Climate models: predictions and projections

12.340 Global Warming Science
May 1, 2012
Dan Cziczo

Reading: IPCC 2007 WG2 Ch 10,11

Today’s Class

- What are climate models? (recap)
- Sub-grid / unresolved processes
- AR4 Predictions
- Global vs. Regional Effects

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Global Climate Modeling

- **General philosophy**:
  - Simulate large-scale motions of atmosphere, oceans, ice
  - Solve approximations to full radiative transfer equations
  - Parameterize processes too small to resolve
  - Some models also try to simulate biogeochemical processes
  - First GCMs developed in 1960s

- Conservation of momentum
- Conservation of mass
- Conservation of water
- Conservation of certain chemical species
- First law of Thermodynamics
- Equation of state
- Radiative transfer equations

What is in a climate model?

- Atmospheric general circulation model
  - Dynamics
  - Sub-grid scale parameterized physics processes
    - Turbulence, solar/infrared radiation transport, clouds.
- Oceanic general circulation model
  - Dynamics (mostly)
- Sea ice model
  - Viscous elastic plastic dynamics
  - Thermodynamics
- Land Model
  - Energy and moisture budgets
  - Biology
- Chemistry
  - Tracer advection, possibly stiff rate equations.

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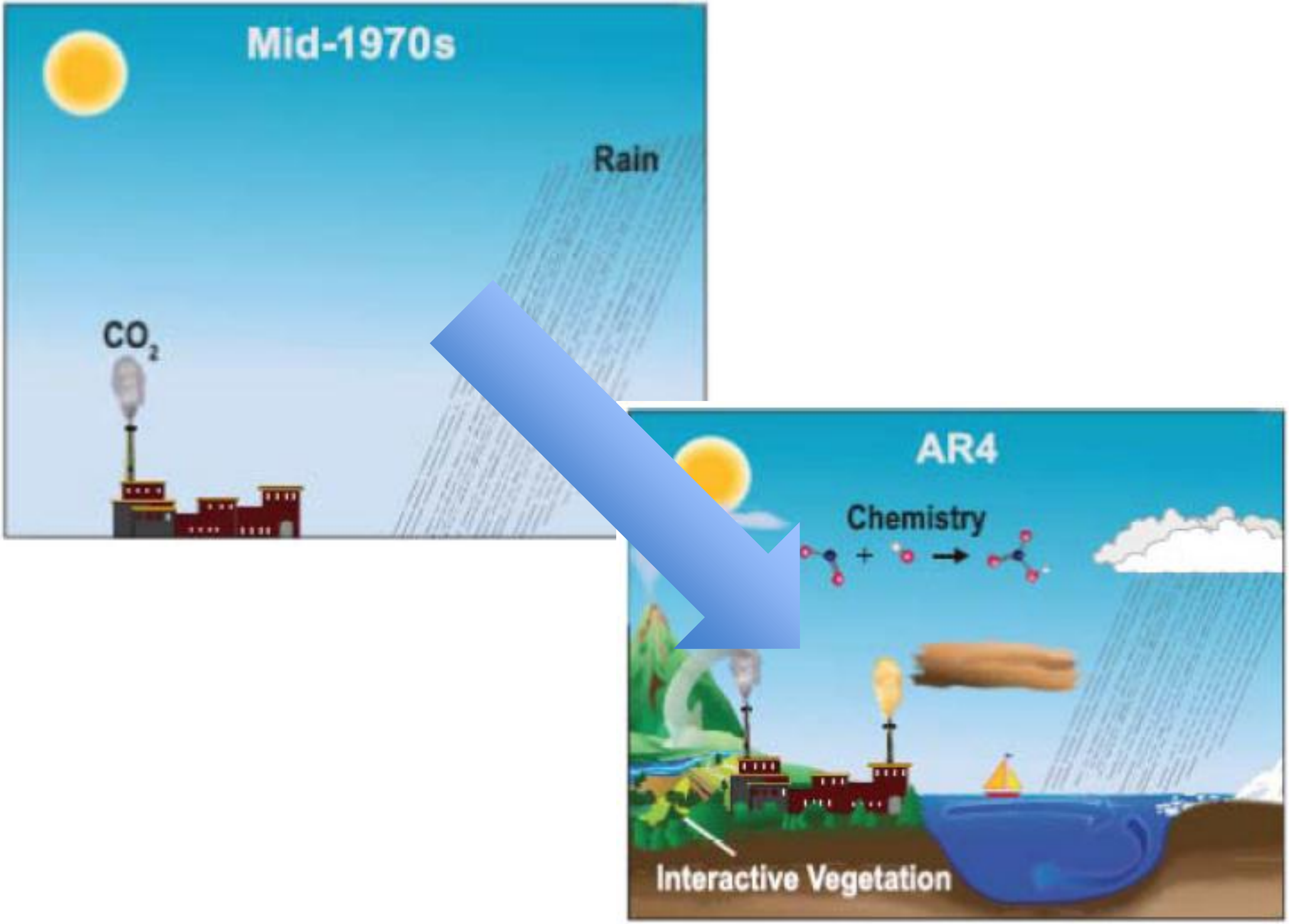

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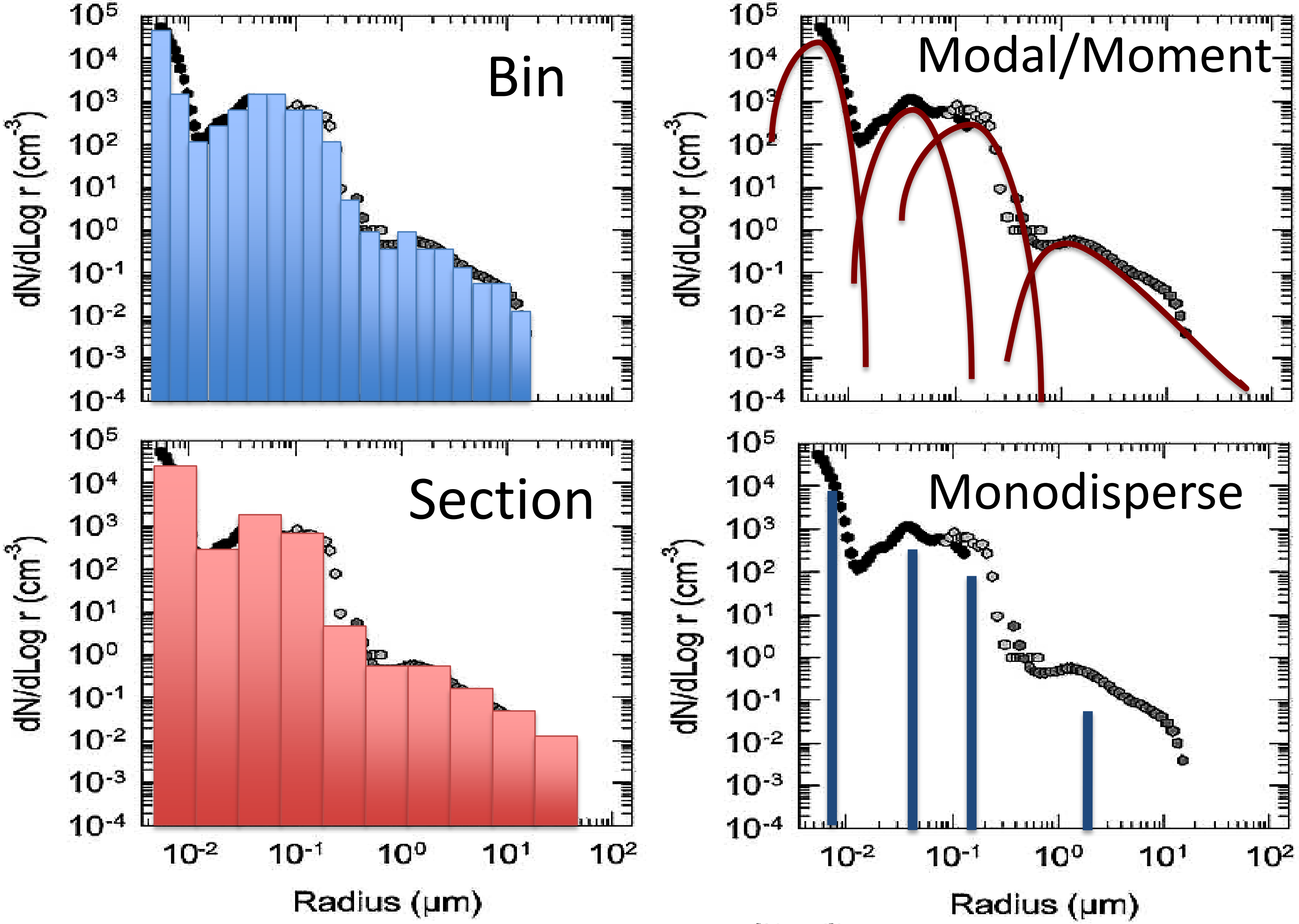
There's Always a 'But'…

Unresolved physical processes must be handled parametrically

- Convection
- Thin and/or broken clouds
- Cloud microphysics
- Aerosols and chemistry (e.g. photochemical processes, ozone)
- Turbulence, including surface fluxes
- Sea ice
- Land ice
- Land surface processes

