Mon Nov 24

Upcoming talks:

Tuesday 25 Nov

12:30 310 ATG Weather discussion

(Thursday night thunder?)

Where we're going (3 weeks to go):

This week: global warming science

KKC Chap 7 (p128-138), Chap 13 (all)

IPCC 2001 Summary for Policymakers (web)

Today: Carbon cycle - natural

Tues: Carbon cycle - perturbed

Wed: Climate change forecasts

Thurs: holiday

Fri: holiday

Next two weeks... see schedule

HW#6 due Wed, Dec 3

Final is Friday, Dec 12 (2nd report due)

Global warming science: topics

<u>Perturbation of the Carbon Cycle</u>

- fundamental basis of concern
- natural changes linked to major climate changes in Earth history
- critical part of climate forecasts
- problem of "the missing sink"
- atmosphere, ocean, biota all involved
- many different timescales are involved

<u>Other topics</u>

- other forcing agents (GHGs and aerosols)
- climate response (global and regional)
- testing the theory (detection and attribution)

Global warming science overview

<u>"Global warming" definition:</u>

The proposition that industrial-era human activity is in the early stages of changing the global climate over the next several centuries. The principle mechanism of change is an enhanced greenhouse effect caused by burning of fossil fuels. The primary index of change is rising global-mean temperature.

<u>"Global warming" BIG questions:</u>

1. Is it real? (science)
2. Is it serious? (consequences)
3. What should we do about it? (response)

Is it real?

1. Is GW real? our focus (i.e. the science)

- Are we forcing the climate system?
- Is the energy balance theory of climate change correct?
- How well can we forecast the climate system response?
- Has the warming already been detected?

$$\Delta T_s = \lambda \, \Delta F$$

ΔF = forcing (changes to energy balance)
ΔT_s = response (predicted or measured)
λ = climate sensitivity (from models or empirical tests)

Note: Global warming debate has tended to focus on detection of the response, ΔT_s. But the fundamental basis for concern is whether or not we are forcing the climate system (i.e. ΔF). This implies fundamental focus should be on the carbon cycle.

Focus on GAAST: has the warming begun?

