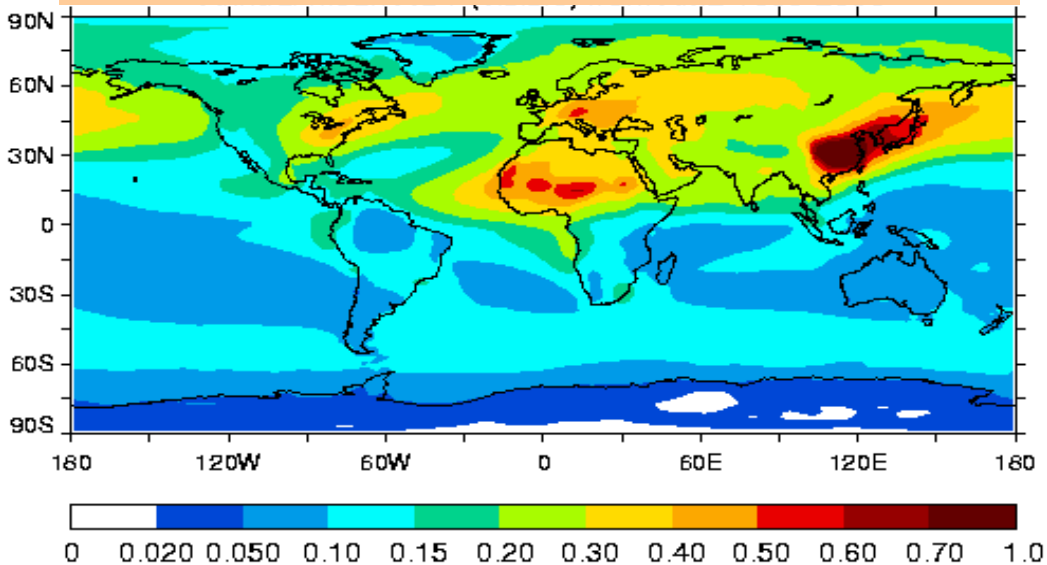
Observations



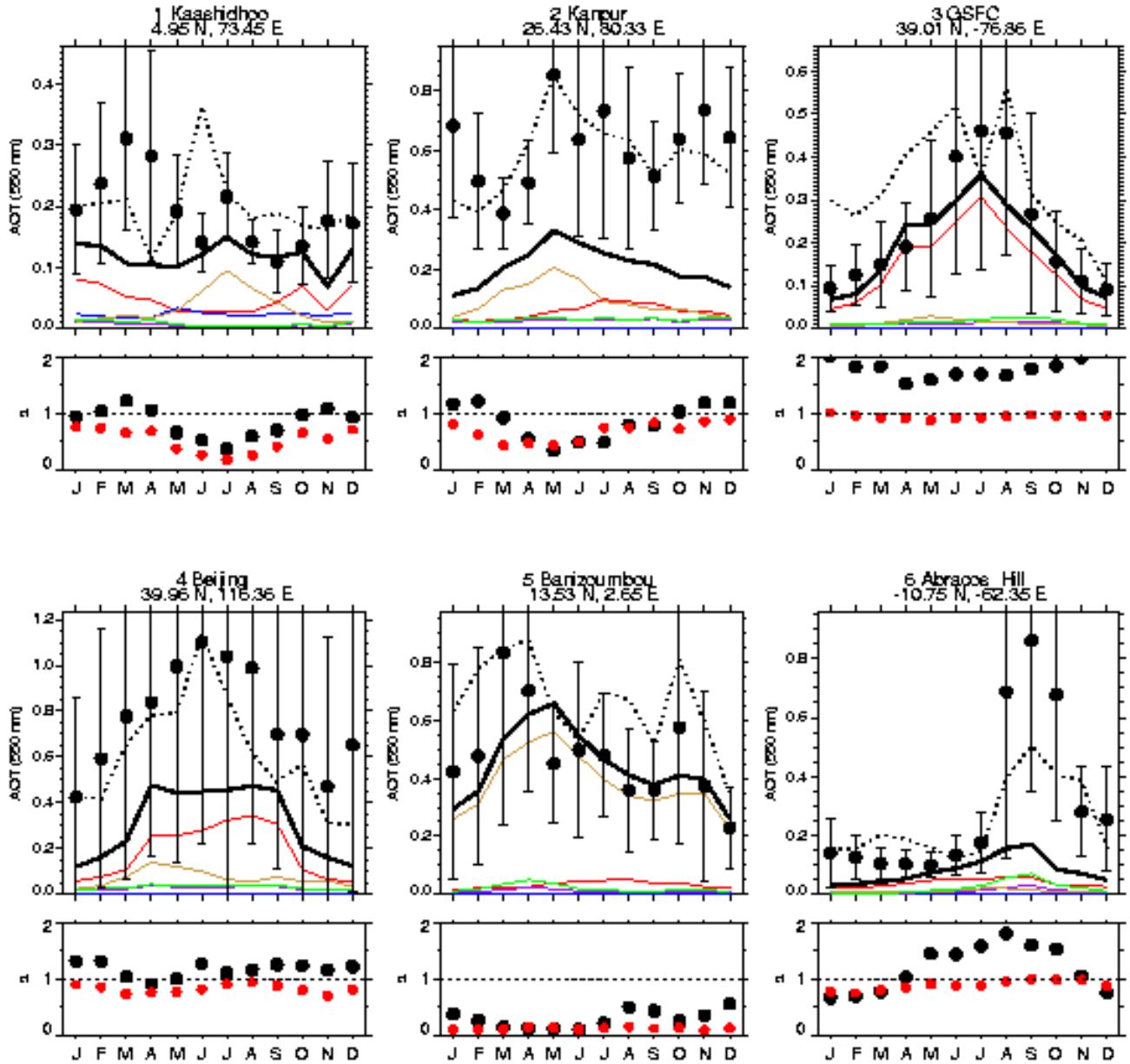
MODIS Annual mean AOT 550nm, 2001



MOZART Annual mean AOT 550nm, 1996-2000



Aerosol Optical Depth: Simulation vs. AERONET, MODIS

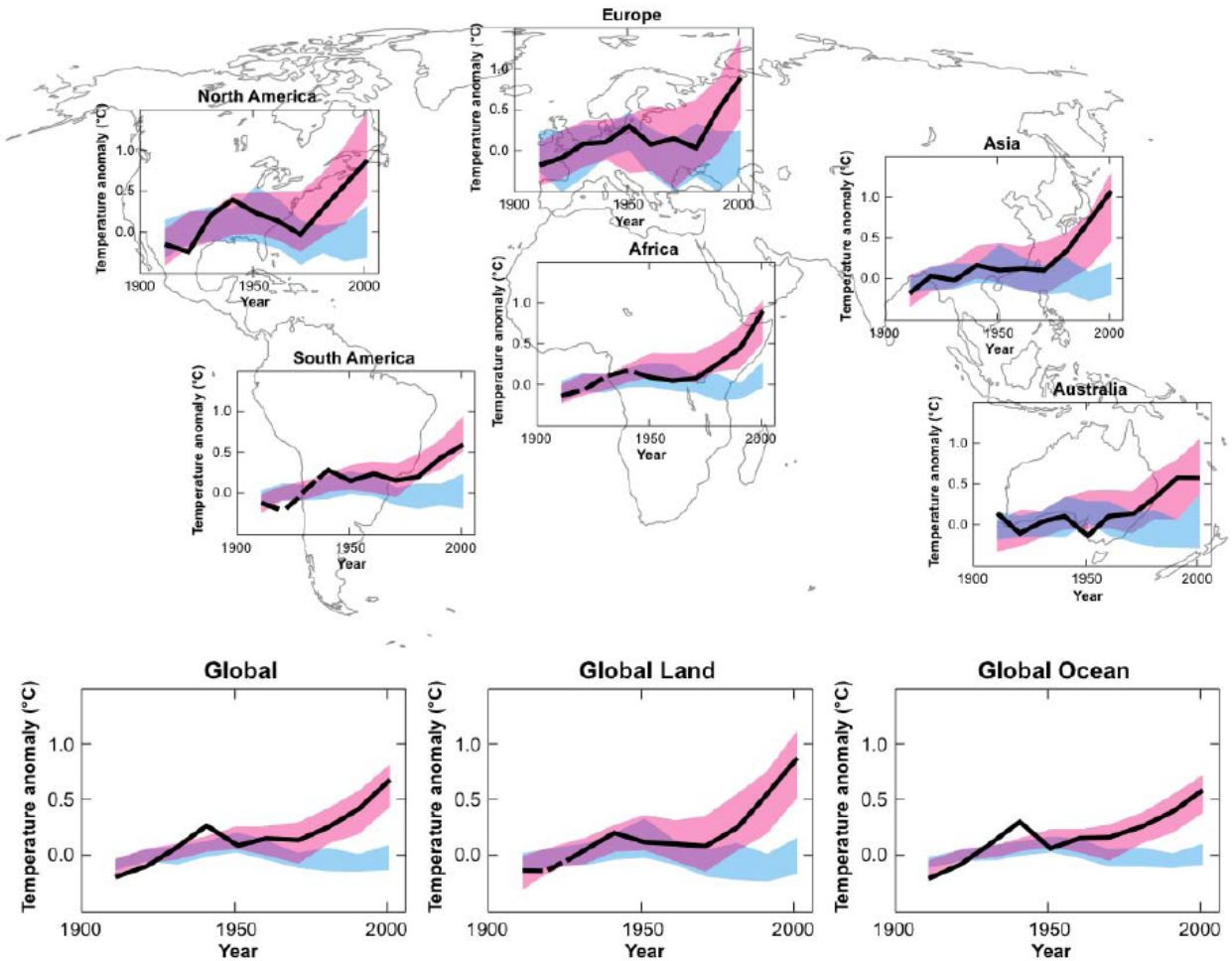


Ginoux et al. (2006)

Continental warming

SPM-4

likely shows a significant anthropogenic contribution over the past 50 years

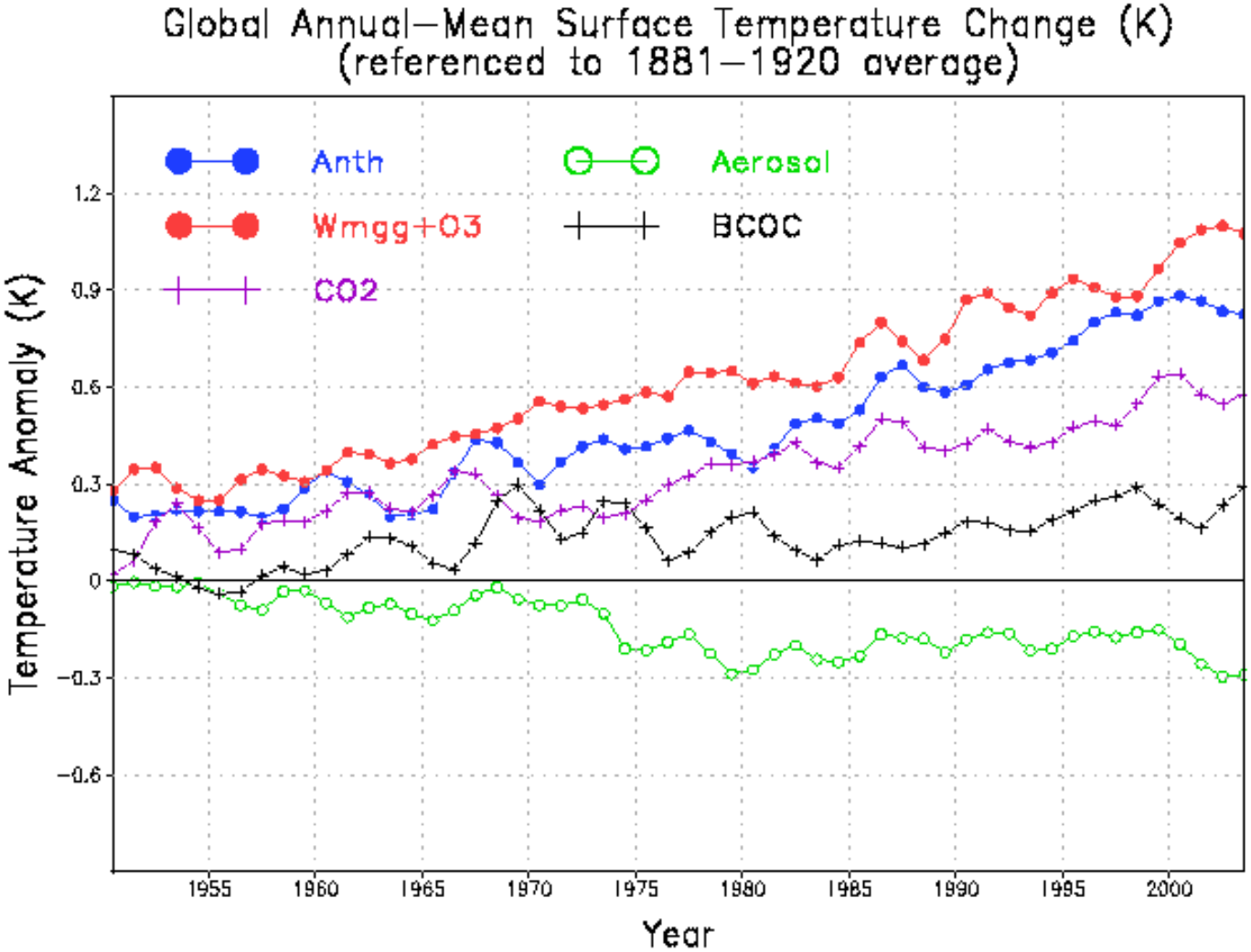


— Observations

All forcing

natural forcing

GFDL Climate Model



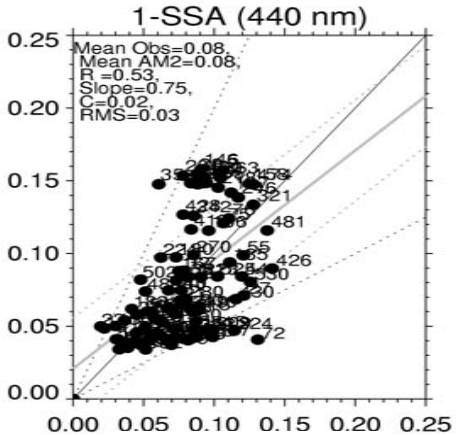
Anthropogenic forcings comprise greenhouse gases and aerosols. Over the 1950-2000 period, contributions by CO2, non-CO2 long-lived gases, ozone, carbonaceous and sulfate aerosols have all been important.

Present……..

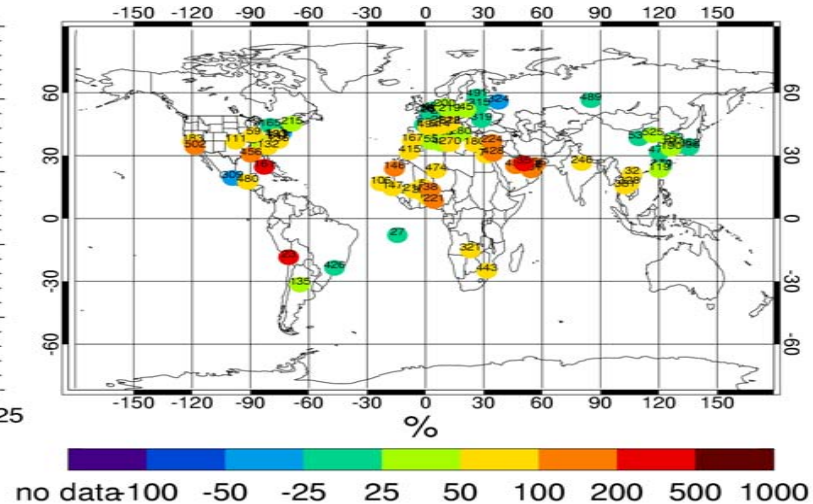
and Future……..

Aerosol co-Albedo

1-w(550)
CM2.1
Off-line Aer
External mx

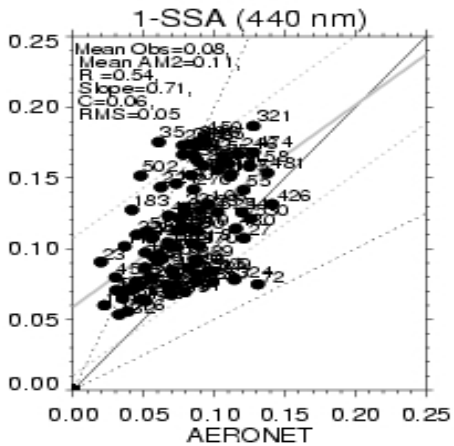


1-w(440)
AERONET

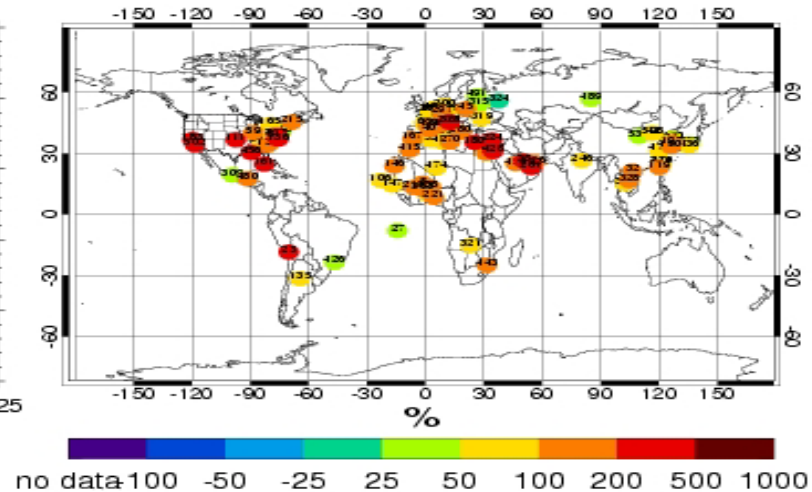


Relative difference (%) model-observation

1-w(550)
AM3
Off-line Aer
Internal mx

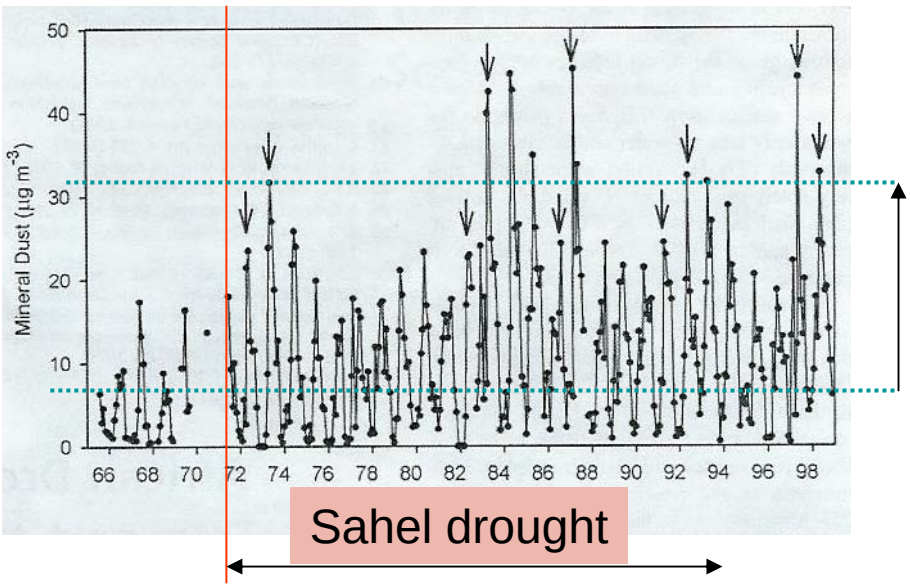


1-w(440)
AERONET



Observed Variability of Dust for the last 50 Years

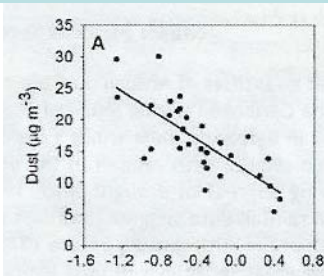
Dust concentration at Barbados (Prospero and Lamb, 2003)



