Lecture 32

Today: Projections of global warming. Some impacts.

Tomorrow: Arguments of global warming "skeptics"

Monday: Impacts of global warming in the Pacific Northwest.
by Dr. Phil Mote (state climatologist for Washington State).

Next week: More impacts and policy.

Human C inputs & where they go

Inputs: (see Fig 16-1 & text):
6.1 GtC/yr burning fossil fuels:
2.0 GtC/yr deforestation, land use change

Outputs:
3GtC/yr accumulates in the atmosphere
2.5 GtC/yr absorbed by the oceans
2.6 GtC/yr taken up by soil/forests
(i.e. land biosphere is a net sink of 0.6 GtC/yr
= 2.6-2.0 GtC/year)

Note: exact distribution between ocean & forest regrowth uptake is not precisely known. The above are rough estimates.

Over different timescales (10-10^6 years), atmospheric CO_2 will be removed by different processes, which we now consider

Box Fig 16-2:
Long-term CO_2 projections

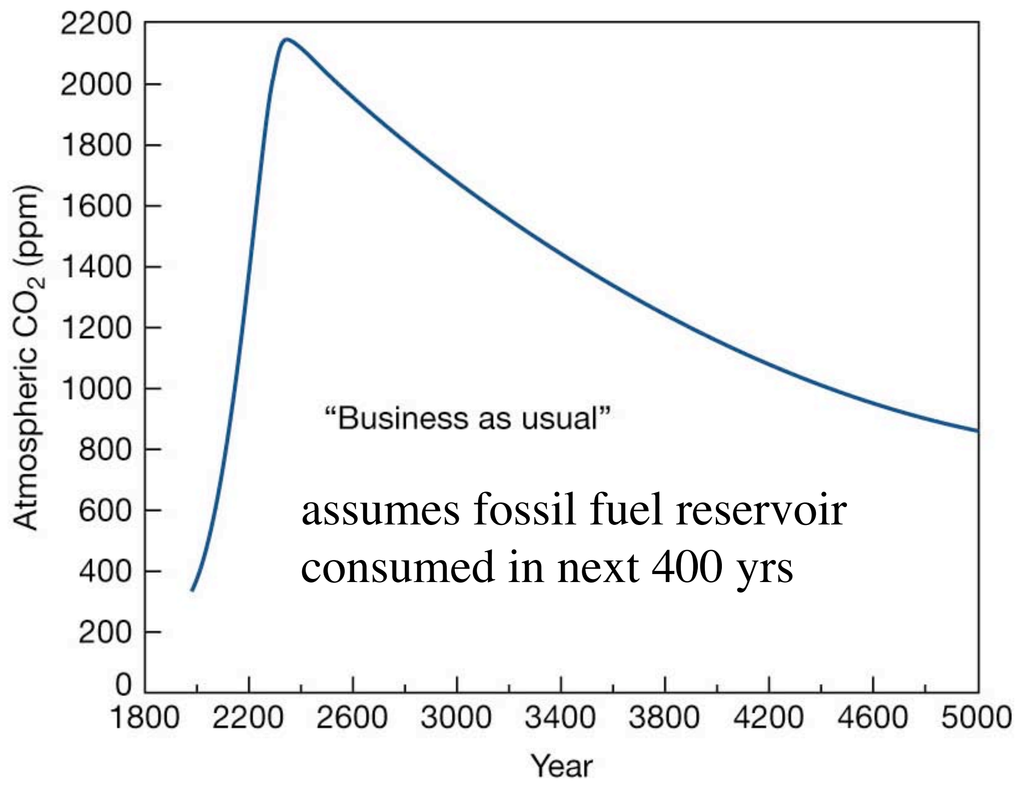
REMOVAL MECHANISMS

1) **Uptake by surface ocean** **(temporary)**
Residence time of C with respect to surface ocean
= 760 GtC/ (90 GtC/yr)
~ 8 years (exchange time)

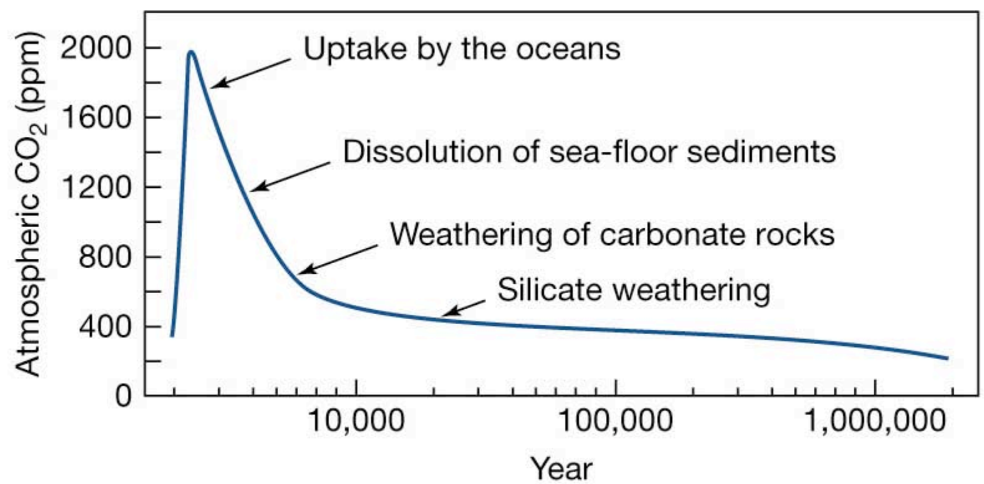
2) **Tranfer to deep ocean** **(temporary)**
~100s -1000 yrs via thermohaline circ.