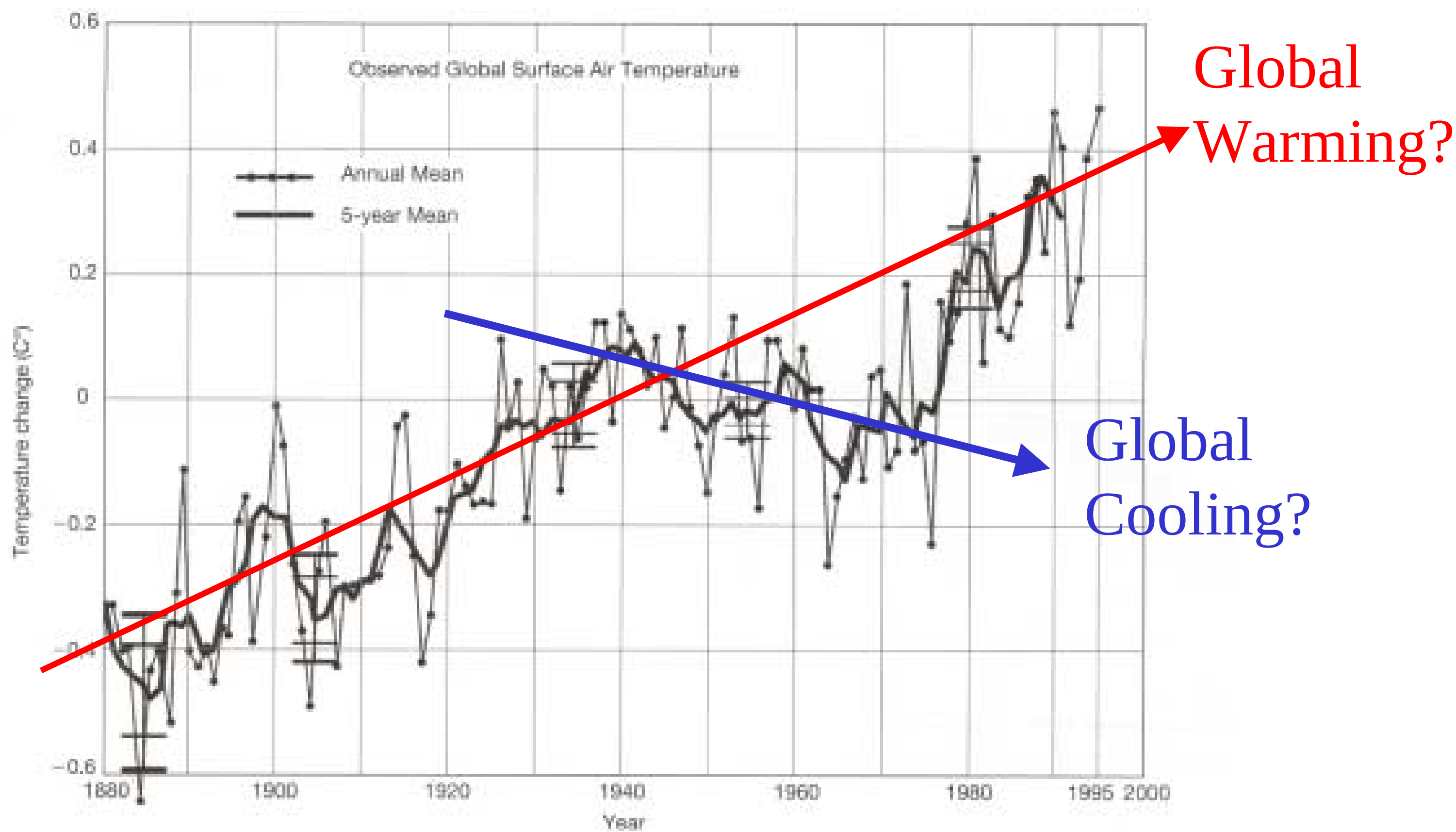
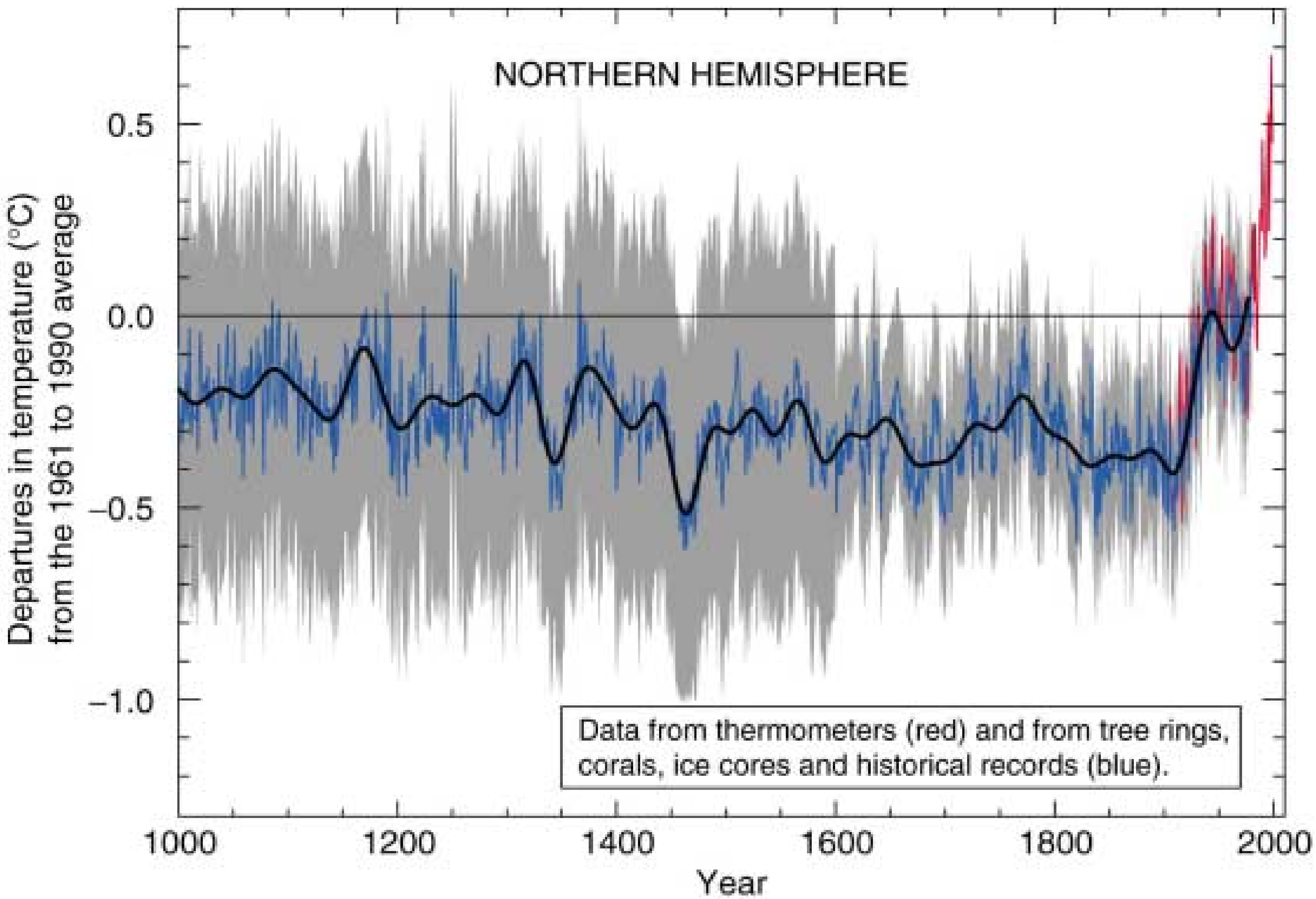


