

Climate Change

Predictions

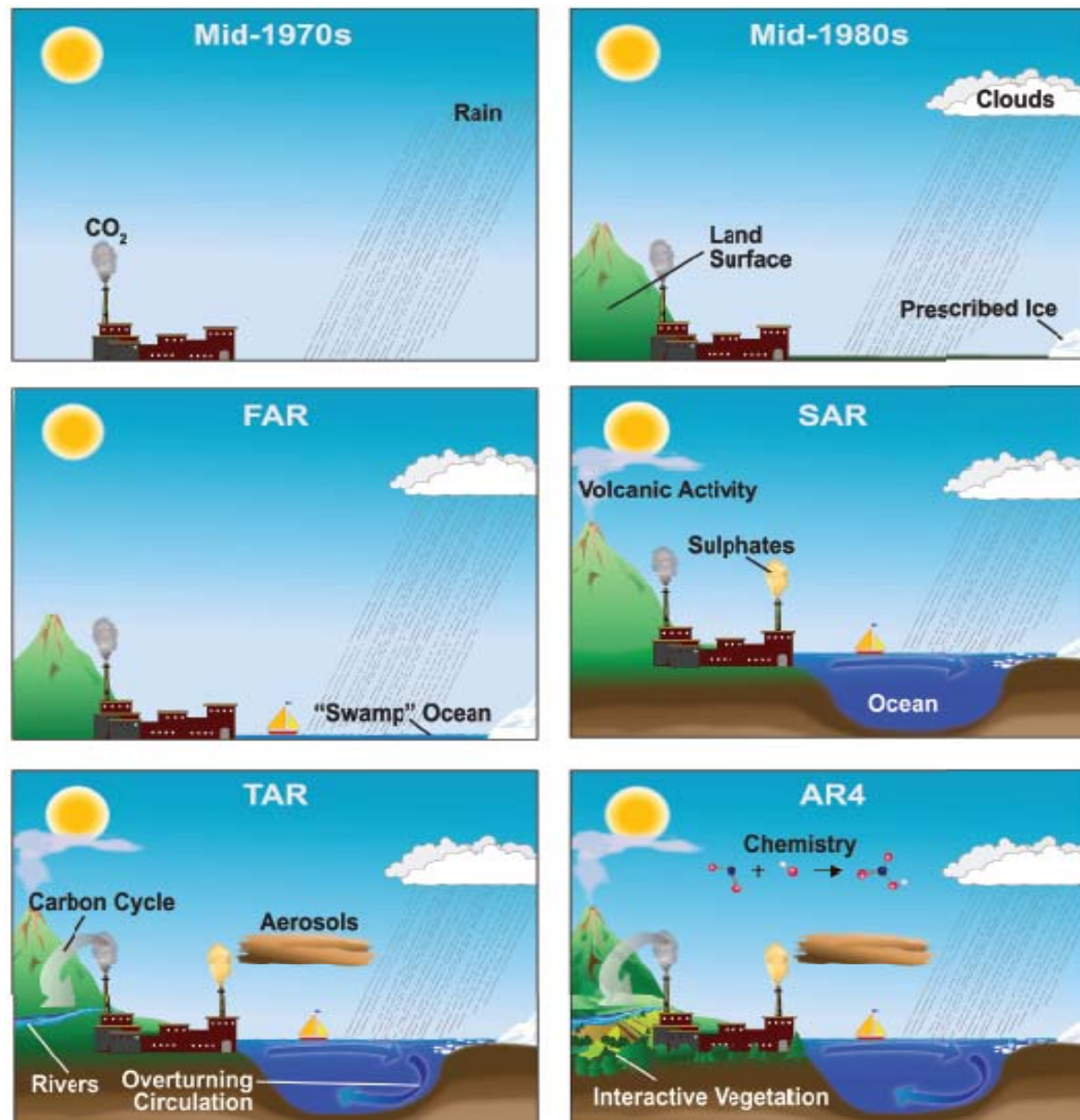
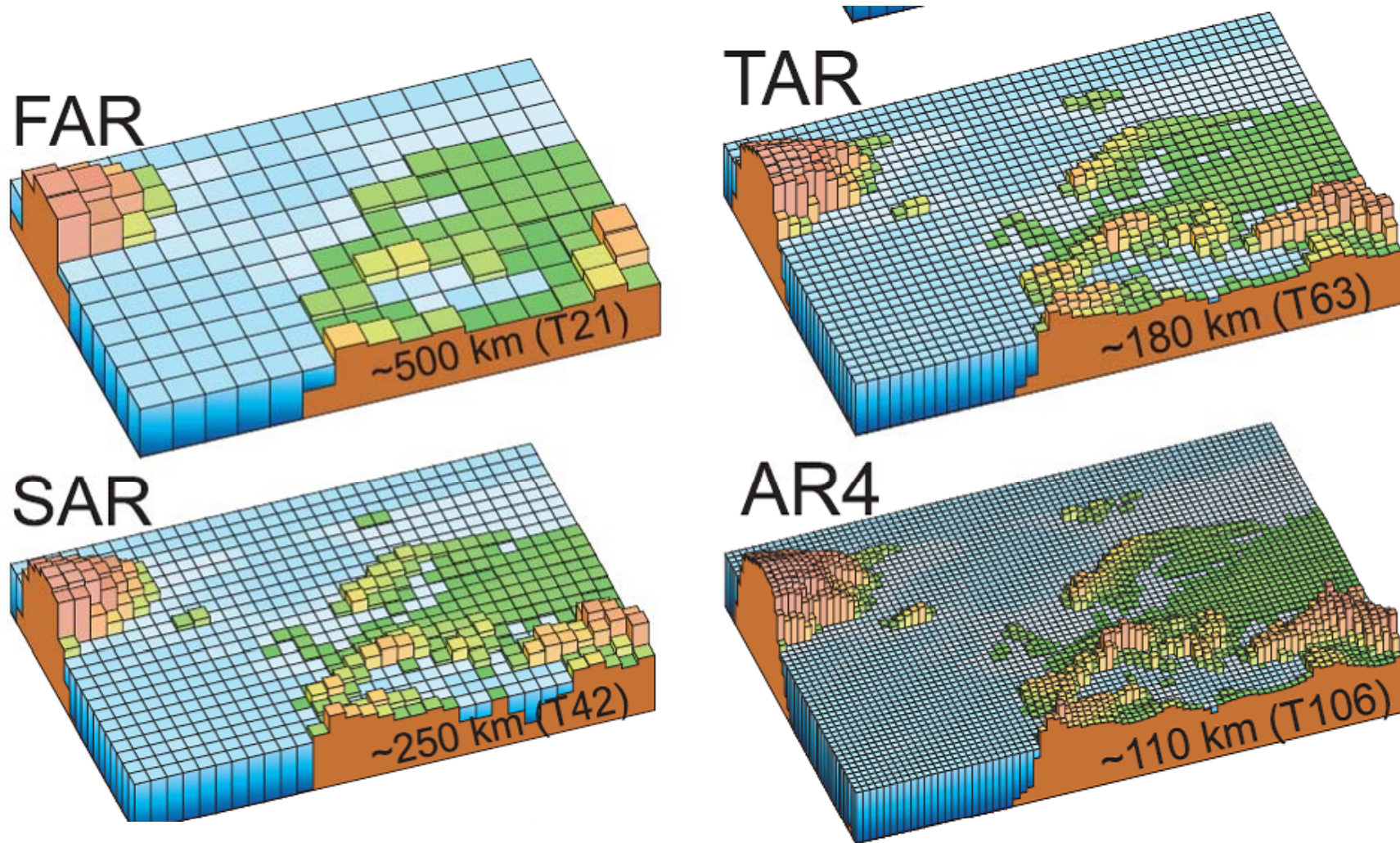


Figure 1.2. The complexity of climate models has increased over the last few decades. The additional physics incorporated in the models are shown pictorially by the different features of the modelled world.