3) **Dissolution of seafloor carbonates**
$CO_2 + CaCO_3 + H_2O = Ca^{2+} + 2HCO_3^-$
1000s of years (still temporary)
4) **Weathering of continental rocks**

carbonate weathering (same chemistry as 3)
temporary, 1000s of years
silicate weathering
permanent removal, 10^5-10^6 years



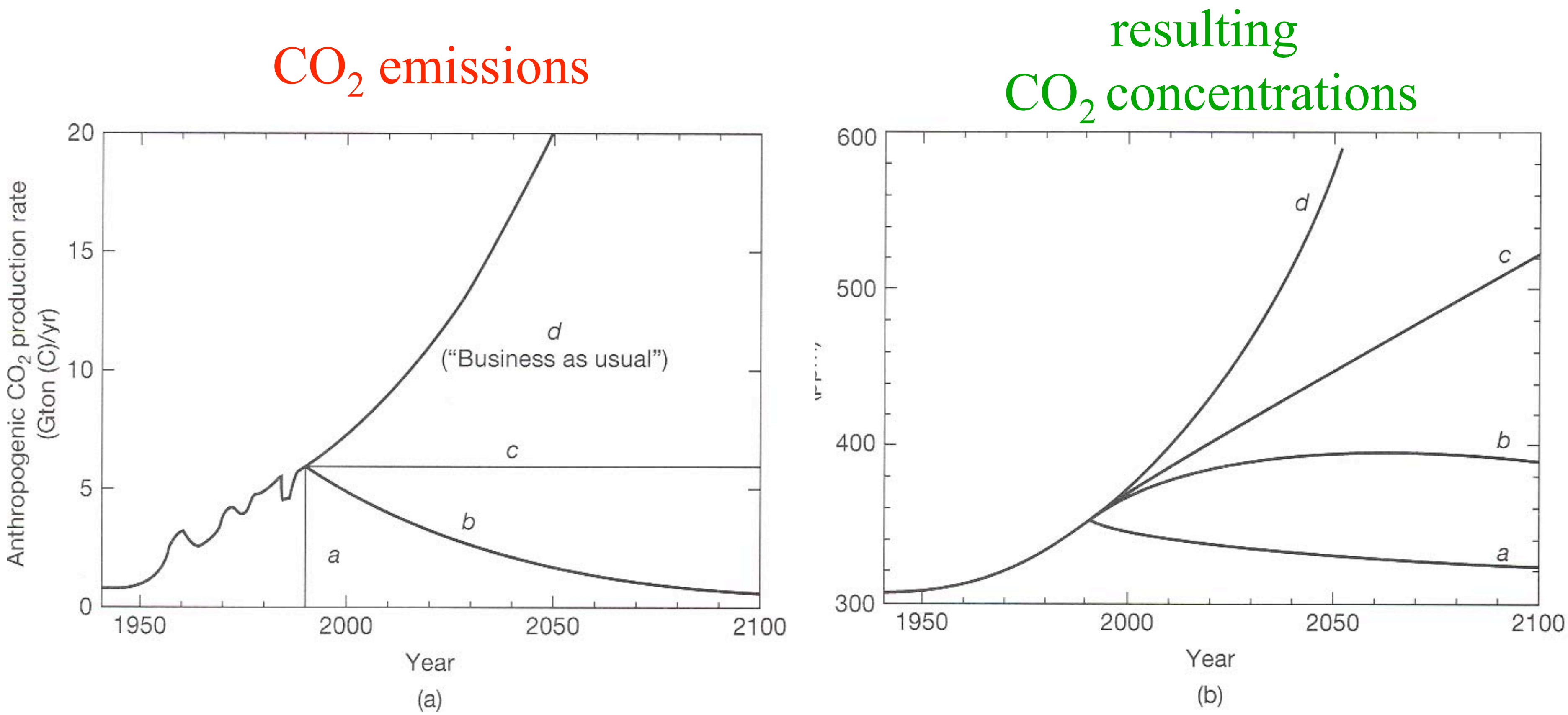
(a)



(b)

Simplified CO_2 scenarios

Question: Which of these are realistic or feasible?



a. stop all emissions immediately

b. begin emissions reduction immediately and go down to 1 Gton C/yr by 2100

c. freeze at 1990 emissions (Kyoto Protocol for entire world)

d. business-as-usual (CO_2 doubles by about 2050)

Estimating the future: other GHGs

CO_2 is not the whole story.
We need to consider
1) other greenhouse gases

2) aerosols

Right: radiative forcing due to CO_2, CH_4, N_2O over last 1000 years

2001 Increased radiative forcing (W/m^2) since 1750 (pre-industrial)	
CO_2	1.46
CH_4	0.48
N_2O	0.15
tropospheric ozone (O_3)	0.35