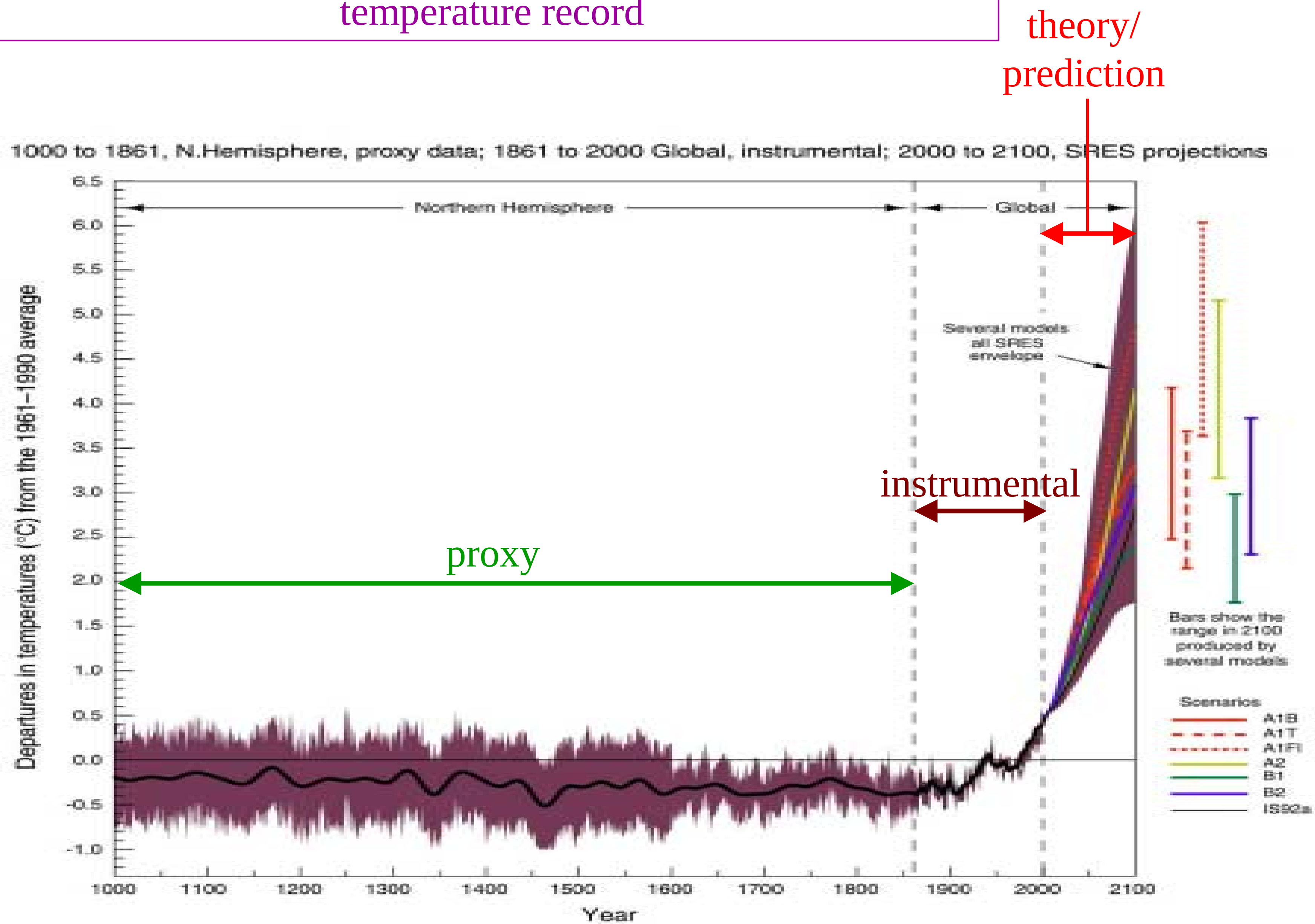
FIGURE 2-4

The globally averaged temperature history from 1950 to 1996, showing the 0.5°C (1°F) cooling associated with the eruption of Mt. Pinatubo in 1991. Anomalies are defined as deviations from the 1951–1980 mean. (From R.W. Christopherson, *Geosystems: An Introduction to Physical Geography*, 3/e, 1997. Reprinted by permission of Prentice Hall, Upper Saddle River, N.J.)

