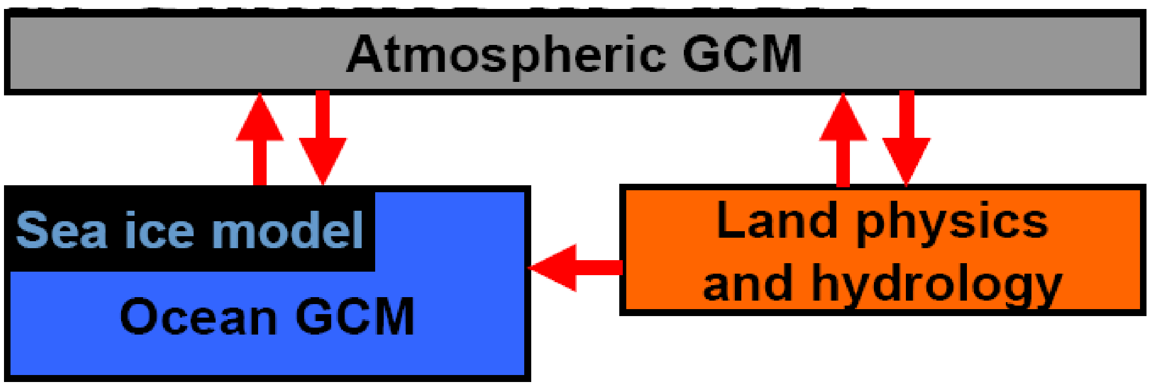
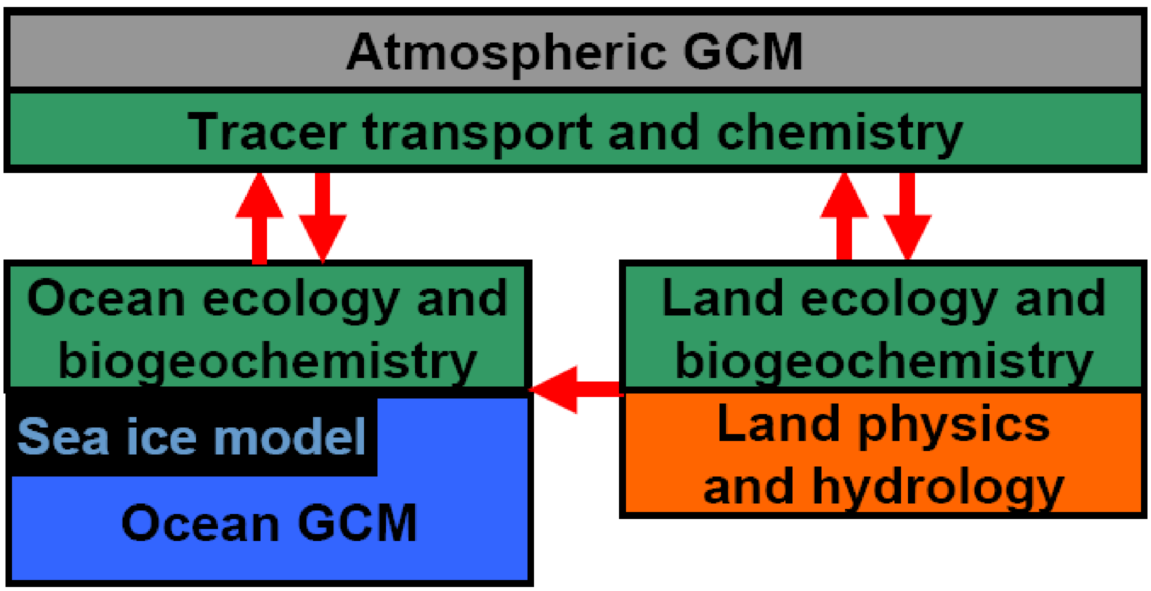
Lecture 23. Climate Model Simulation

1. CONSTRUCTING MODEL

a. Model development





Flexible Modeling System (FMS)

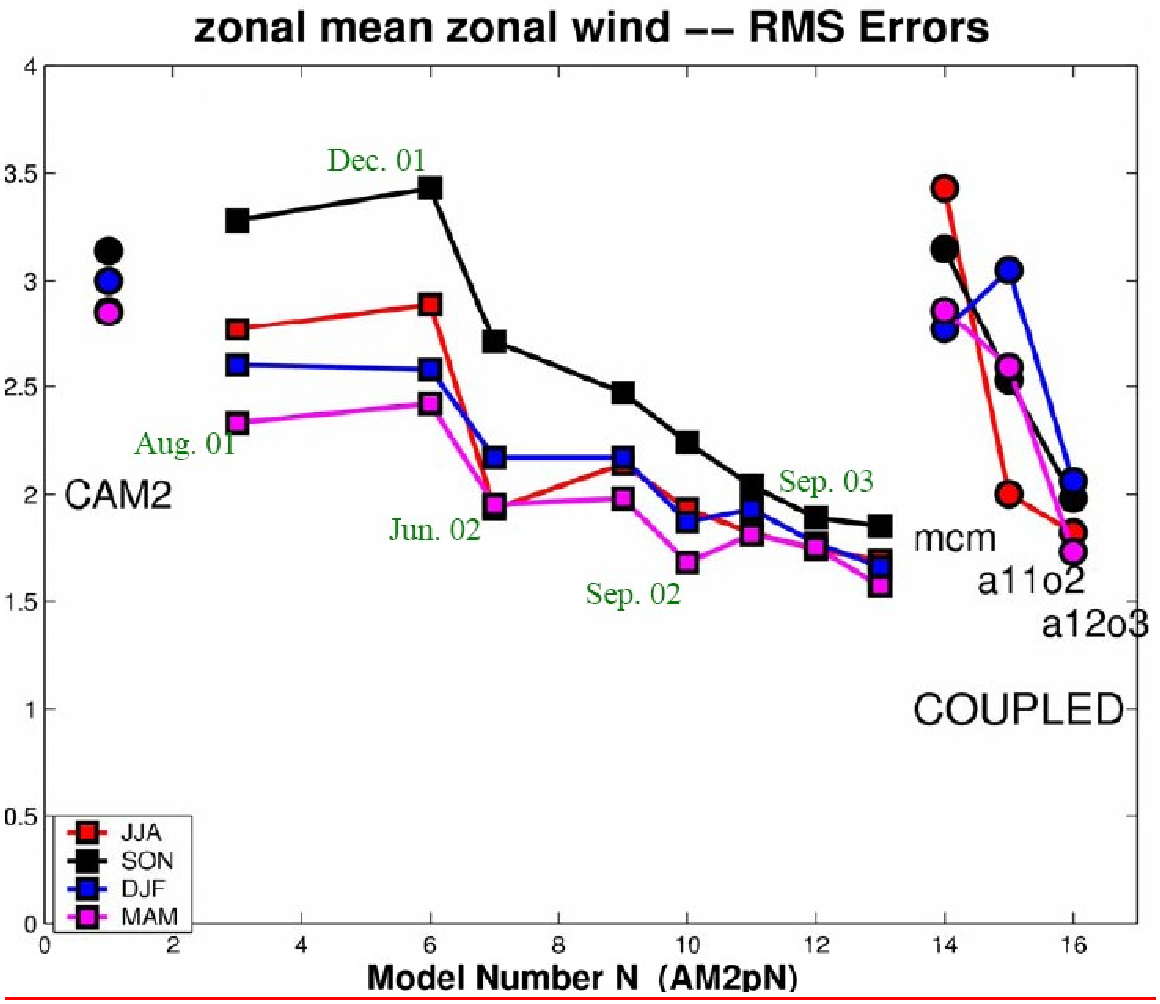
FMS is a software framework for supporting the efficient development, construction, execution, and scientific interpretation of atmospheric, oceanic, and climate system models. FMS provides essentially a framework of standardization of model components.

GFDL Model Development Teams: Atmosphere (GAMDT), Land (LMDT), Ocean (OMDT), Coupled (CMDT)

Model performance:

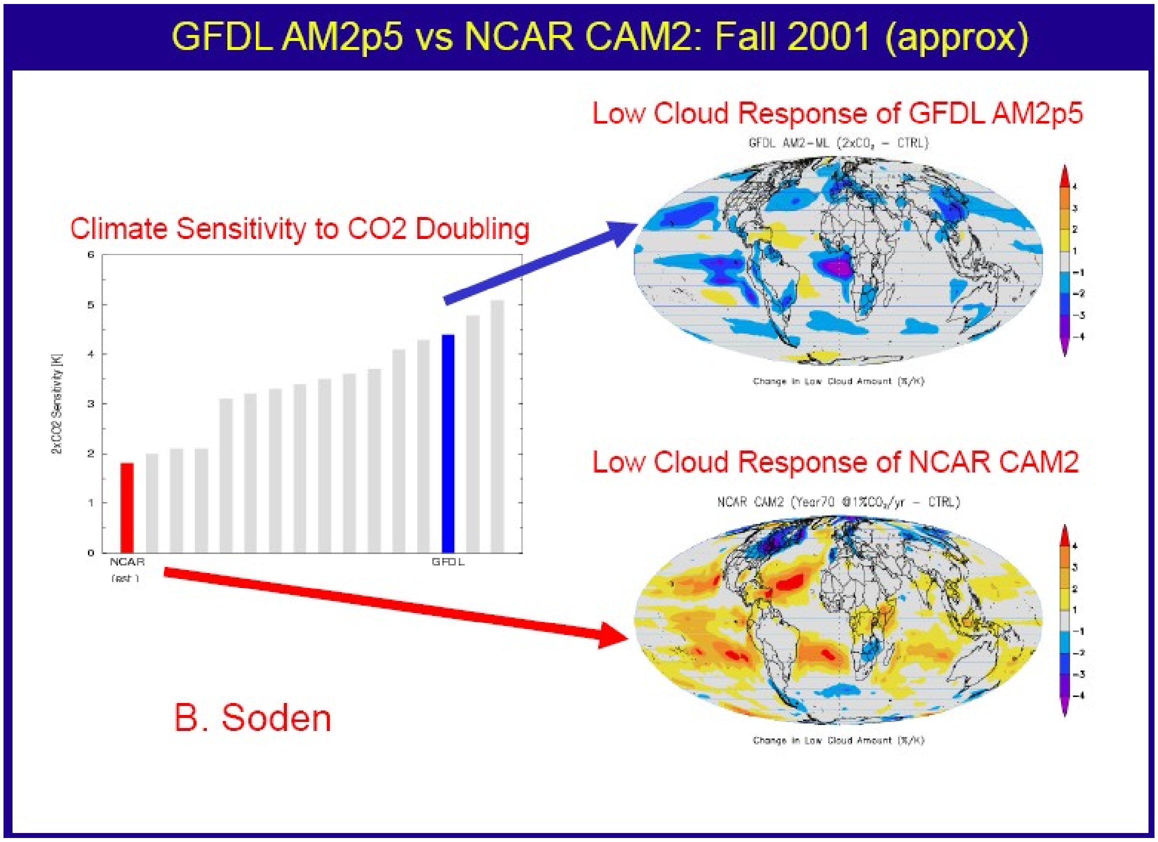
Overall improvement of GFDL atmospheric and coupled models over 2.5 year period:

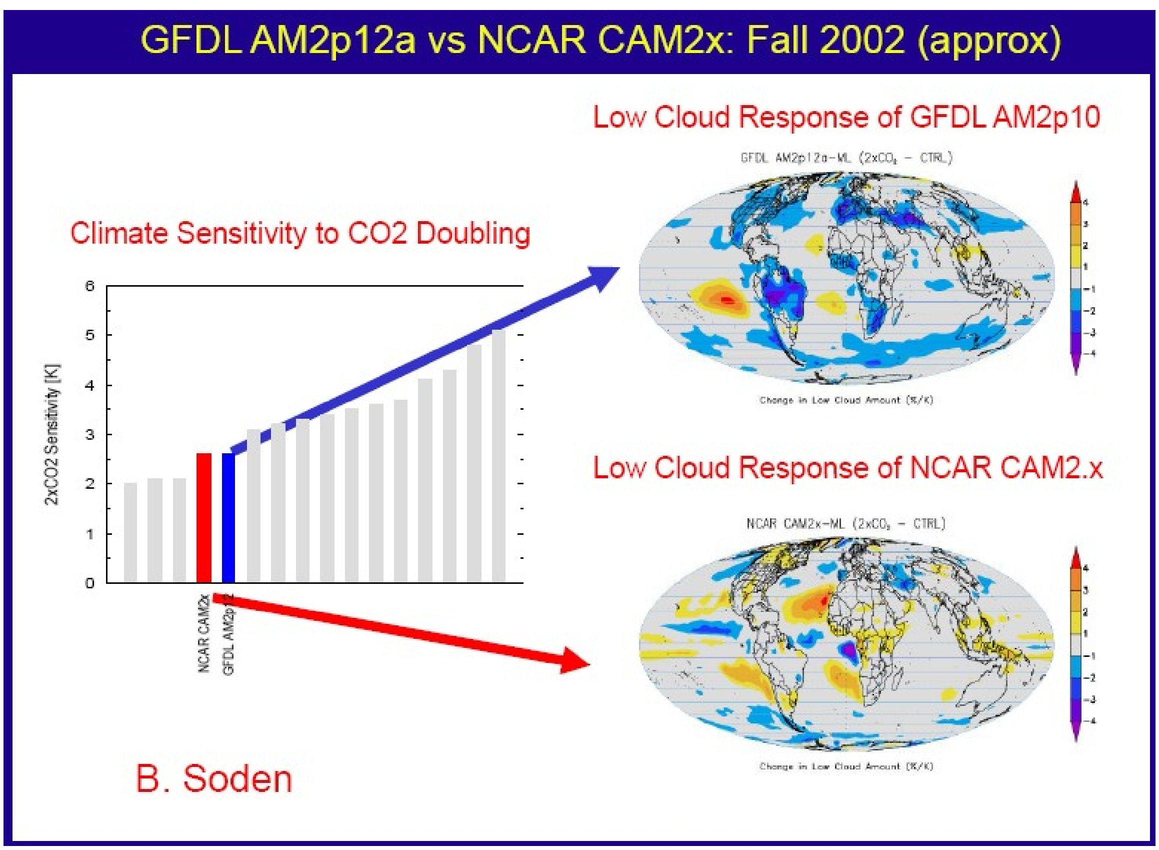
- Reduction of climate drift.
- Convergence of the quality of the simulations for all seasons



Model intercomparison of climate sensitivity:

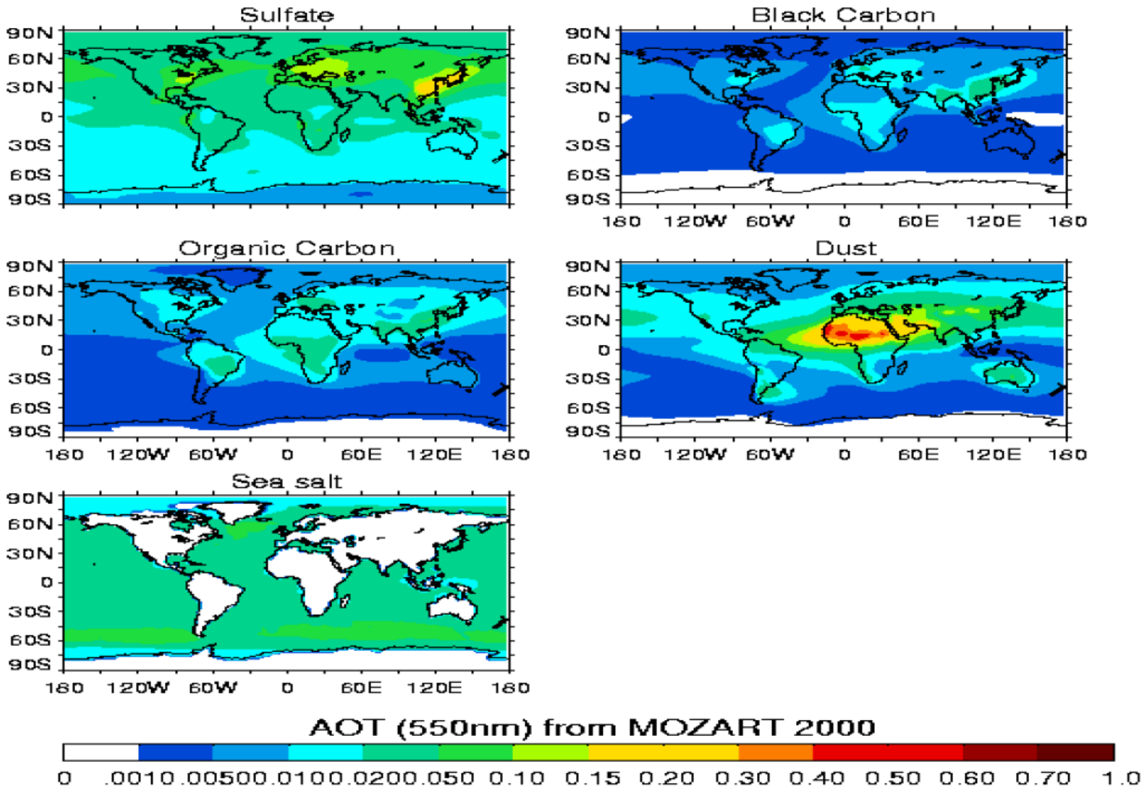
Comparison of 2 models (GFDL/AM2 & NCAR/CAM2) at 1 year interval
No observed data involved, and no (explicit) coordination between the models occurs.

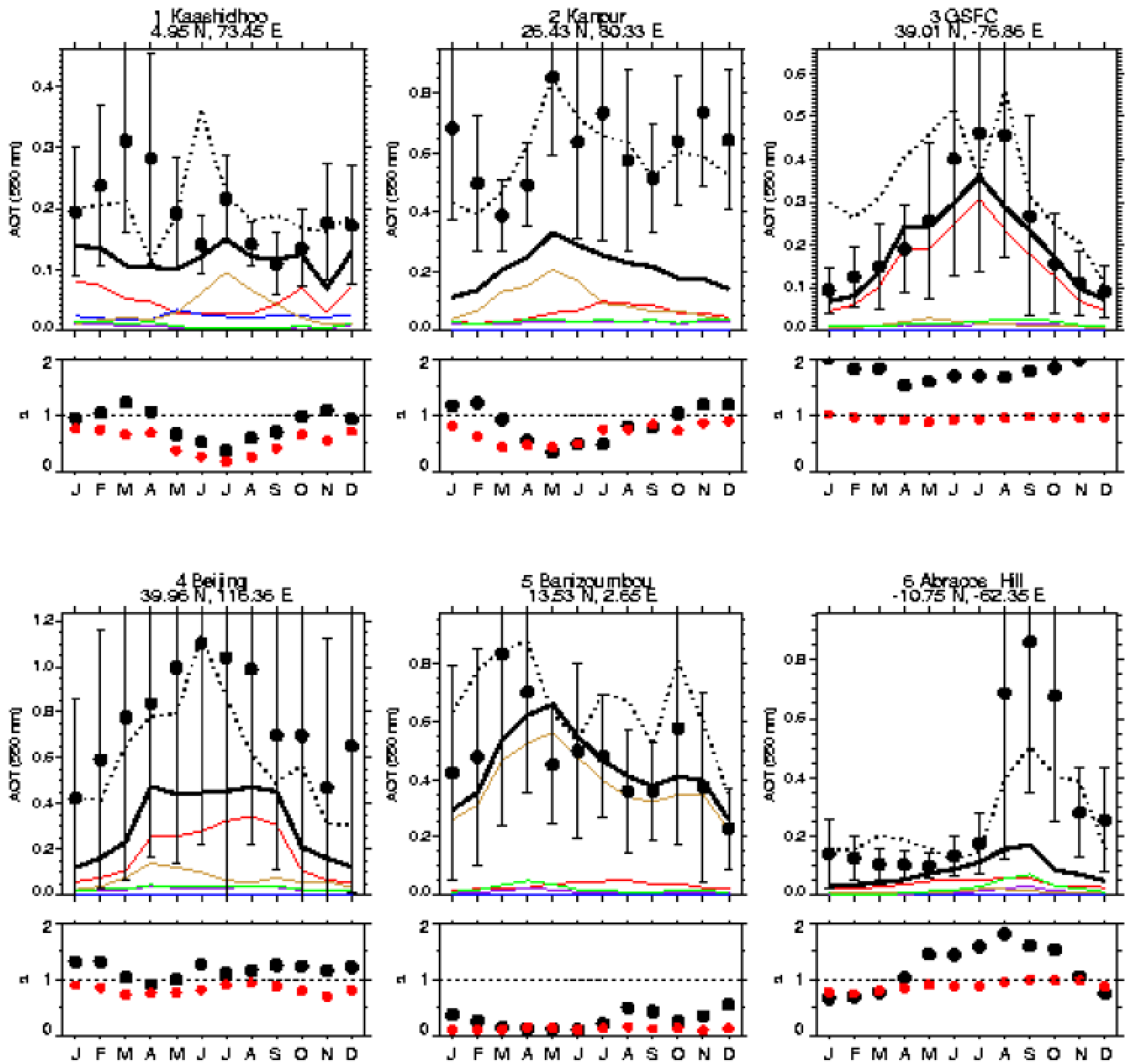

GFDL AM2p5 vs NCAR CAM2: Fall 2001 (approx)
Climate Sensitivity to CO2 Doubling
2xCO2 Sensitivity [K]
NCAR
GFDL
Low Cloud Response of GFDL AM2p5
GFDL AM2-ML (2xCO2 - CTRL)
Change in Low Cloud Amount (%/K)
Low Cloud Response of NCAR CAM2
NCAR CAM2 (Year70 @1%CO2/yr - CTRL)
Change in Low Cloud Amount (%/K)
B. Soden


GFDL AM2p12a vs NCAR CAM2x: Fall 2002 (approx)
Climate Sensitivity to CO2 Doubling
2xCO2 Sensitivity [K]
NCAR CAM2x
GFDL AM2p12
Low Cloud Response of GFDL AM2p10
GFDL AM2p12a-ML (2xCO2 - CTRL)
Change in Low Cloud Amount (%/K)
Low Cloud Response of NCAR CAM2.x
NCAR CAM2x-ML (2xCO2 - CTRL)
Change in Low Cloud Amount (%/K)
B. Soden

b. Diagnostics tools

i. Comparison with data





GFDL AM2 automated diagnostics package
[AEROCOM](): Aerosol Comparisons between Observations and Models

ii. Model intercomparison

PCMDI: Program for Climate Model Diagnosis and Intercomparison includes: Atmospheric models (AMIP), Coupled models (CMIP), Seasonal prediction (SMIP), Aqua planet (APE), Paleoclimate models (PMIP)

AEROCOM:Aerosol Comparisons between Observations and Models

c. Tuning parameters

1 Goal

- Net radiation TOA between 0 and 1 W/m^2.
- SWABS and OLR within the range 235 to 240 W/m^2.