Source:
IPCC (2007),
WG1



Source: IPCC (2007), WG1

Atmosphere

momentum $\frac{\partial \vec{u}}{\partial t} + \vec{u} \bullet \nabla \vec{u} + 2\Omega \times \vec{u} = -\frac{1}{\rho} \nabla p + g\ddot{\mathbf{R}} + \vec{F} + \mathfrak{I}(\vec{u})$

mass $\frac{\partial \rho}{\partial t} + \nabla \bullet (\rho \vec{u}) = 0$

$$p = \rho R T; \rho = f(T, q)$$

energy $\frac{\partial T}{\partial t} + \vec{u} \bullet \nabla T = SW \updownarrow + LW \updownarrow + SH + LH + \mathfrak{I}(T)$

$$SW = f(\text{clouds, aerosols, ...})$$

$$LW = f(T, q, CO_2, GHG \dots)$$

water vapor $\frac{\partial q}{\partial t} + \vec{u} \bullet \nabla q = Evap - Condensation + \mathfrak{I}(q)$

$\mathfrak{I}$ **convective mixing**

Ocean

$$\frac{\partial \vec{u}_2}{\partial t} + \vec{u}_2 \bullet \nabla \vec{u}_2 + 2\Omega \times \vec{u}_2 = -\frac{1}{\rho_0} \nabla p + \vec{F} + \underbrace{\vec{\tau}|_0}_{\text{wind stress}}$$

$$\nabla \bullet \vec{u}_2 + \frac{\partial w}{\partial z} = 0$$

$$0 = -\frac{\partial p}{\partial z} + \rho g; \rho = f(T, s)$$

$$\frac{\partial T}{\partial t} + \vec{u}_3 \bullet \nabla T = \underbrace{Q|_0}_{\text{surface heating}} + \mathfrak{I}(T)$$

$$\frac{\partial s}{\partial t} + \vec{u}_3 \bullet \nabla s = \underbrace{\frac{s_0}{\rho_0 \Delta z} (E - P)|_0}_{\text{freshwater flux}} + \mathfrak{I}(s)$$

Climate dynamics is complicated...

... and it is non-linear!

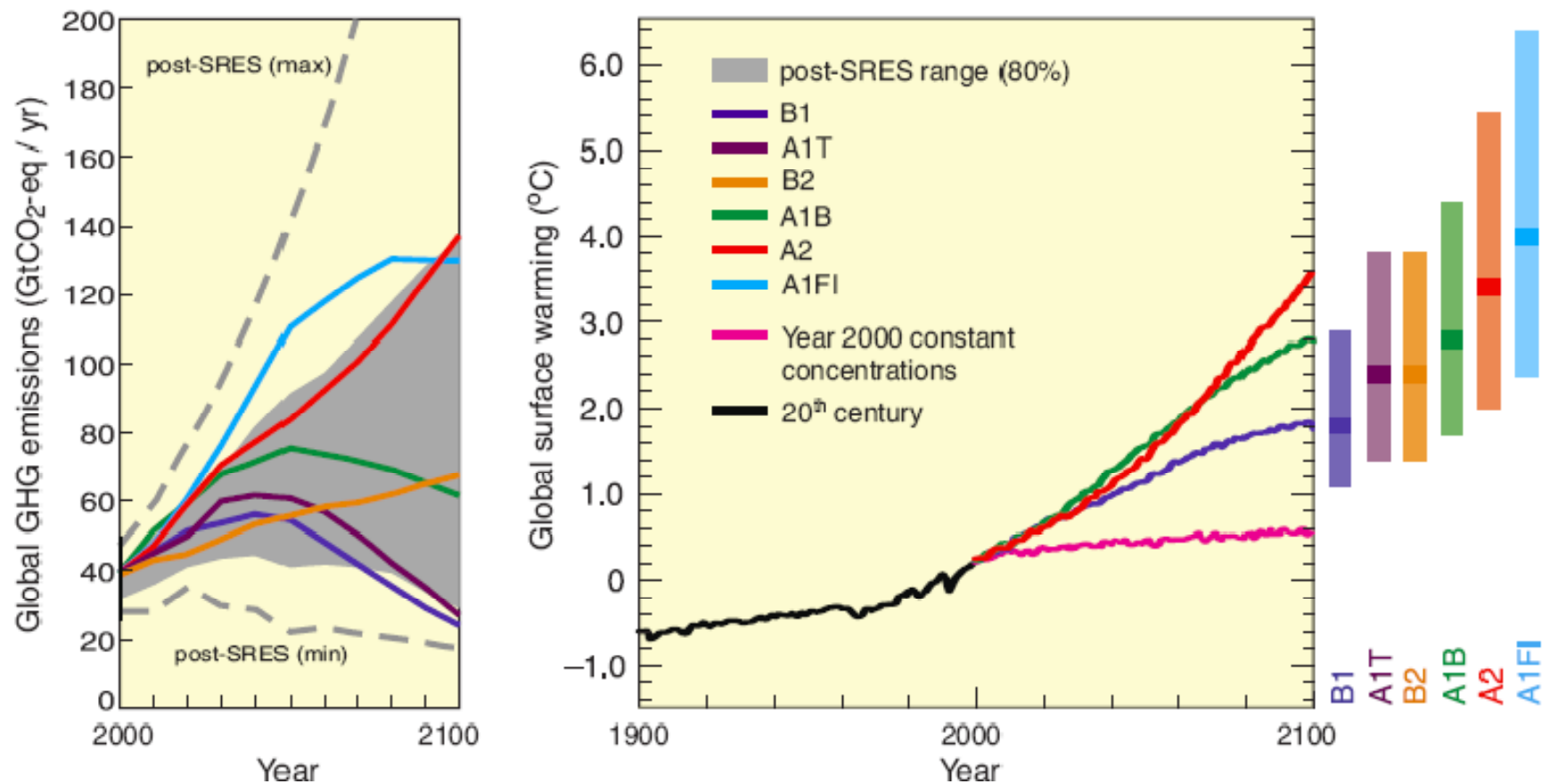
What does that mean?