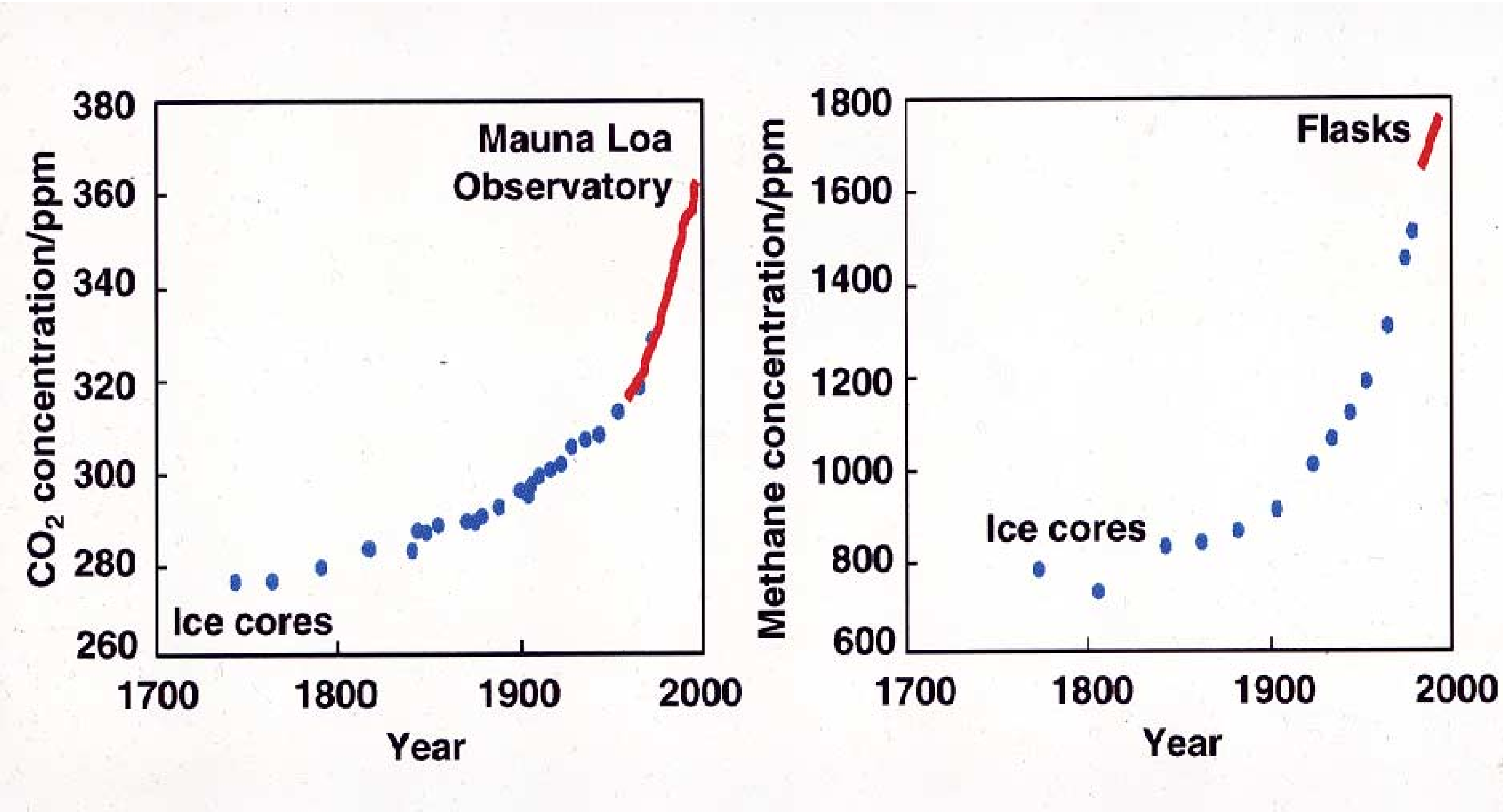
Focus on GAAST: is recent warming anomalous?