2 Frequently used parameters

Parameter	Units	am2p14	am3p2	am3p3	am3p4	Brief description
strat_cloud_nml						
rthresh	μm	8.0	10.0	7.0	9.5	Liquid cloud drop radius threshold for autoconversion; smaller values will predominantly reduce low cloud SW reflection and increase SWABS.
eros_scale	1/s	1.0e-6	1.0e-6	1.0e-6	1.0e-5	Main erosion scale (inverse time scale); larger values will erode clouds faster and reduce overall cloud amount.
eros_choice	logical	.true.	.true.	.true.	.true.	Logical to activate separate erosion scales for clouds in convective and turbulent regions.
eros_scale_c	1/s	8.0e-6	5.0e-5	5.0e-5	5.0e-5	Erosion scale for clouds in convective regions; applies when convective mass flux is greater than mc_thresh.
mc_thresh	kg/m^2/s	1.0e-3	1.0e-3	1.0e-3	1.0e-3	Mass-flux threshold for eros_scale_c
eros_scale_t	1/s	5.0e-5	8.0e-5	5.0e-4	5.0e-4	Erosion scale for clouds in turbulent regions; applies when eddy diffusivity is greater than diff_thresh.
diff_thresh	m^2/s	0.1	0.1	0.1	0.1	Diffusion threshold for eros_scale_t
vfact	none	1.0	2.0	1.5	1.5	Multiplicative factor controlling ice crystal sedimentation velocity. Increasing vfact will increase OLR.
cfact	none	1.0	0.3	0.3	0.3	Multiplicative factor controlling the rate of the Bergeron process. Smaller values slow down the conversion from liquid to ice, resulting in more liquid clouds and more SW reflection.
uw_plume_nml						
auto_th0	kg/kg	N/A	5.0e-4	5.0e-4	5.0e-4	Total condensate threshold for the formation of precipitation in the UW shallow convective plume. Lower values will generate more precipitation and less low clouds, affecting primarily SWABS.

d. Flux adjustments

Up to a decade ago, most GCM were using flux adjustments of heat, freshwater and surface stress to reduce climate drift. Actually most models are free of these corrections.

Motivation of flux adjustments: The atmosphere and ocean interact through fluxes of heat, momentum and fresh water. In transient GCMs, the atmosphere and ocean models are generally run independently before being coupled together. This coupling of the atmosphere and ocean component models can highlight discrepancies in the surface fluxes that may lead to a drift away from the observed climate. This climate drift may be reduced by flux adjustment whereby the heat and freshwater fluxes, and possibly the surface stresses, are modified before being imposed on the ocean by the addition of a correction or adjustment. Flux adjustment terms are calculated from the difference between the modeled surface fluxes and those required to keep the model close to current climate. After running the model for a period suitable for the calculation of average flux adjustments, these terms are applied throughout the control and climate change experiments. The main purpose of flux adjustment is to ensure that any perturbation in forcing is applied about a realistic reference climate so that distortion of the major climate feedback processes is minimized.

2. IPCC simulations

Climate model simulation for IPCC consists of:

1. One 300 to 500-year control run
2. A 3 to 5-member ensemble simulating the 1860-2000 historical period
3. Four 3 to 5-member ensembles corresponding to the IPCC A2, A1B, B1 and constant-20-th-Century-forcing future scenarios

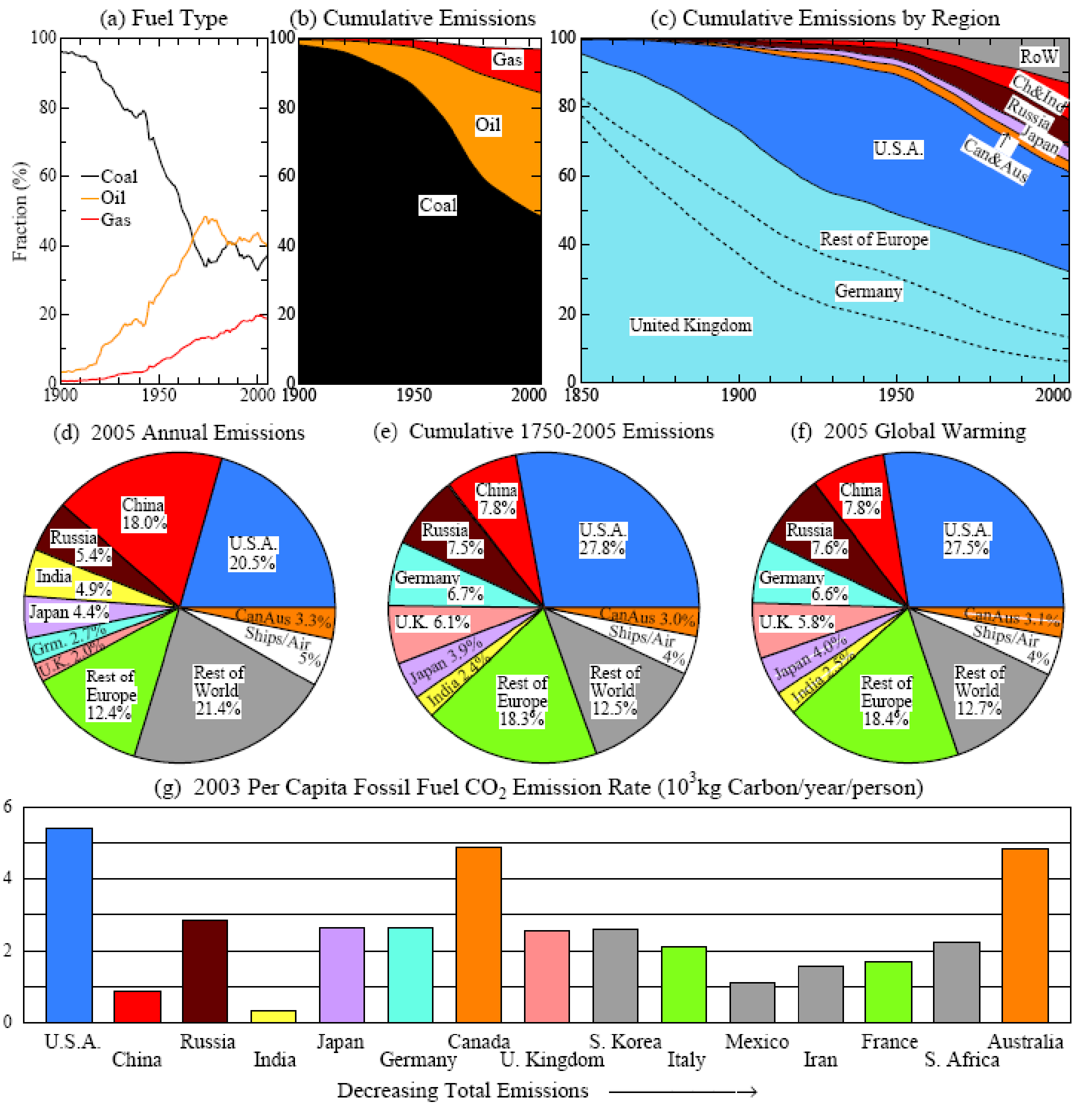
Control runs : Control runs establish the basic climate of the model. Control runs are long integrations where the model input forcings (solar irradiance, sulfates, ozone, greenhouse gases) are held constant and are not allowed to evolve with time. Usually the input forcings are held fixed either at present day values (i.e., for year 2000 or 2000 Control Run) or a pre-industrial values (i.e., for 1870 or 1870 Control Run). Note that in this context, "fixed" can have two different meanings. The solar forcing values are held fixed a constant, non varying number. The sulfate, ozone and greenhouse gases values, however, are fixed to continually cycle over the same 12-month input dataset every year.

Ensembles: Climate models are an imperfect representation of the earth's climate system and climate modelers employ a technique called ensembling to capture the range of possible climate states. A climate model run ensemble consists of two or more climate model runs made with the exact same climate model, using the exact same boundary forcings, where the only difference between the runs is the initial conditions. An individual simulation within a climate model run ensemble is referred to as an ensemble member. The different initial conditions result in different simulations for each of the ensemble members due to the nonlinearity of the climate model system. Essentially, the earth's climate can be considered to be a special ensemble that consists of only one member. Averaging over a multi-member ensemble of model climate runs gives a measure of the average model response to the forcings imposed on the model.