Factor 4 increase

Correlation at Barbados (Prospero and Lamb, 2003)

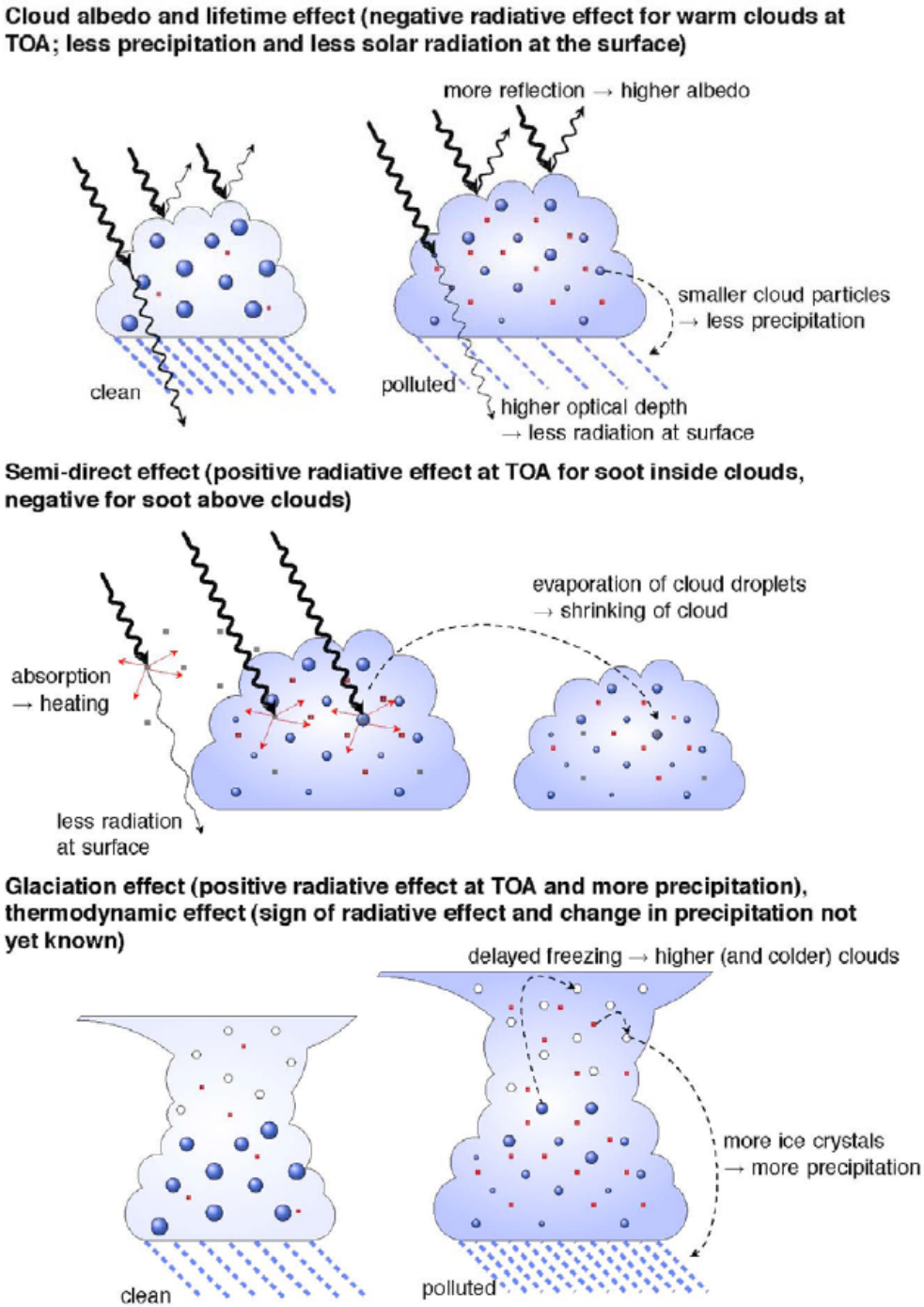
Barbados Dust



Sahel Precipitation Index (previous year)

Since 1970ies dust concentration in Caribbean (Prospero and Lamb, 2003) and dust deposition in French Alps (De Angelis and Gaudichet, 1991) have increased by a factor 4-5

Aerosol-cloud interactions

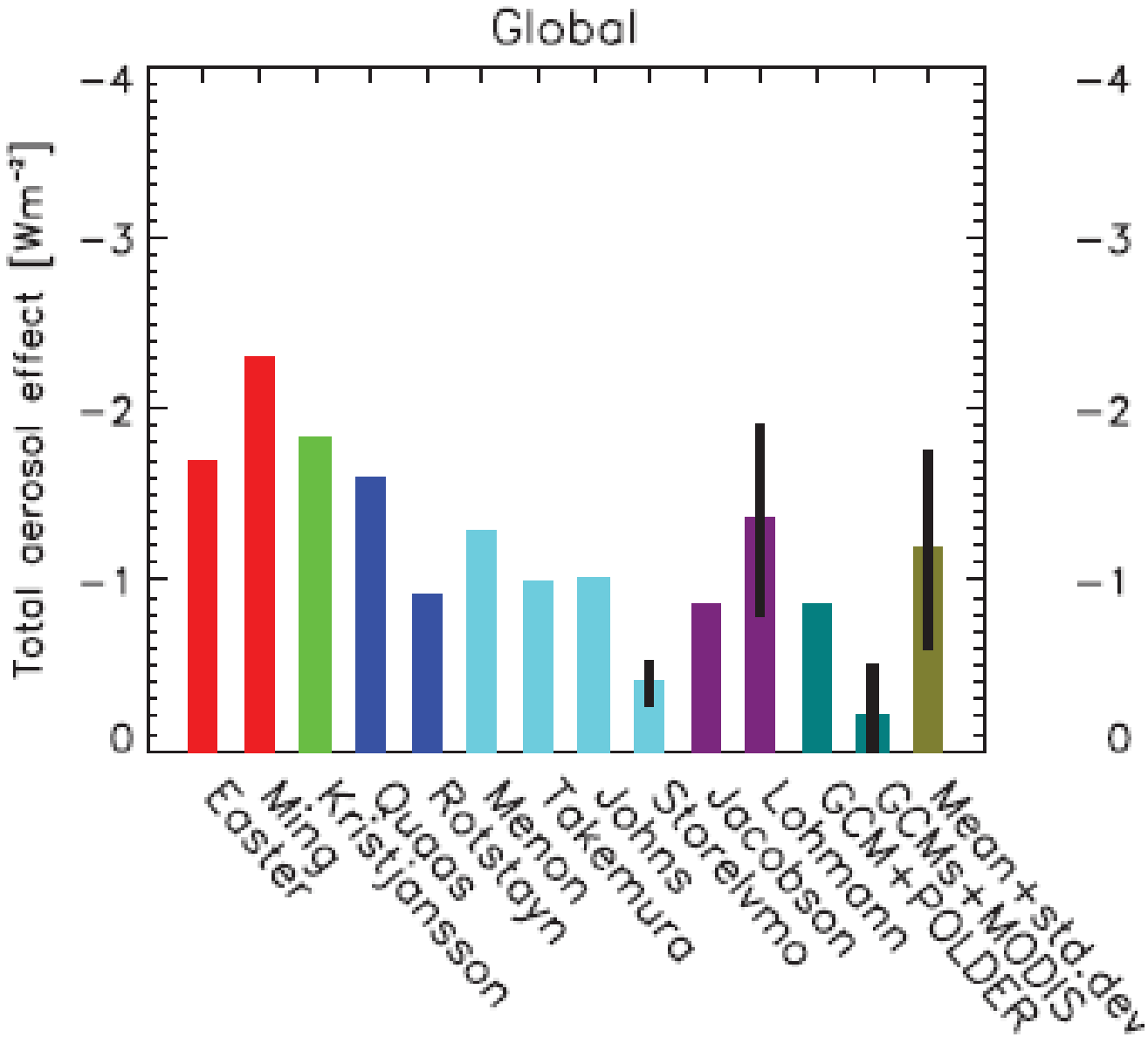


Only the change of cloud albedo induced by aerosols in the context of liquid water clouds, is considered to be radiative forcing

Other processes are not considered as radiative forcings. However, they are included in climate models that explicitly consider the relevant processes

Aerosol effects on ice clouds are poorly understood, and are not quantified.

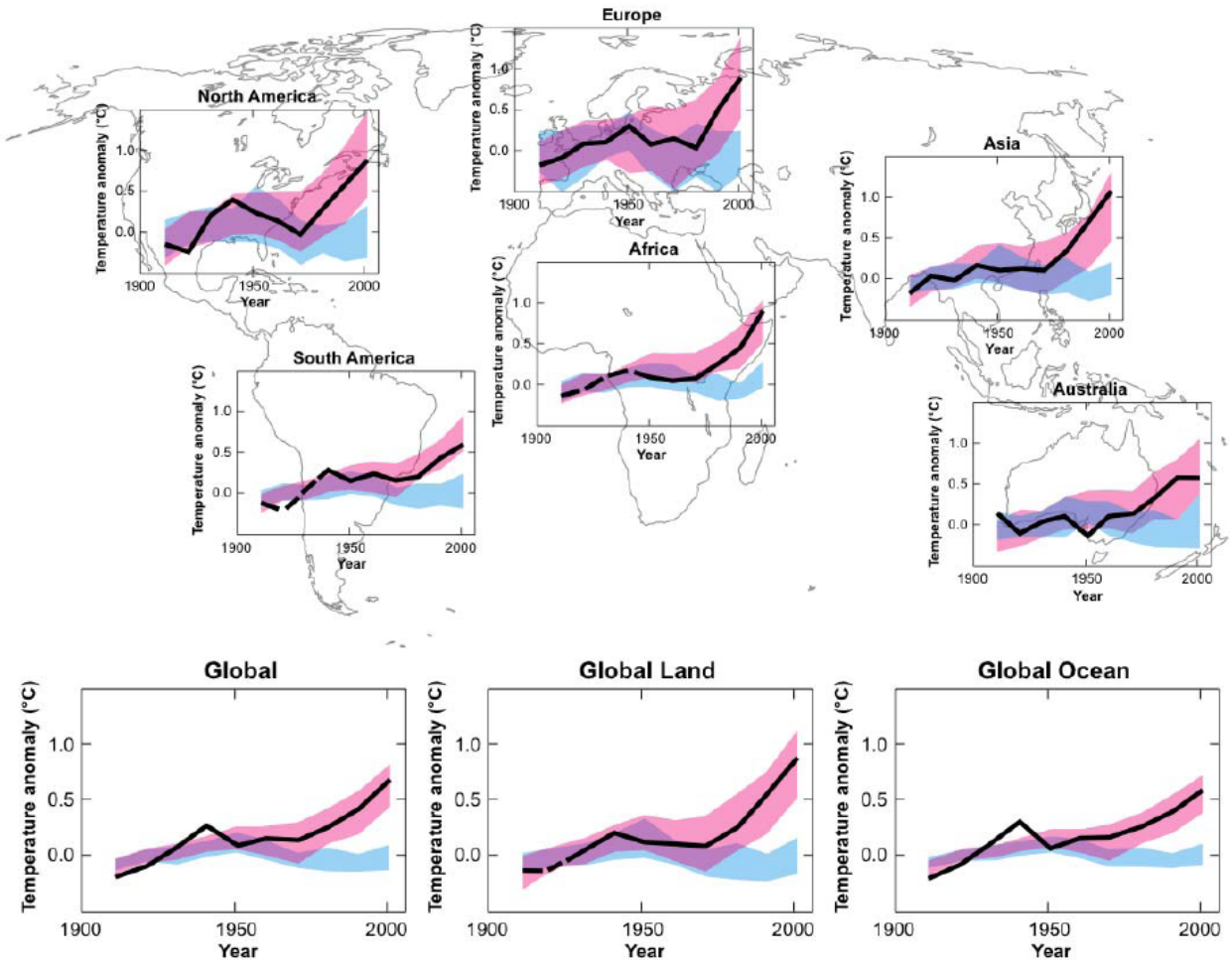
Aerosol cloud interactions [Figure 7.20]


Global
Total aerosol effect [Wm^{-2}]
−4
−3
−2
−1
0
Easter
Ming
Kristjansson
Quaas
Rotstayn
Menon
Takemura
Johns
Storelvmo
Jacobson
Lohmann
GCM+POLDER
GCMs+MODIS
Mean+std.dev