Simple example, not heating the atmosphere but just a bucket of water:

www.exploratorium.edu/complexity/java/lorenz.html

Projected Climate Change and Its Impacts (1)

Scenarios for GHG emissions from 2000 to 2100 (in the absence of additional climate policies)
and projections of surface temperatures



IPCC (200), Synthesis Report, SPM

EMISSION SCENARIOS OF THE IPCC (TAR used by AR4 WGI)

- A1.: • **Rapid economic growth**, global **population peaks** mid-century & **declines** thereafter
- Rapid introduction of new and more **efficient technologies**.
 - **Convergence** among regions, capacity building and increased interaction with a substantial reduction in regional differences in per capita income

Distinguishes: fossil-intensive (A1FI), non-fossil energy sources (A1T) and a balance across all sources (A1B)

- A2.: • **Heterogeneous** world, selfreliance and preservation of local identities
- Fertility patterns across regions converge slowly, **continuously increasing population**.
 - Economic development is primarily regionally oriented, per capita **economic growth and technological change** more **fragmented and slower** than other storylines

- B1.: • **As in the A1: Convergent world**, improved equity, population peaks in mid-century
- But: rapid change in economic structures toward a **service and information economy**, reductions in material intensity, introduction of clean, resource-efficient technologies

- B2.: • **As in A2: emphasis on local and regional solutions** to economic, social and environmental issues
- Continuously increasing global **population**, but at a **lower rate than in A2**
 - **Intermediate levels of economic development**
 - Less rapid and more diverse technological change than in the B1 and A1 storylines.

Future CO₂ emissions and concentrations

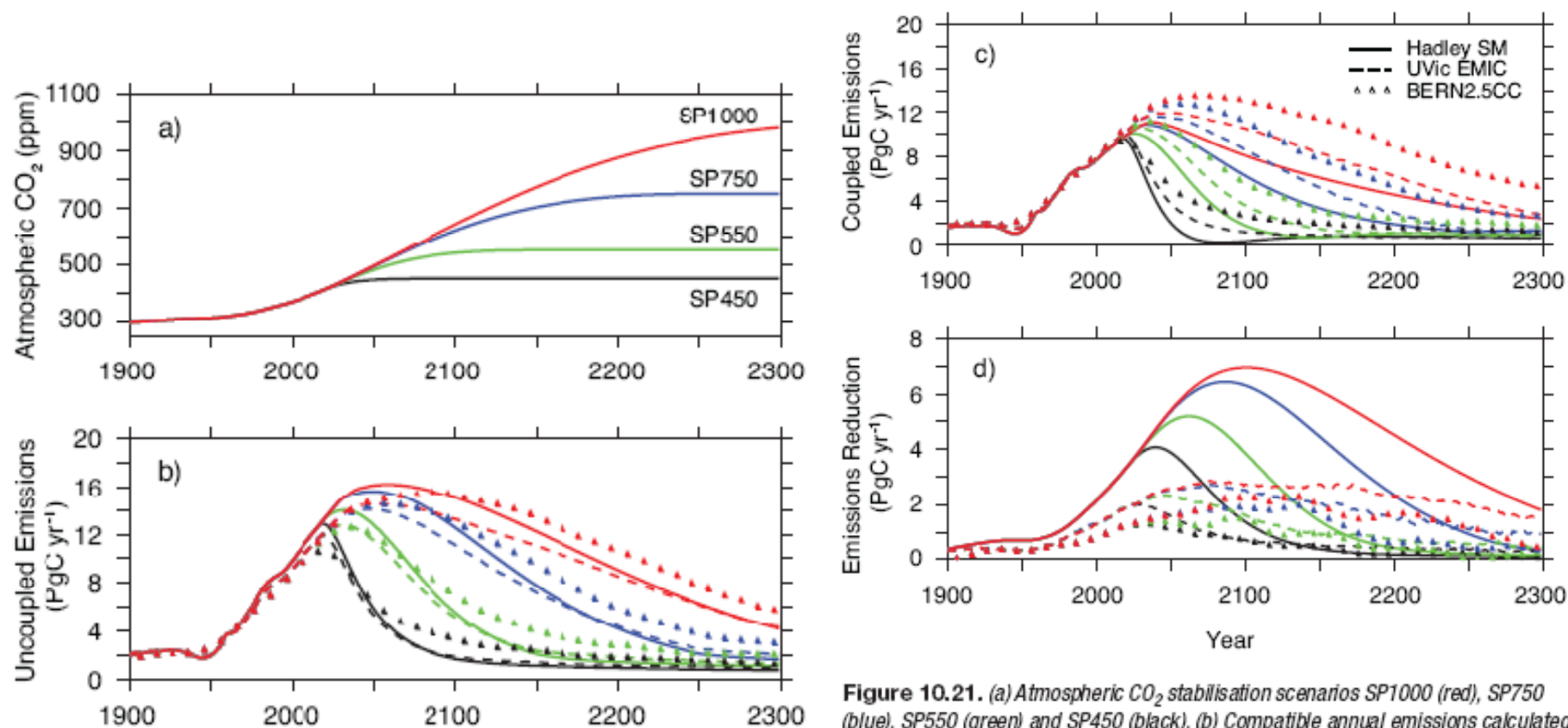


Figure 10.21. (a) Atmospheric CO₂ stabilisation scenarios SP1000 (red), SP750 (blue), SP550 (green) and SP450 (black). (b) Compatible annual emissions calculated by three models, the Hadley simple model (Jones *et al.*, 2006; solid), the UVic EMIC (Matthews, 2005; dashed) and the BERN2.5CC EMIC (Joos *et al.*, 2001; Plattner *et al.*, 2001; triangles) for the three stabilisation scenarios without accounting for the impact of climate on the carbon cycle (see Table 8.3 for details of the latter two models). (c) As for (b) but with the climate impact on the carbon cycle accounted for. (d) The difference between (b) and (c) showing the impact of the climate-carbon cycle feedback on the calculation of compatible emissions.