SRES Scenarios:

a. HISTORICAL SIMULATION

i. Time series Boundary conditions

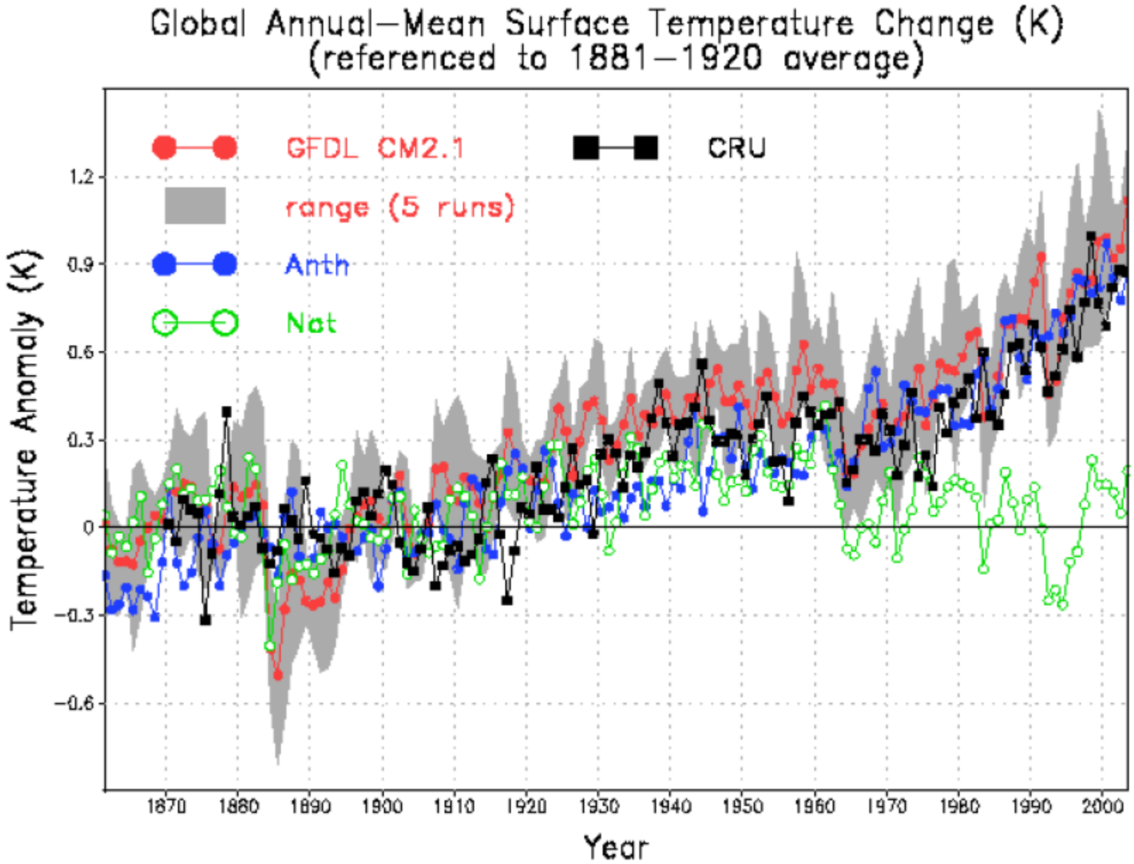


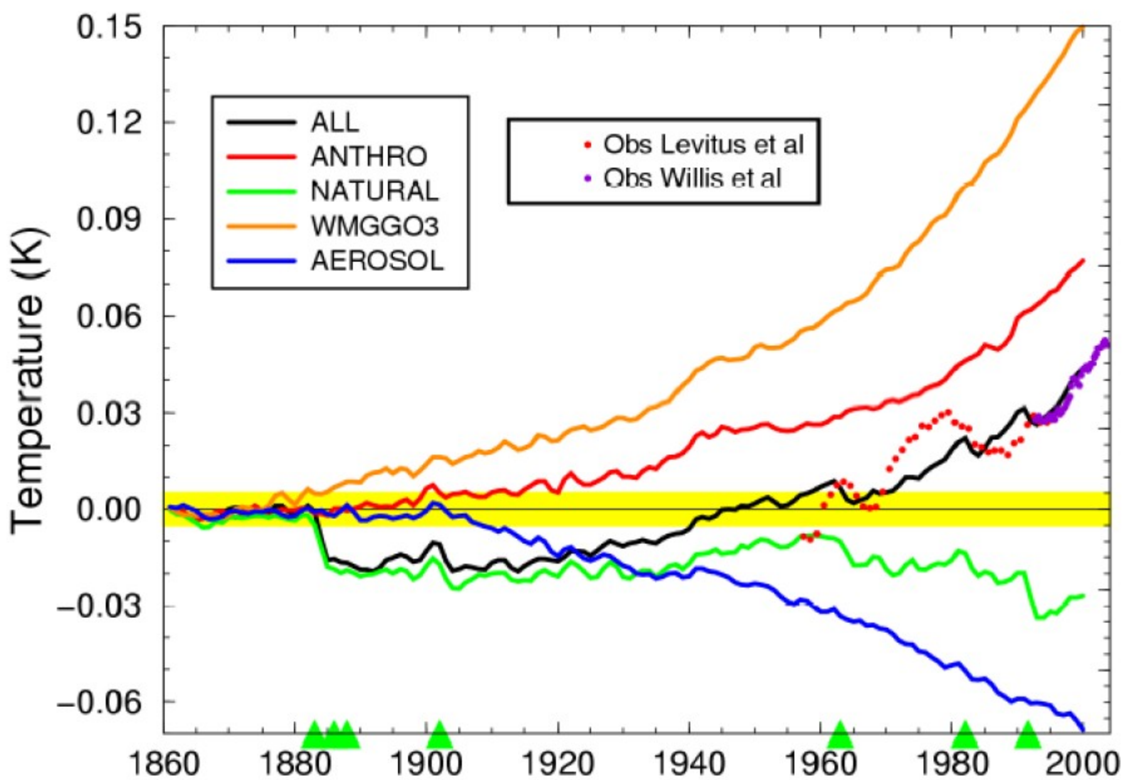
EDGAR-HYDE emissions of GHG and aerosols (1890 to 1990)

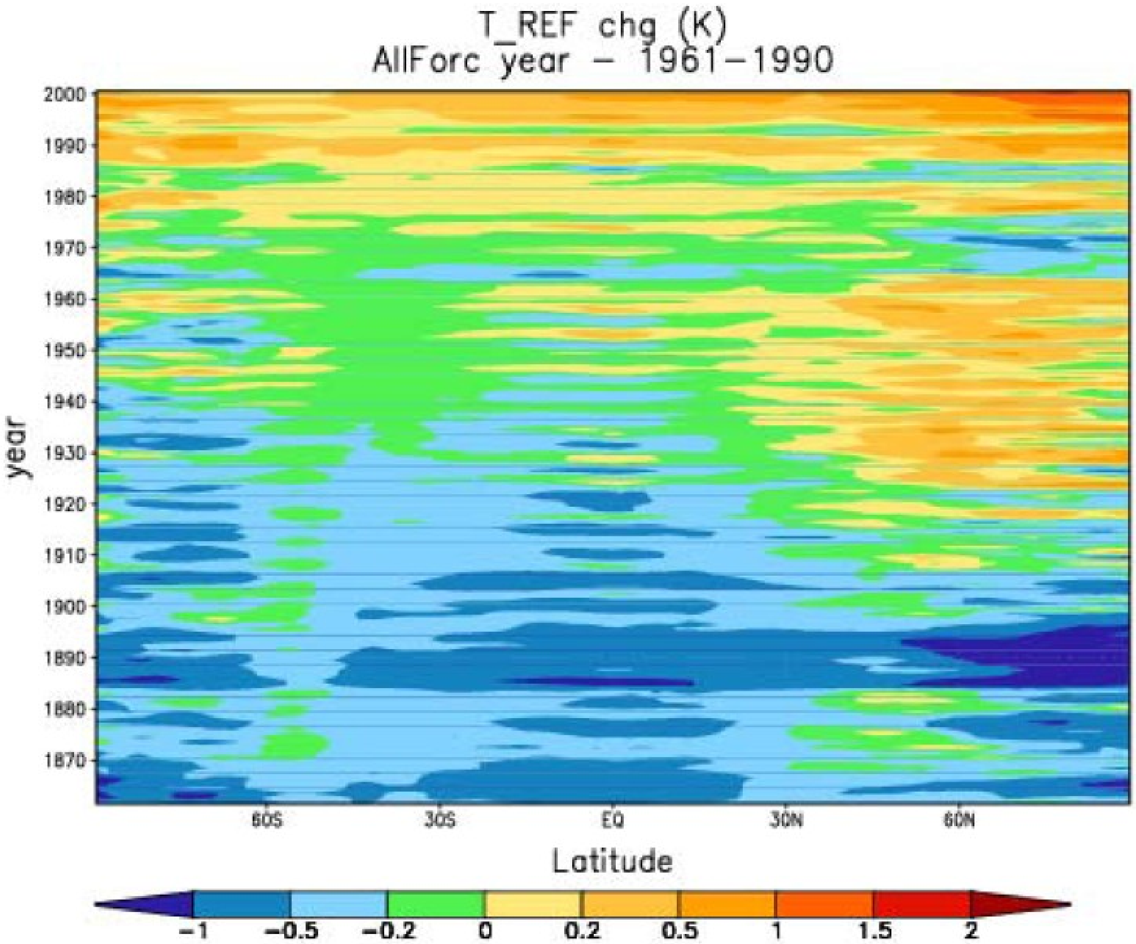
AEROCOM emission (1750 & 2000) of aerosols

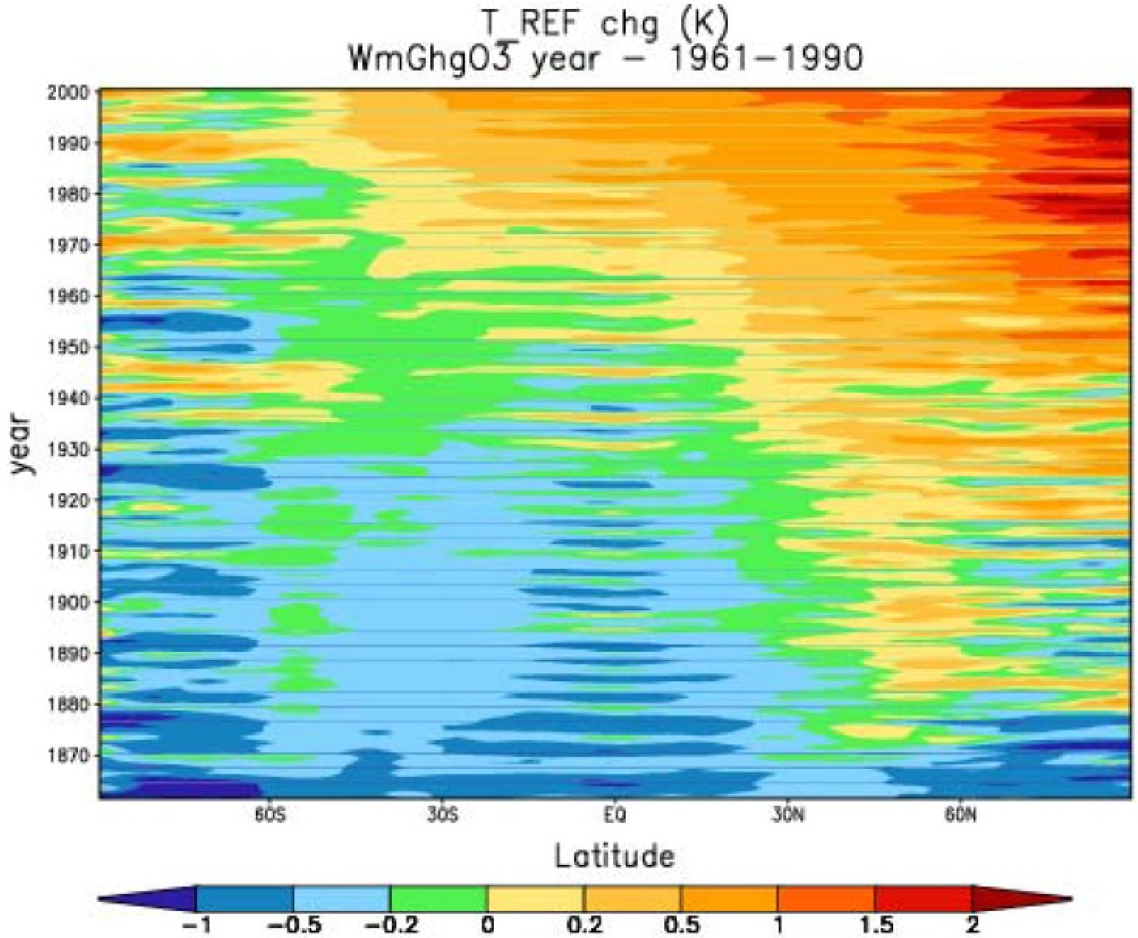
GEIA data portal of emission inventories