Continental warming

SPM-4

likely shows a significant anthropogenic contribution over the past 50 years

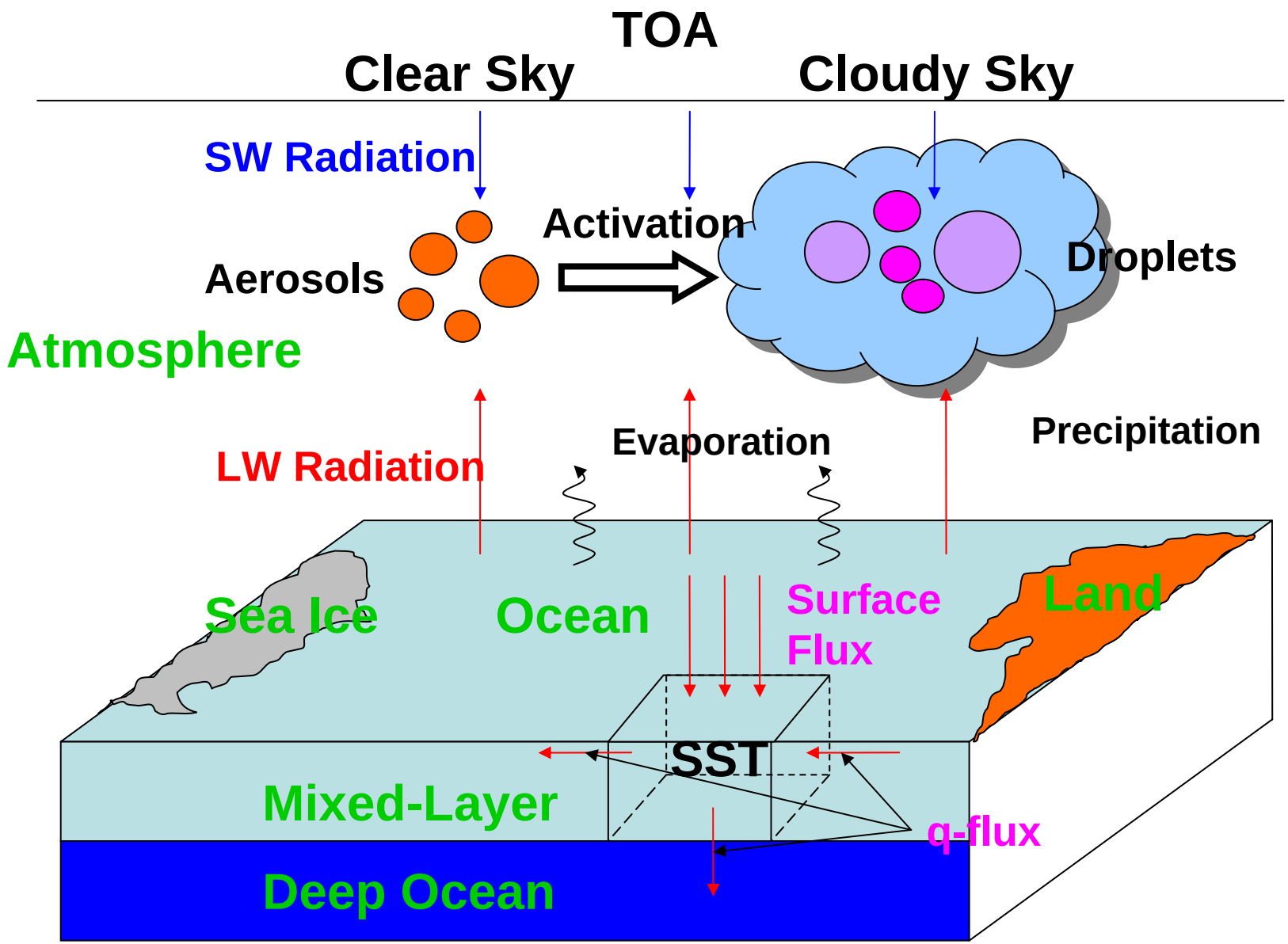


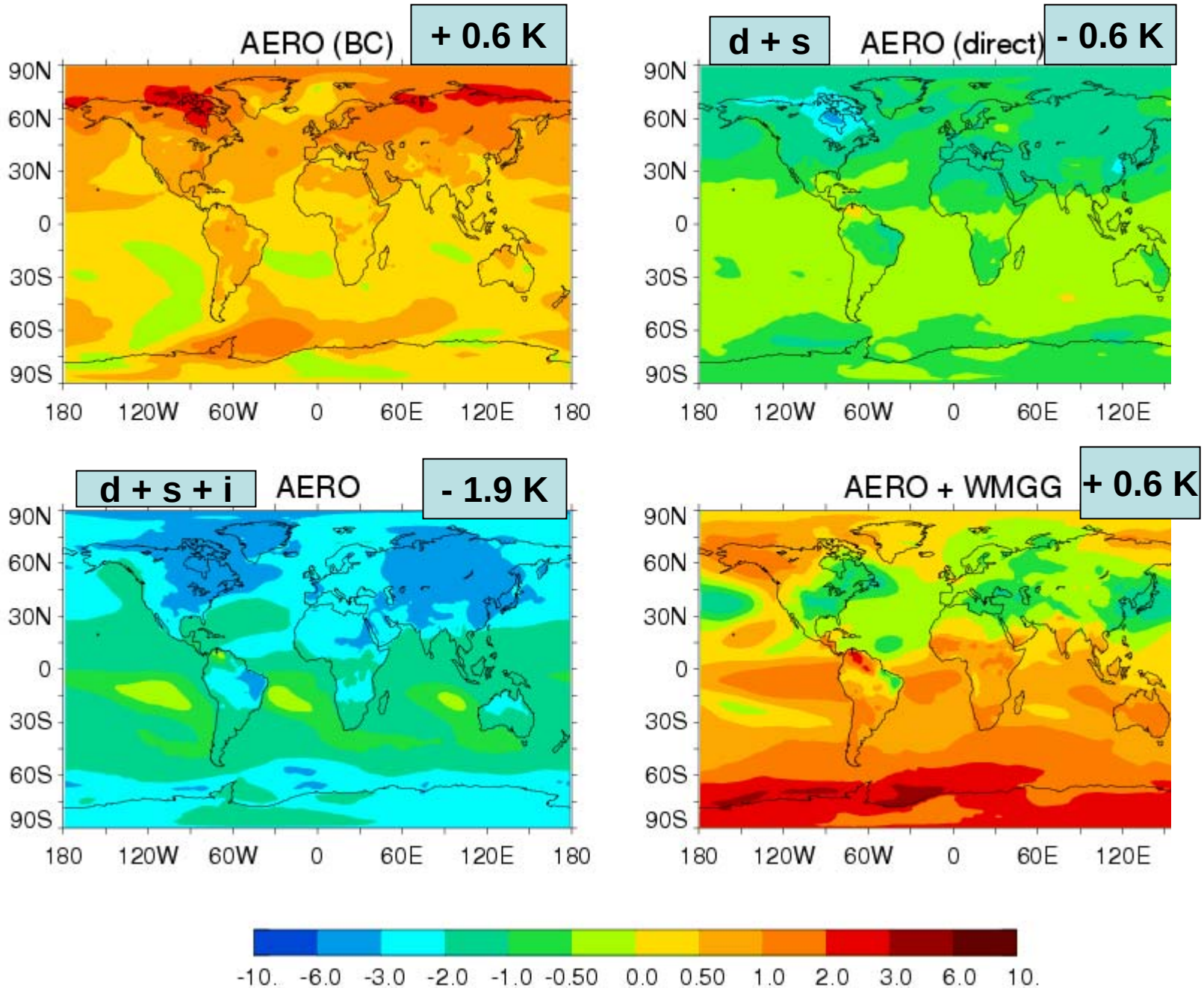
— Observations

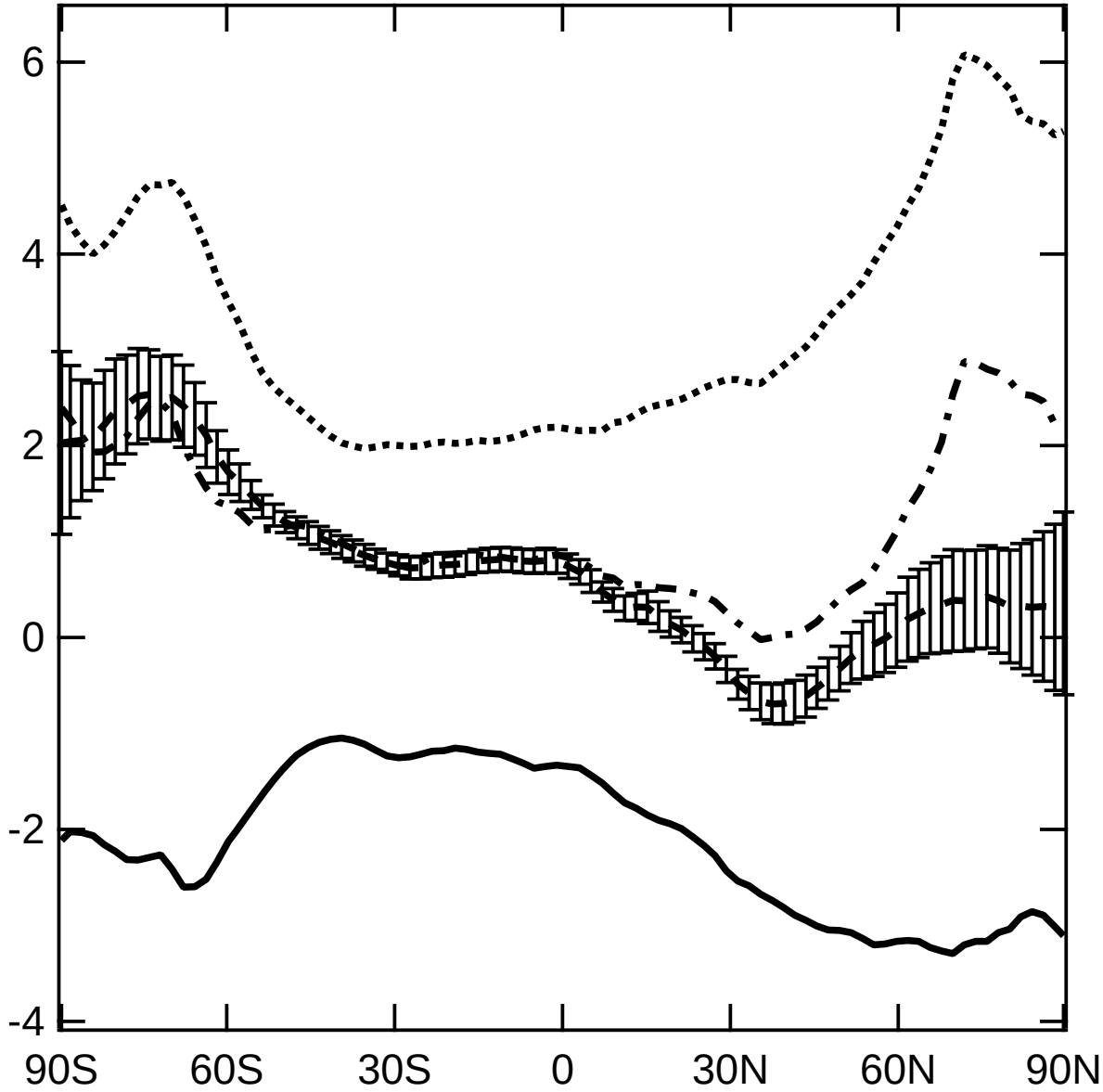
All forcing

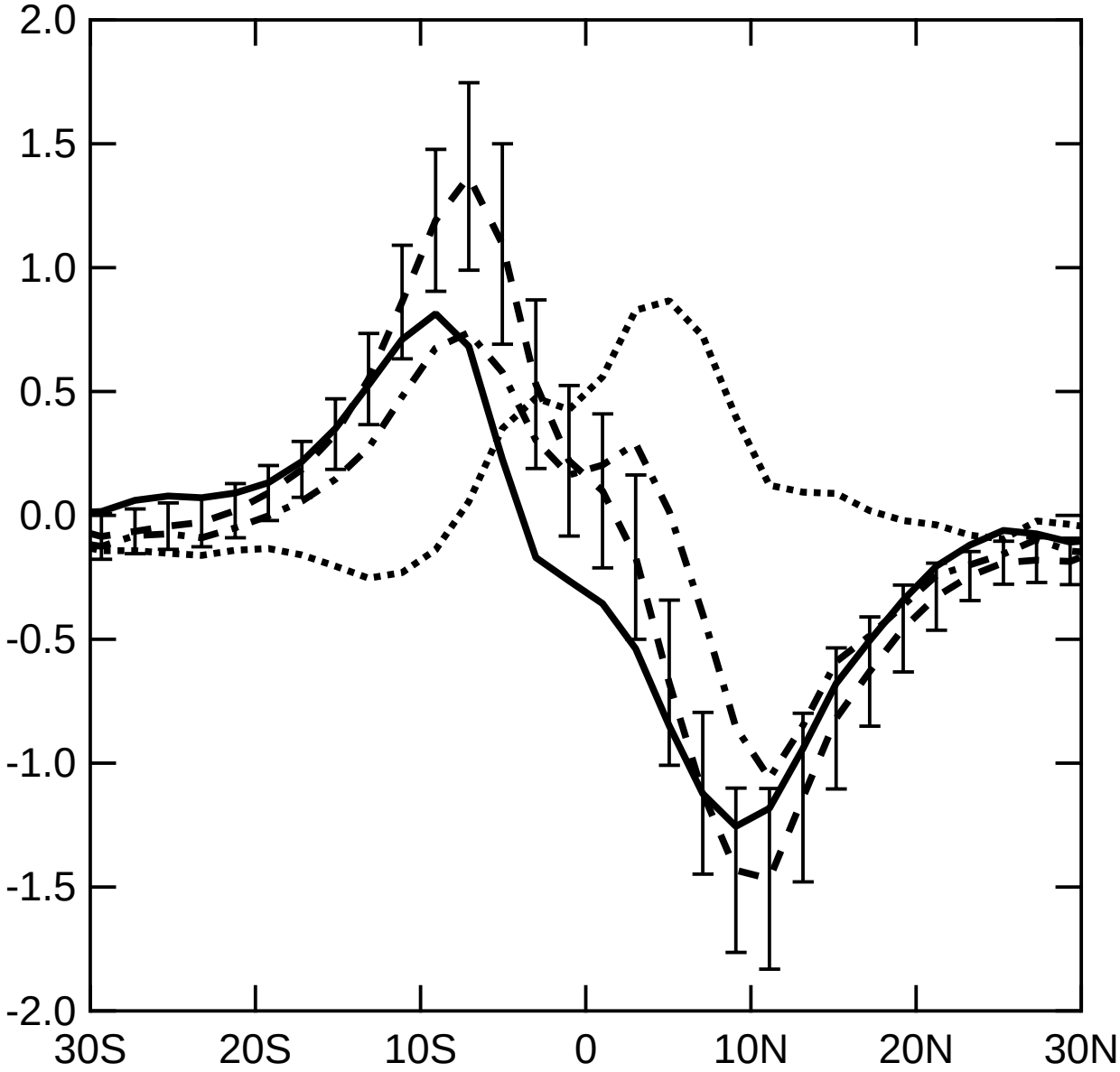
natural forcing

A coupled atmosphere – mixed-layer ocean general circulation model

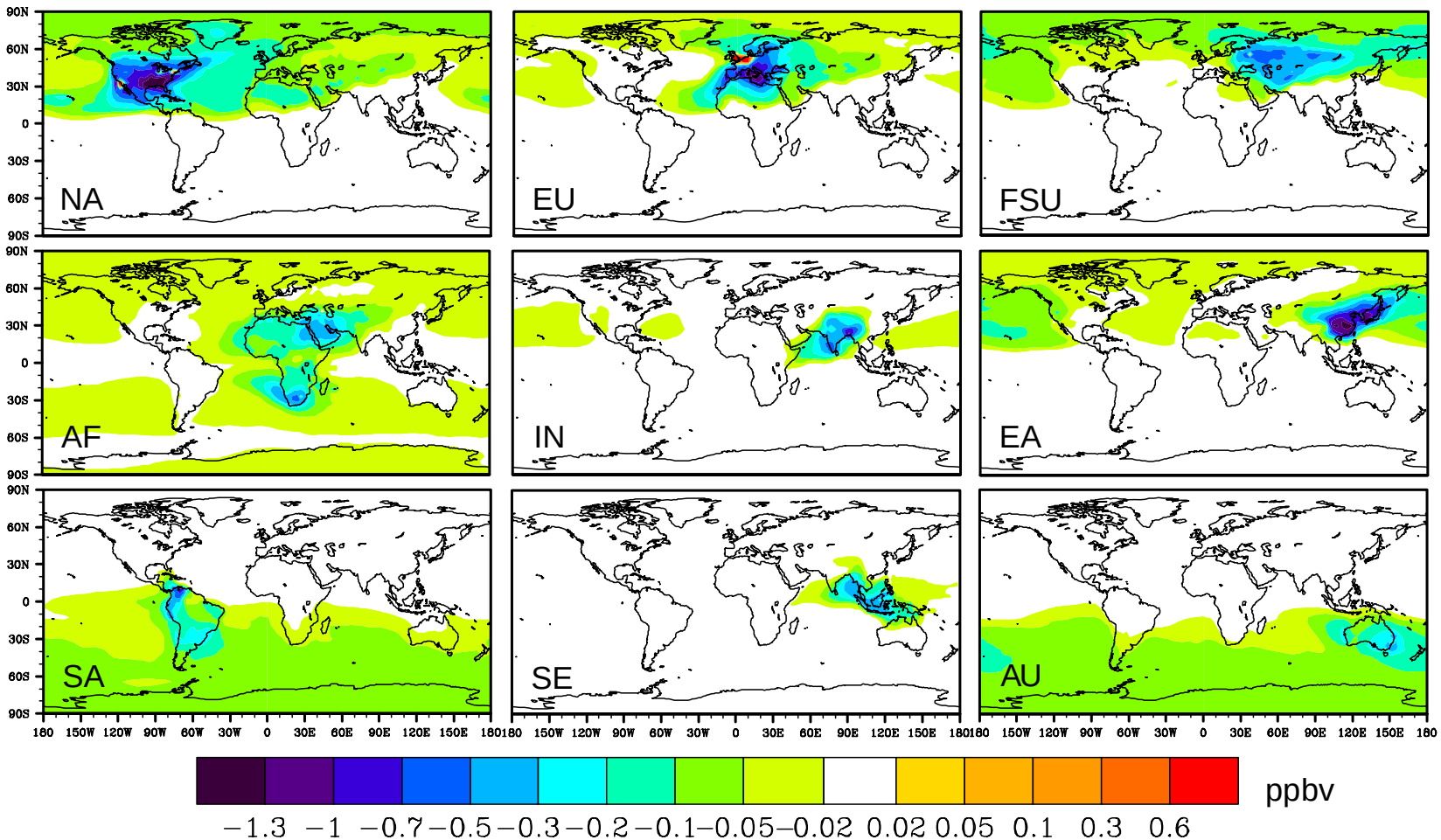



AERO (BC)
+ 0.6 K
d + s
AERO (direct)
- 0.6 K
d + s + i
AERO
- 1.9 K
AERO + WMGG
+ 0.6 K
90N
60N
30N
0
30S
60S
90S
180
120W
60W
0
60E
120E
180
-10.
-6.0
-3.0
-2.0
-1.0
-0.50
0.0
0.50
1.0
2.0
3.0
6.0
10.


6
4
2
0
-2
-4
90S
60S
30S
0
30N
60N
90N


2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
30S
20S
10S
0
10N
20N
30N

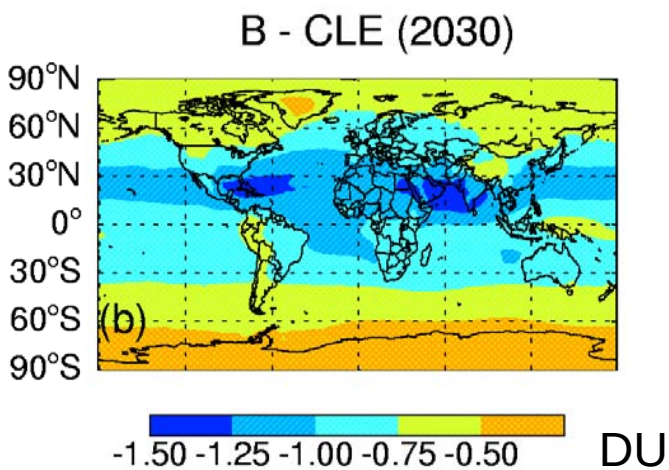
Long-Range Transport:
Influence of regional NO_x emissions on global surface ozone



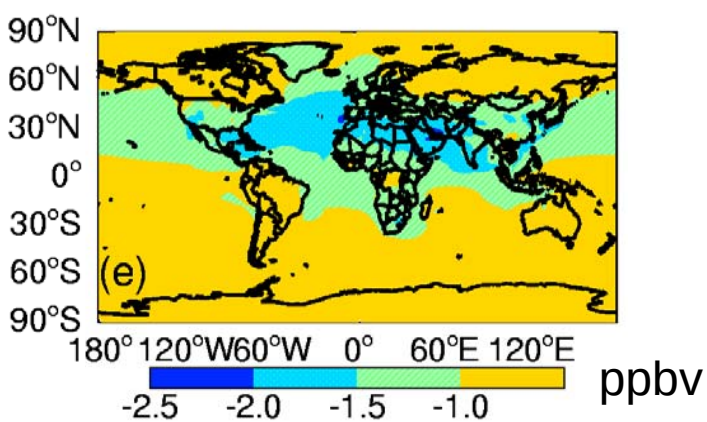
West et al., manuscript in preparation

Ozone Reduction from Decreasing Methane Emissions

Tropospheric ozone column



Average 8-hour maximum surface ozone

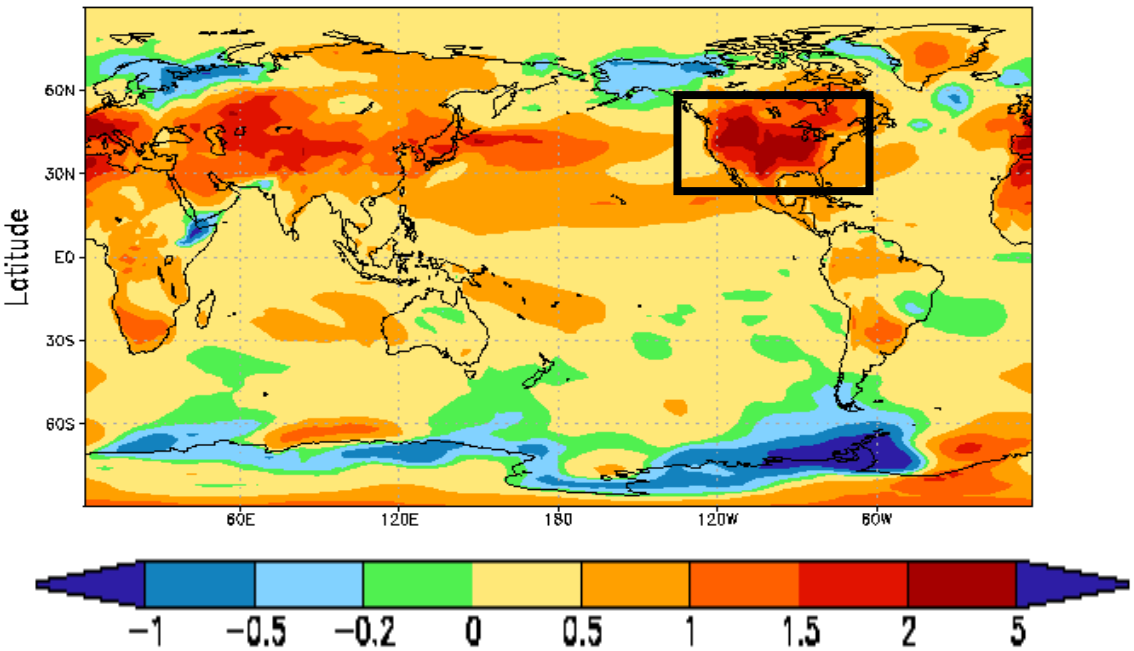


Effect of 125 Tg/yr (29%) reduction in anthropogenic methane emissions in 2030 versus CLE (current legislation) scenario

Fiore et al., submitted to JGR

A “WIN-LOSE” CASE: Global decreases in sulfate aerosol contribute to warmer U.S. summers

Change in Summer Temperature from 2000 to 2090 (°C) resulting from projected changes in air pollutants



Warming over U.S. is due in part to decreases in sulfate driven by pollution control efforts (better air quality; not so for climate)

in GFDL Climate Model [Levy *et al*., 2006]

Present……..