Representing aerosol size distributions in models



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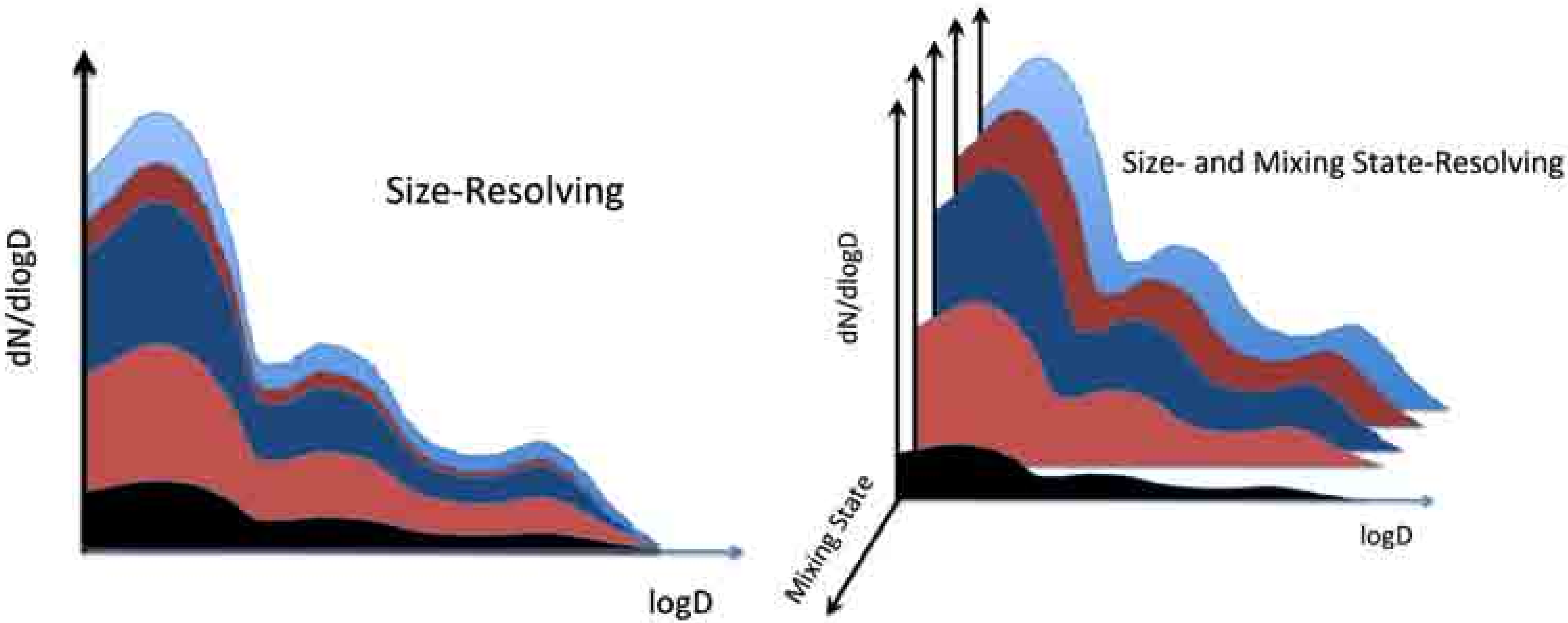
Representing aerosol composition in models



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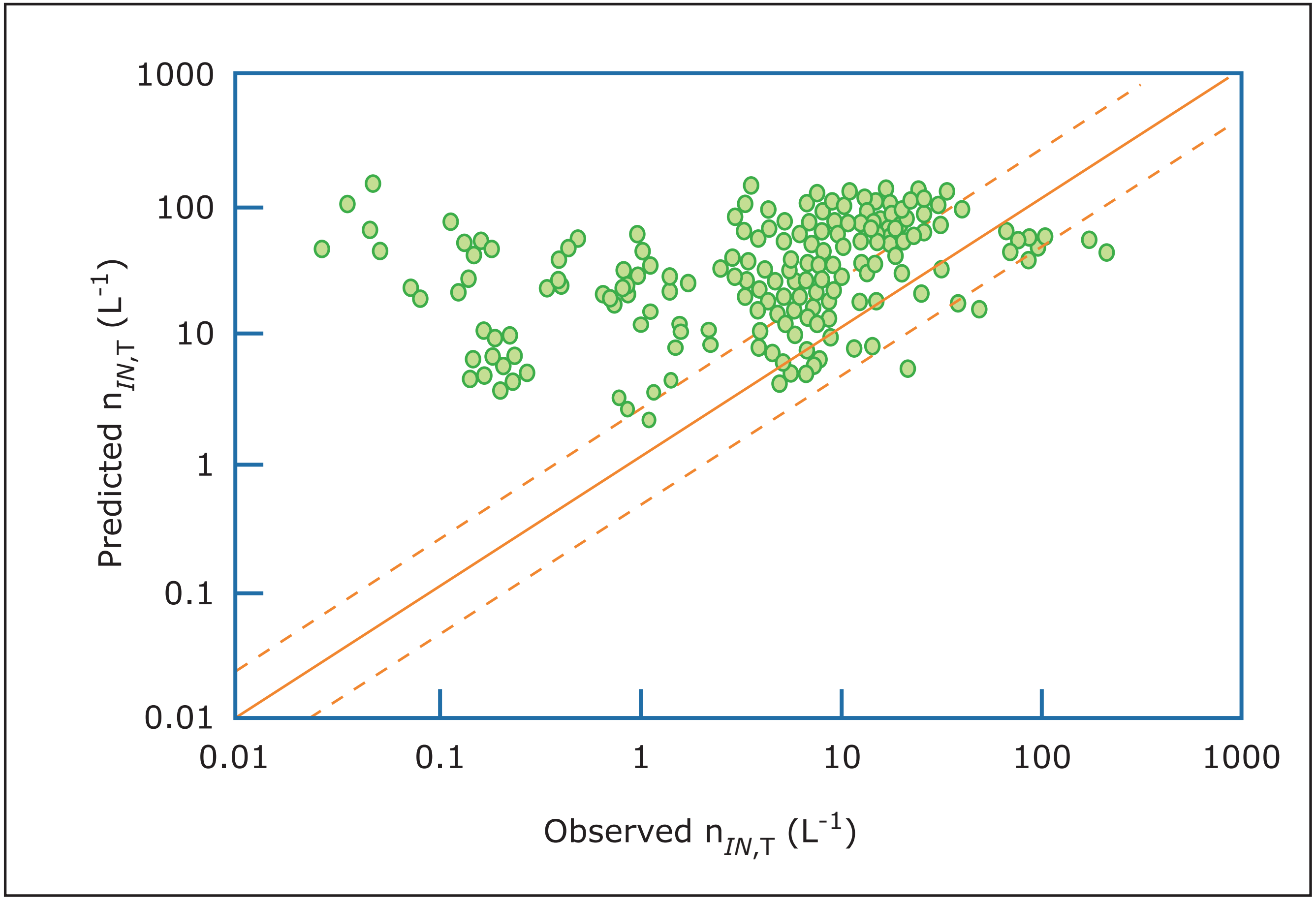

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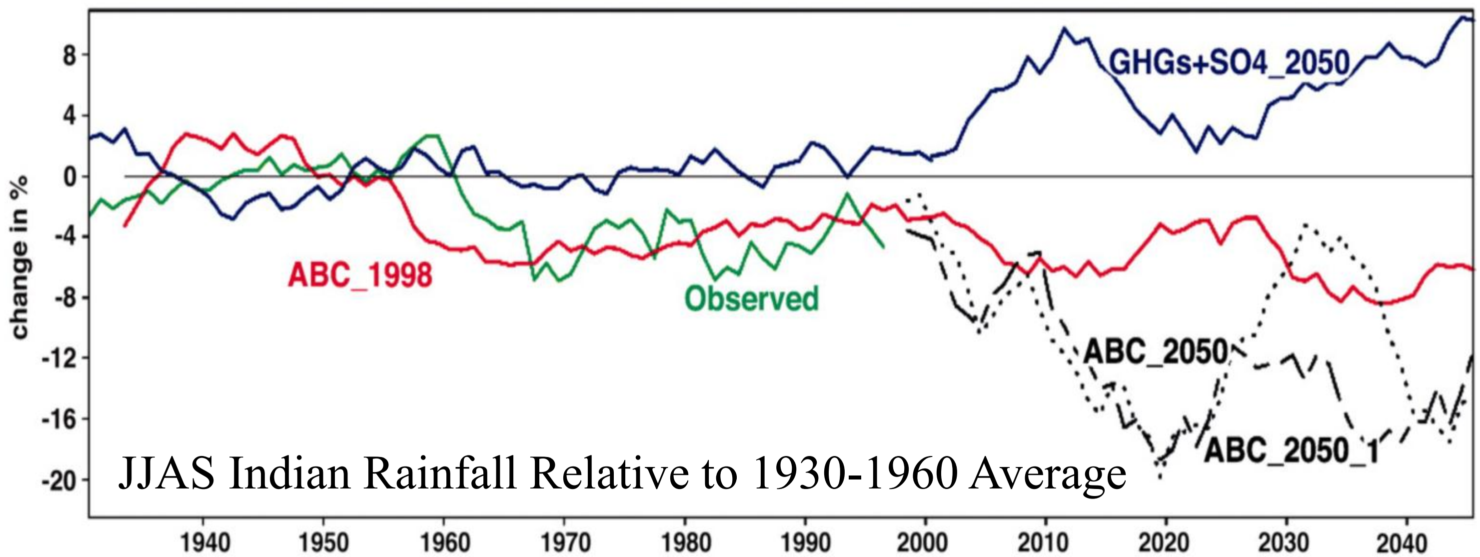
Aerosol and Indian Summer Monsoon



Wrong with only GHG considered. Wrong if only sulfate considered. “Right” with correct size and composition.