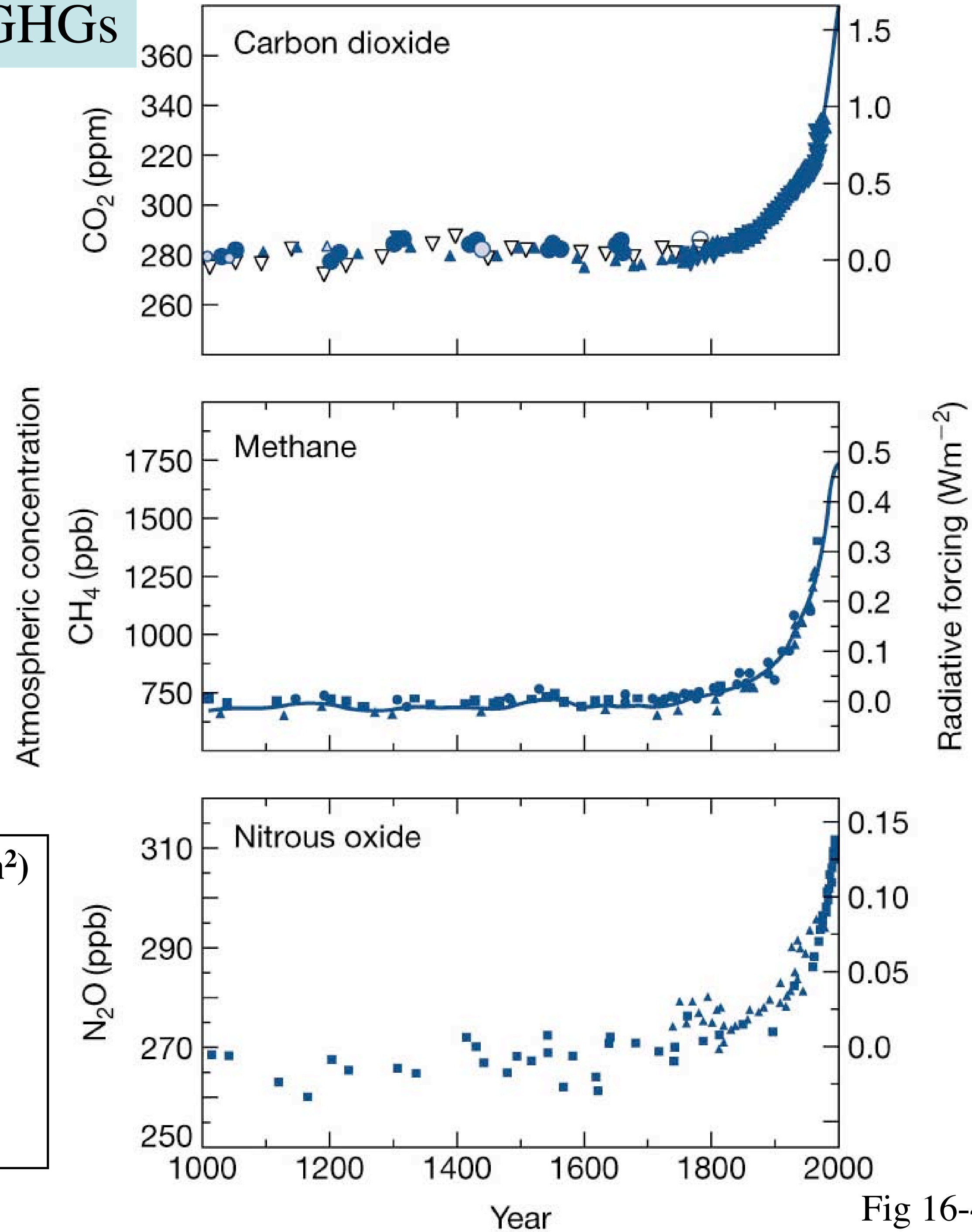


Fig 16-4

non-CO_2 forcings: other GHGs

<u>other greenhouse gases:</u>

- CH_4 (methane) — Rice paddies (40% of emssions), cow/ruminant flatulence (15%), (world population of cows = 1.3b, 100m in the USA), landfills, coal/gas/oil production

- N_2O (nitrous oxide) — Denitrification (the process by which bacteria break down nitrogen in organic matter and release N_2 and N_2O), nitrate fertilizers. (30% anthropogenic, 70% natural).

- O_3 (tropospheric ozone) — Not directly emitted. Formed in photochemical reactions from human and natural precursors. (e.g., reactions between human-emitted NO and hydrocarbons can lead to ozone).
(10 ppb in remote areas, 100 ppb downwind of metropolitan areas)

- Halocarbons (CFCs and halons) — Refrigerants, blowing agents, etc (all human)

non-CO_2 forcings: aerosols

aerosols:

- direct effect: reflect sunlight back to space
- indirect effect: modify clouds (more droplets) causing increase in albedo

- The addition of aerosol forcing played a key role in the IPCC 1995 report.

- Gave greater confidence that the models showed the "signal" of anthropogenic influence on climate had been detected.

  IPCC 1990: "generally consistent"

  IPCC 1995: "a discernable influence"

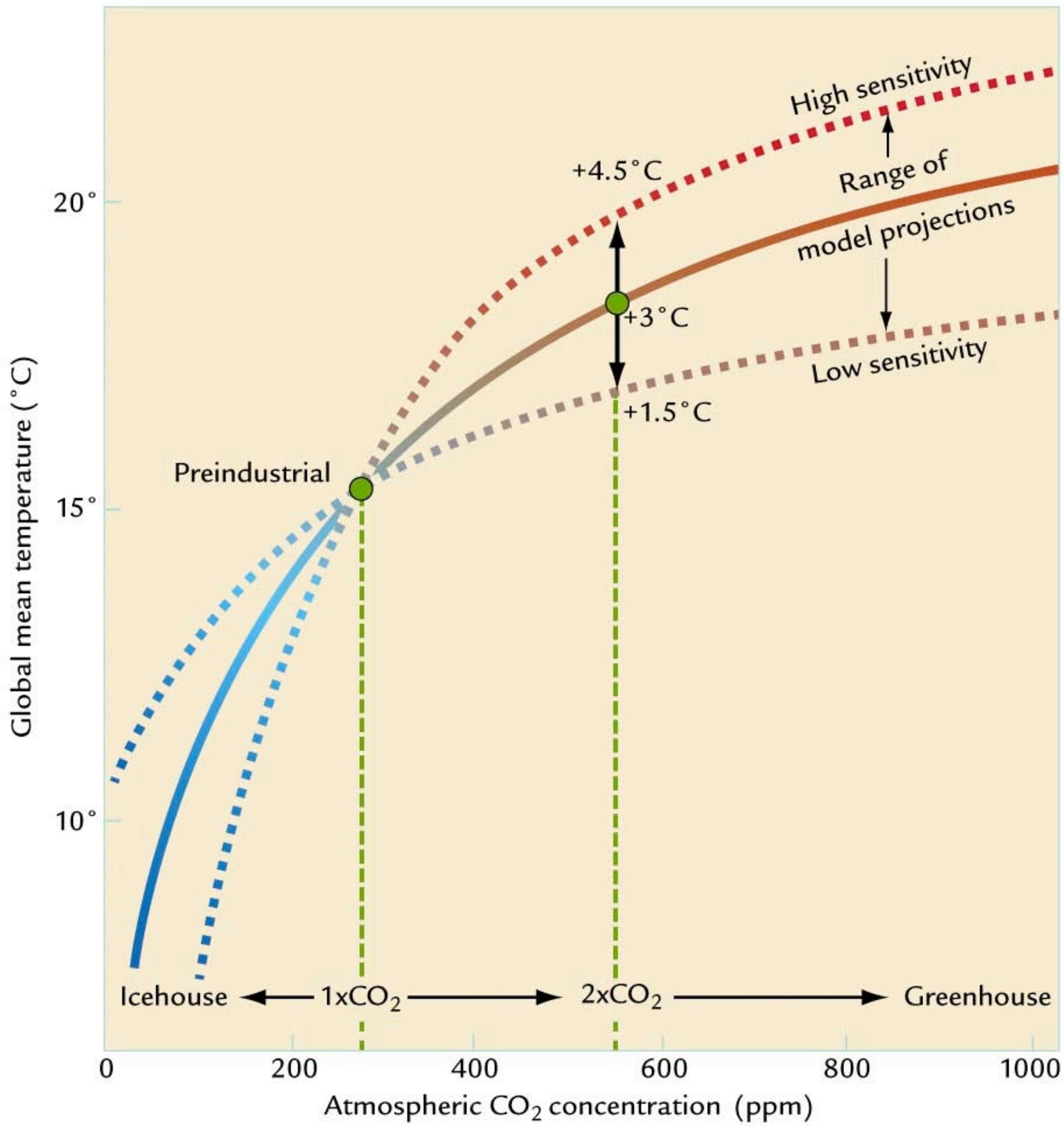
  IPCC 2001: "new and stronger evidence that most of the observes warming over the past 50 years is attributable to human activities."