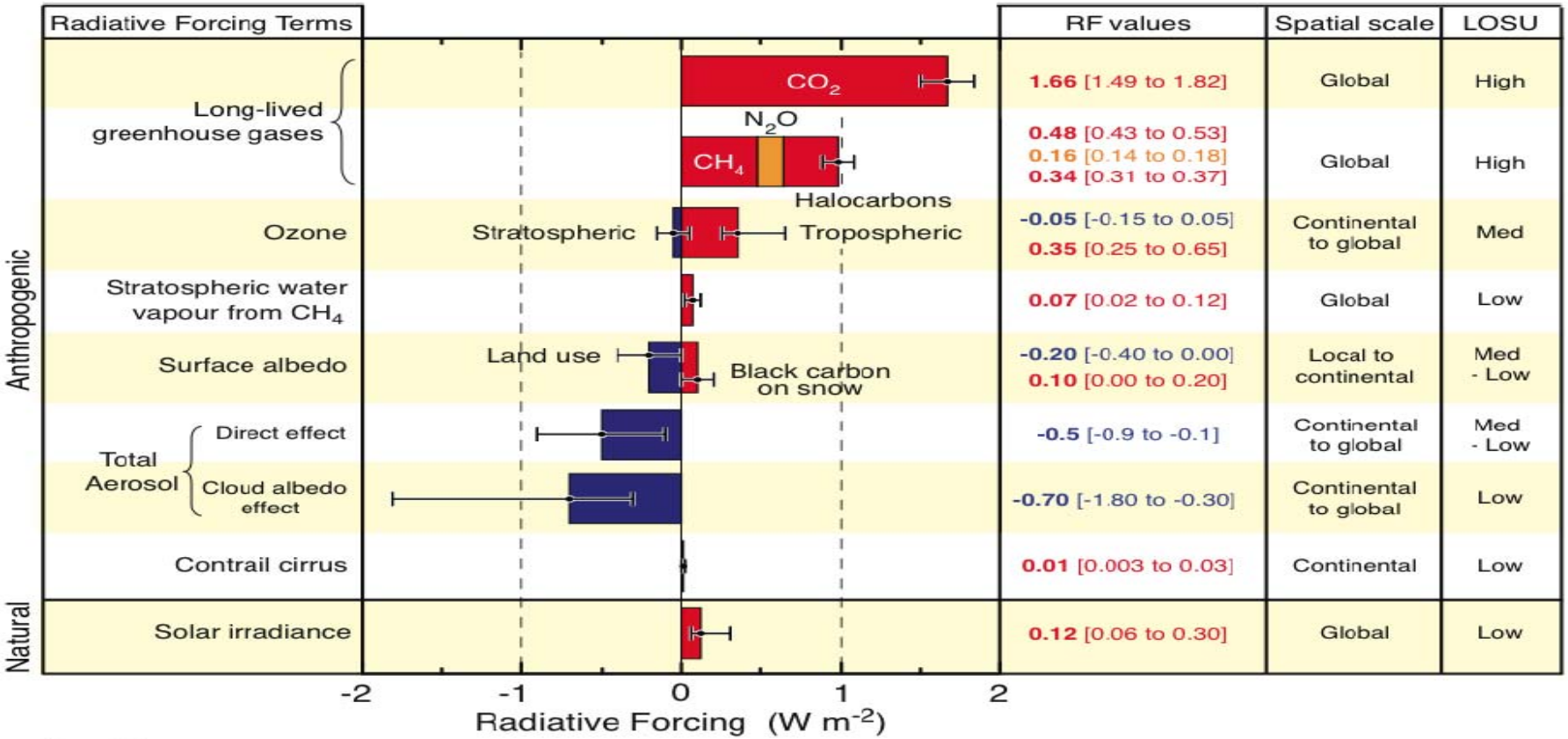
and Future……..

- Aerosol direct effect….including dust
- Aerosol internal mixture (sulfate+carbonaceous)
- Aerosol-Cloud interactions
- Climate forcing – Global Pollution links

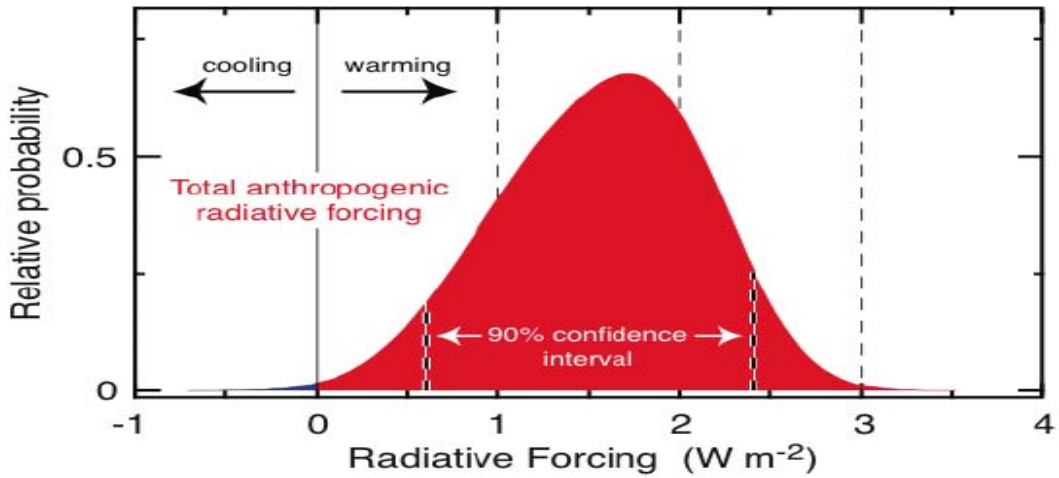
Emerging……..post-AR4……..

- Desire for a specific focus on climate change in the near-term (~2030), with simultaneous attention to pollutants and high spatial resolution for capturing the regionality.

- Interests of the Impacts, Adaptation, Mitigation communities in the results from climate models [both near-term and long-term (e.g., carbon cycle feedback)]

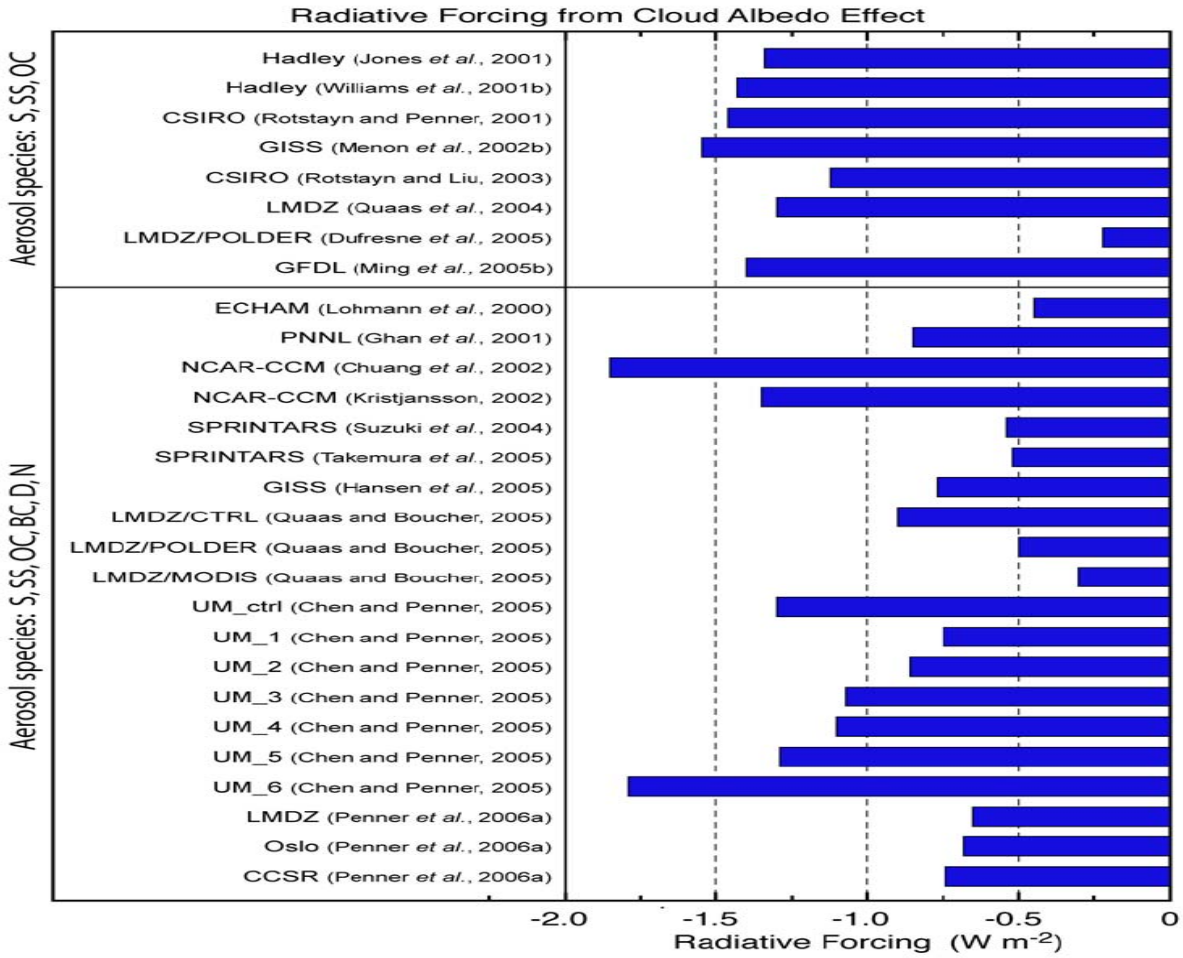


Panel A.



Agents of Climate Forcing

Estimates of the Cloud Albedo radiative forcing due to aerosols from different models [Figure 2.14]

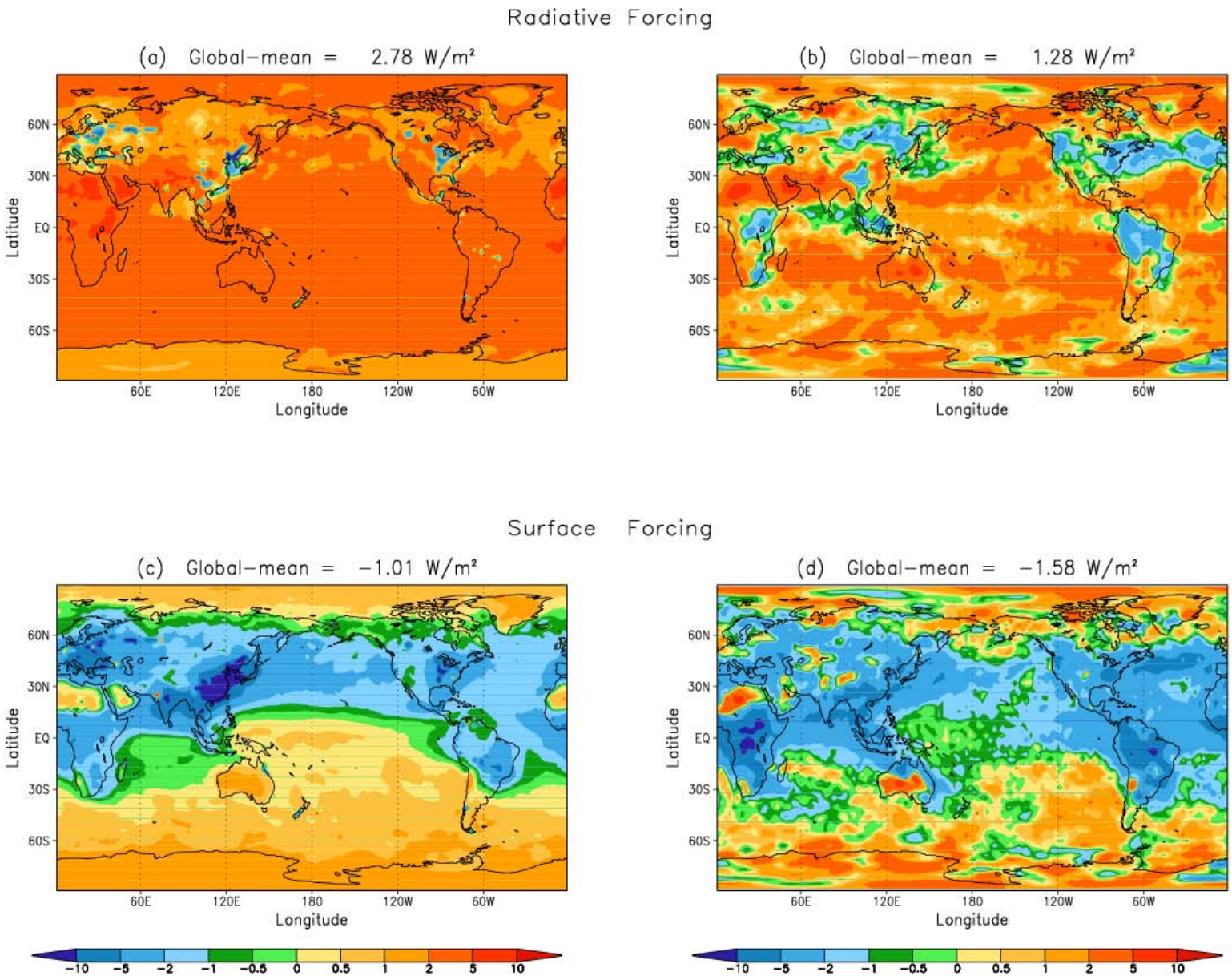


***Best estimate*:**
-0.7 W/m^2

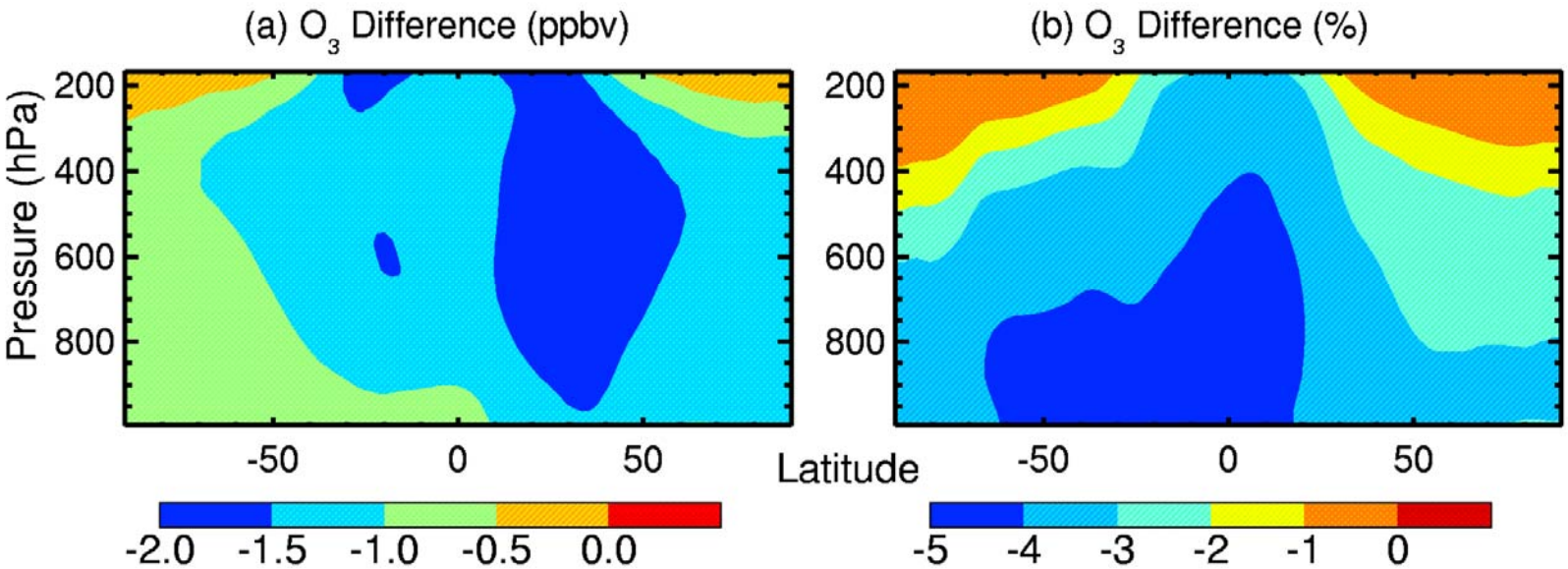
***Range*:**
-1.8 to -0.3 W/m^2

More model studies since the TAR, many include more species

Those with more aerosol species or constrained by satellite observations have a weaker radiative forcing