Different stabilization scenarios for future emissions Source: IPCC (2007:WG1)

Predictions: Temperature

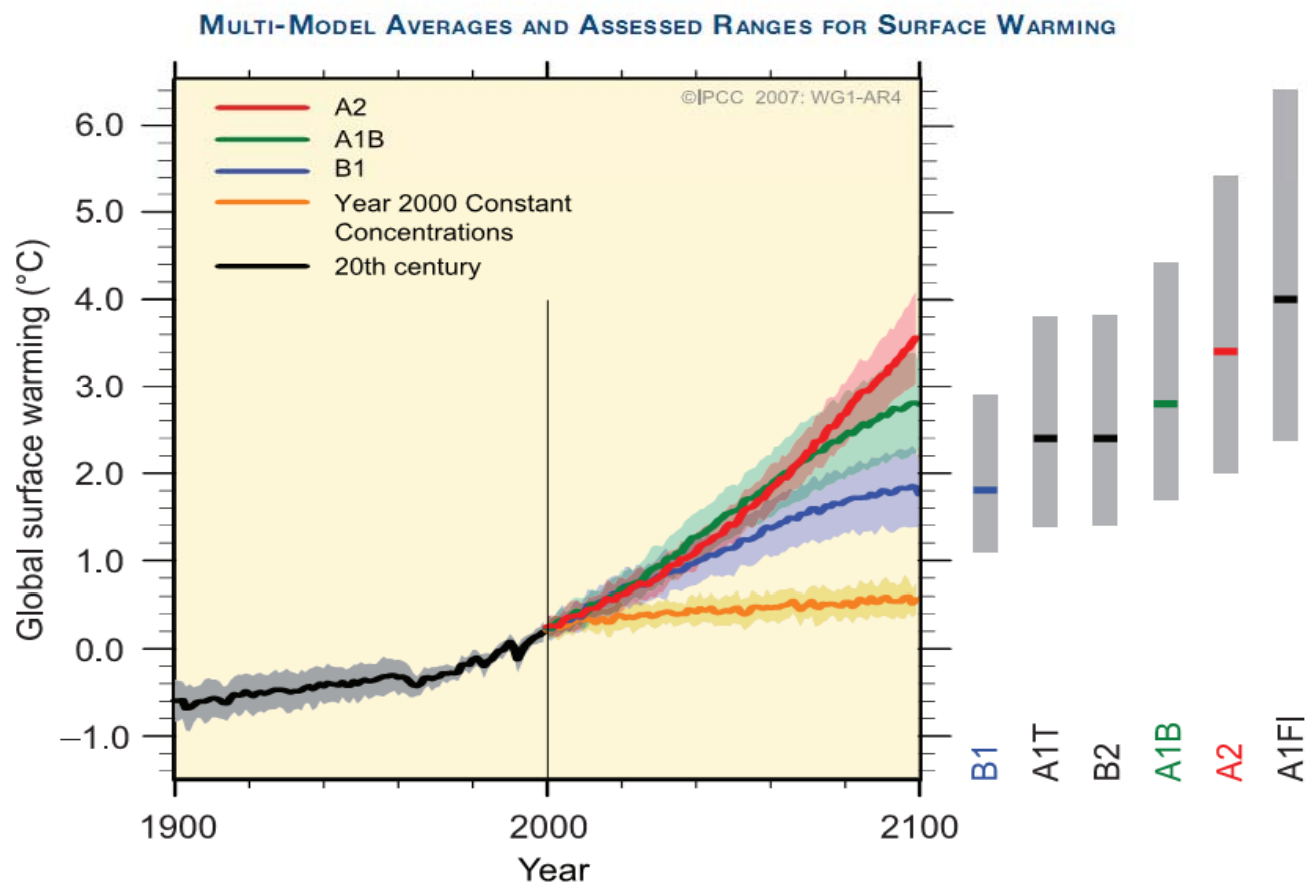
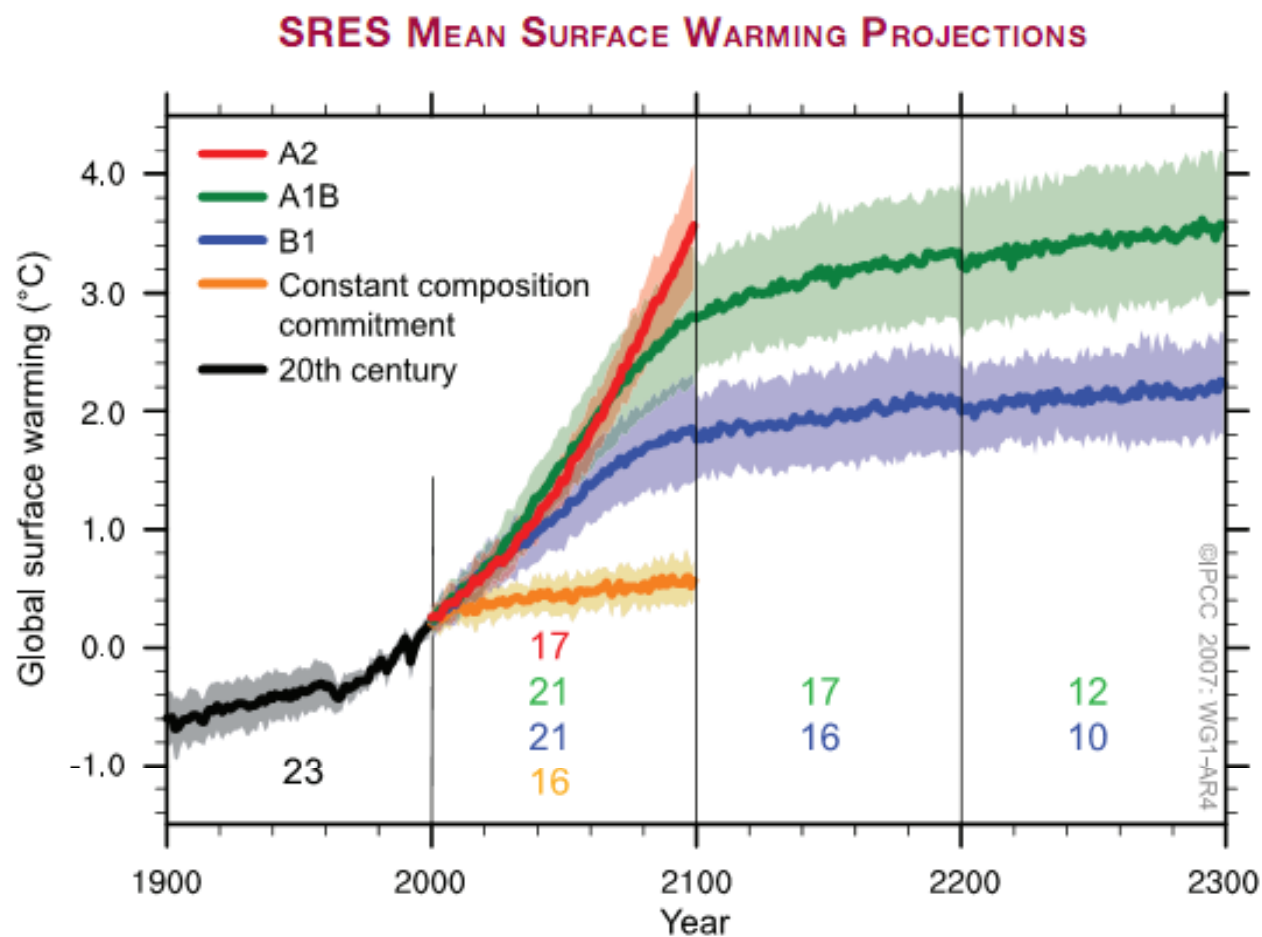


Figure SPM.5. Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1, shown as continuations of the 20th century simulations. Shading denotes the ± 1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values. The grey bars at right indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios. The assessment of the best estimate and likely ranges in the grey bars includes the AOGCMs in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints.