Focus on GAAST: Global warming forecast in context of temperature record

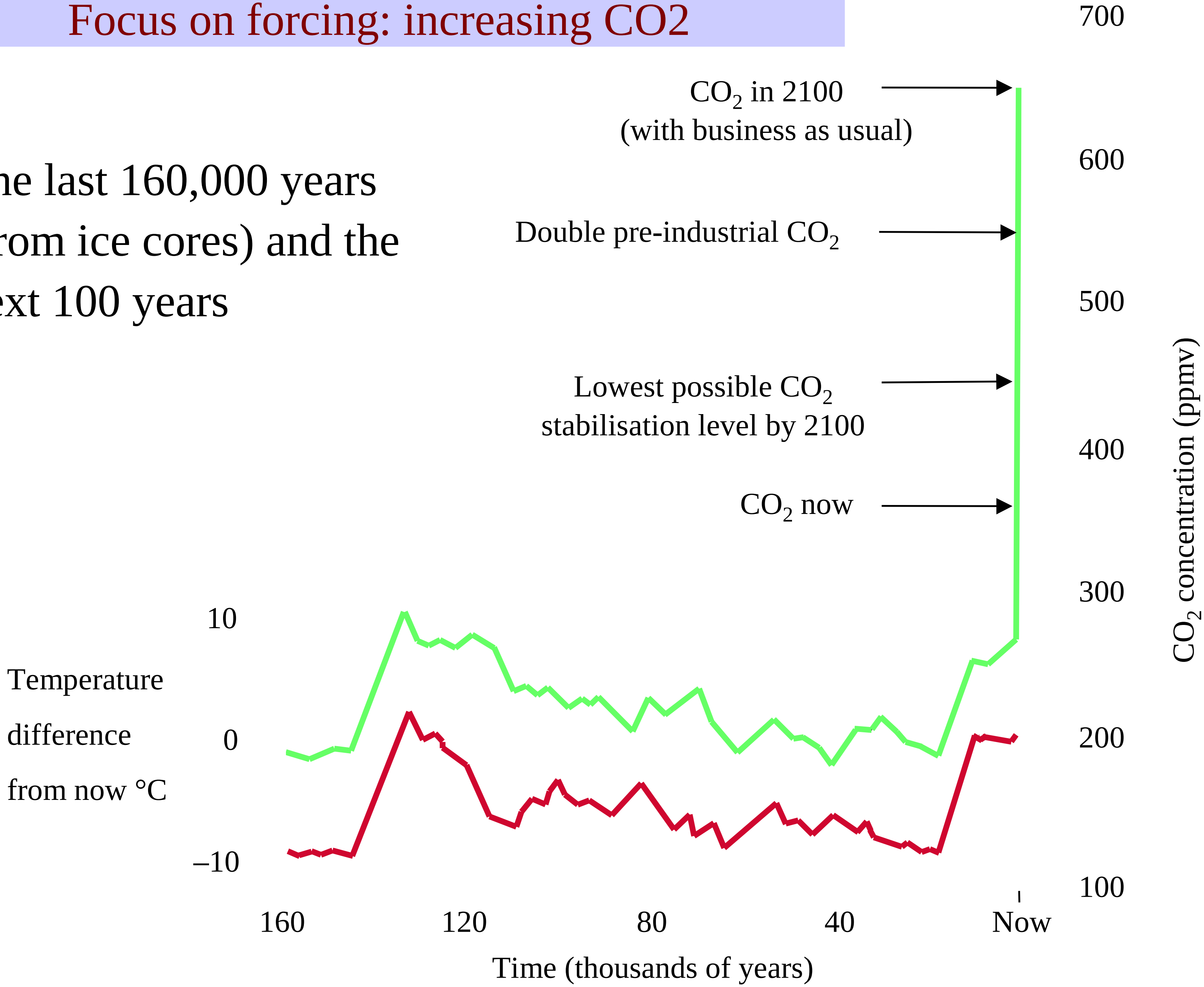


Focus on forcing: increasing CO2 and CH4

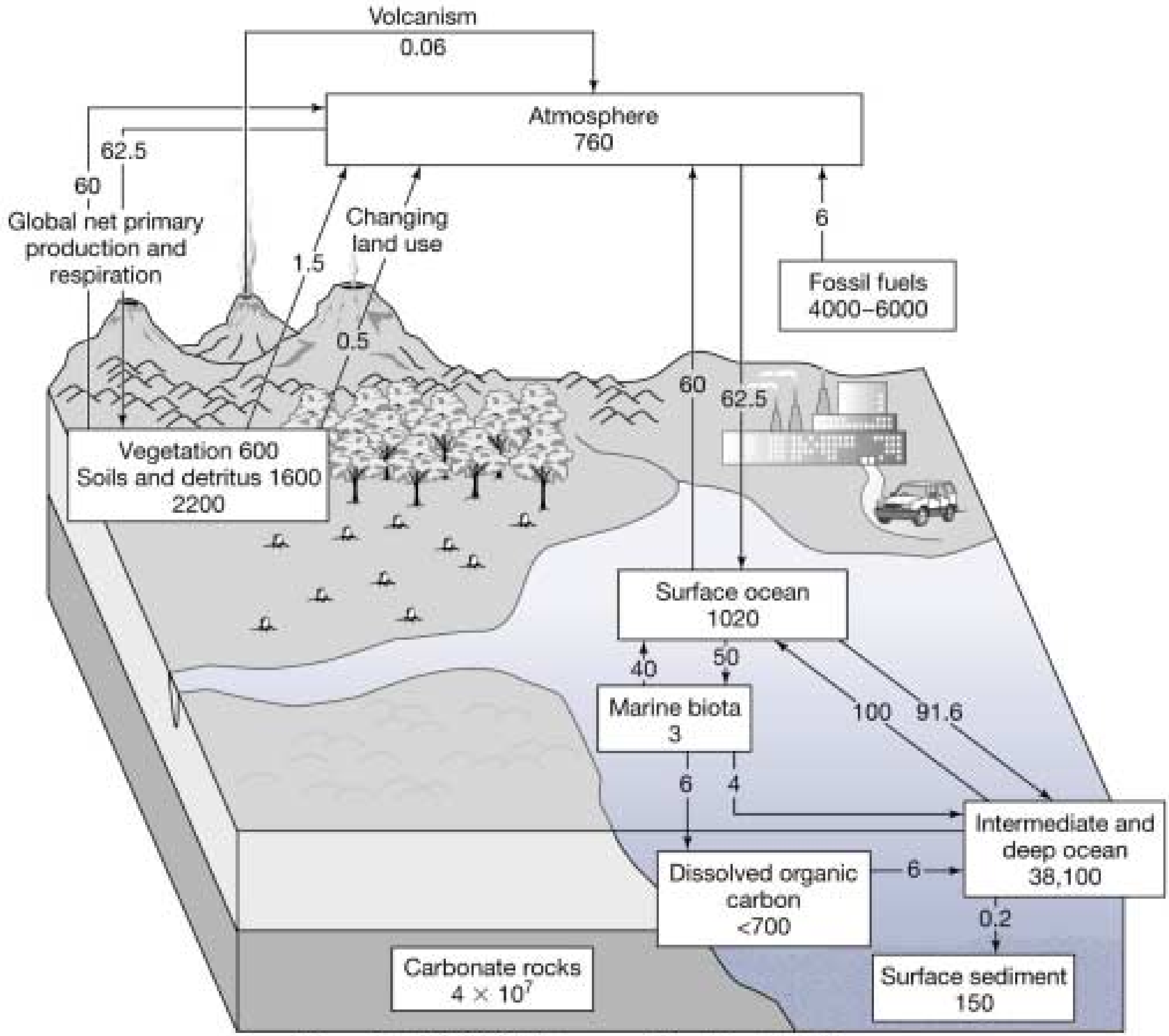


Focus on forcing: increasing CO2

The last 160,000 years (from ice cores) and the next 100 years



Global Carbon Cycle: Fig 13-1



Carbon cycle: reservoirs and couplings

Group	Reservoir	Burden (Gton,C)	Group
1	Atmosphere	760	
1	Land	2190	
1	Ocean Mixed Layer	1023	2