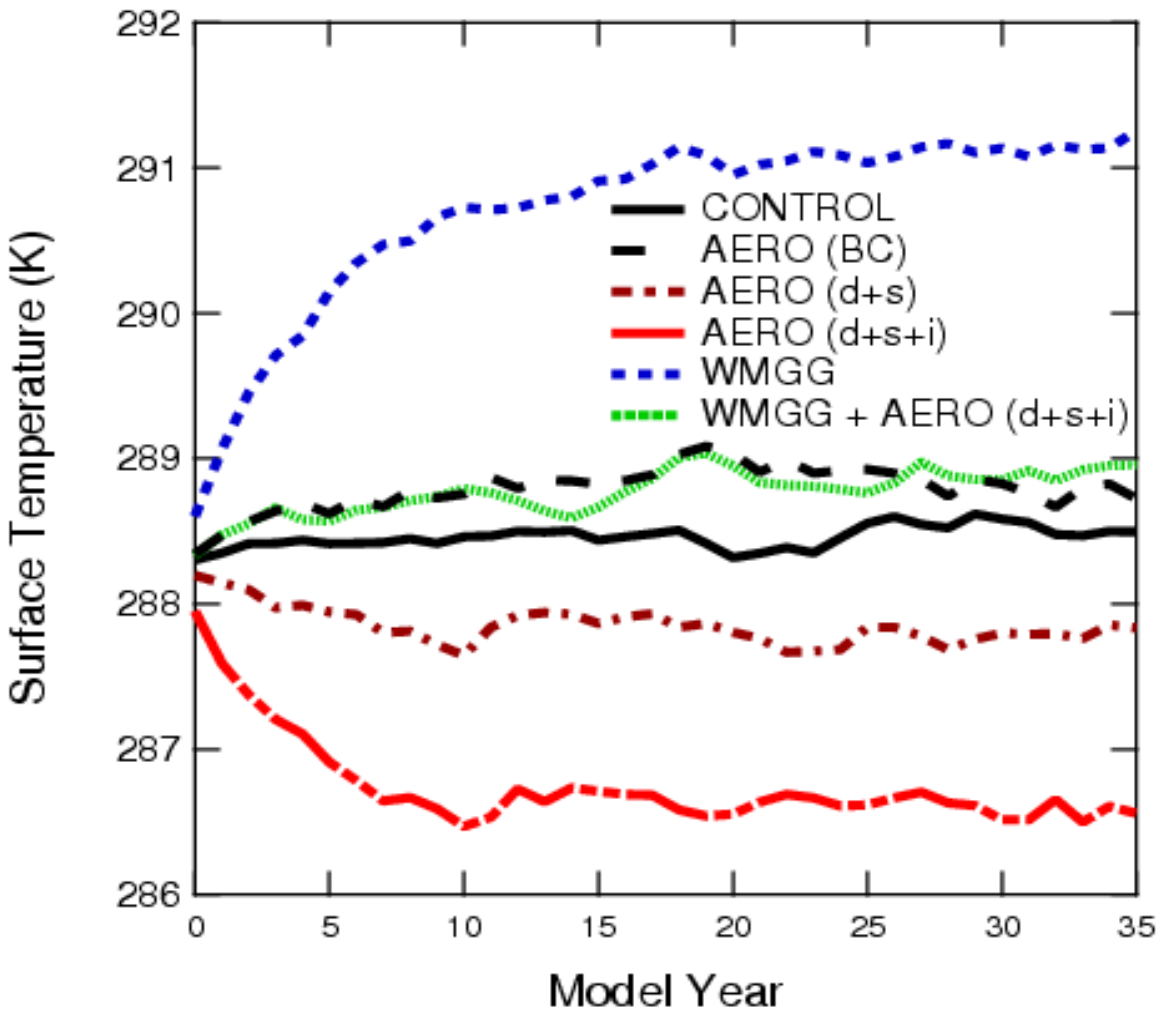

Radiative Forcing
(a) Global−mean = 2.78 W/m²
(b) Global−mean = 1.28 W/m²
Surface Forcing
(c) Global−mean = −1.01 W/m²
(d) Global−mean = −1.58 W/m²
Latitude
60N
30N
EQ
30S
60S
Longitude
60E
120E
180
120W
60W
−10
−5
−2
−1
−0.5
0
0.5
1
2
5
10

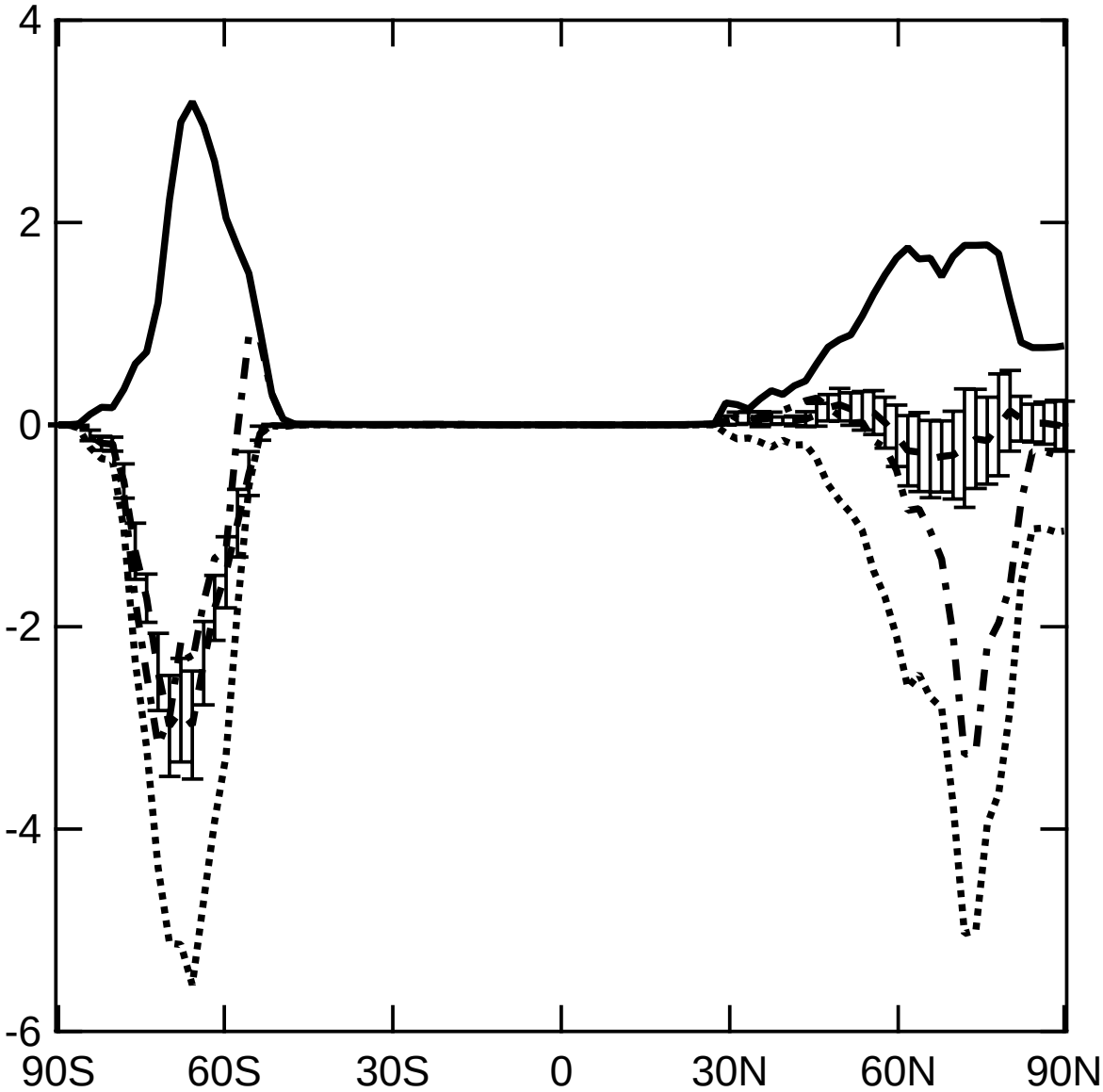
Ozone Reduction from Decreasing Methane Emissions

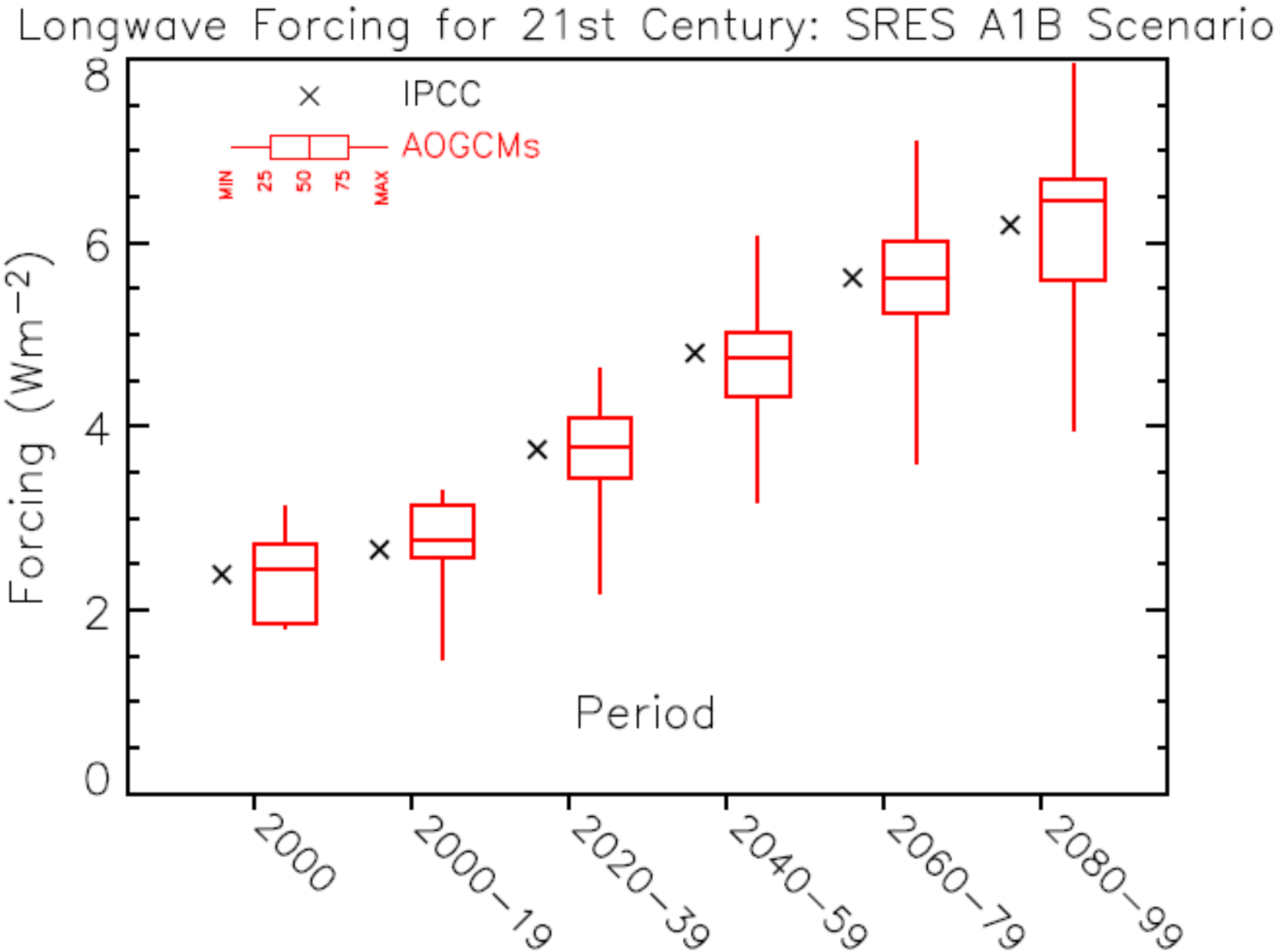


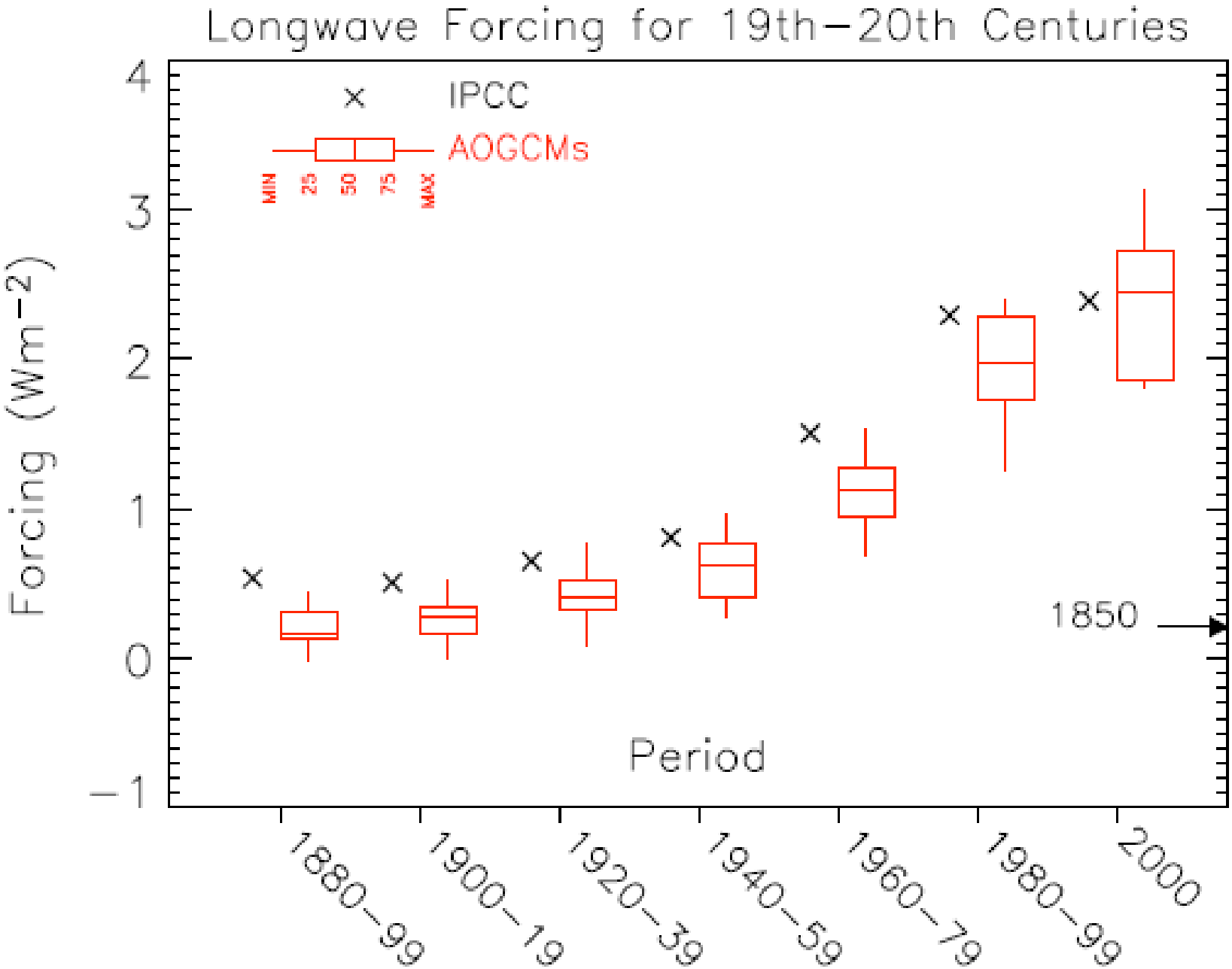
Distribution of tropospheric ozone reduction from a sustained 97 Tg/yr (18%) reduction in total methane emissions (after 30 years)