... and the even longer run:



IPCC AR₄ TS. Multi-model means of surface warming (compared to the 1980–1999 base period) with forcing kept constant beyond 2100. Orange line: Forcing kept constant at 2000 level.

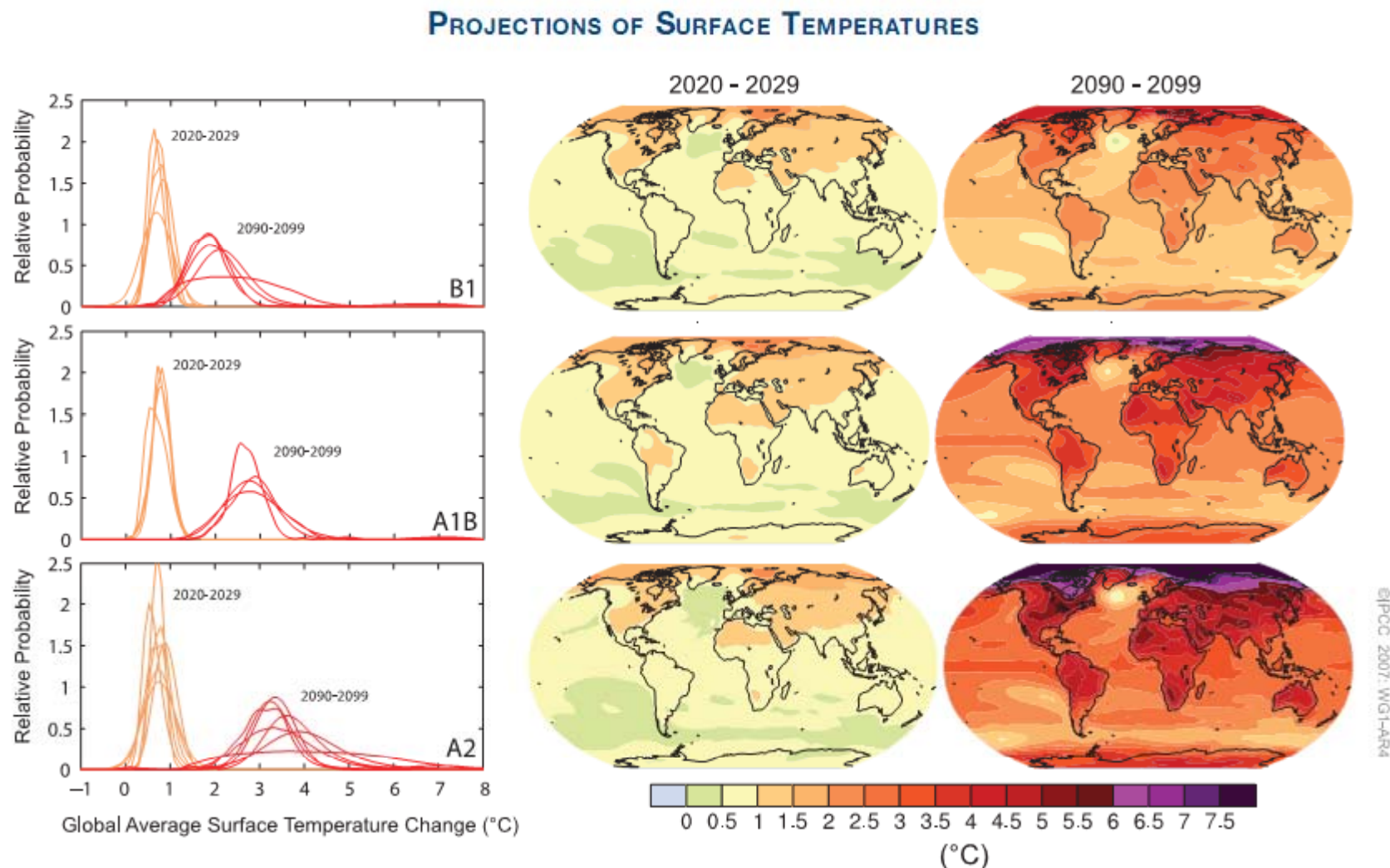


Figure SPM.6. Projected surface temperature changes for the early and late 21st century **relative to the period 1980–1999**. The central and right panels show the AOGCM multi-model average projections for the B1 (top), A1B (middle) and A2 (bottom) SRES scenarios averaged over the decades 2020–2029 (centre) and 2090–2099 (right). The left panels show corresponding uncertainties as the relative probabilities of estimated global average warming from several different AOGCM and Earth System Model of Intermediate Complexity studies for the same periods.