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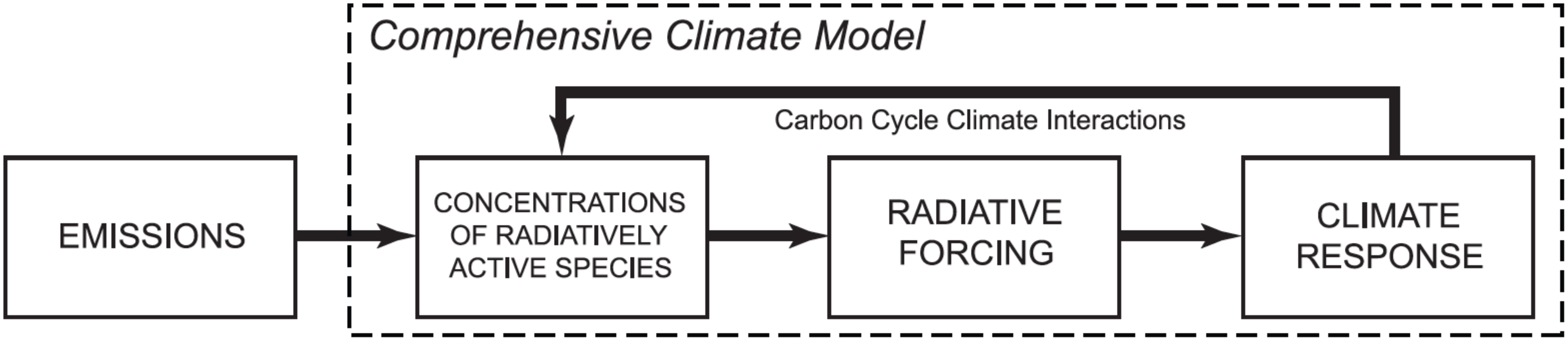
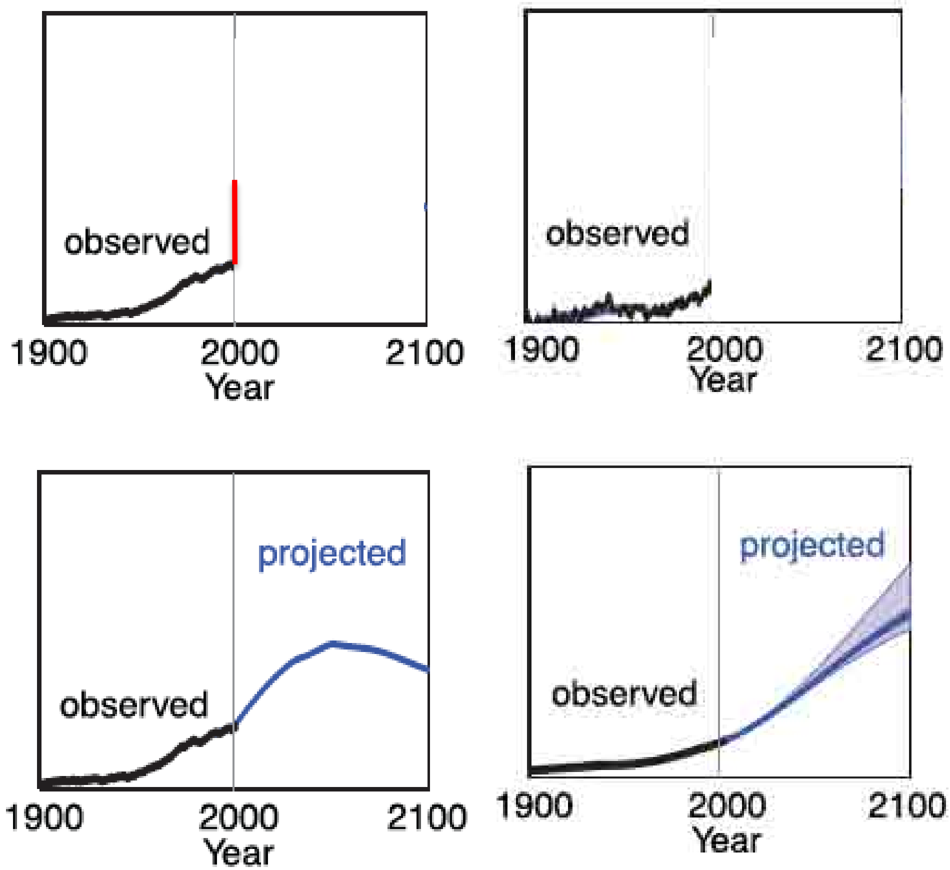
Following from AR4 WG2 Ch 10





Test 1, 2 (Sensitivity, Postcast)

Forecast 1, 2 (Scenarios)

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Table 10.3. *Total instantaneous forcing at 200 hPa (W m⁻²) from AOGCMs and LBL codes in RTMIP (W.D. Collins et al., 2006). Calculations are for cloud-free climatological mid-latitude summer conditions.*

Radiative Species	CO_2	CO_2	N_2O + CFCs	CH_4 + CFCs	All LLGHGs	Water Vapour
Forcing[a]	2000–1860	2x–1x	2000–1860	2000–1860	2000–1860	1.2x–1x
AOGCM mean	1.56	4.28	0.47	0.95	2.68	4.82
AOGCM std. dev.	0.23	0.66	0.15	0.30	0.30	0.34
LBL mean	1.69	4.75	0.38	0.73	2.58	5.08
LBL std. dev.	0.02	0.04	0.12	0.12	0.11	0.16

Table 10.2. *All-sky radiative forcing for doubled atmospheric CO_2. See Table 8.1 for model details.*

Model[Source]	Longwave ($W\ m^{-2}$)	Shortwave ($W\ m^{-2}$)
CGCM 3.1 (T47/T63)[a]	3.39	–0.07
CSIRO-MK3.0[b]	3.42	0.05
GISS-EH/ER[a]	4.21	–0.15
GFDL-CM2.0/2.1[b]	3.62	–0.12
IPSL-CM4[c]	3.50	–0.02
MIROC 3.2-hires[d]	3.06	0.08
MIROC 3.2-medres[d]	2.99	0.10
ECHAM5/MPI-OM[a]	3.98	0.03
MRI-CGCM2.3.2[b]	3.75	–0.28
CCSM3[a]	4.23	–0.28
UKMO-HadCM3[a]	4.03	–0.22
UKMO-HadGEM1[a]	4.02	–0.24
Mean ± standard deviation[e]	3.80 ± 0.33	–0.13 ± 0.11

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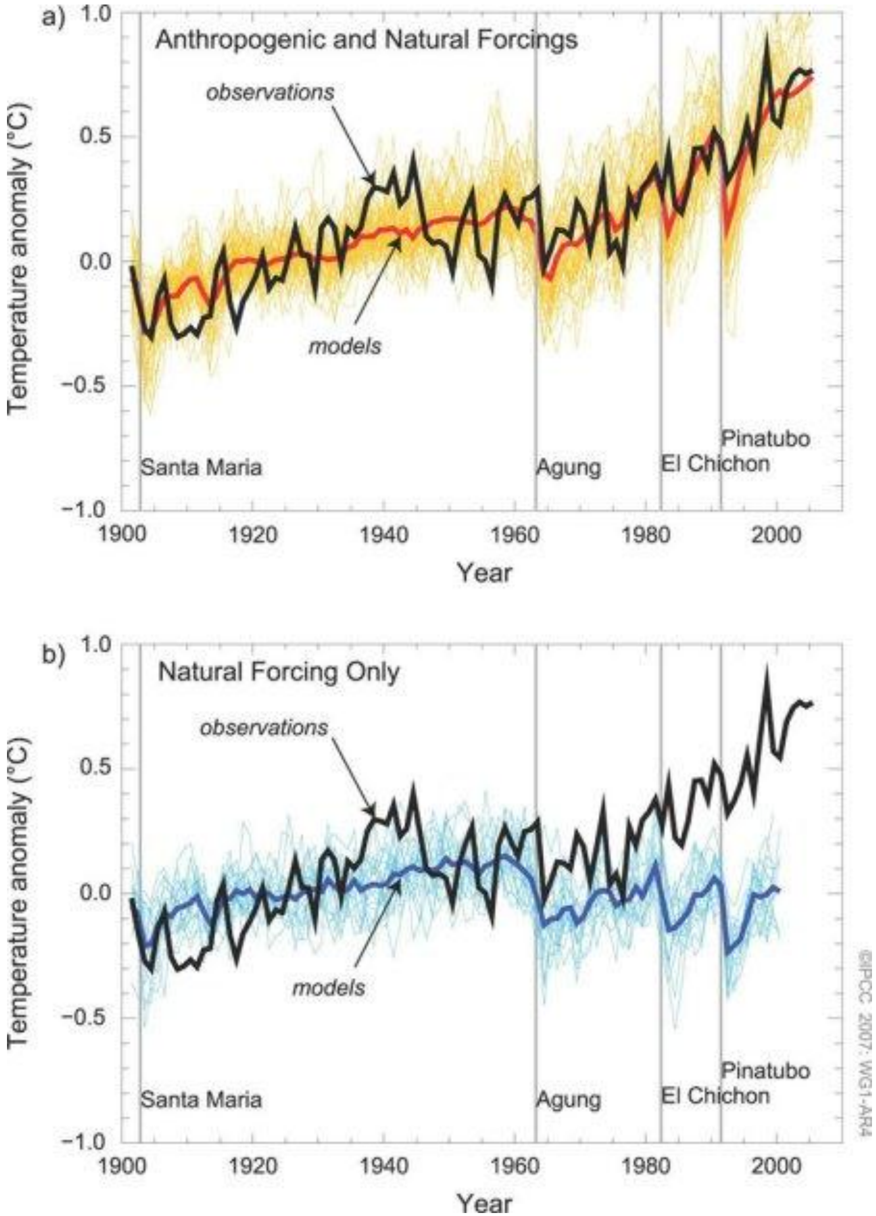
Global mean temperature (black) and simulations using many different global models (colors) including all forcings