3	Deep Ocean	38,100	2
3	Carbonate Rocks	40,000,000	

1: Coupled by biological processes and CO_2 solubility... fast

2: Coupled by thermo-haline circulation (and other mixing, upwelling processes) ... slow

3: Coupled by geological processes... very slow

Carbon Cycle: Chemistry

Inorganic carbon cycle (Urey, 1952):

weathering $CaSiO_3 + CO_2 \rightarrow CaCO_3 + SiO_2$

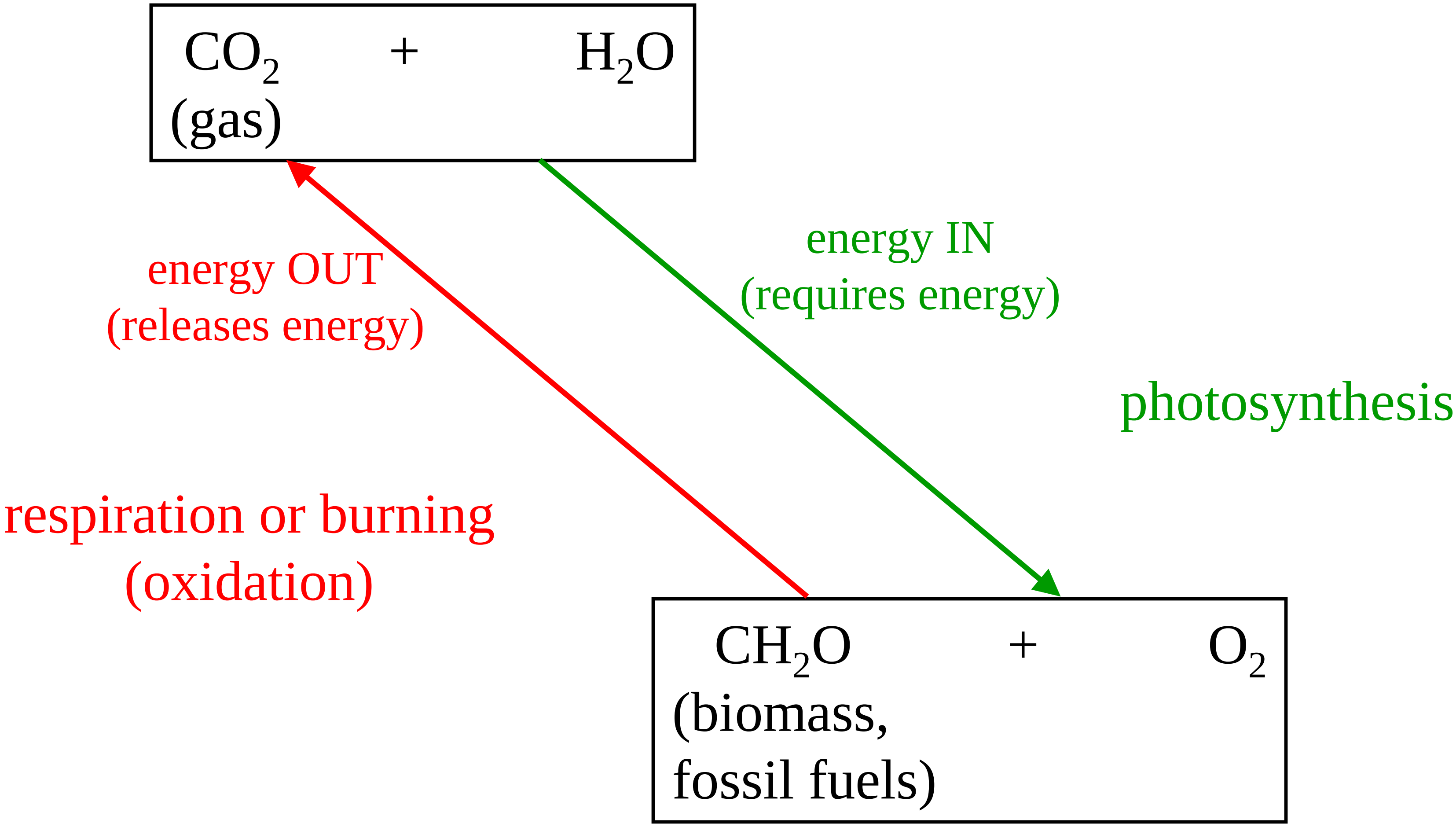
metamorphosis $CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$