Prediction: Change in Precipitation by 2090-99

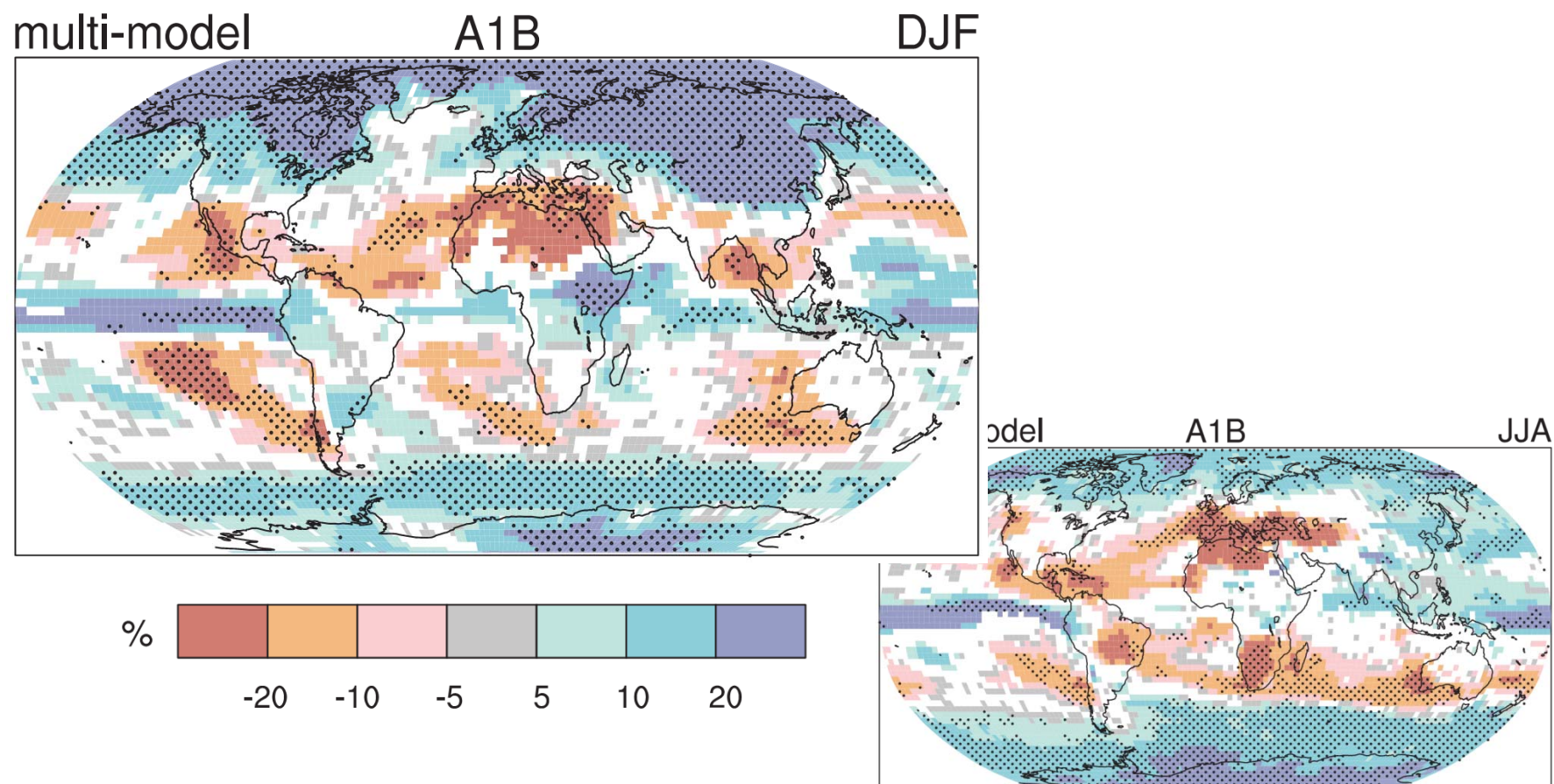
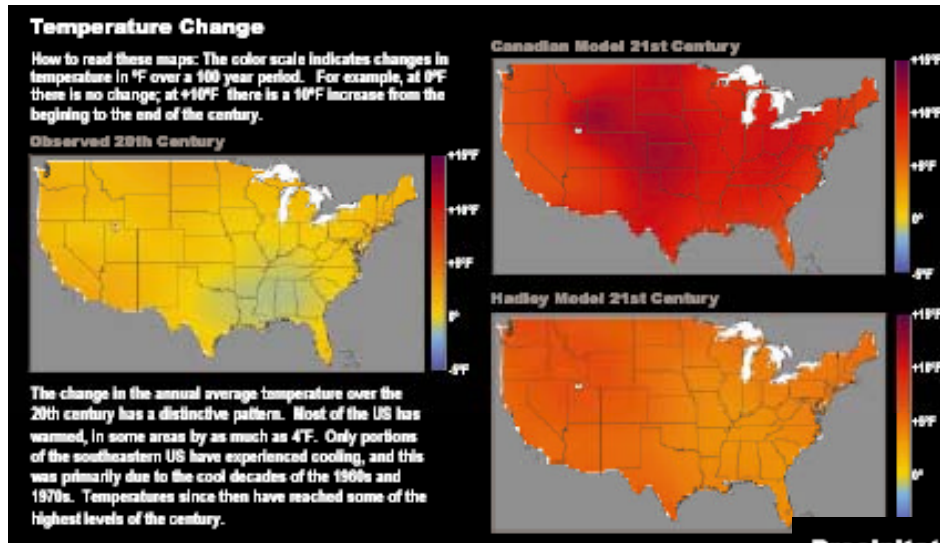


Figure SPM.7. Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change. {Figure 10.9}

America's climate



Precipitation Change

Observed 20th Century

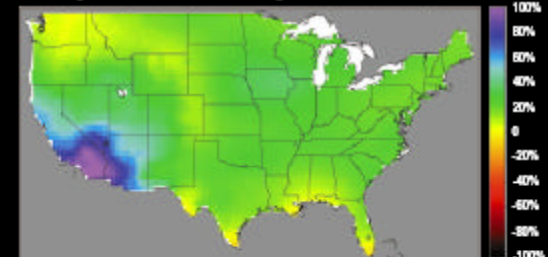


Significant increases in precipitation have occurred across much of the US in the 20th century. Some localized areas have experienced decreased precipitation. The Hadley and Canadian model scenarios for the 21st century project substantial increases in precipitation in California and Nevada, accelerating the observed 20th century trend (some other models do not simulate these increases). For the eastern two-thirds of the nation, the Hadley model projects continued increases in precipitation in most areas. In contrast, the Canadian model projects decreases in precipitation in these areas, except for the Great Lakes and Northern Plains, with decreases exceeding 20% in a region centered on the Oklahoma panhandle. Trends are calculated relative to the 1961-90 average.