ii. Ensemble runs from PI to PD

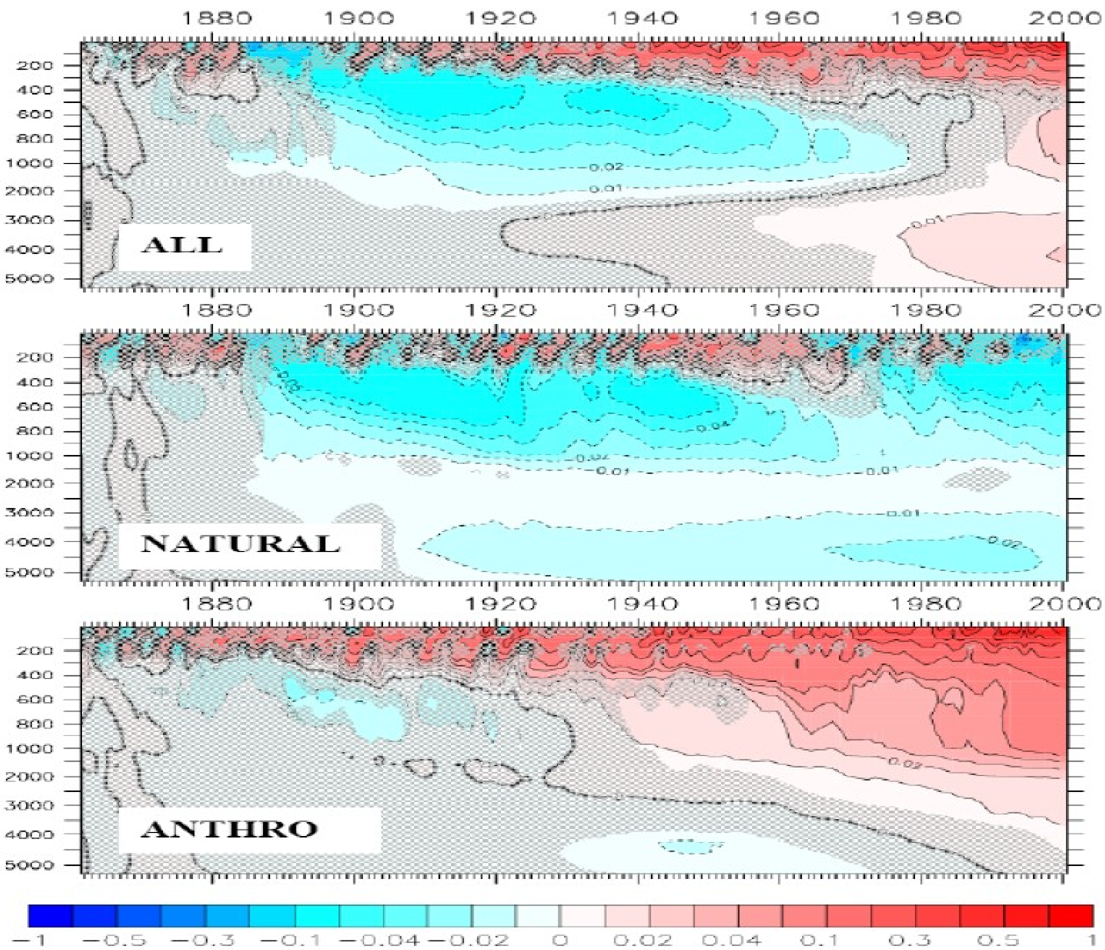

Global Annual-Mean Surface Temperature Change (K)
(referenced to 1881-1920 average)
GFDL CM2.1
range (5 runs)
Anth
Nat
CRU
Temperature Anomaly (K)
1.2
0.9
0.6
0.3
0
-0.3
-0.6
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Year

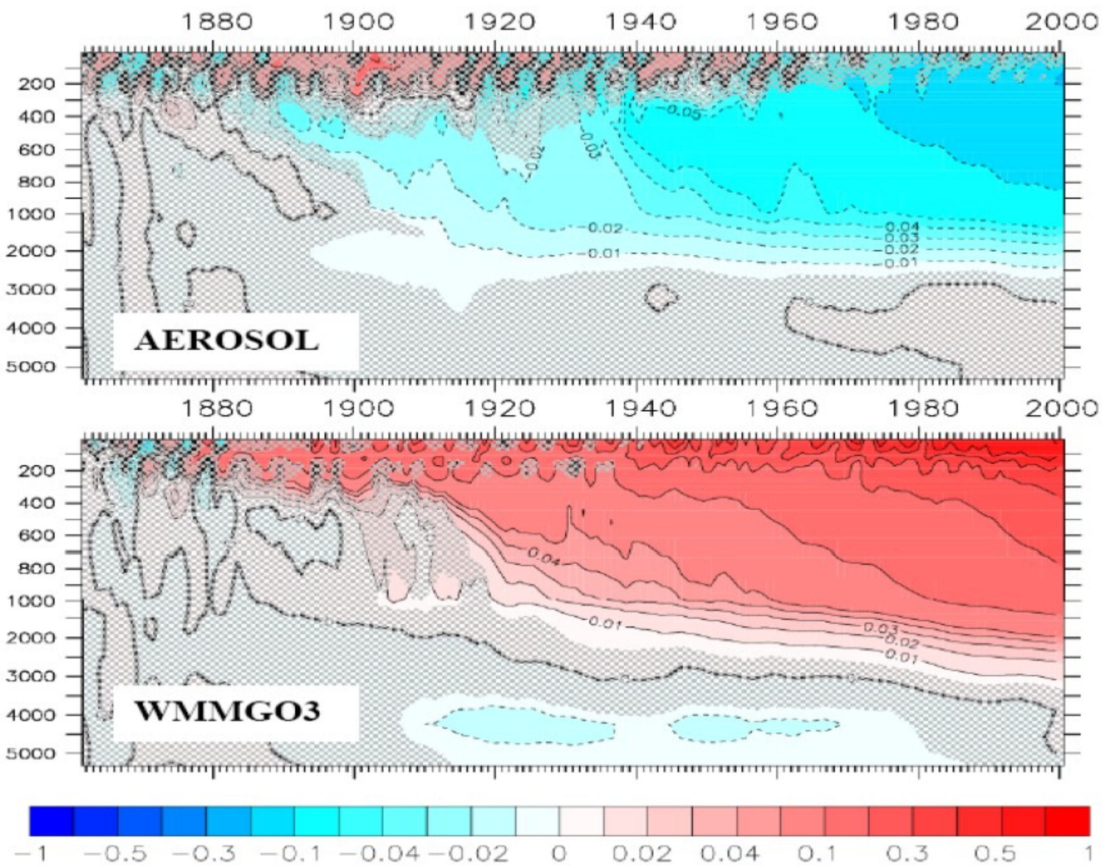

ALL
ANTHRO
NATURAL
WMGGO3
AEROSOL
Obs Levitus et al
Obs Willis et al
Temperature (K)
0.15
0.12
0.09
0.06
0.03
0.00
-0.03
-0.06
1860
1880
1900
1920
1940
1960
1980
2000


T_REF chg (K)
AllForc year − 1961−1990
year
2000
1990
1980
1970
1960
1950
1940
1930
1920
1910
1900
1890
1880
1870
60S
30S
EQ
30N
60N
Latitude
−1
−0.5
−0.2
0
0.2
0.5
1
1.5
2



T_REF chg (K)
WmGhgO3 year - 1961-1990
year
2000
1990
1980
1970
1960
1950
1940
1930
1920
1910
1900
1890
1880
1870
60S
30S
EQ
30N
60N
Latitude
-1
-0.5
-0.2
0
0.2
0.5
1
1.5
2


ALL
NATURAL
ANTHRO
1880 1900 1920 1940 1960 1980 2000
200 400 600 800 1000 2000 3000 4000 5000
−1 −0.5 −0.3 −0.1 −0.04 −0.02 0 0.02 0.04 0.1 0.3 0.5 1



b. PROJECTION OF FUTURE CLIMATE

i. Constructing Scenarios

Future greenhouse gas emissions are the product of very complex dynamic systems, determined by driving forces such as demographic development, socio-economic development, and technological change. Their future evolution is highly uncertain. Scenarios are not specific predictions or forecasts of future climate. Rather, scenarios are plausible alternative futures. Each scenario is an example of what can happen under particular assumptions on use of fossil fuel and other human activities. Scenarios assist in climate modeling, help to examine potential climate change and explore vulnerabilities of humans and ecosystems under a changed climate. IPCC Special Report on Emissions Scenarios (SRES) (Summary for policymakers or Full report) describes these scenarios.