•Problem: forcing estimates for aerosols are poorly known +0.1 to -3 W/m^2 (see Lecture 30, Tad Anderson).

• NOTE: However, aerosols get washed out of the atmosphere in ~1 week, but greenhouse gases continue to accumulate.

• If aerosols have a strong negative forcing, climate sensitivity could be higher than we think.

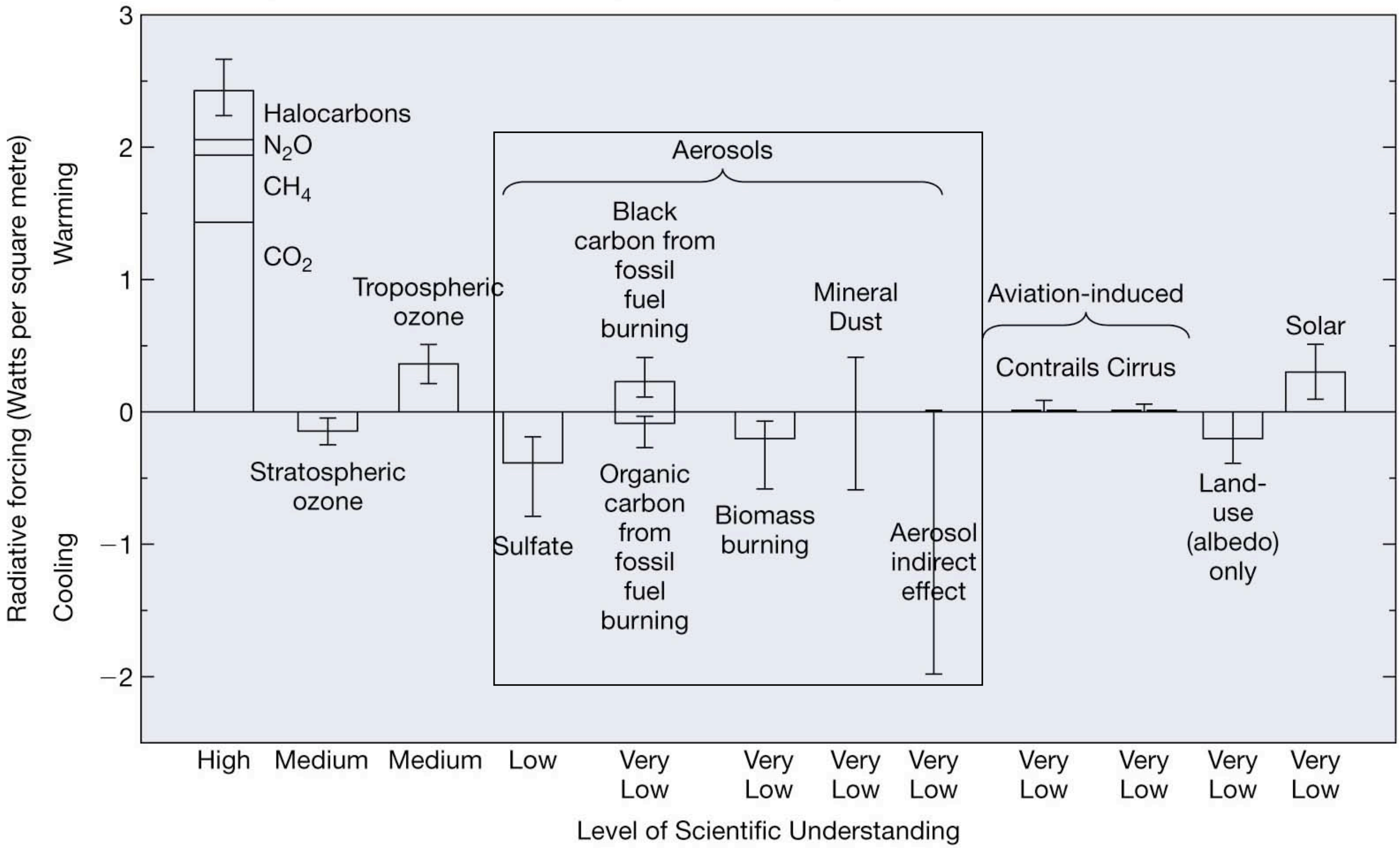
effect of climate sensitivity,



Even for the same forcing increase, different models will give different mean global temperature increase depending on .

IPCC 2001, SPM, Fig 3 (or textbook Fig 16-5): Forcings

The global mean radiative forcing of the climate system for the year 2000, relative to 1750



Need to add all these up to get the overall radiative forcing change, ΔF

Paths to CO_2 stabilization

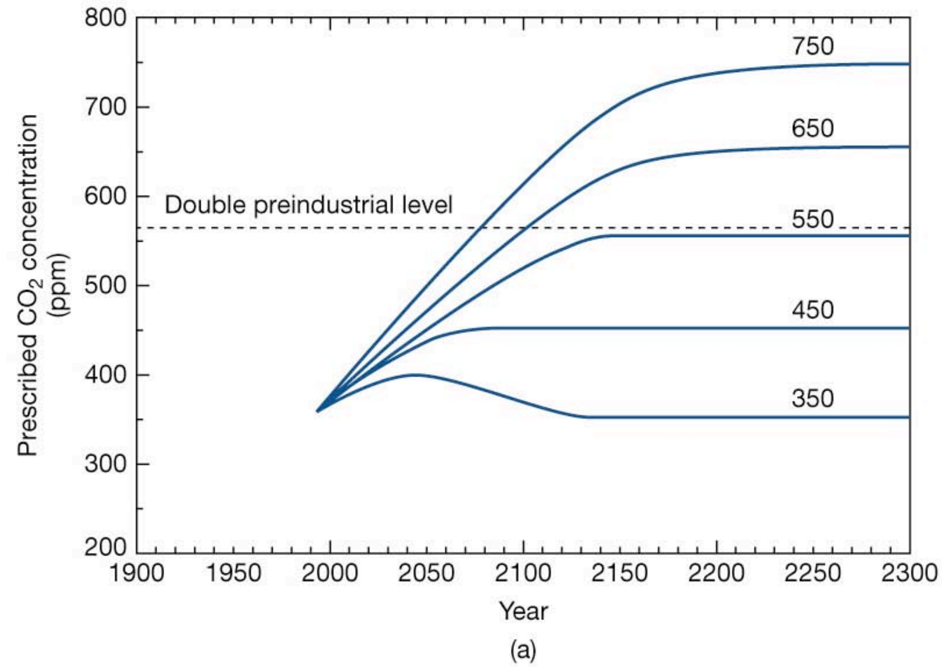
UN Framework Convention on Climate Change calls to avoid "dangerous interference with the climate system"

UNFCCC signed by 162 countries, including the US, at the 1992 Rio Earth Summit.
http://www.unfccc.de/index.html

Question 1: But what level of CO_2 constitutes "dangerous interference with the climate system"?