Canadian Model 21st Century

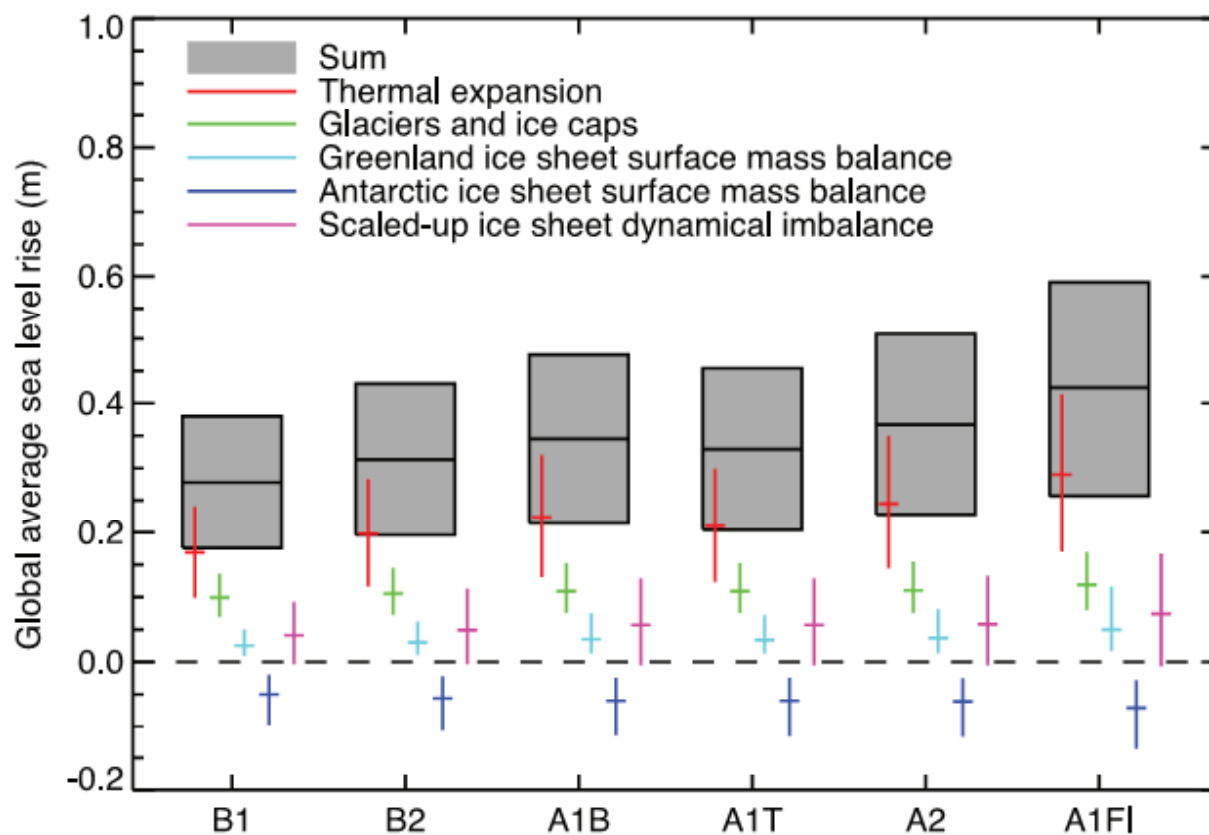


Hadley Model 21st Century



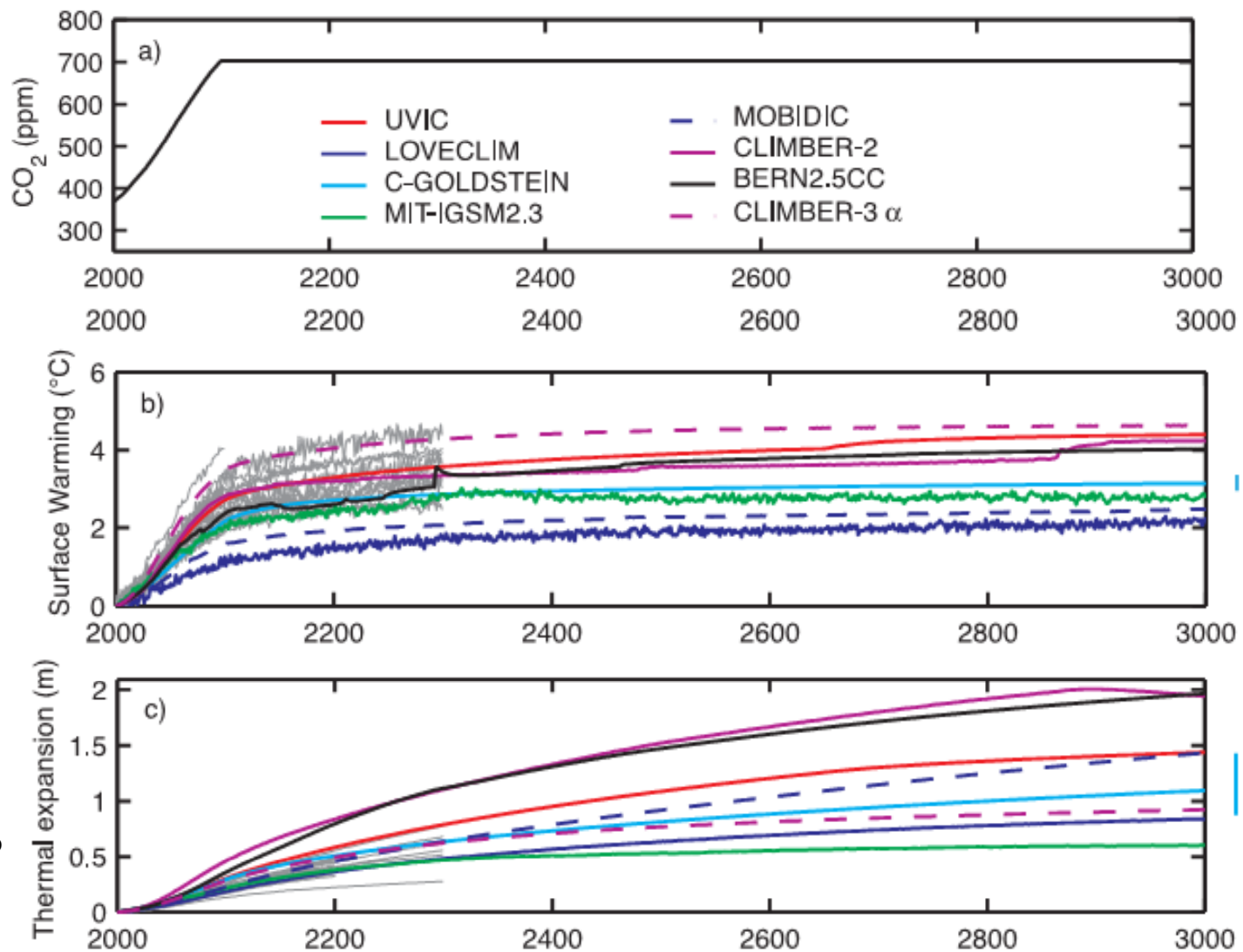
National Assessment
(2000)

Prediction: Sea Level Rise (end of century)