Organic carbon cycle:

photosynthesis $CO_2 + H_2O \rightarrow CH_2O + O_2$

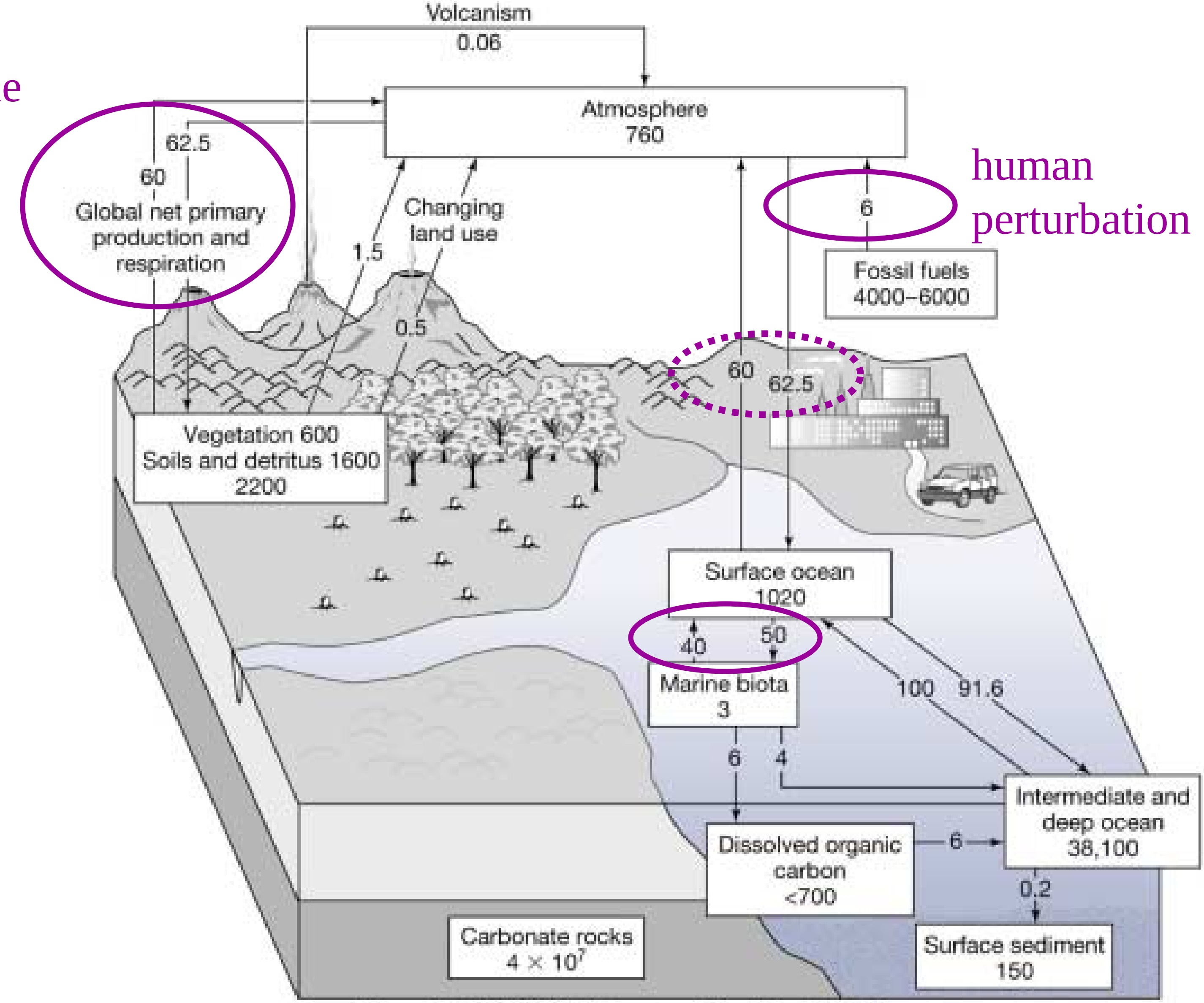
respiration/burning $CH_2O + O_2 \rightarrow CO_2 + H_2O$