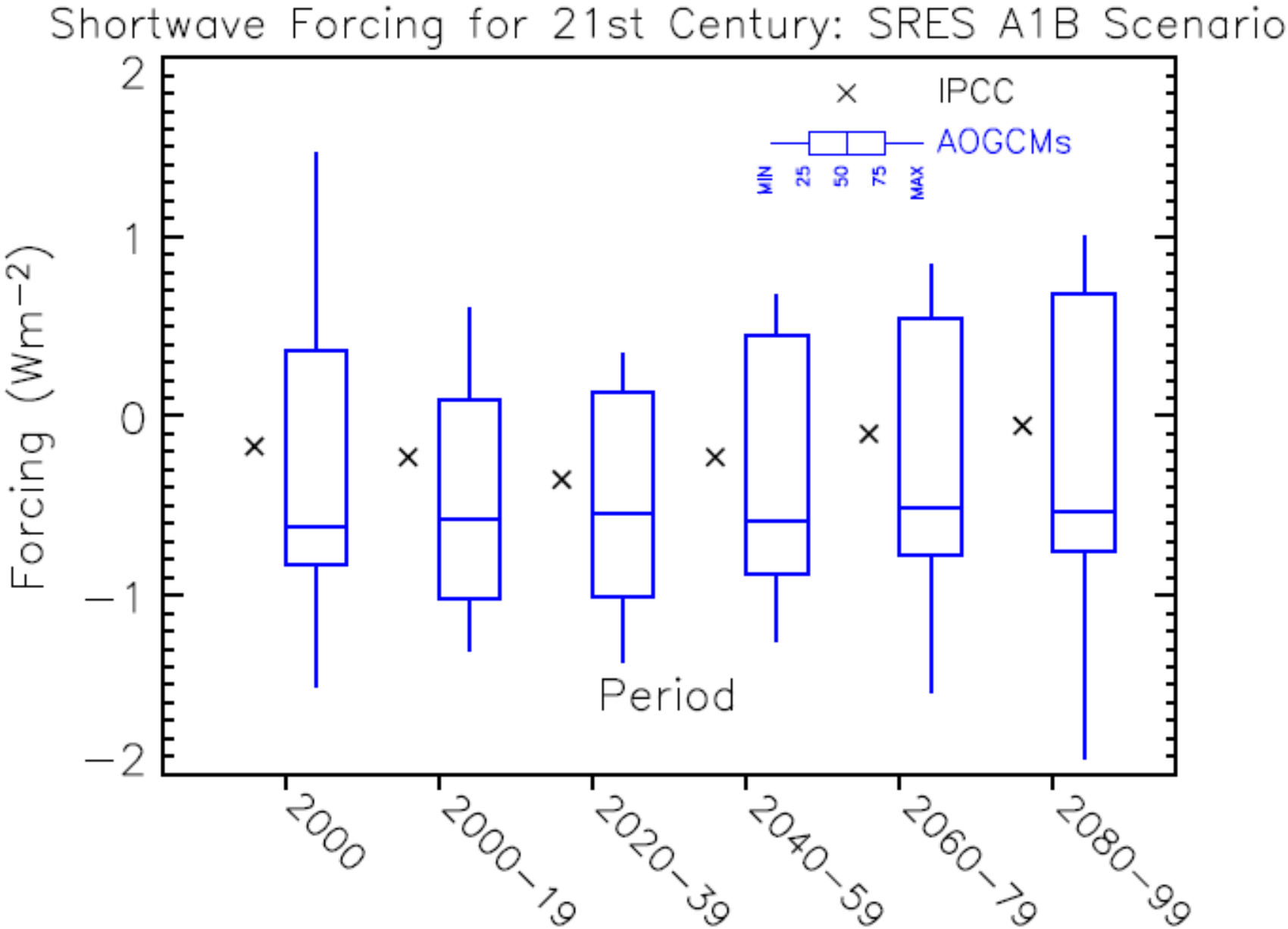
Fiore et al., submitted to JGR

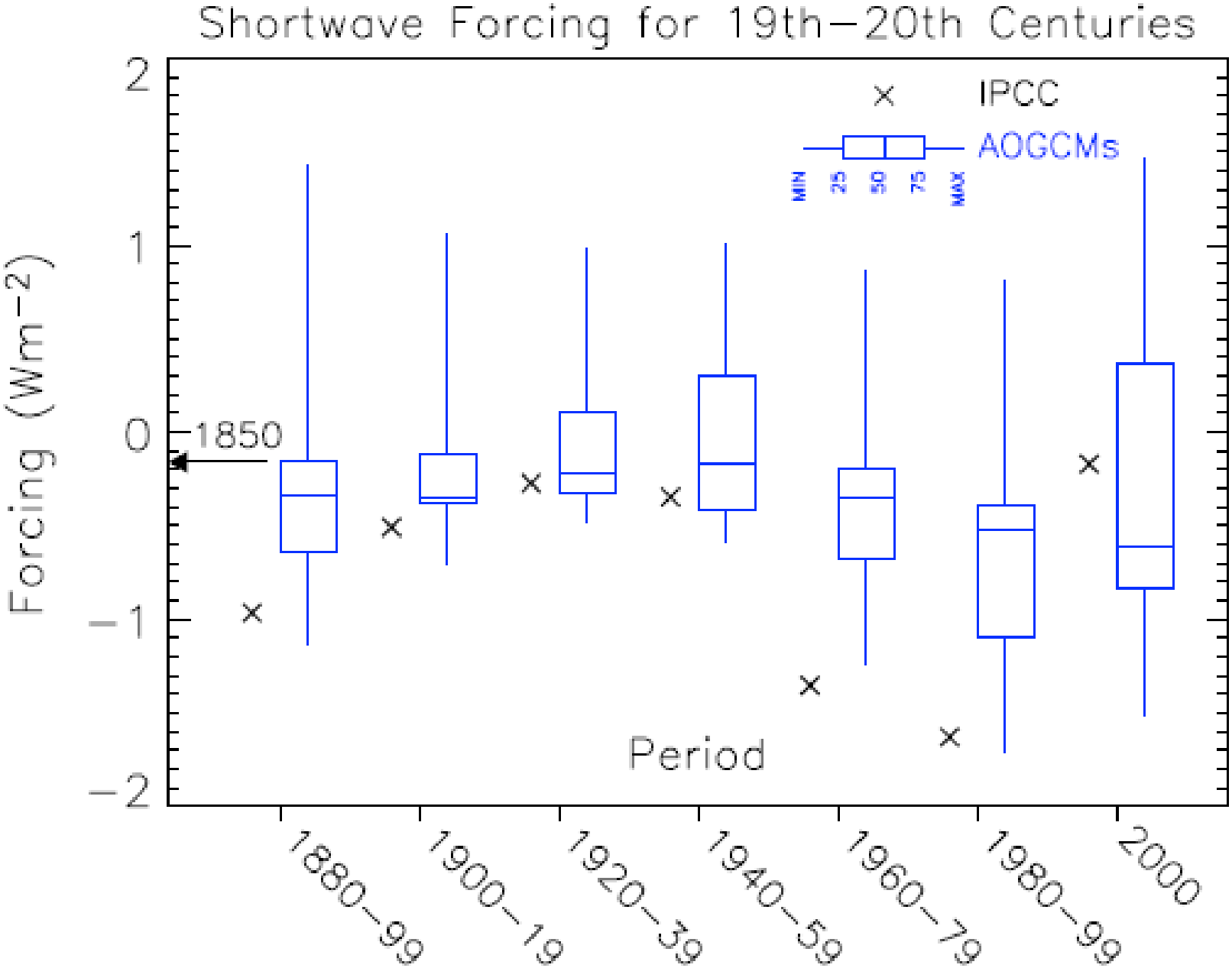

292
291
290
289
288
287
286
0
5
10
15
20
25
30
35
Surface Temperature (K)
Model Year
CONTROL
AERO (BC)
AERO (d+s)
AERO (d+s+i)
WMGG
WMGG + AERO (d+s+i)

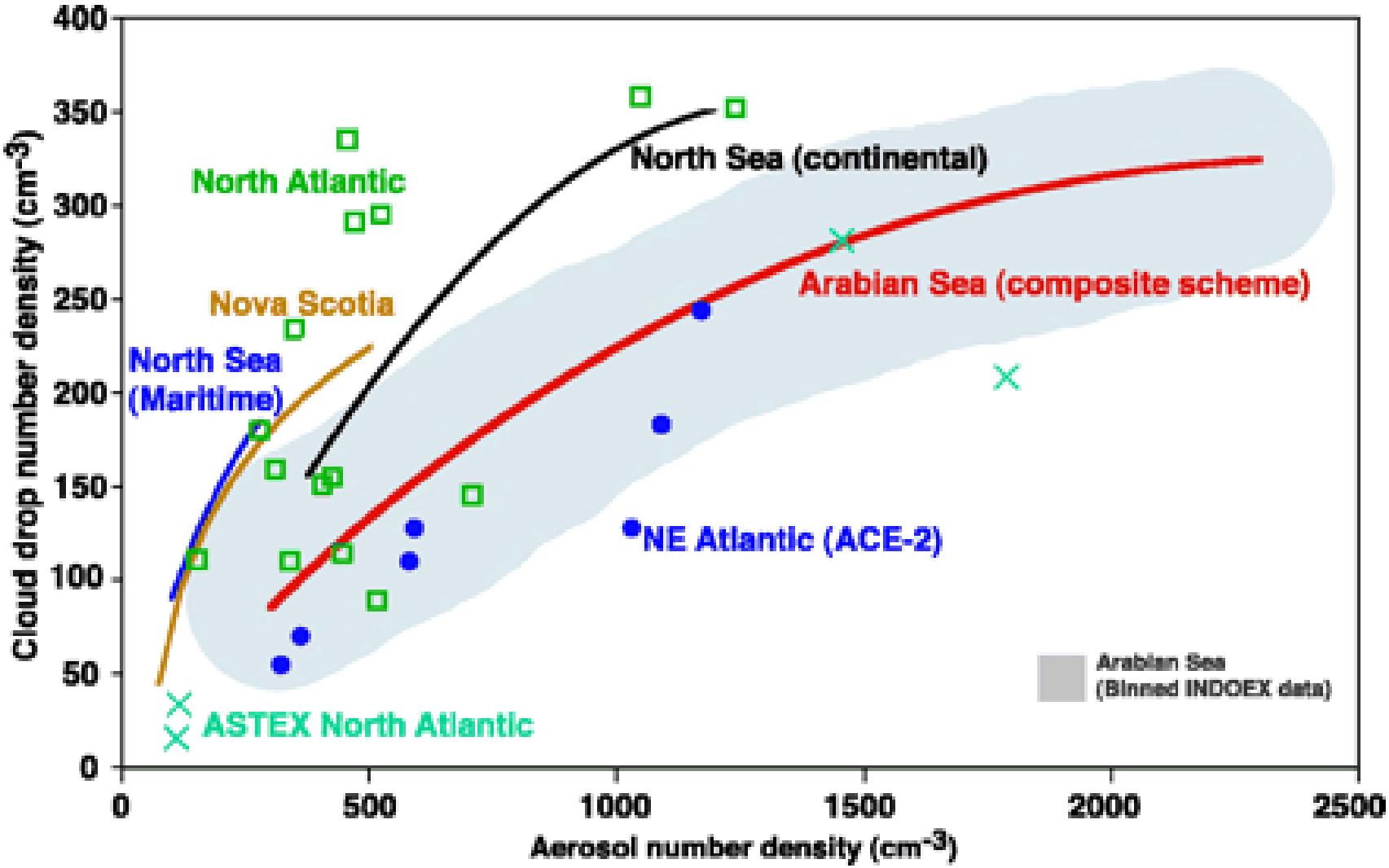

4
2
0
-2
-4
-6
90S
60S
30S
0
30N
60N
90N


Longwave Forcing for 21st Century: SRES A1B Scenario
IPCC
AOGCMs
MIN
25
50
75
MAX
Forcing (Wm^{-2})
0
2
4
6
8
Period
2000
2000–19
2020–39
2040–59
2060–79
2080–99


Longwave Forcing for 19th–20th Centuries
IPCC
AOGCMs
MIN
25
50
75
MAX
Forcing (Wm^{-2})
4
3
2
1
0
−1
1850
Period
1880–99
1900–19
1920–39
1940–59
1960–79
1980–99
2000


Shortwave Forcing for 21st Century: SRES A1B Scenario
IPCC
AOGCMs
MIN
25
50
75
MAX
Forcing (Wm−2)
2
1
0
−1
−2
Period
2000
2000−19
2020−39
2040−59
2060−79
2080−99


Shortwave Forcing for 19th–20th Centuries
IPCC
AOGCMs
MIN
25
50
75
MAX
1850
Forcing (Wm−2)
2
1
0
−1
−2
Period
1880–99
1900–19
1920–39
1940–59
1960–79
1980–99
2000



Ramanathan et al. (2001)

Aerosol Indirect Effects (1st and 2nd)

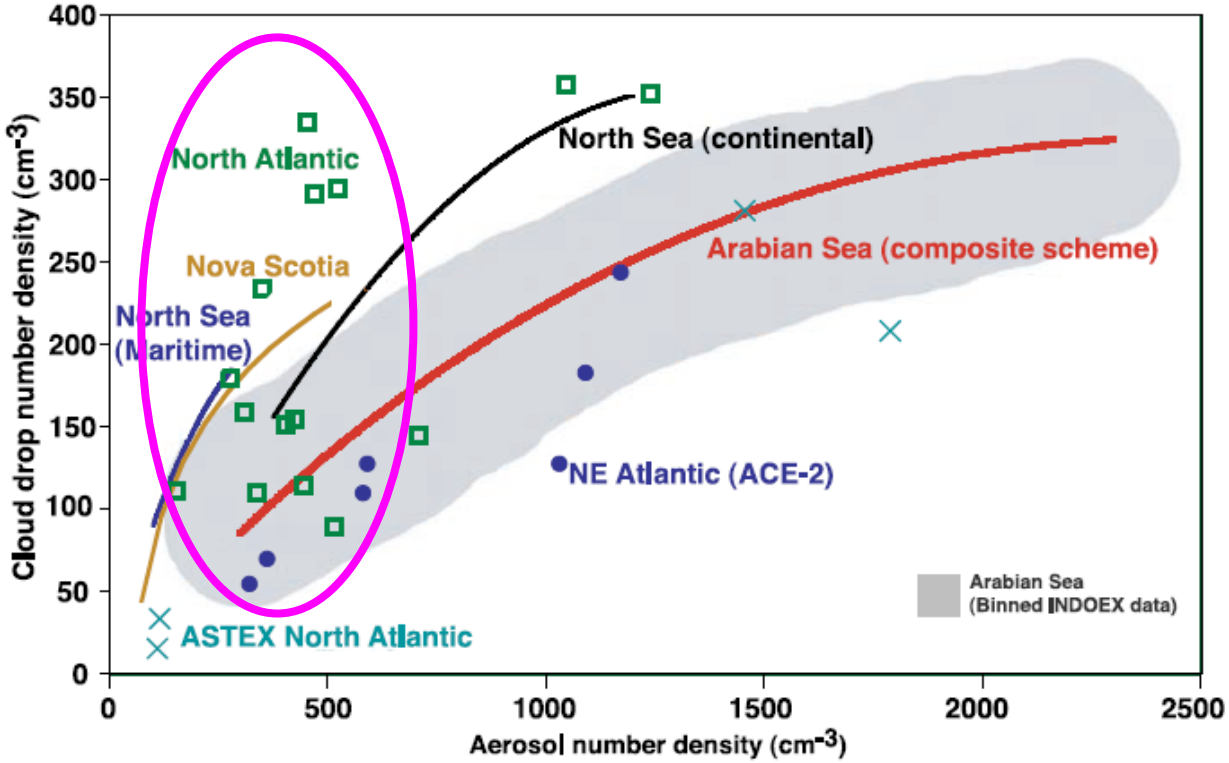
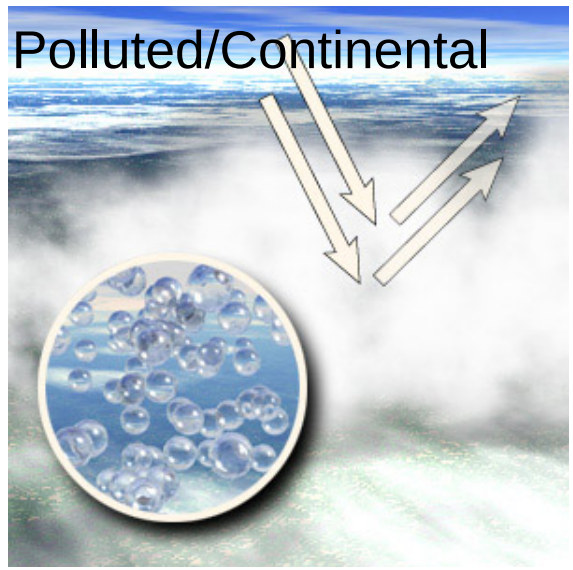
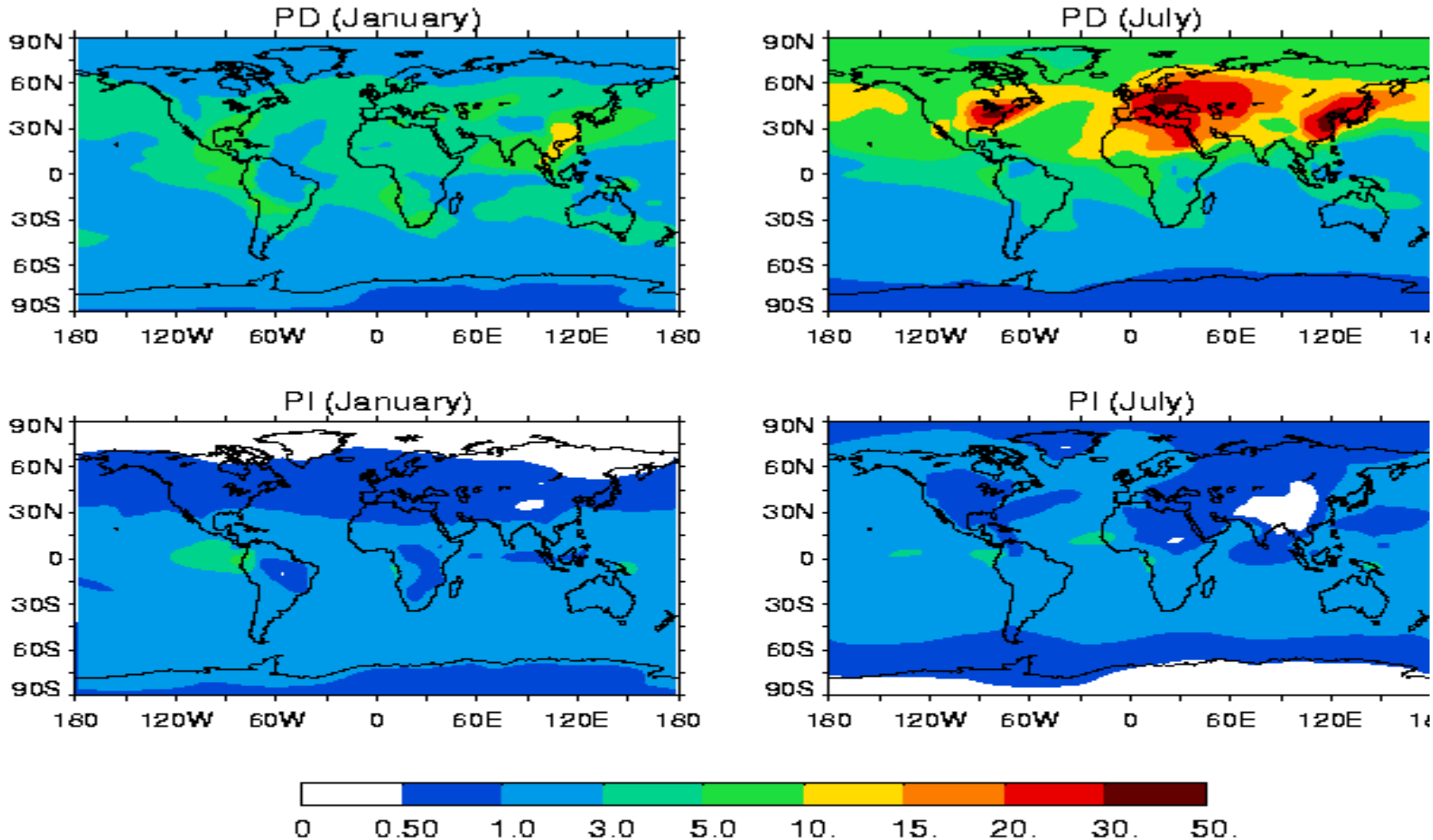
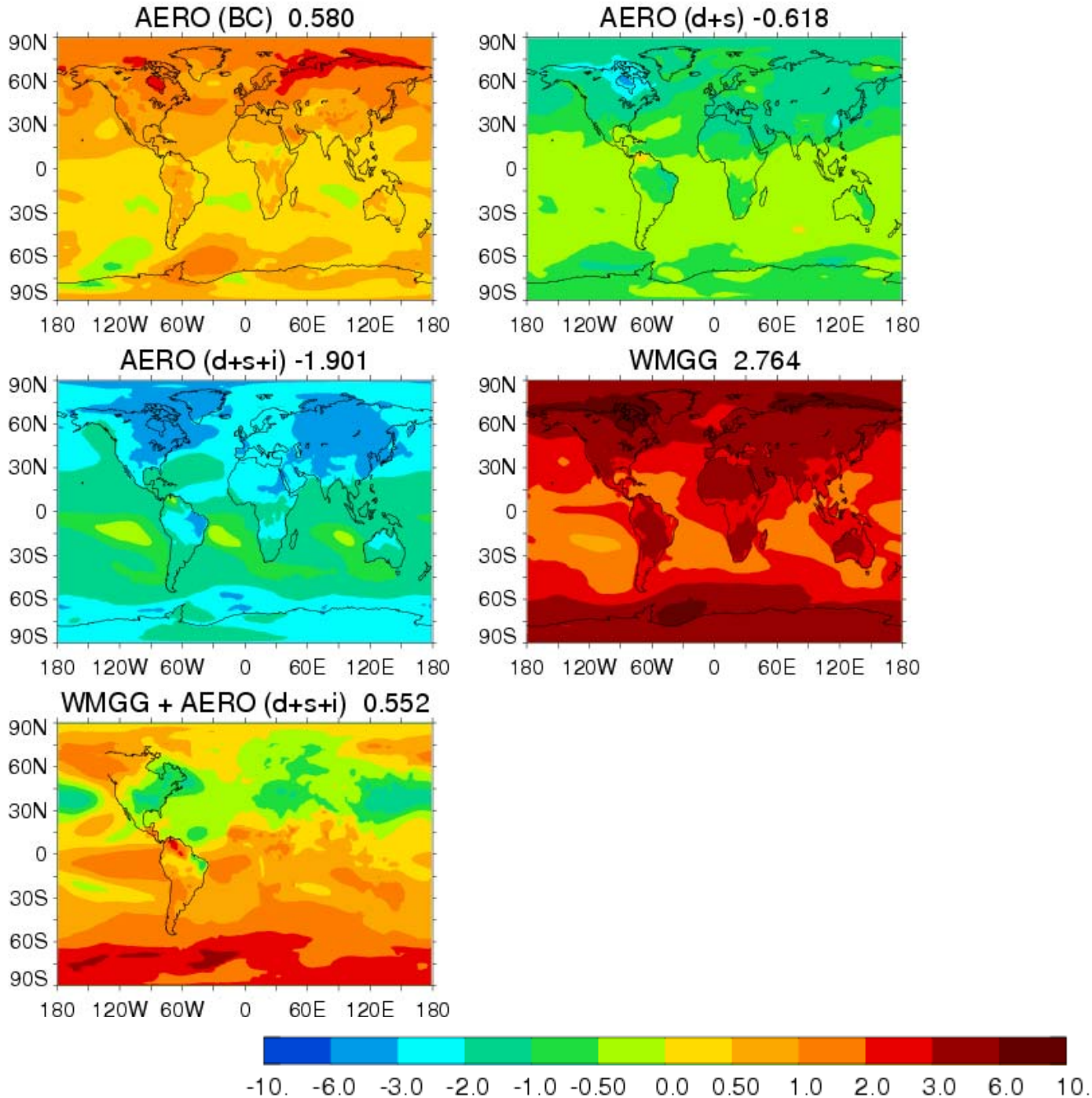