Question 2: What emission pathway keeps us below that level?

Note: Question 1 is far more difficult for science to answer.



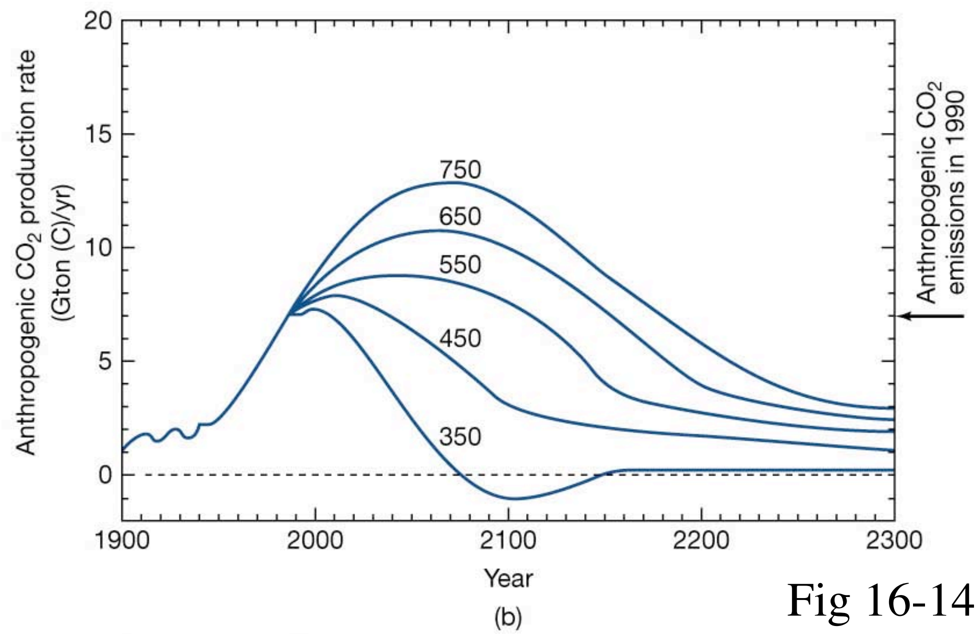


Fig 16-14

Non-CO_2 Forcings

small difference, i.e. CO_2 dominates

Global Warming Forecast Equation

$$\Delta T = \lambda * \Delta F * lag\_factor$$

Table 2: Climate forcing scenarios

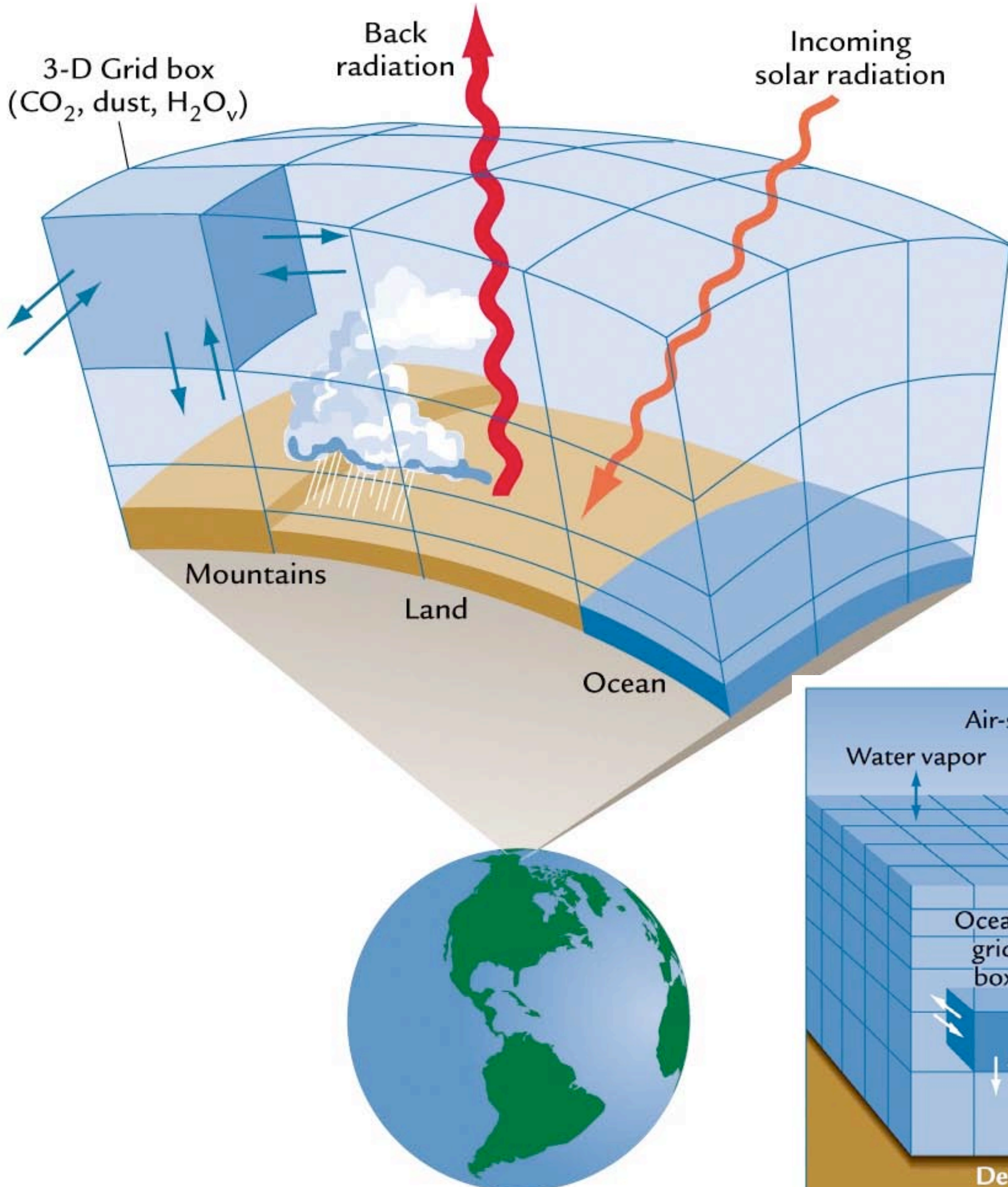
Scenario	2050 Emissions (Gton C/yr)	2050 Concentration (ppm)	2050 CO_2 forcing (W/m^2)	2050 Total Forcing (W/m^2)
B1	11	485	3.0	3.3
A1B	16.5	520	3.4	4.1
A1F1	24	560	3.7	4.8

IPCC Emission Scenarios:
- B1 = population peak in mid-21st century, more clean energy
- A1B = rapid economic growth, balance of energy sources
- A1F1 = rapid economic growth, fossil fuel intensive

• The current consensus view is that non-CO_2 forcings (positive GHGs and negative aerosols) add up to a net forcing close to zero.
(Actually depends on what the aerosol forcing contribution is).