The main characteristics of the four SRES storylines and scenario families

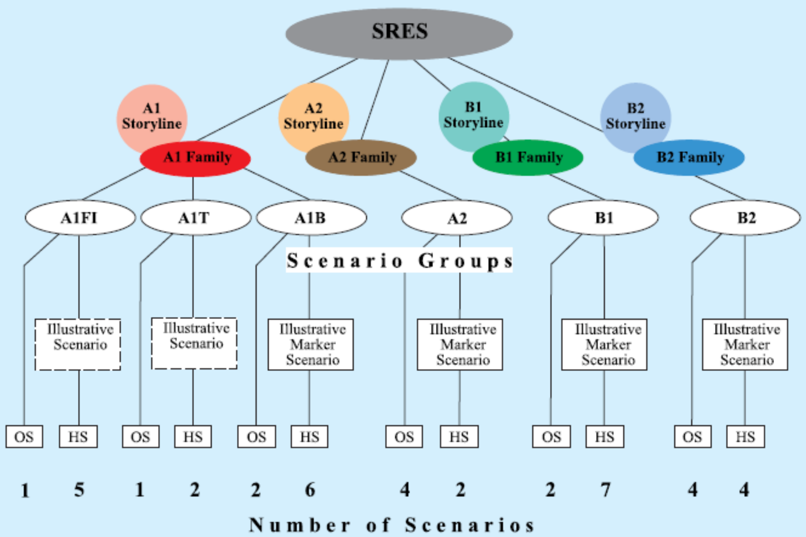
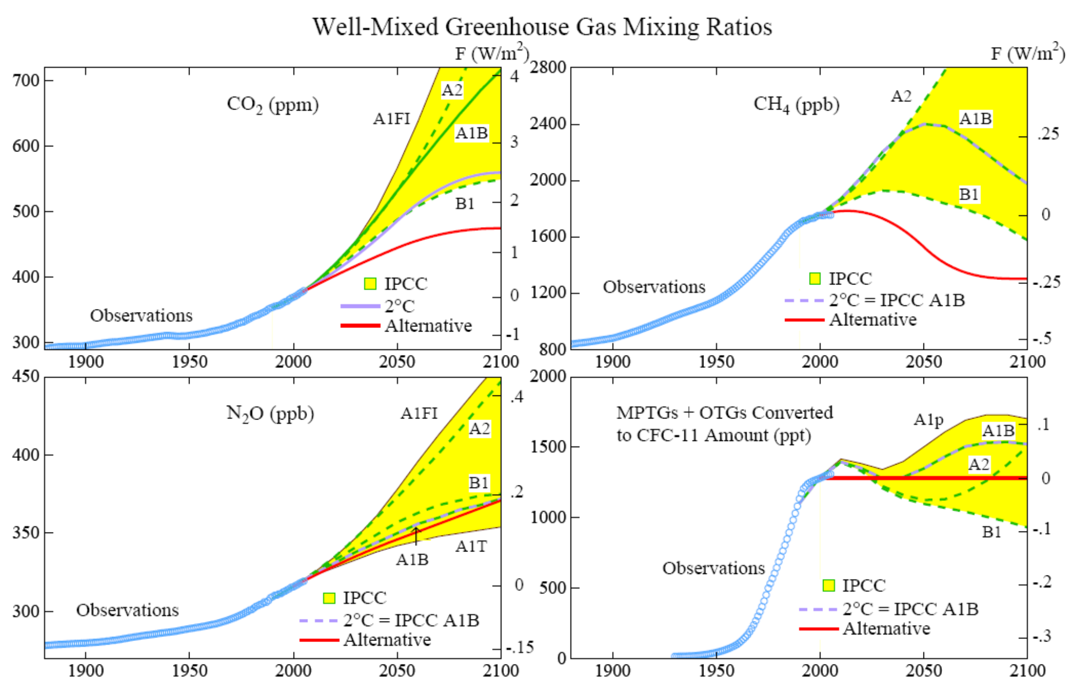
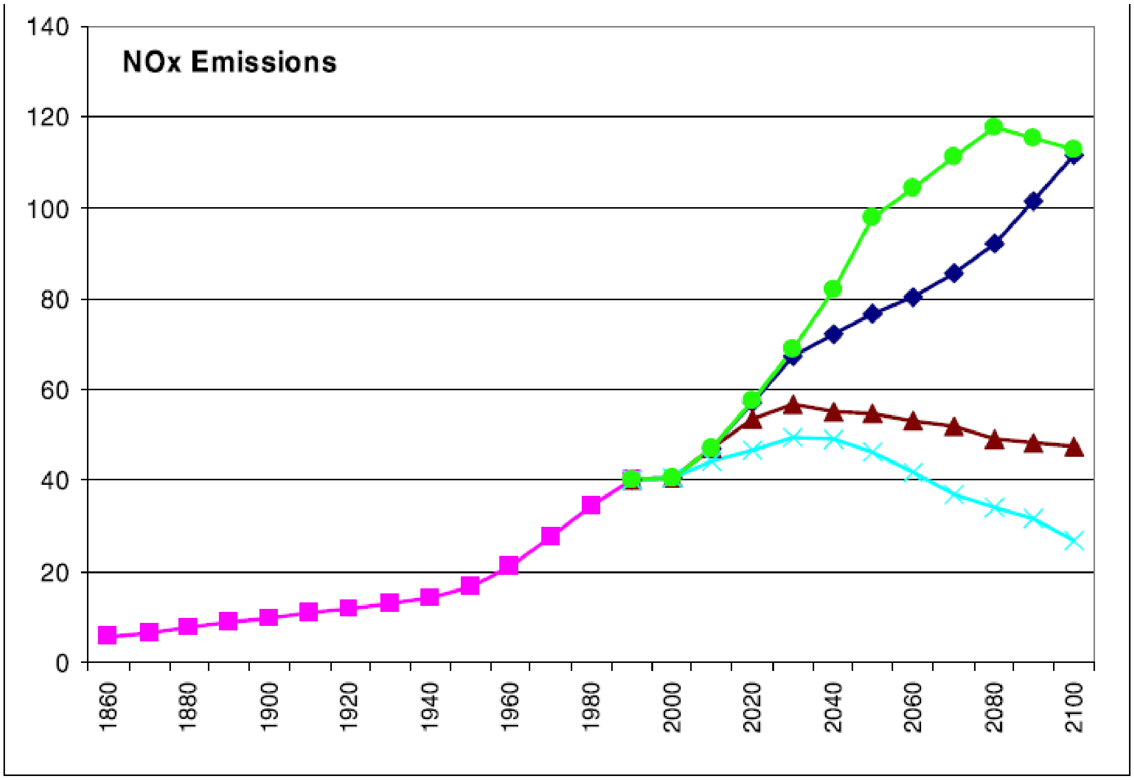
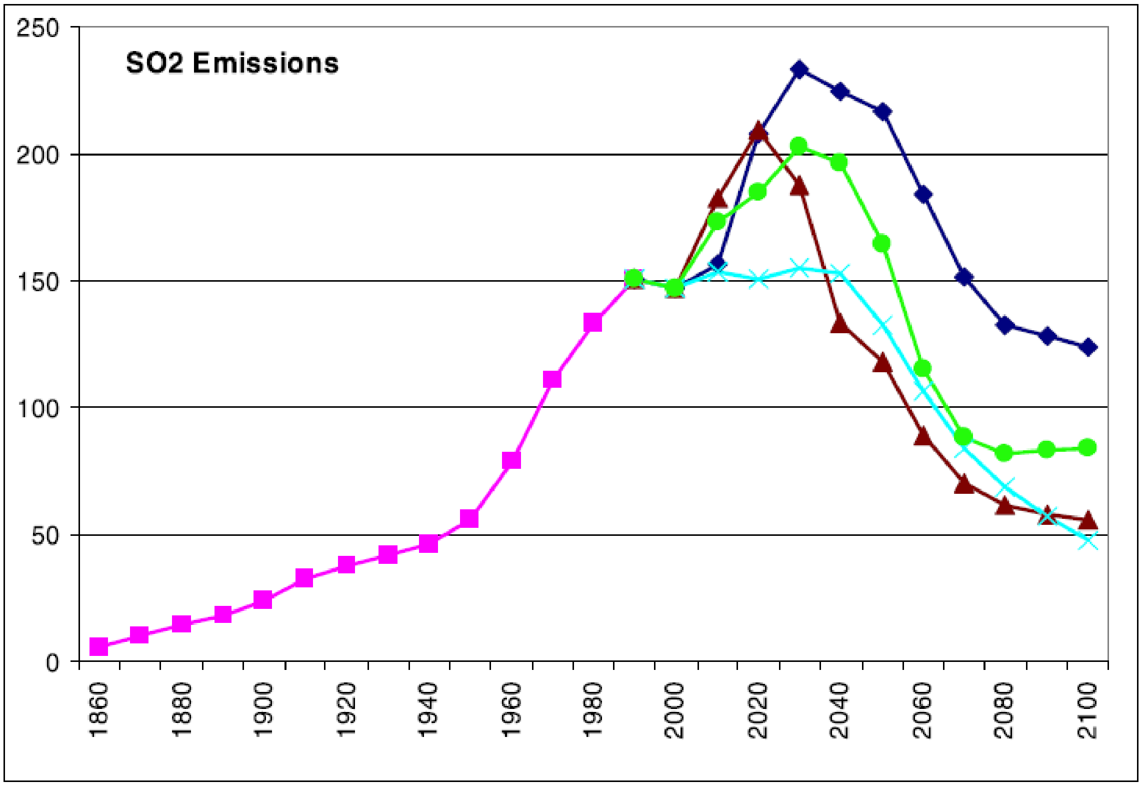


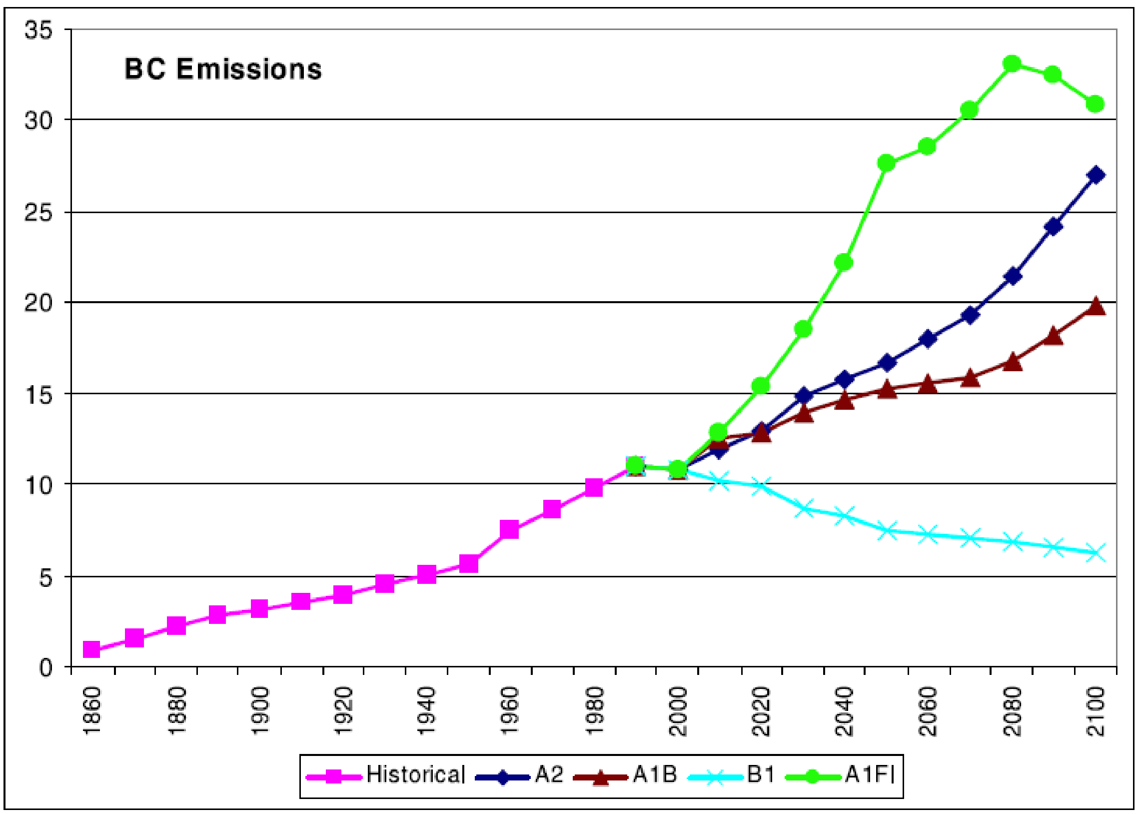
Figure 1: Schematic illustration of SRES scenarios. Four qualitative storylines yield four sets of scenarios called "families": A1, A2, B1, and B2. Altogether 40 SRES scenarios have been developed by six modeling teams. All are equally valid with no assigned probabilities of occurrence. The set of scenarios consists of six scenario groups drawn from the four families: one group each in A2, B1, B2, and three groups within the A1 family, characterizing alternative developments of energy technologies: A1FI (fossil fuel intensive), A1B (balanced), and A1T (predominantly non-fossil fuel). Within each family and group of scenarios, some share "harmonized" assumptions on global population, gross world product, and final energy. These are marked as "HS" for harmonized scenarios. "OS" denotes scenarios that explore uncertainties in driving forces beyond those of the harmonized scenarios. The number of scenarios developed within each category is shown. For each of the six scenario groups an illustrative scenario (which is always harmonized) is provided. Four illustrative marker scenarios, one for each scenario family, were used in draft form in the 1998 SRES open process and are included in revised form in this Report. Two additional illustrative scenarios for the groups A1FI and A1T are also provided and complete a set of six that illustrates all scenario groups. All are equally sound.