To some extent, “success” of 20th century simulations is a result of model curve fitting

Same as above, but models run with only natural forcings



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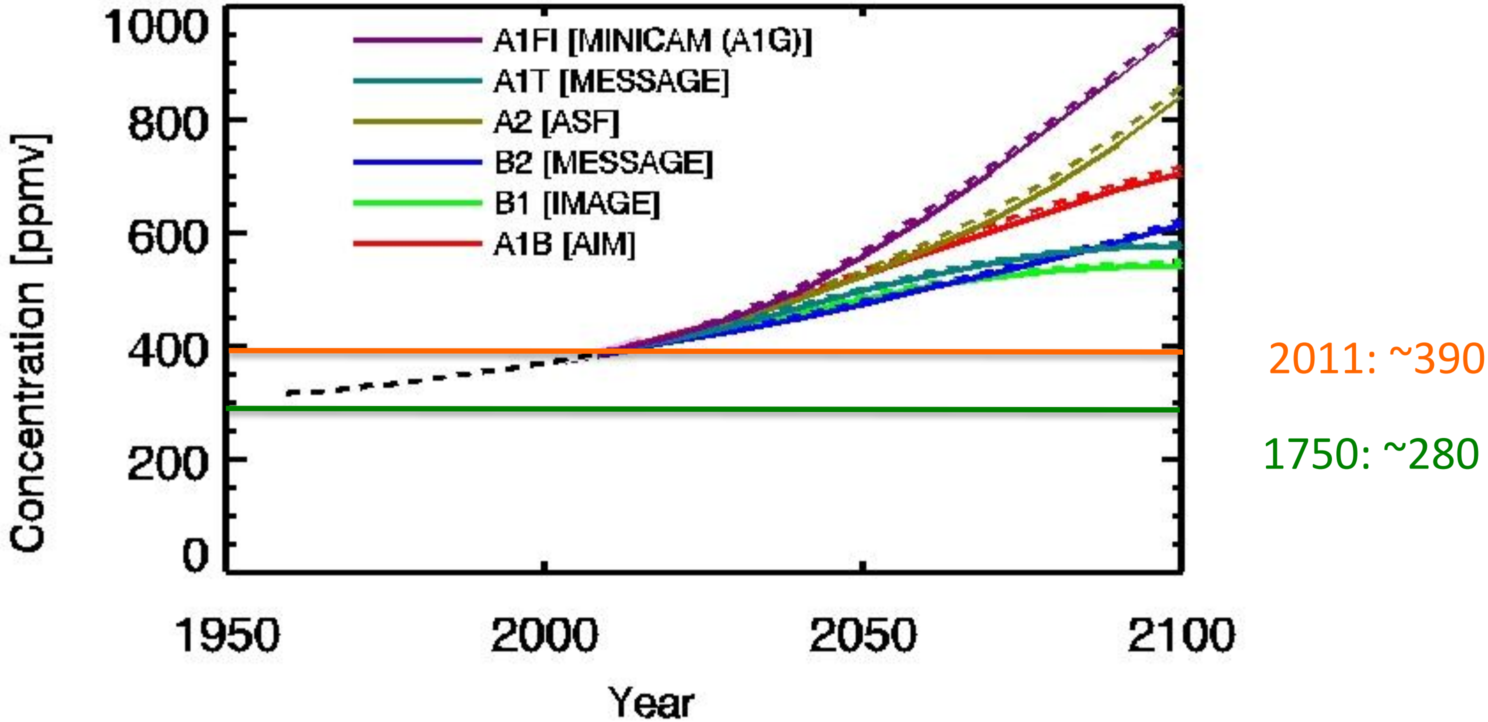
AR4 Scenarios



A1 "Family" – Rapid on average since 1850 through 2100. Shift of countries toward "developed". Various commitments to new technology – none, in some areas, in whole world. Assumes abundant resources. A1B is commonly used intermediate.

A2 – Slowdown of global economy and consolidation.

B1 – Global commitment to environment and sustainable resources.

B2 – Similar to B1 but with more regionalism.

IPCC Data Distribution Centre (DDC), Figure 1 from http://www.ipcc-data.org/ddc_co2.html. Used with permission.

Model ID	Model, Country
1	BCC-CM1, China
2	BCCR-BCM2.0, Norway
3	CCSM3, USA *
4	CGCM3.1(T47), Canada
5	CGCM3.1(T63), Canada
6	CNRM-CM3, France
7	CSIRO-MK3.0, Australia
8	ECHAM5/MPI-OM, Germany
9	ECHO-G, Germany/Korea
10	FGOALS-g1.0, China
11	GFDL-CM2.0, USA
12	GFDL-CM2.1, USA
13	GISS-AOM, USA
14	GISS-EH, USA
15	GISS-ER, USA
16	INM-CM3.0, Russia
17	IPSL-CM4, France
18	MIROC3.2(hires), Japan
19	MIROC3.2(medres), Japan
20	MRI-CGCM2.3.2, Japan
21	PCM, USA
22	UKMO-HadCM3, UK
23	UKMO-HadGEM1, UK

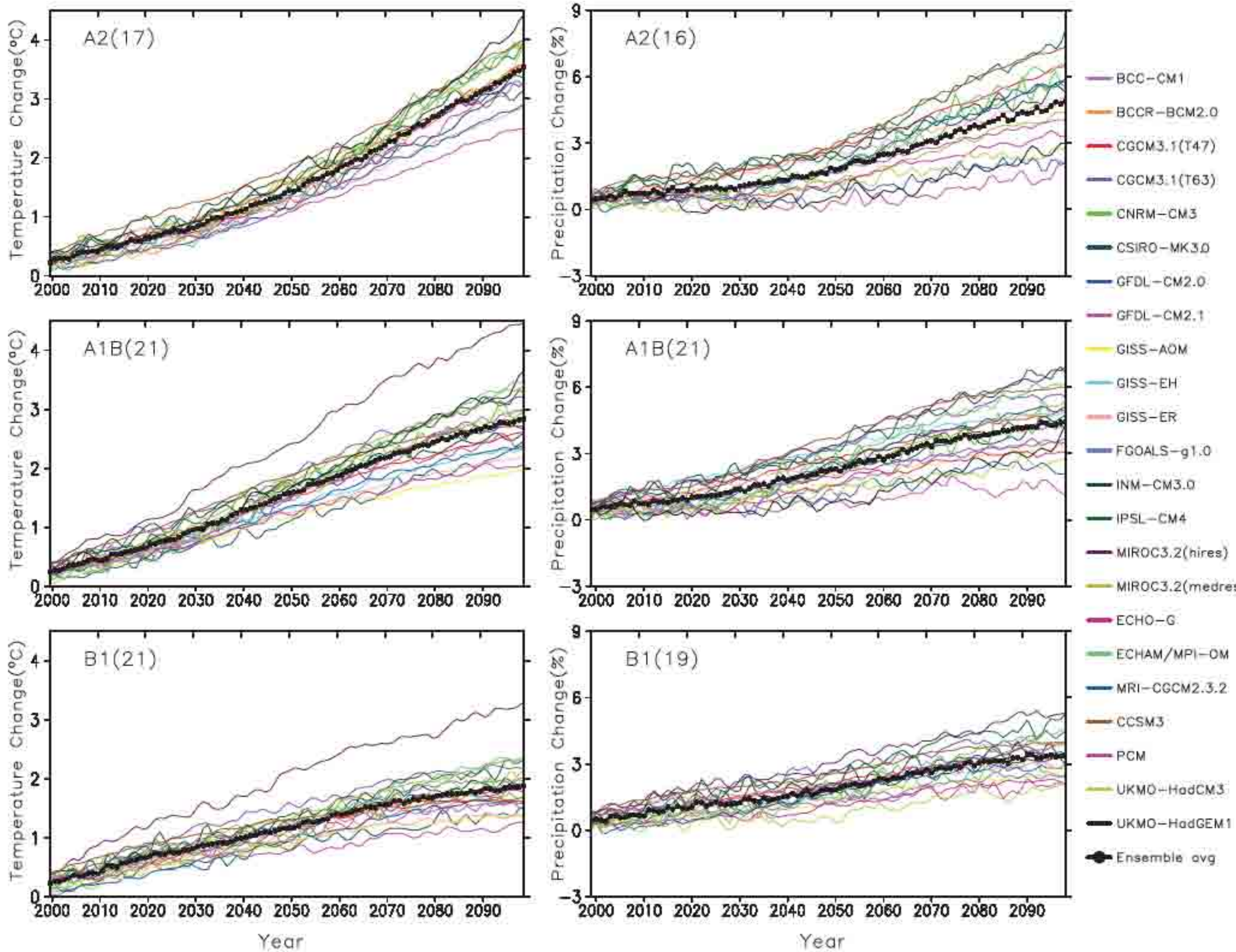


Figure 10.5. *Time series of globally averaged (left) surface warming (surface air temperature change, °C) and (right) precipitation change (%) from the various global coupled models for the scenarios A2 (top), A1B (middle) and B1 (bottom). Numbers in parentheses following the scenario name represent the number of simulations shown. Values are annual means, relative to the 1980 to 1999 average from the corresponding 20th-century simulations, with any linear trends in the corresponding control run simulations removed. A three-point smoothing was applied. Multi-model (ensemble) mean series are marked with black dots. See Table 8.1 for model details.*