•In any case, the question of forcing is primarily a question of CO_2 concentration.

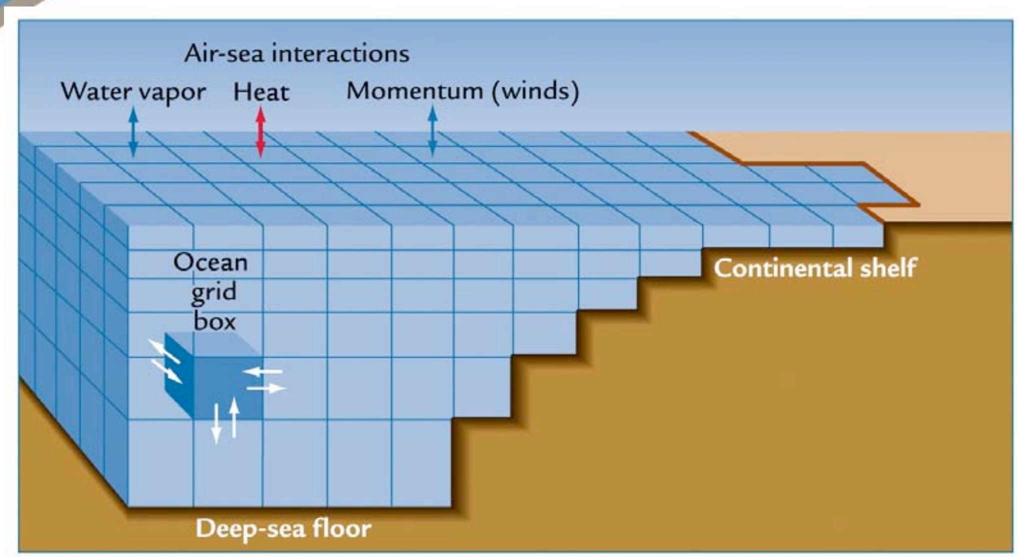
GCMs for climate prediction



GCMs = General Circulation Models

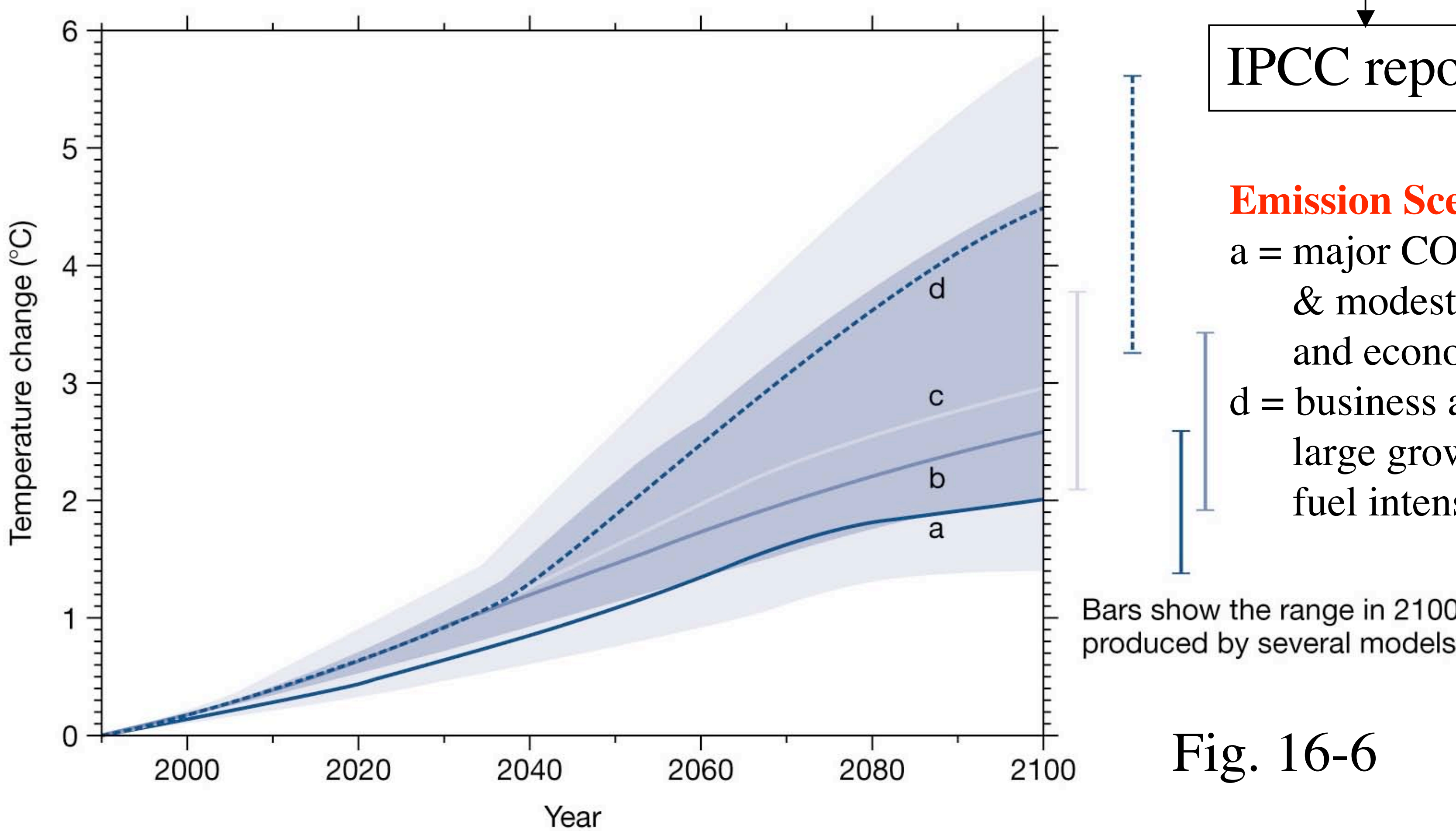
Atmosphere-Ocean GCMs are used. (see Chap. 6 of the textbook).