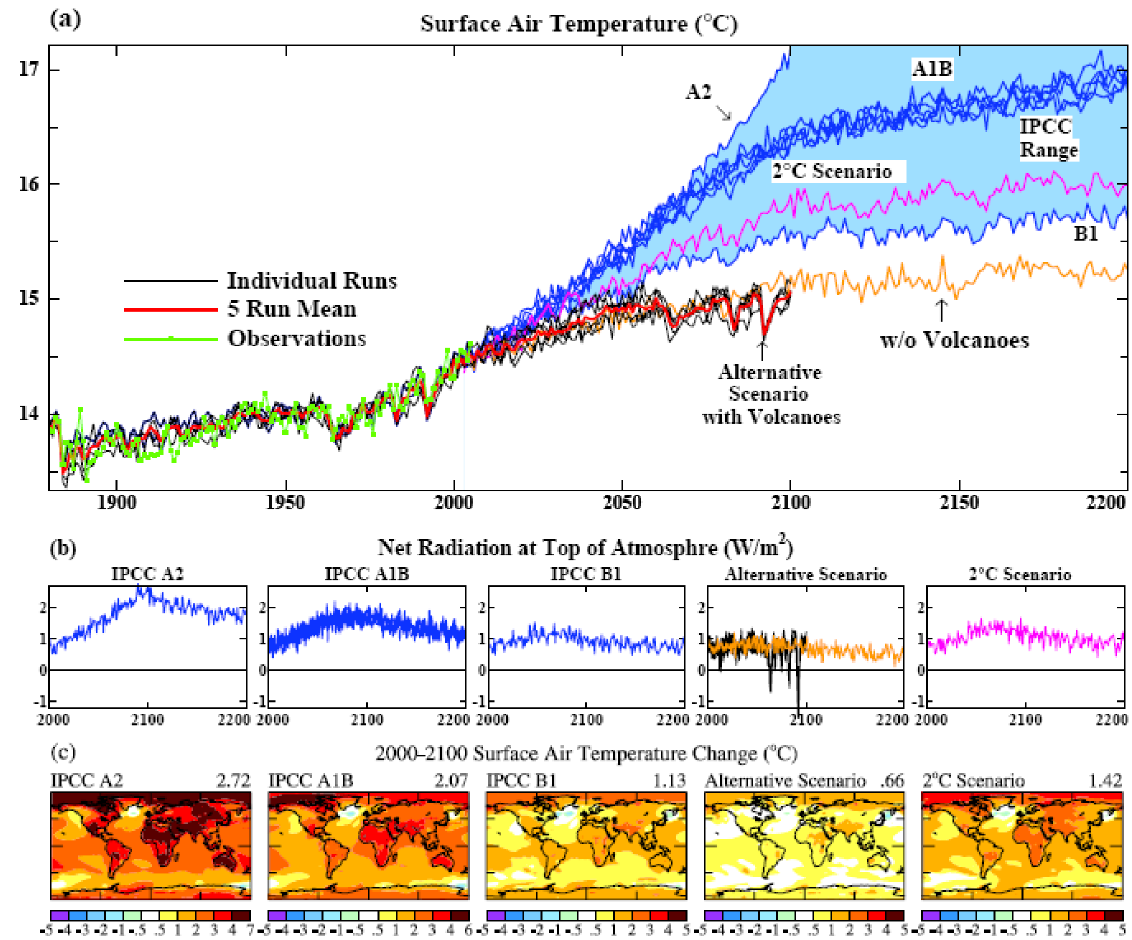


NOx Emissions
140
120
100
80
60
40
20
0
1860
1880
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100