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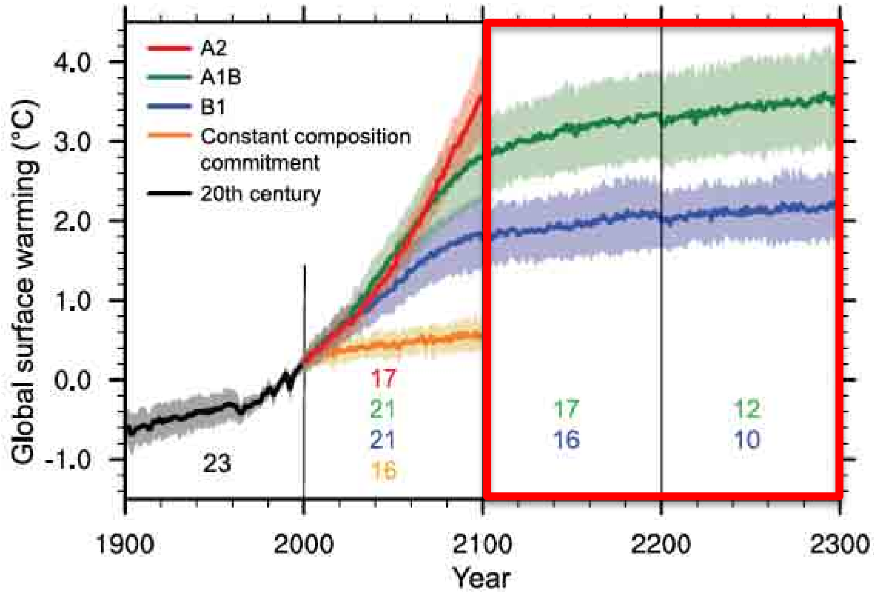

	Global mean warming (°C)			
	2011–2030	2046–2065	2080–2099	2180–2199
A2	0.64	1.65	3.13	
A1B	0.69	1.75	2.65	3.36
B1	0.66	1.29	1.79	2.10
Commit[a]	0.37	0.47	0.56	

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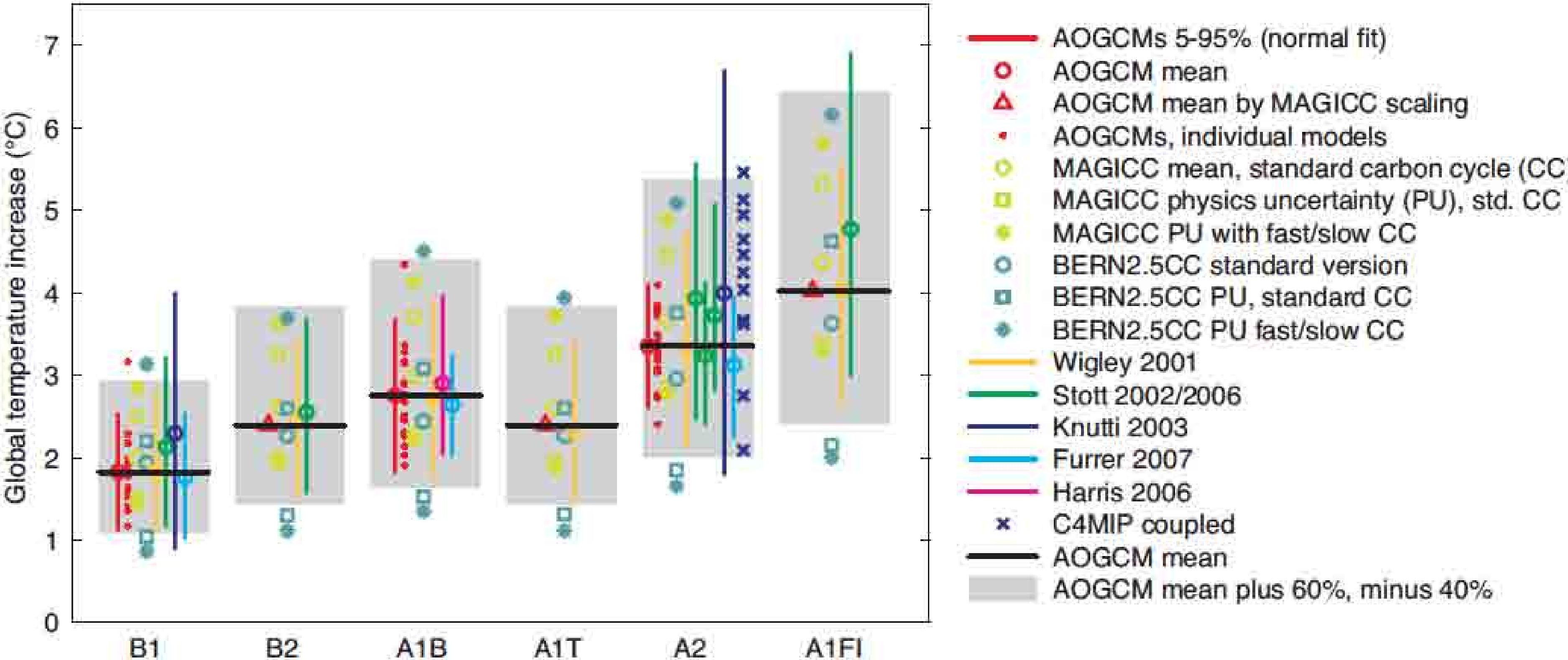

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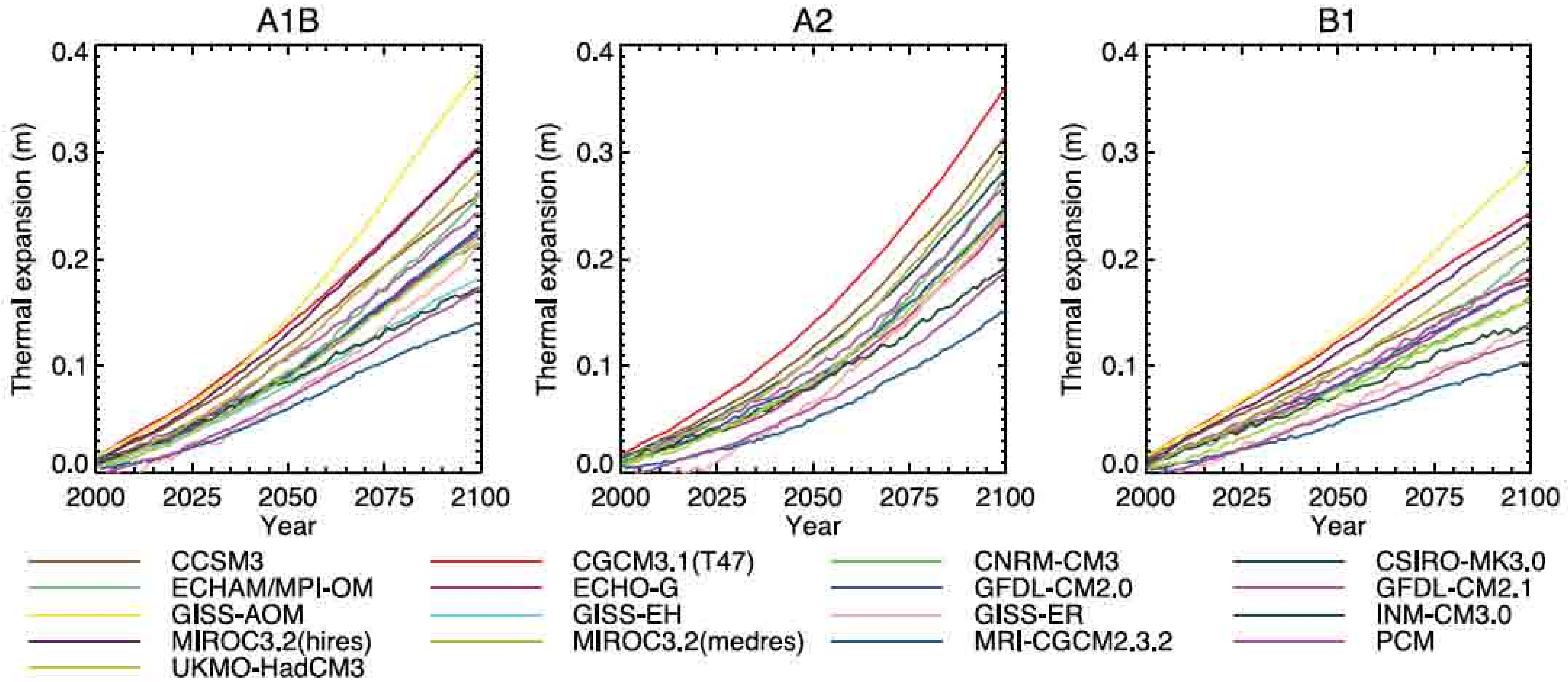

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We're talking this….