These computer models calculate the physics and chemistry of the atmosphere and ocean. The world is divided up into a 3-D grid and energy and mass fluxes between grid boxes are calculated in time.



IPCC Predictions

IPCC emission scenarios: CO_2, CH_4, N_2O, SO_2 (aerosols) → GCMs used by researchers around the world → Resulting predictions: - global temperature (also regional climate (precipitation, etc.)) → IPCC report



Emission Scenarios

a = major CO_2 controls & modest population and economic growth

d = business as usual: large growth, fossil fuel intensive

Fig. 16-6

How do we know that climate models produce credible results?

Comparison against recent past change

Observations of climate quantities from numerous sites around the globe are available from recent decades. Some records also go back a over a hundred years.
Models are compared against a range of different indicators (such as surface temperature, rainfall and surface pressure).

Comparison against observed climate variability

The climate varies naturally from day to day, month to month, year to year, and on longer timescales. Climate models incorporate enough realistic physics to make sure they can credibly reproduce the observed natural variability.

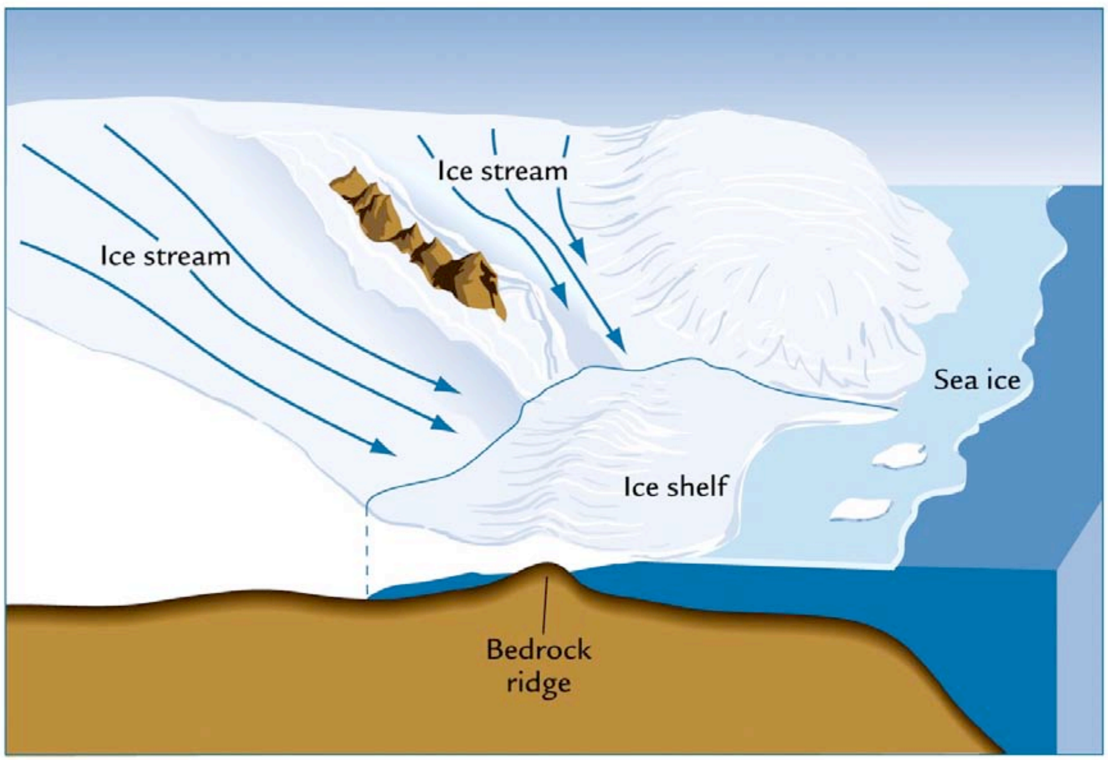
Comparison against paleo-climate measurements

Climate models can be used to simulate climates of the more distant past, such as the Last Glacial Maximum (the peak of the last ice age, c.21000 BC). Model results are compared to ‘proxy measurements’ of past climate changes.

The advantage of testing a model against both recent measurements and past climates, such as the Last Glacial Maximum, is that the model has then been validated for a large range of different climate conditions.

Climate Impact: Sea level change

2 effects: **- thermal expansion** of seawater
- snowfall vs. melting on ice sheets
(net melting of LAND ice raises sea level).