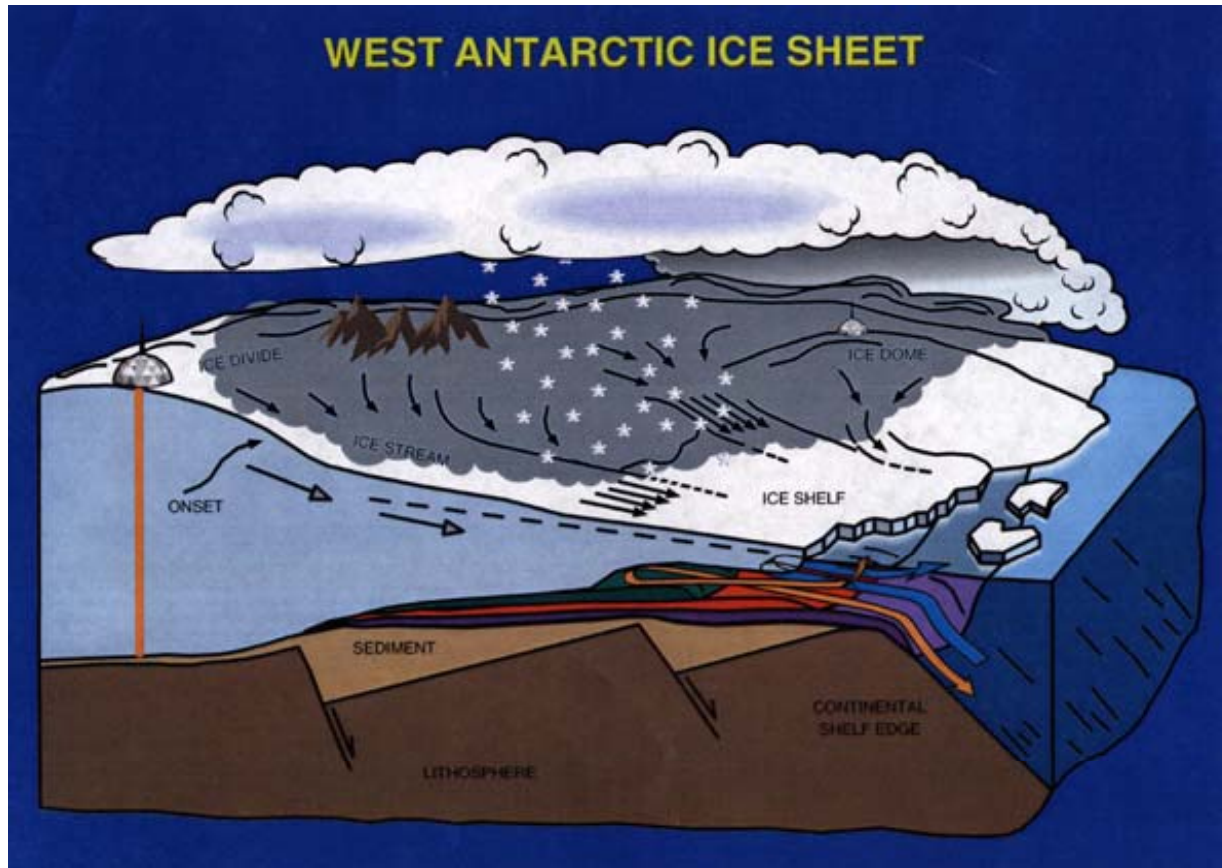


AR4 Figure 10.33. Projections and uncertainties (5 to 95% ranges) of global average sea level rise and its components in 2090 to 2099 (relative to 1980 to 1999) for the six SRES marker scenarios. The projected sea level rise assumes that the part of the present-day ice sheet mass imbalance that is due to recent ice flow acceleration will persist unchanged. It does not include the contribution shown from scaled-up ice sheet discharge, which is an alternative possibility. It is also possible that the present imbalance might be transient, in which case the projected sea level rise is reduced by 0.02 m. It must be emphasized that we cannot assess the likelihood of any of these three alternatives, which are presented as illustrative. The state of understanding prevents a best estimate from being made.

Thermal Expansion and Time Lags

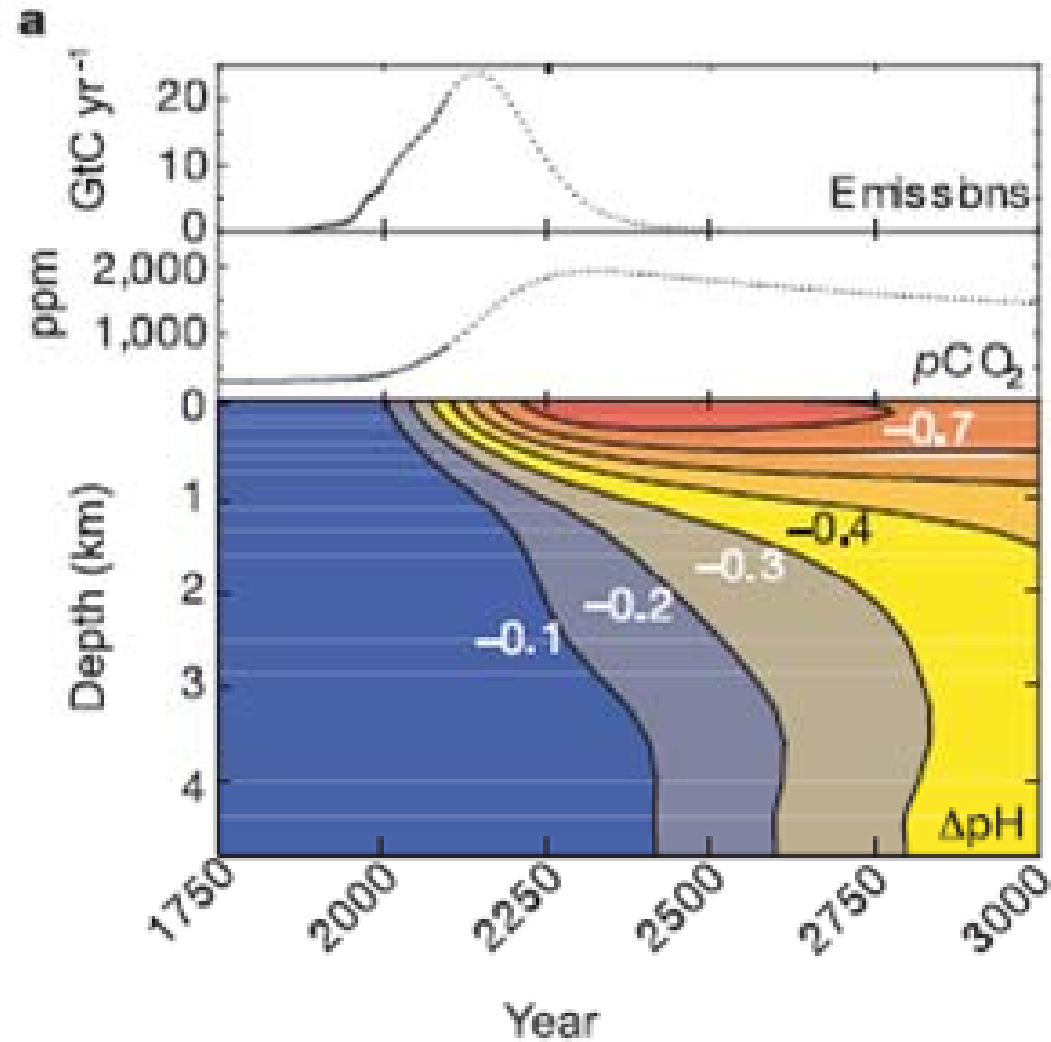


Source:
AR4 Chap 10



Block diagram showing a schematic cross-section of the West Antarctic ice sheet, which is drained by ice streams underlain by water saturated, unconsolidated sediment. The underlying lithosphere (bedrock) may play role in the presence of the ice streams.
Taken from <http://www.nsf.gov/pubs/1996/nstc96rp/sb4.htm>.

Co2 uptake and ocean acidification



Phenomenon ^a and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend ^b	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	<i>Very likely^c</i>	<i>Likely^d</i>	<i>Virtually certain^d</i>
Warmer and more frequent hot days and nights over most land areas	<i>Very likely^e</i>	<i>Likely (nights)^d</i>	<i>Virtually certain^d</i>
Warm spells/heat waves. Frequency increases over most land areas	<i>Likely</i>	<i>More likely than not^f</i>	<i>Very likely</i>
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	<i>Likely</i>	<i>More likely than not^f</i>	<i>Very likely</i>
Area affected by droughts increases	<i>Likely in many regions since 1970s</i>	<i>More likely than not</i>	<i>Likely</i>
Intense tropical cyclone activity increases	<i>Likely in some regions since 1970</i>	<i>More likely than not^f</i>	<i>Likely</i>
Increased incidence of extreme high sea level (excludes tsunamis) ^g	<i>Likely</i>	<i>More likely than not^{f,h}</i>	<i>Likelyⁱ</i>

Table SPM.2. Recent trends, assessment of human influence on the trend and projections for extreme weather events for which there is an observed late-20th century trend.