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…not this

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From National Geographic, 20th Century Fox

Today's Class

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- Sub-grid / unresolved processes
- AR4 Predictions
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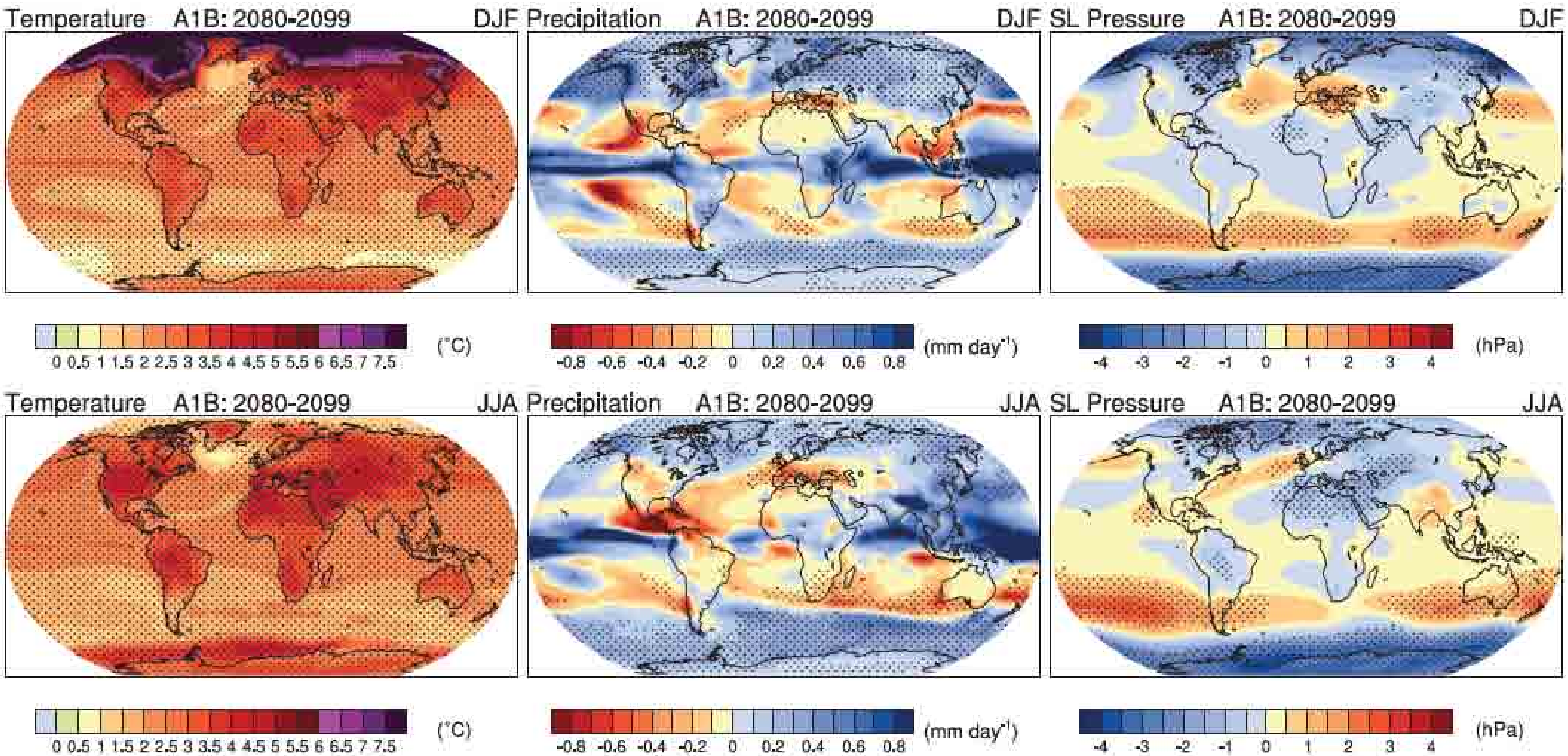
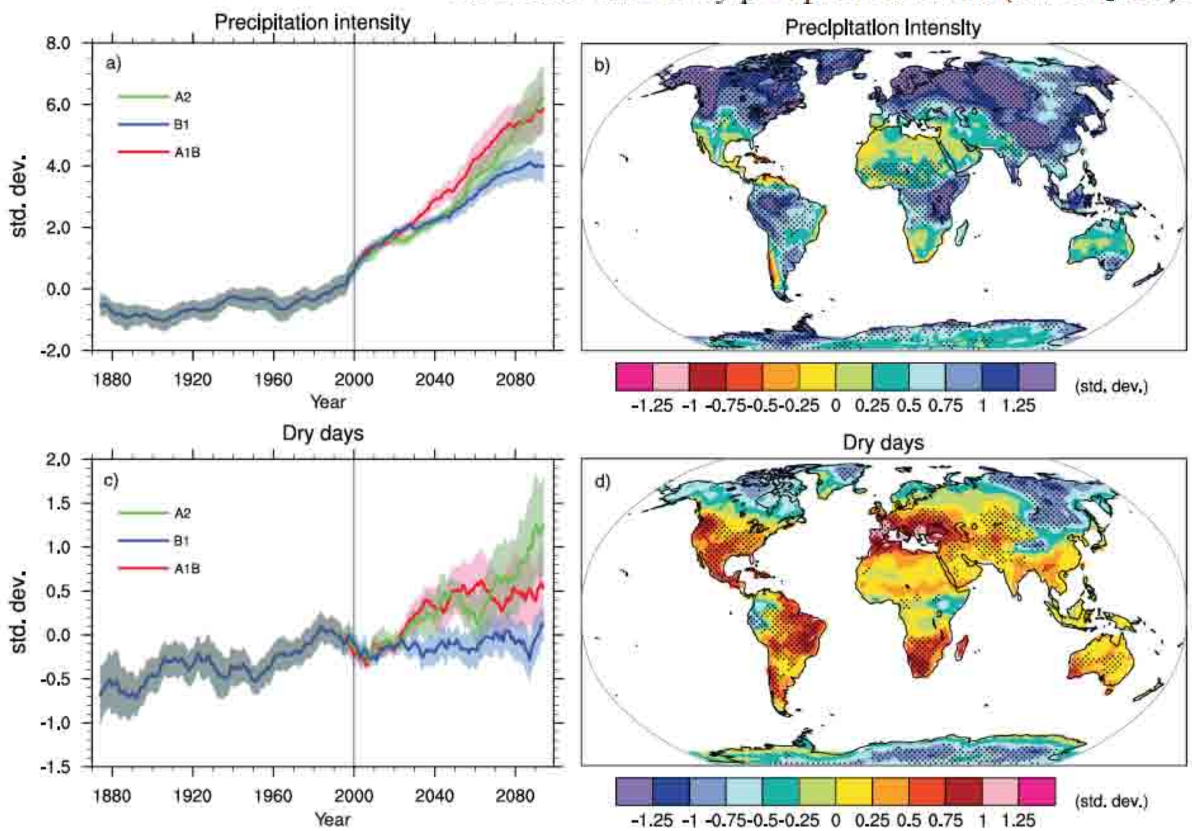


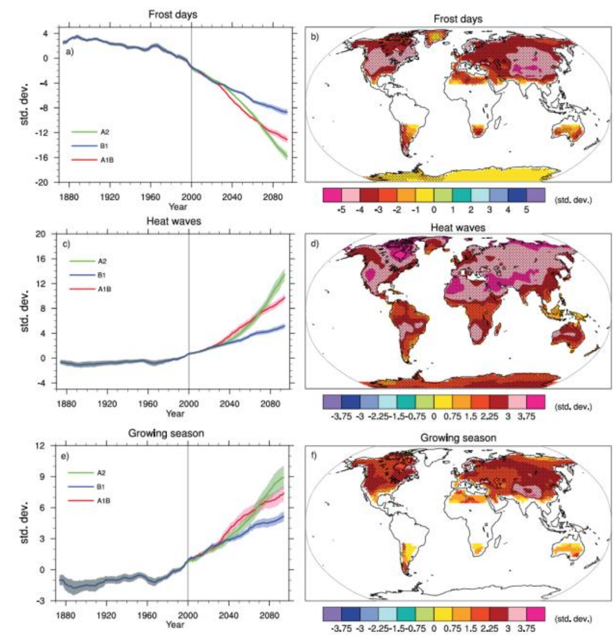
Figure 10.9. *Multi-model mean changes in surface air temperature (°C, left), precipitation (mm day^{-1}, middle) and sea level pressure (hPa, right) for boreal winter (DJF, top) and summer (JJA, bottom). Changes are given for the SRES A1B scenario, for the period 2080 to 2099 relative to 1980 to 1999. Stippling denotes areas where the magnitude of the multi-model ensemble mean exceeds the inter-model standard deviation. Results for individual models can be seen in the Supplementary Material for this chapter.*

Frequently Asked Question 10.1

Are Extreme Events, Like Heat Waves, Droughts or Floods, Expected to Change as the Earth's Climate Changes?

Yes; the type, frequency and intensity of extreme events are expected to change as Earth's climate changes, and these changes could occur even with relatively small mean climate changes. Changes in some types of extreme events have already been observed, for example, increases in the frequency and intensity of heat waves and heavy precipitation events (see FAQ 3.3).