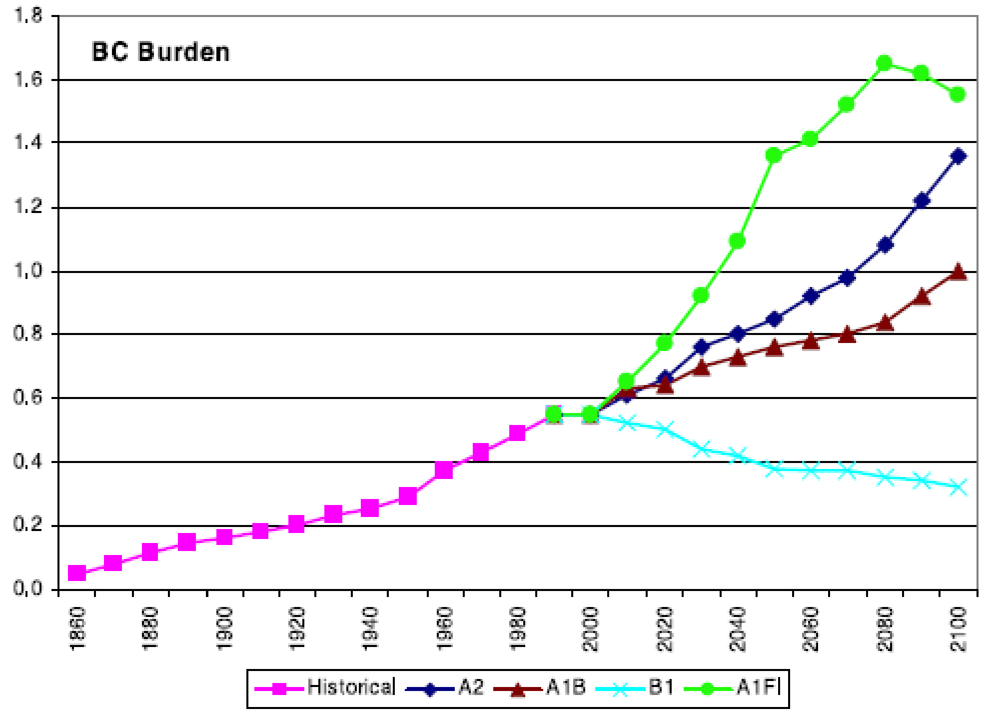




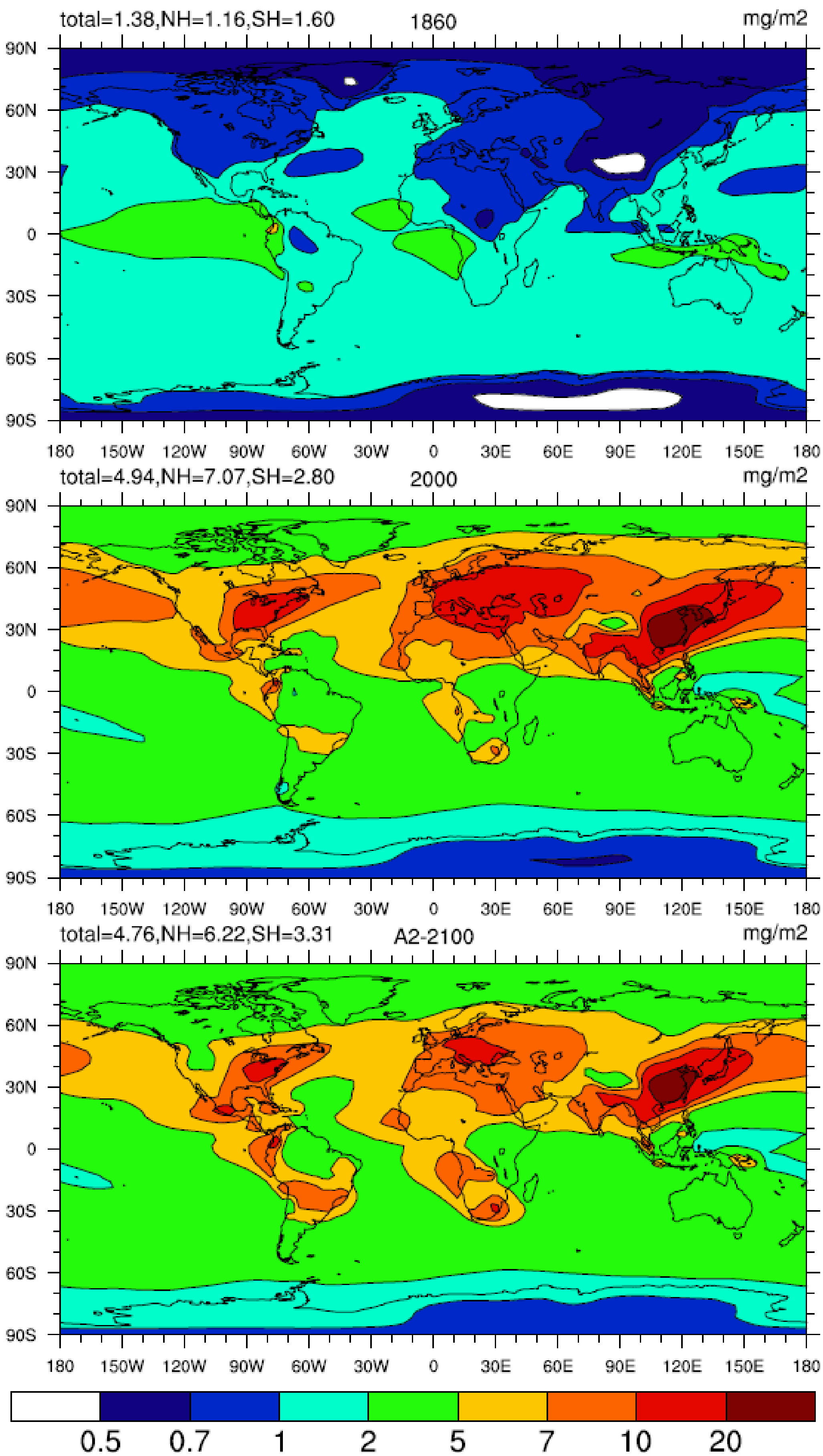
c. Future predictions

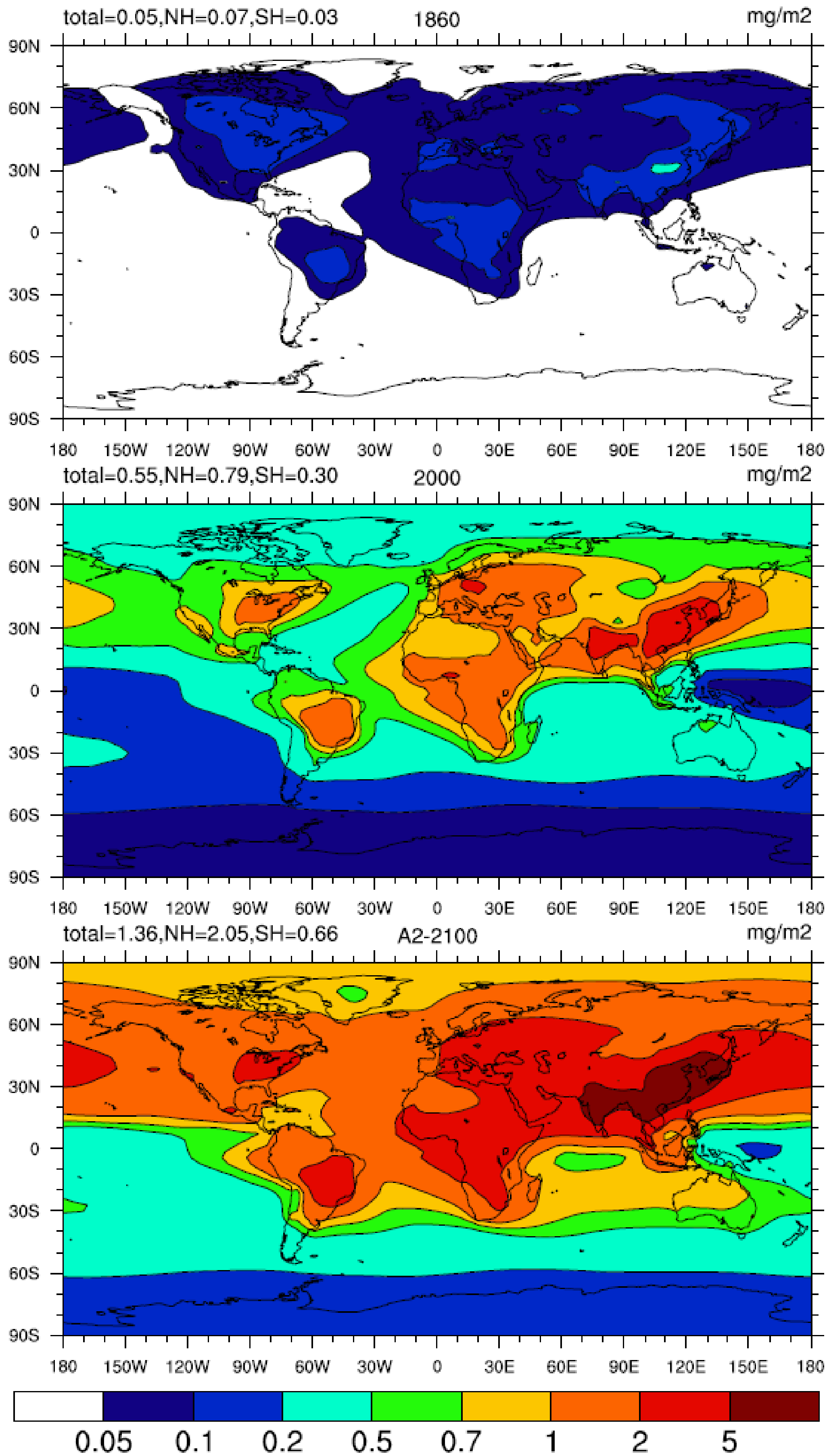


(a)
Surface Air Temperature (°C)
A2
A1B
IPCC Range
2°C Scenario
B1
Individual Runs
5 Run Mean
Observations
w/o Volcanoes
Alternative Scenario with Volcanoes
(b)
Net Radiation at Top of Atmosphre (W/m²)
IPCC A2
IPCC A1B
IPCC B1
Alternative Scenario
2°C Scenario
(c)
2000-2100 Surface Air Temperature Change (°C)
IPCC A2 2.72
IPCC A1B 2.07
IPCC B1 1.13
Alternative Scenario .66
2°C Scenario 1.42

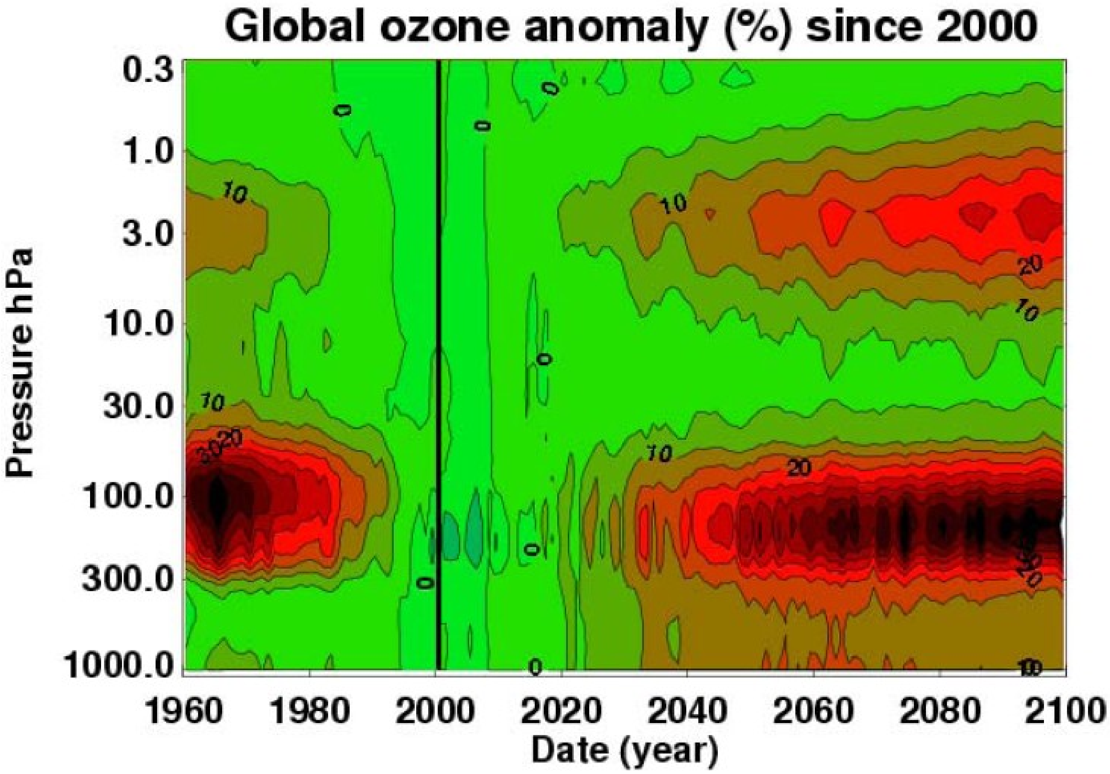


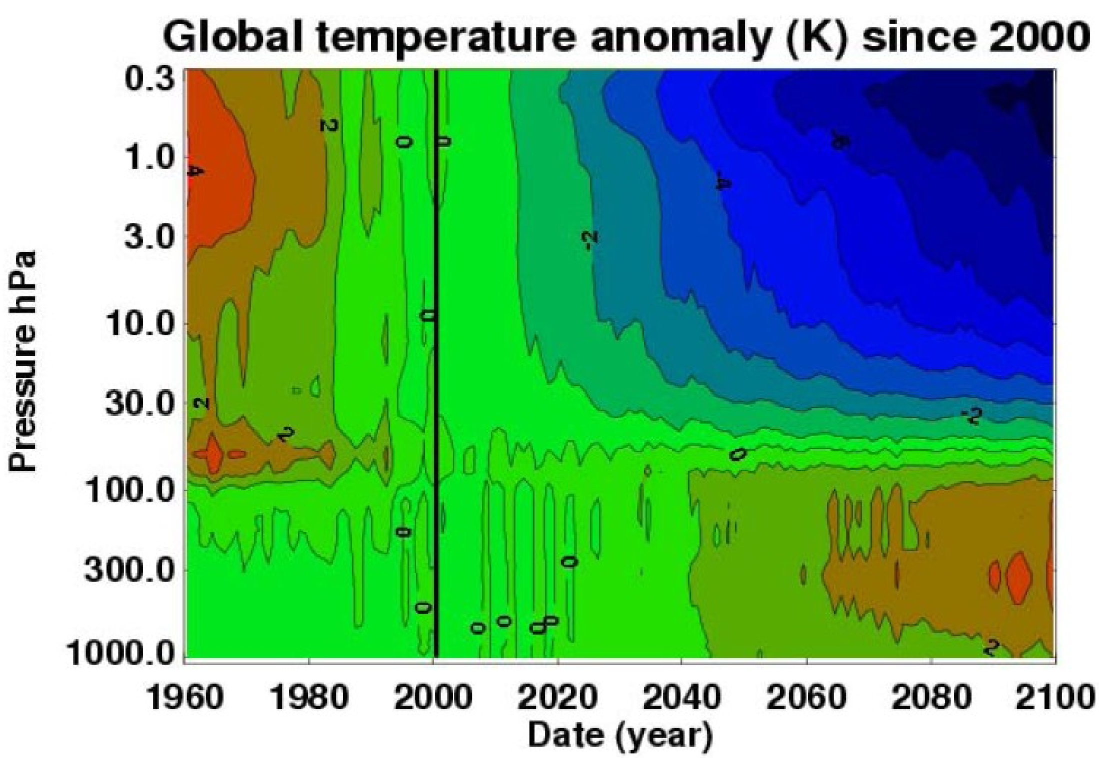
BC Burden
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
1860
1880
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100
Historical
A2
A1B
B1
A1FI


total=1.38,NH=1.16,SH=1.60
1860
mg/m2
total=4.94,NH=7.07,SH=2.80
2000
mg/m2
total=4.76,NH=6.22,SH=3.31
A2-2100
mg/m2
90N
60N
30N
0
30S
60S
90S
180
150W
120W
90W
60W
30W
0
30E
60E
90E
120E
150E
180
0.5
0.7
1
2
5
7
10
20



total=0.05,NH=0.07,SH=0.03
1860
mg/m2
total=0.55,NH=0.79,SH=0.30
2000
mg/m2
total=1.36,NH=2.05,SH=0.66
A2-2100
mg/m2
90N 60N 30N 0 30S 60S 90S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
0.05 0.1 0.2 0.5 0.7 1 2 5


Global ozone anomaly (%) since 2000
Pressure hPa
0.3
1.0
3.0
10.0
30.0
100.0
300.0
1000.0
1960
1980
2000
2020
2040
2060
2080
2100
Date (year)


Global temperature anomaly (K) since 2000
Pressure hPa
0.3
1.0
3.0
10.0
30.0
100.0
300.0
1000.0
1960
1980
2000
2020
2040
2060
2080
2100
Date (year)