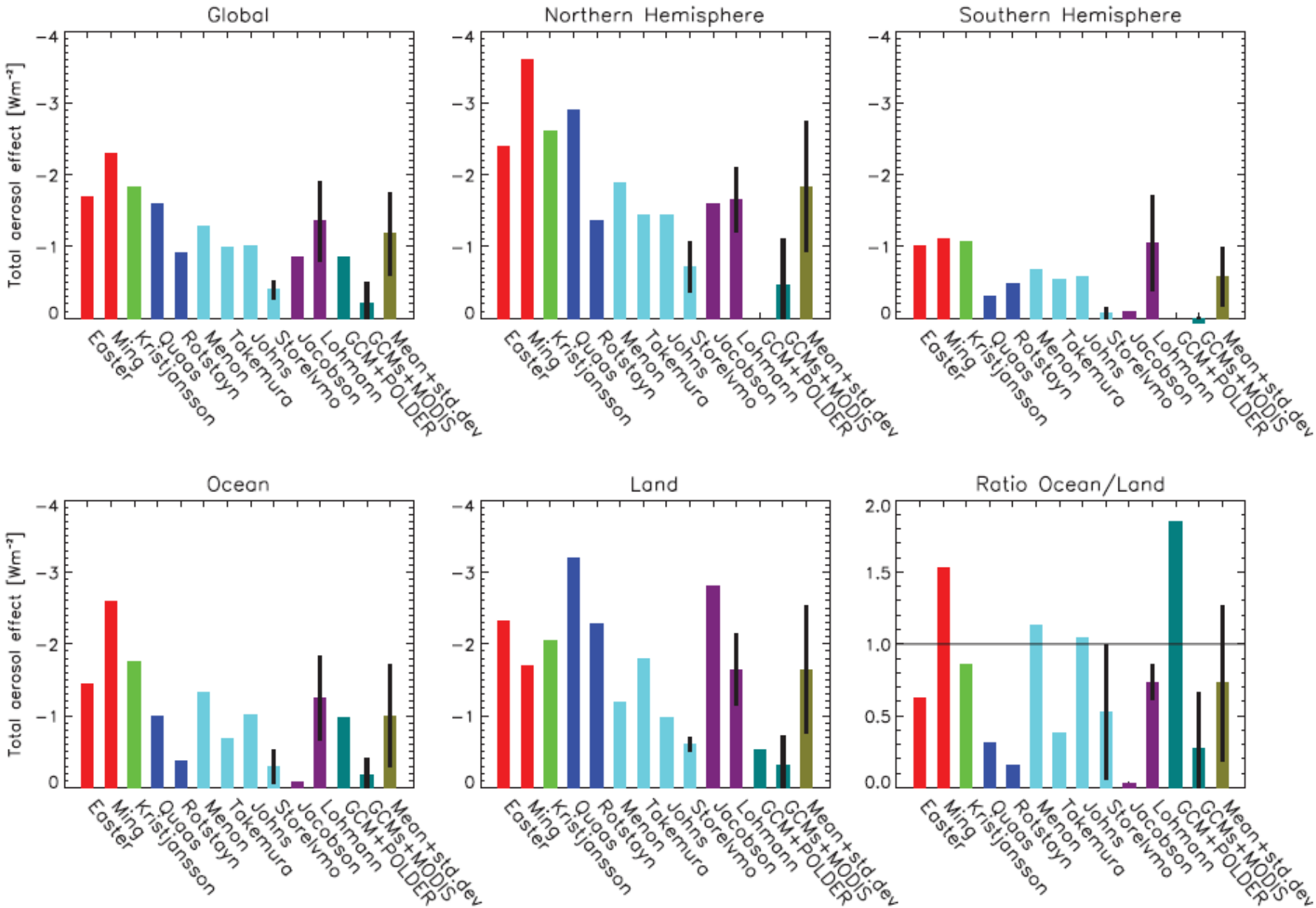
Fig. 5. Aircraft data illustrating the increase in cloud drops with aerosol number concentration. References for the data are as follows: North Sea (*28*), Nova Scotia and North Atlantic (*29*), ACE-2 (*30*), Astex (*31*), the thick red line is obtained from a composite theoretical parameterization that fits the INDOEX aircraft data for the Arabian Sea (*23*). The gray-shaded region is the INDOEX aircraft data for the Arabian Sea (*32*).

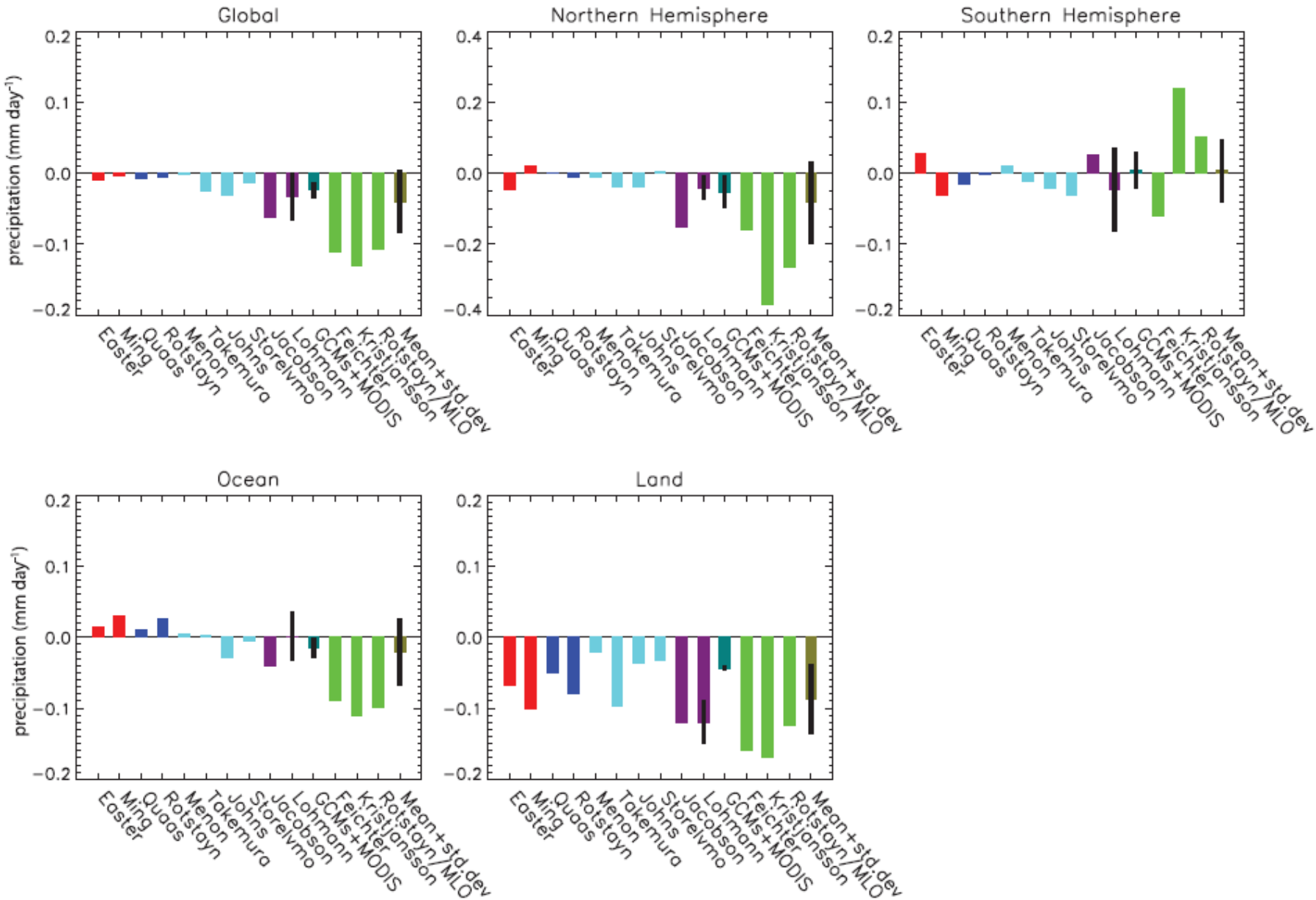
Ramanathan et al. (2001)

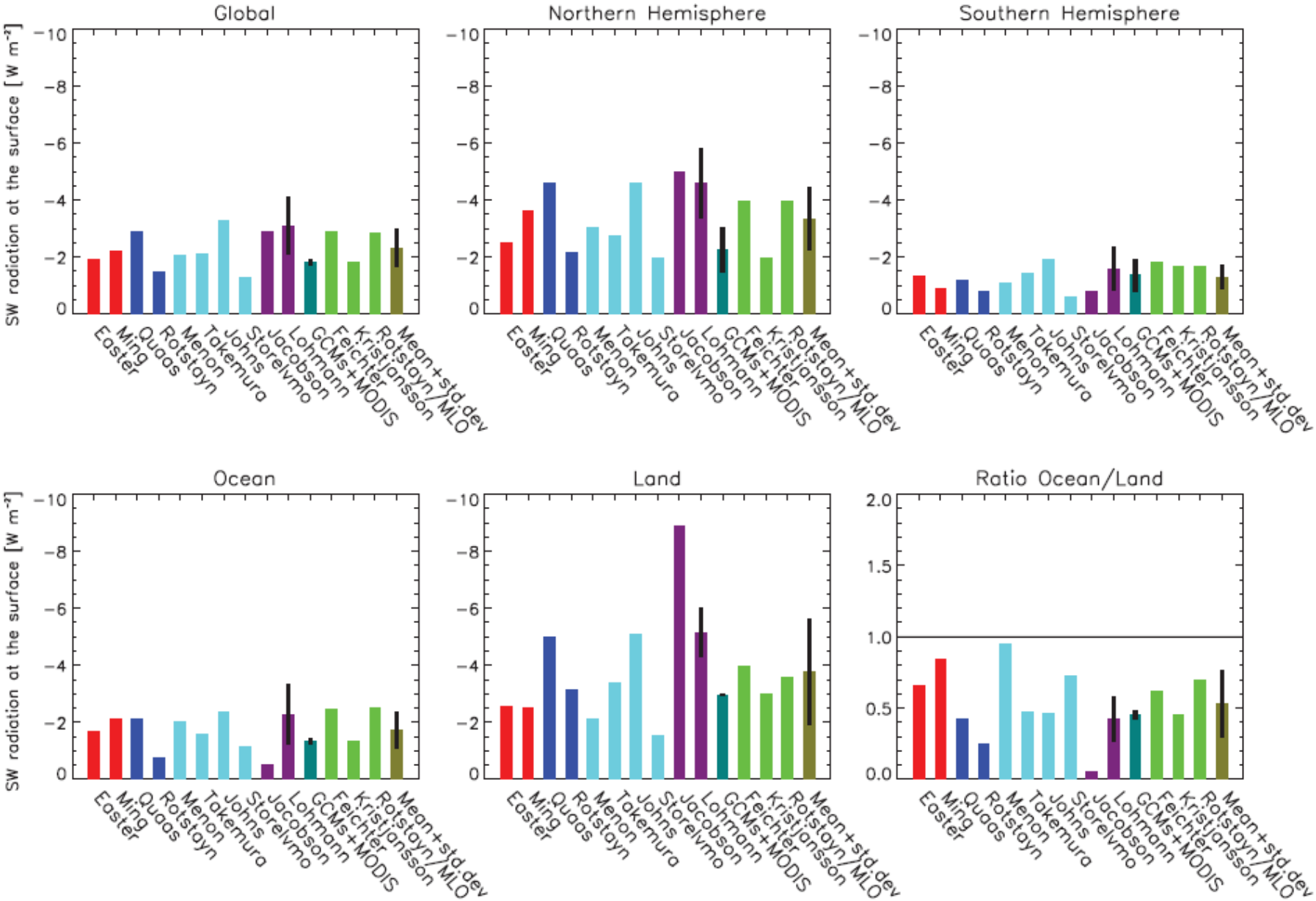



PD (January)
PD (July)
PI (January)
PI (July)
90N
60N
30N
0
30S
60S
90S
180
120W
60W
0
60E
120E
180
0
0.50
1.0
3.0
5.0
10.
15.
20.
30.
50.

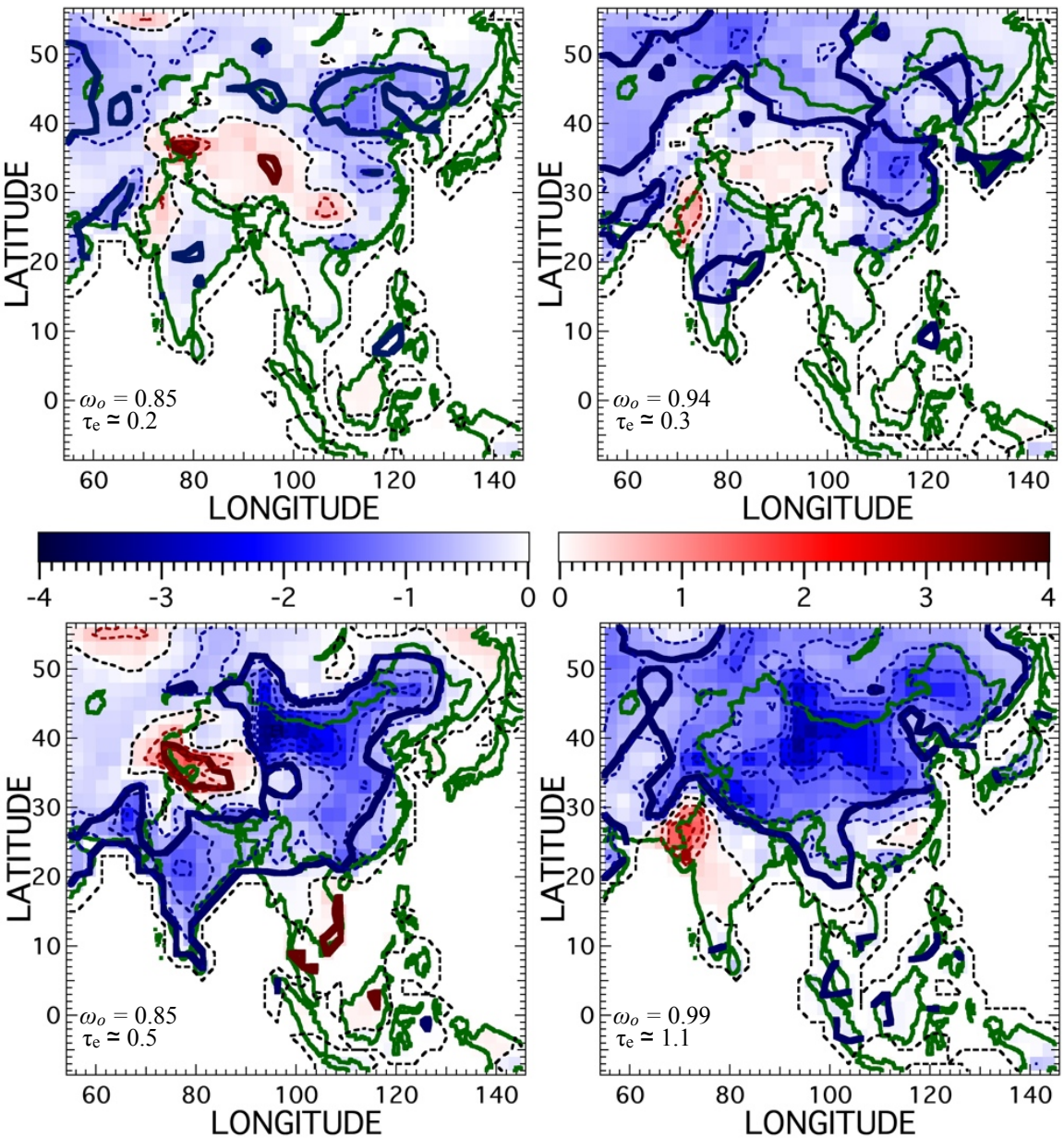

AERO (BC) 0.580
AERO (d+s) -0.618
AERO (d+s+i) -1.901
WMGG 2.764
WMGG + AERO (d+s+i) 0.552
90N
60N
30N
0
30S
60S
90S
180 120W 60W 0 60E 120E 180
-10. -6.0 -3.0 -2.0 -1.0 -0.50 0.0 0.50 1.0 2.0 3.0 6.0 10.