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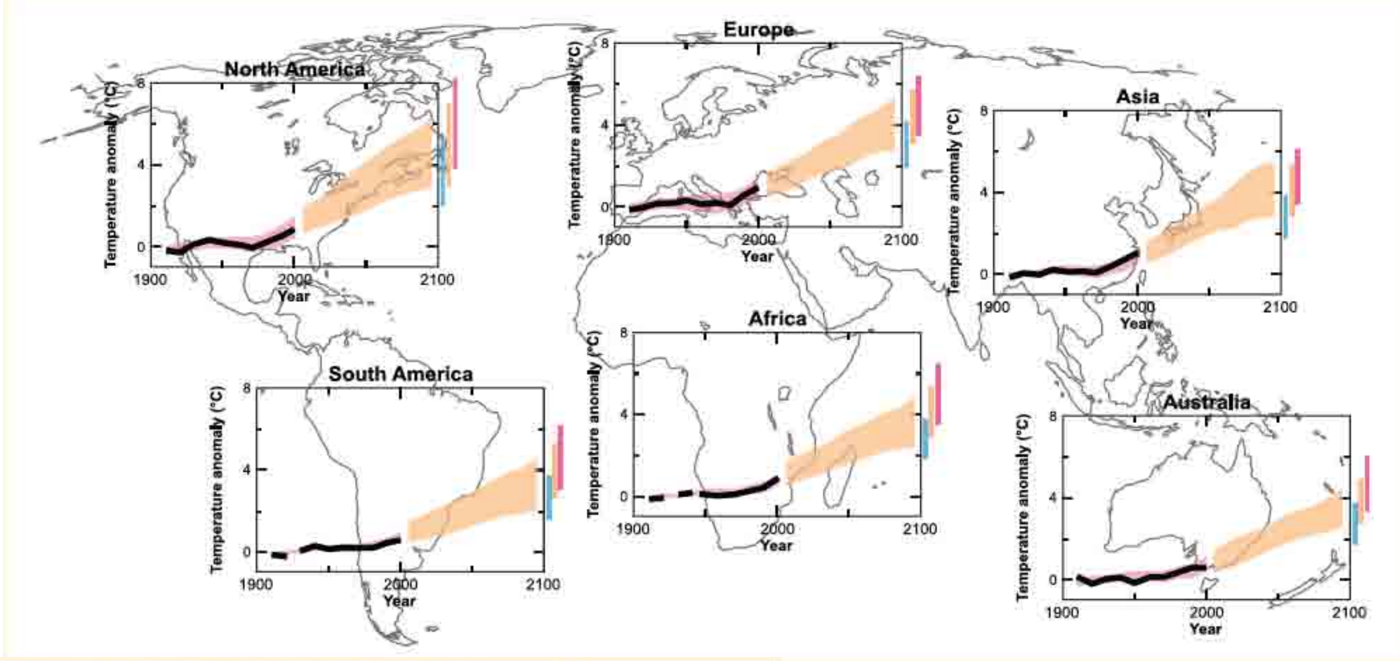

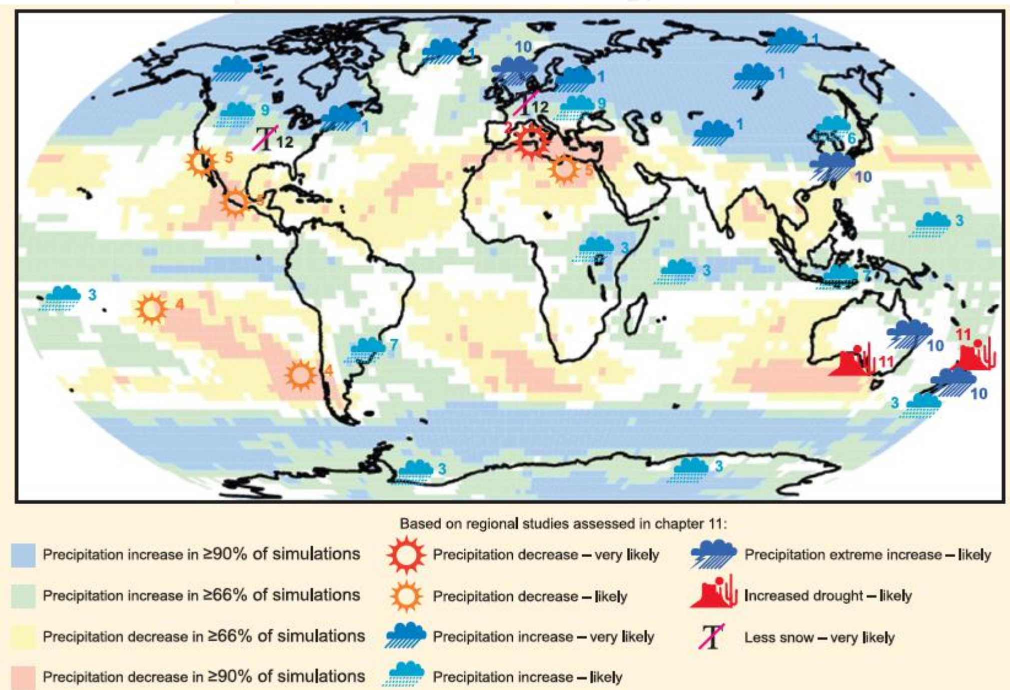

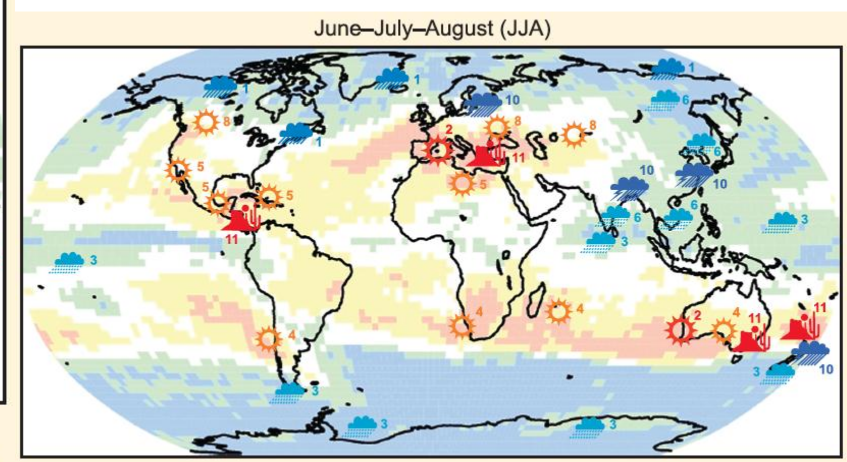

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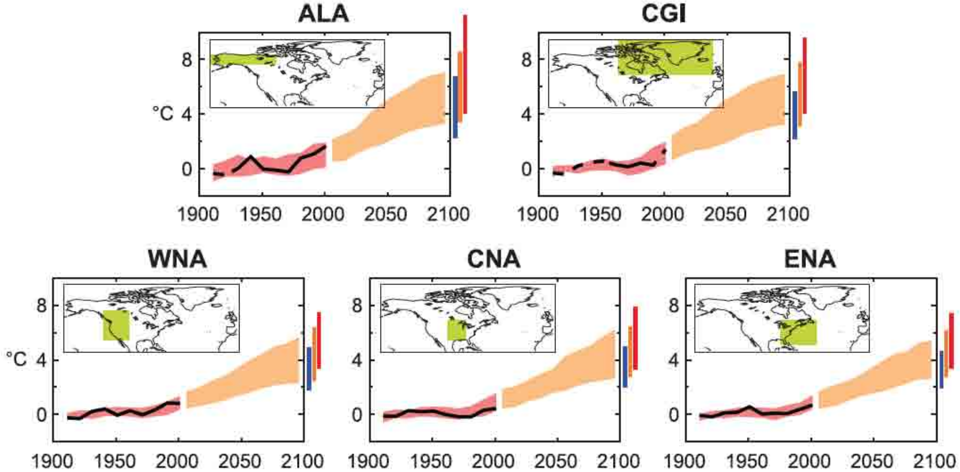
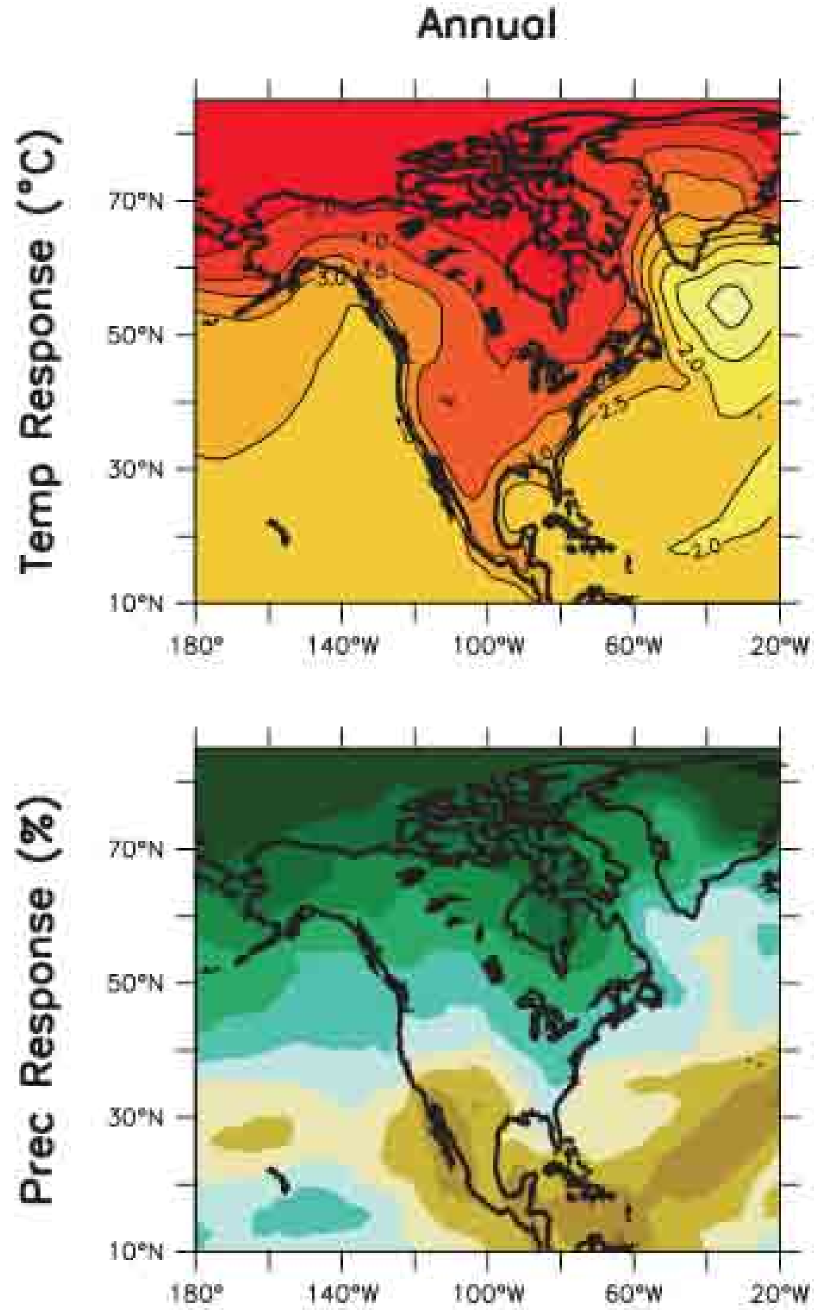