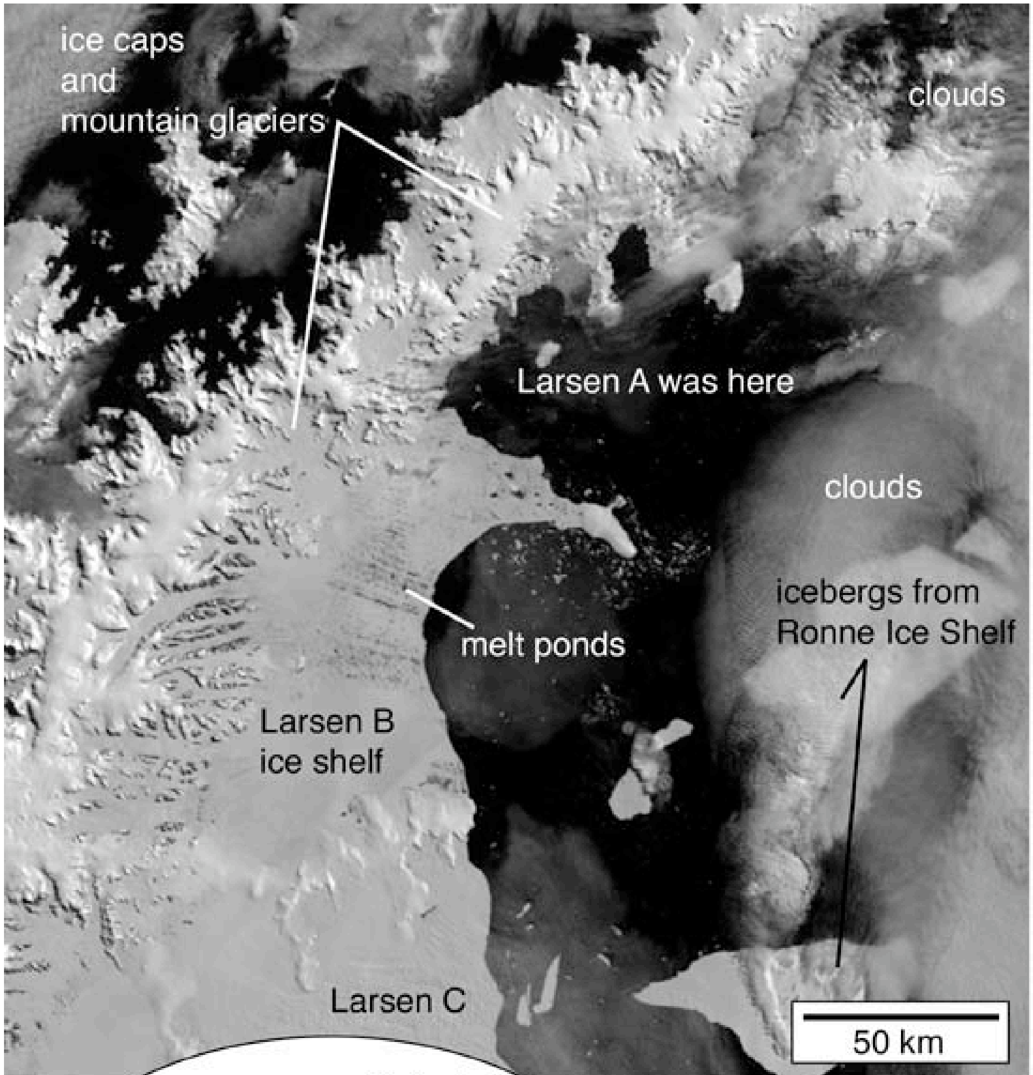


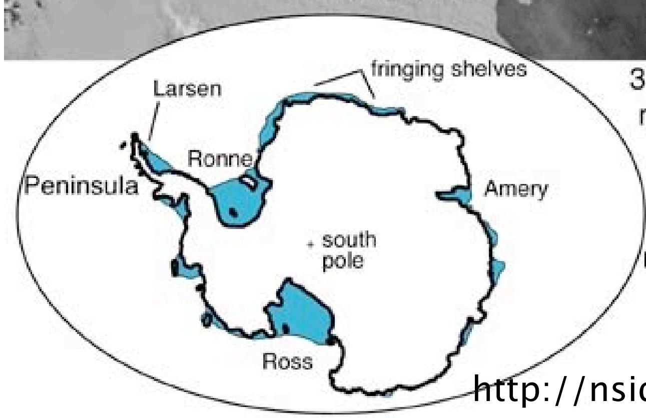
Main concern is land-based icesheets
Greenland ice-sheet = 7 m of sea level if all melted

Antarctic ice-sheet = 60-70 m of sea level if all melted.
But only West ice-sheet is vulnerable. East is on high ground.

Picture: Ice-shelves could collapse into the warmer sea, causing glacial flow, frictional heating, and more glacial flow in positive feedback.

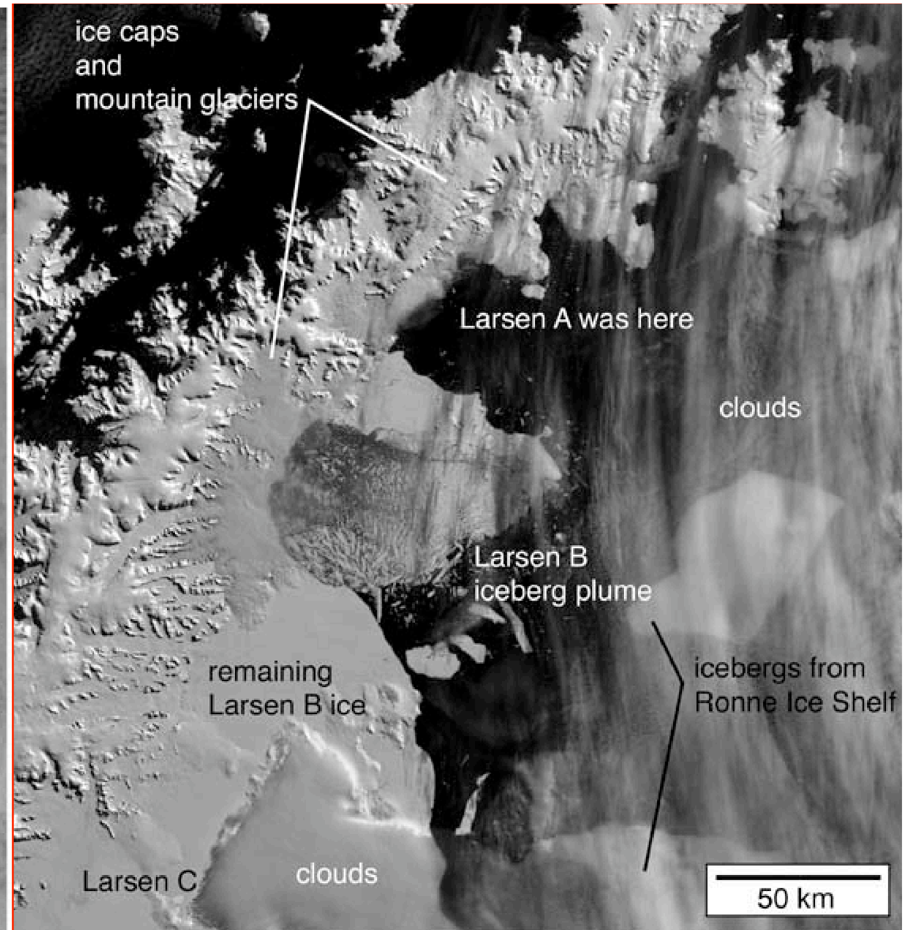
This is theory: is it truth or fiction?





31 January 2002 image of the northeast Antarctic Peninsula

The Peninsula's fringing ice shelves are retreating, in response to recent warming.



5 March 2002 image of the northeastern Antarctic Peninsula

The northern part of the Larsen B ice shelf has disintegrated, sending approximately 720 cubic kilometers of icebergs into the ocean. Because the ice was already floating, it does not affect sea level. The southern edge of the break-out tracks to the melt-pond boundary observed in the 31 January image.

720 km^3 of Larsen B iceshelf disintegrated Jan-Mar 2002 = 29 trillion bags of party ice!

http://nsidc.org/iceshelves/larsenb2002/