Global
Northern Hemisphere
Southern Hemisphere
Ocean
Land
Ratio Ocean/Land
Total aerosol effect [Wm⁻²]
−4
−3
−2
−1
0
2.0
1.5
1.0
0.5
0.0
Easter
Ming
Kristjansson
Quaas
Rotstayn
Menon
Takemura
Johns
Storelvmo
Jacobson
Lohmann
GCM+POLDER
GCMs+MODIS
Mean+std.dev

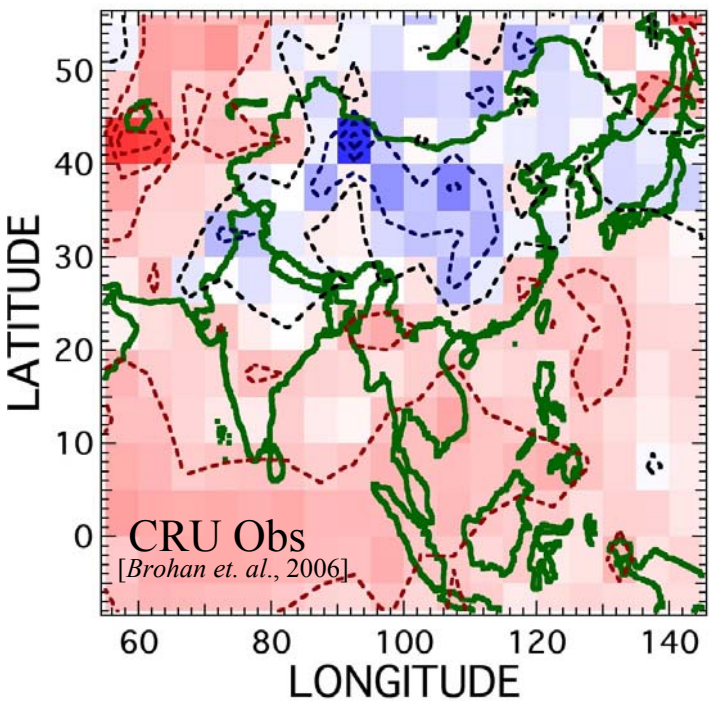

Global
Northern Hemisphere
Southern Hemisphere
Ocean
Land
precipitation (mm day⁻¹)
0.2
0.1
0.0
−0.1
−0.2
0.4
−0.4
Easter
Ming
Quoas
Rotstayn
Menon
Takemura
Johns
Storelvmo
Jacobson
Lohmann
GCMs+MODIS
Feichter
Kristjansson
Rotstayn/MLO
Mean+std.dev


Global
Northern Hemisphere
Southern Hemisphere
Ocean
Land
Ratio Ocean/Land
SW radiation at the surface [W m⁻²]
−10
−8
−6
−4
−2
0
2.0
1.5
1.0
0.5
0.0
Easter
Ming
Quaas
Rotstayn
Menon
Takemura
Johns
Storelvmo
Jacobson
Lohmann
GCMs+MODIS
Feichter
Kristjansson
Rotstayn/MLO
Mean+std.dev

ΔT_s [K] relative to BASE

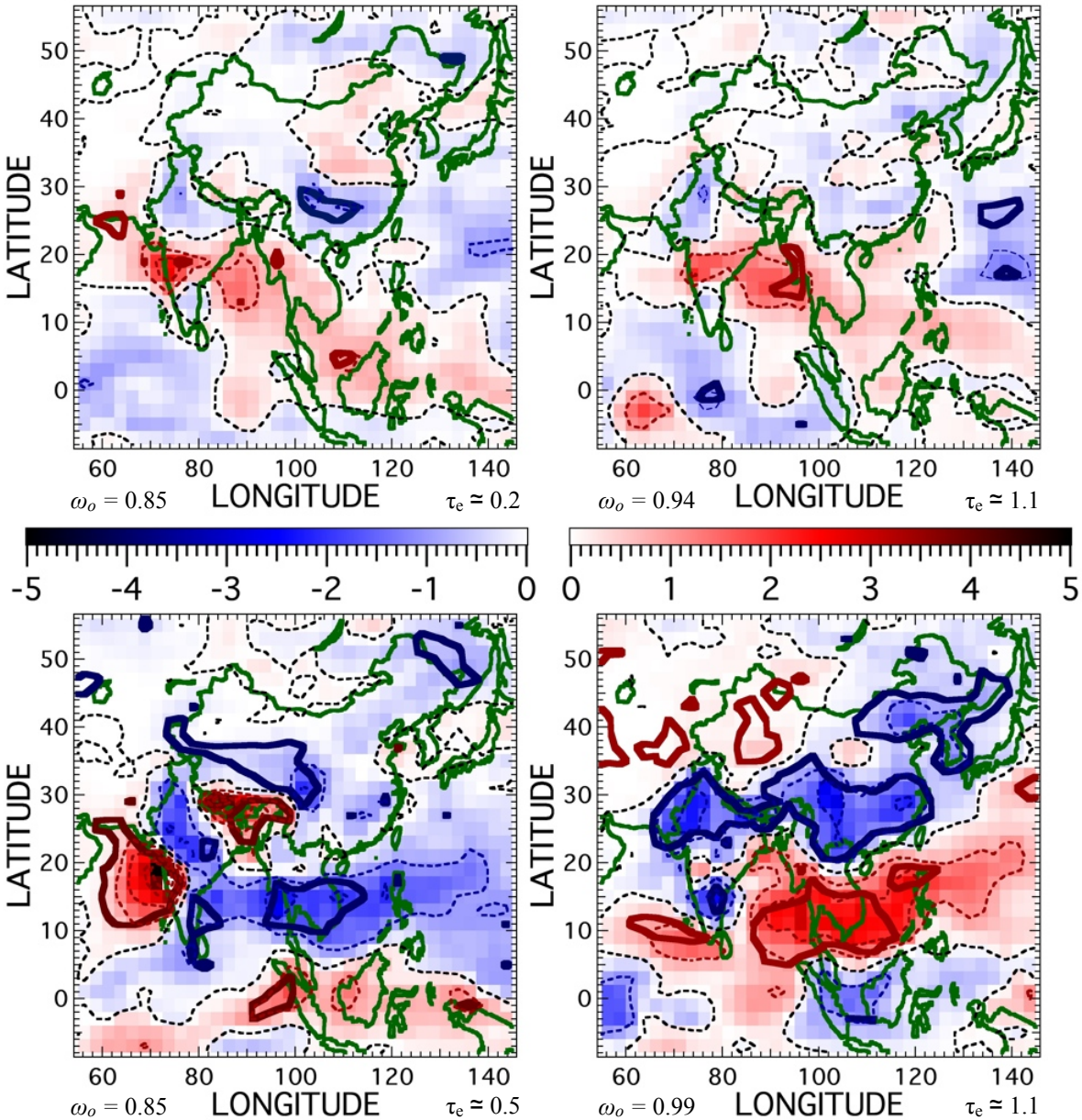


For all plots:
Dashed Contour Interval: 1 K
Thick Contour: 90% Confidence

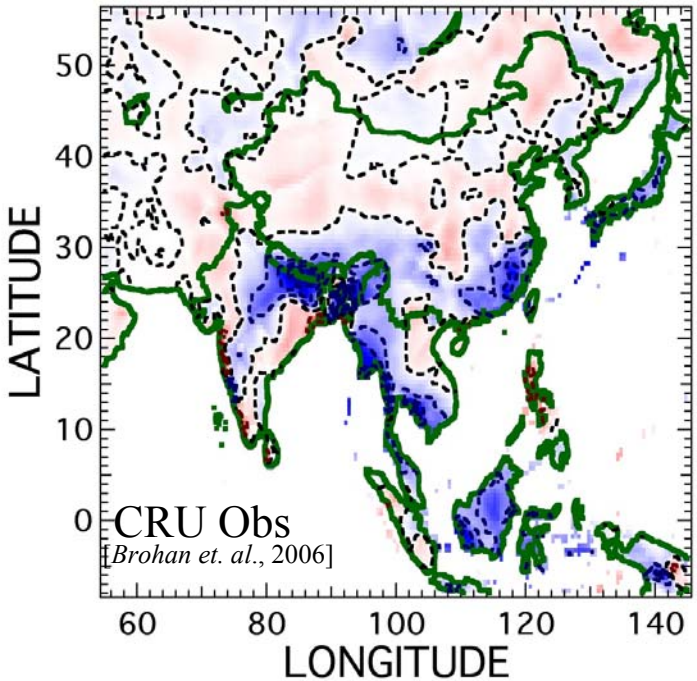


AVG(1995-1985)- AVG(1955 - 1945)

ΔP [mm d^{-1}] relative to BASE

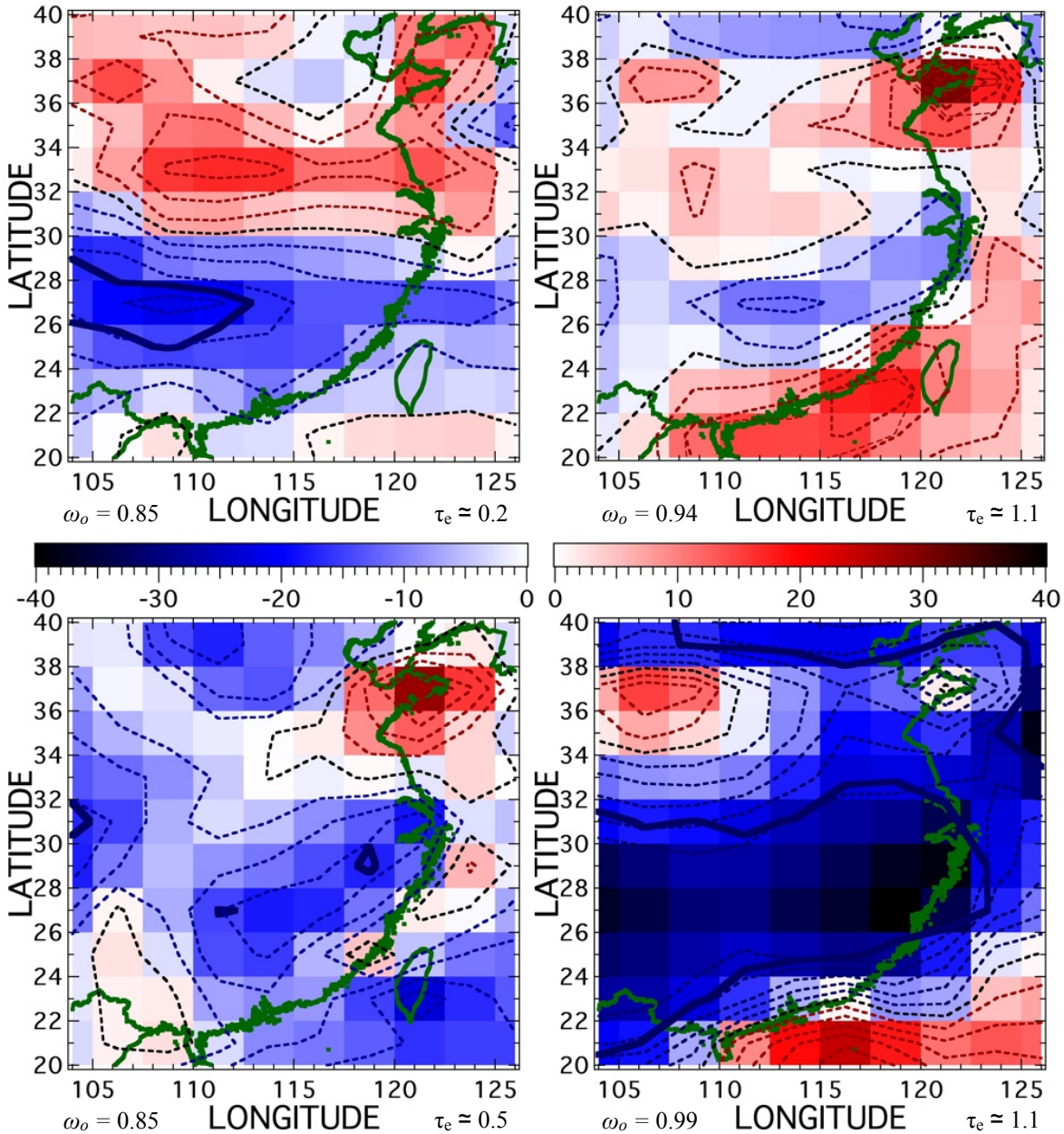


For all plots:
Dashed Contour Interval: 1 mm d^{-1}
Thick Contour: 90% Confidence

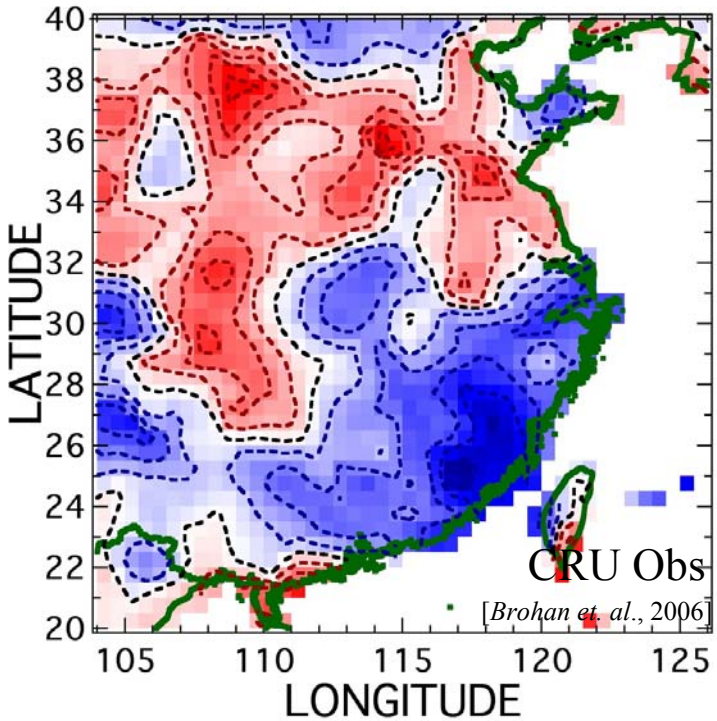


AVG(1995-1985)- AVG(1955 - 1945)

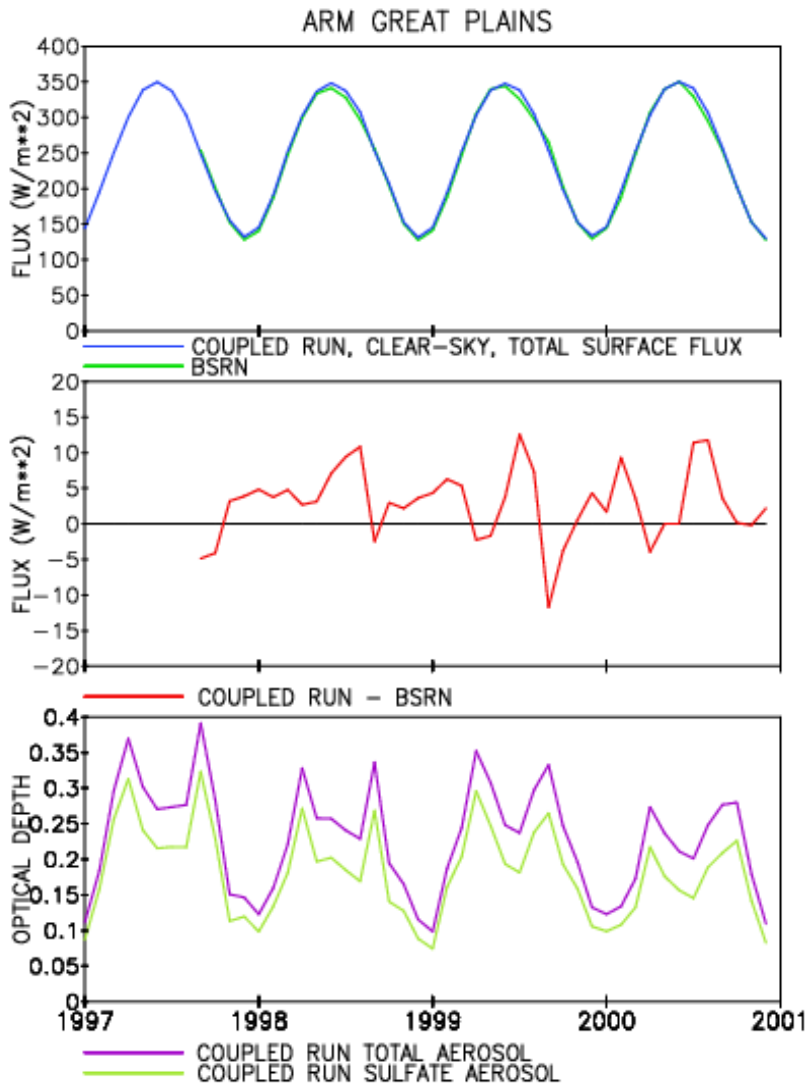
% Change in Precipitation relative to BASE

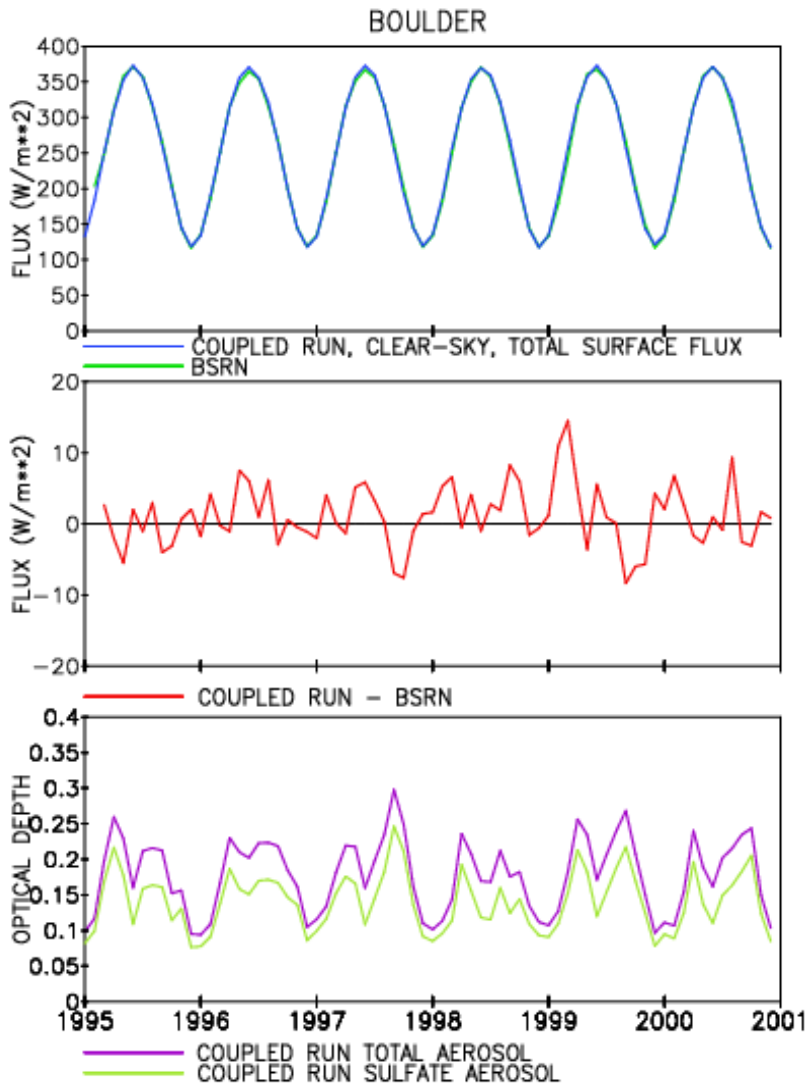


For all plots:
Dashed Contour Interval: 5% change
Thick Contour: 90% Confidence



$$\frac{\text{AVG(1995-1985)- AVG(1955 - 1945)}}{\text{AVG(1955 - 1945)}}$$


ARM GREAT PLAINS
FLUX (W/m**2)
400
350
300
250
200
150
100
50
0
COUPLED RUN, CLEAR-SKY, TOTAL SURFACE FLUX
BSRN
FLUX (W/m**2)
20
15
10
5
0
-5
-10
-15
-20
COUPLED RUN - BSRN
OPTICAL DEPTH
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1997
1998
1999
2000
2001
COUPLED RUN TOTAL AEROSOL
COUPLED RUN SULFATE AEROSOL


BOULDER
FLUX (W/m**2)
400
350
300
250
200
150
100
50
0
COUPLED RUN, CLEAR-SKY, TOTAL SURFACE FLUX
BSRN
FLUX (W/m**2)
20
10
0
-10
-20
COUPLED RUN - BSRN
OPTICAL DEPTH
0.4
0.35
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