Figure 11.11. *Temperature anomalies with respect to 1901 to 1950 for five North American land regions for 1906 to 2005 (black line) and as simulated (red envelope) by MMD models incorporating known forcings; and as projected for 2001 to 2100 by MMD models for the A1B scenario (orange envelope). The bars at the end of the orange envelope represent the range of projected changes for 2091 to 2100 for the B1 scenario (blue), the A1B scenario (orange) and the A2 scenario (red). The black line is dashed where observations are present for less than 50% of the area in the decade concerned. More details on the construction of these figures are given in Box 11.1 and Section 11.1.2.*



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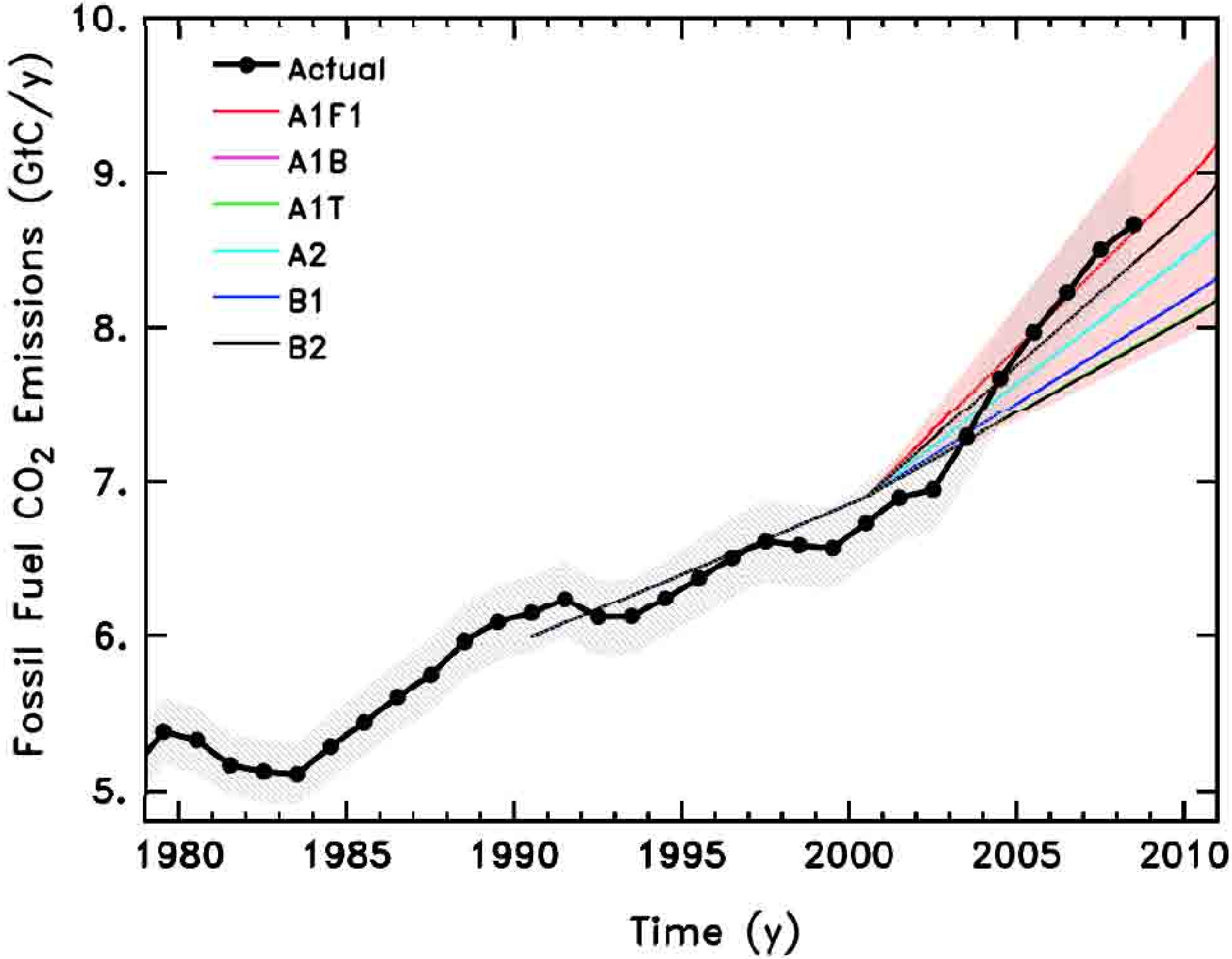
How Are We Doing?

Global CO_2 Emissions from Fossil Fuels



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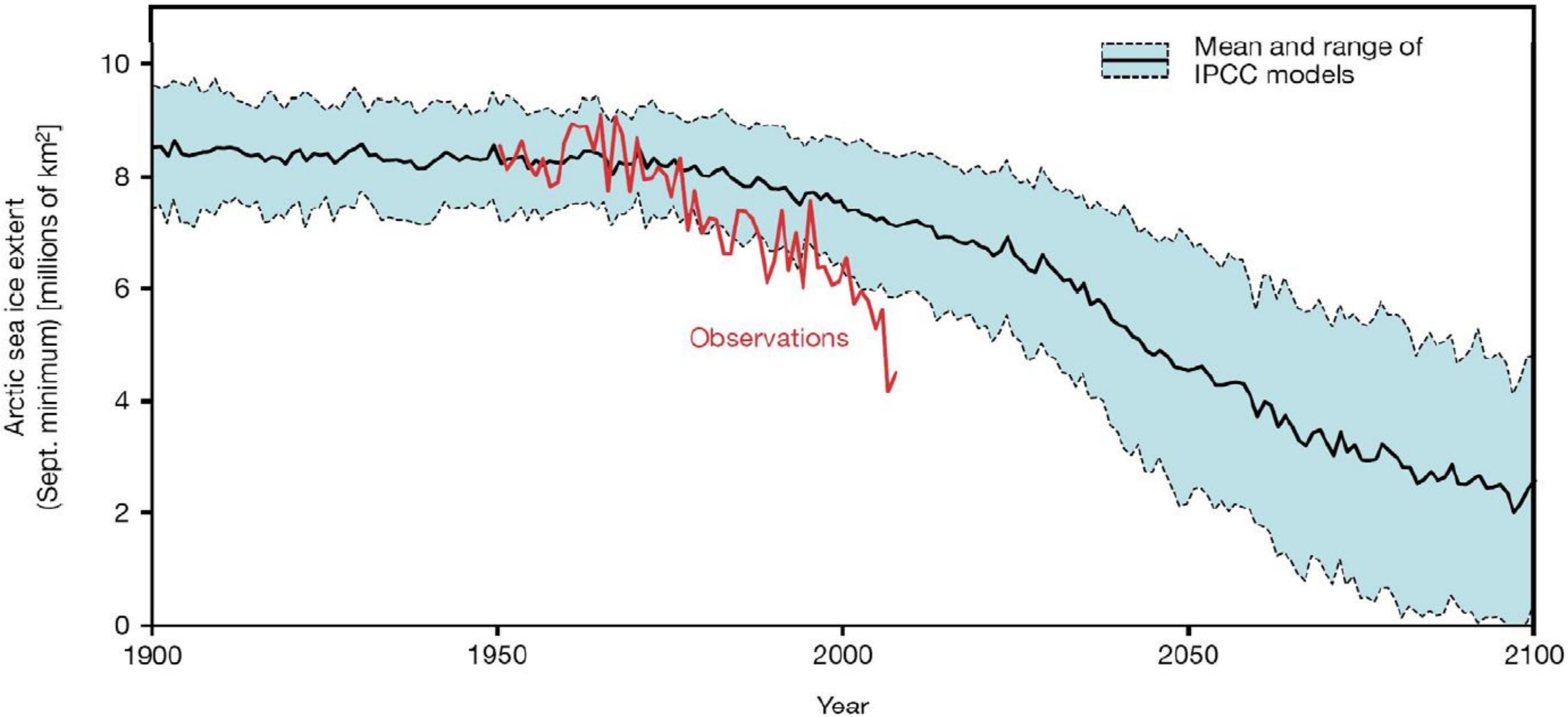
Arctic sea ice:

Arctic sea ice is responding sensitively to global warming. While changes in winter sea ice cover are moderate, late summer sea ice is projected to disappear almost completely towards the end of the 21st century. A number of positive feedbacks in the climate system accelerate the melt back of sea ice. The ice-albedo feedback allows open water to receive more heat from the Sun during summer, and the increase in ocean heat transport to the Arctic through the advection of warmer waters and stronger circulation further reduces ice cover. Minimum arctic sea ice cover is observed in September. Model simulations indicate that the September sea ice cover decreases substantially in response to global warming, generally evolving on the time scale of the warming. With sustained warming, the late summer disappearance of a major fraction of arctic sea ice is permanent.

Observed and modeled Arctic sea-ice extent



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The Triangle