Organic carbon cycle and energy



Global Carbon Cycle: Fig 13-1

Major atmospheric fluxes associated with the organic carbon cycle

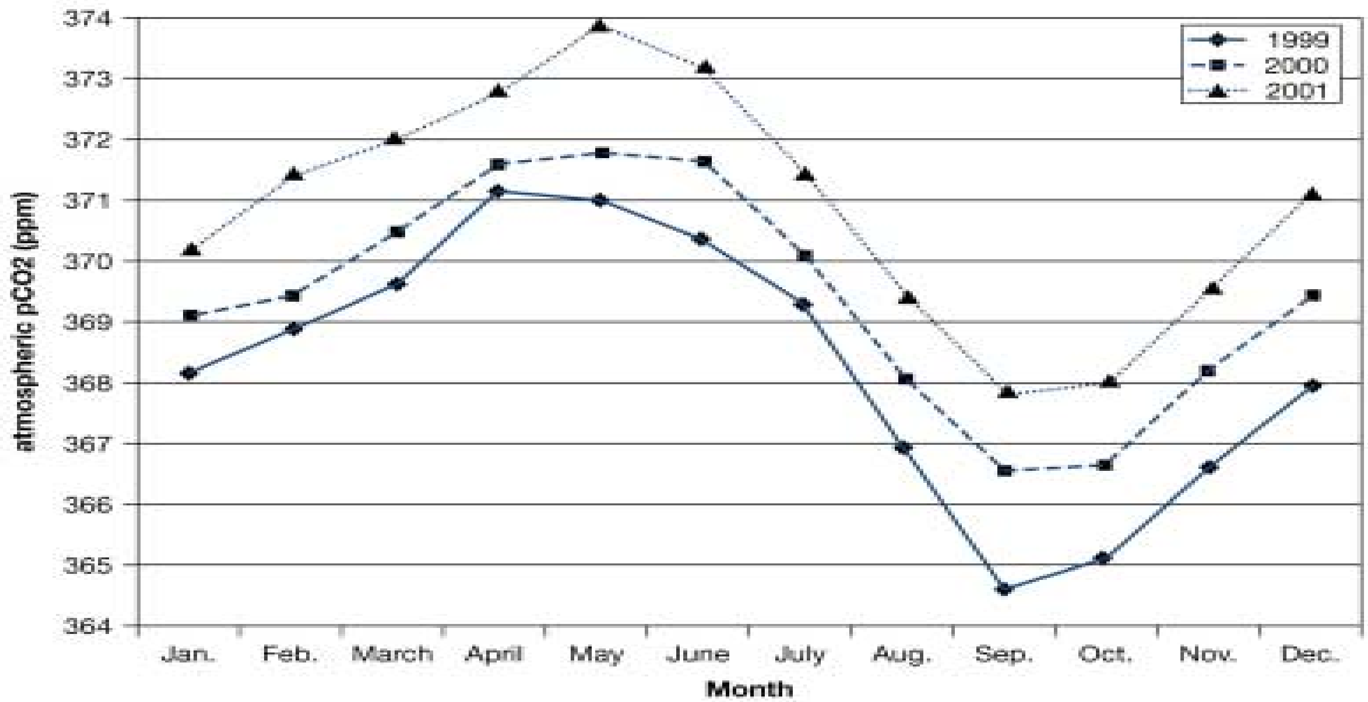


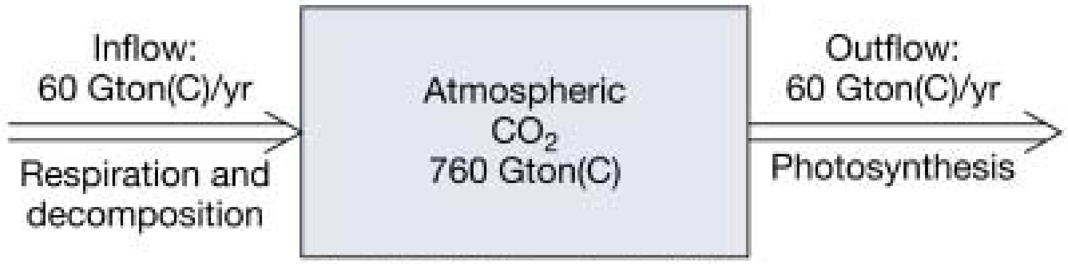
human perturbation

"Breathing of the Biosphere"

annual cycle of CO2 at Mauna Loa

and year-by-year increase





natural annual cycle: big flow, but not net change

What is the residence time of CO2 in the atmosphere based on these fluxes?

Forest Policy:

We need to establish a clear "forest policy".

For your own safety and well-being (especially in this class) please remember it!

"Mature forests are a reservoir of carbon,
not a sink."

<u>Forest Policy:</u>

"Mature forests are a <u>reservoir</u> of carbon, not a sink."

Text:

"Clearing of forests… results in a substantial release of carbon into the atmosphere, both from the trees themselves and from the soil beneath them." [p. 256]

"Deforestation of North America during the 19th century, the pioneer effect, was responsible for most of the rise in atmospheric CO_2 between 1800 and 1850." [p 256]

Forest Policy:

"Mature forests are a reservoir of carbon, not a source or sink."

Earth in the Balance by Al Gore:

"By rapidly destroying the [tropical] forests…, we are damaging [the earth's] ability to remove excess CO_2." [p. 293]

POLICY VIOLATON !!!

Tues Nov 25

Upcoming talks:

Today

12:30 310 ATG   Weather discussion

(Thursday night thunder?)

Announcements:

a few hard copies of IPCC report are available

Today:

Human perturbation of carbon cycle

"Emission scenarios" and projected consequences (key to HW#6)

Forest Policy:

"Mature forests are a reservoir of carbon, not a sink."

Consider three land owners, each with a mature forest containing 100 units of carbon locked up in the biomass of the trees.

#1: leaves it alone

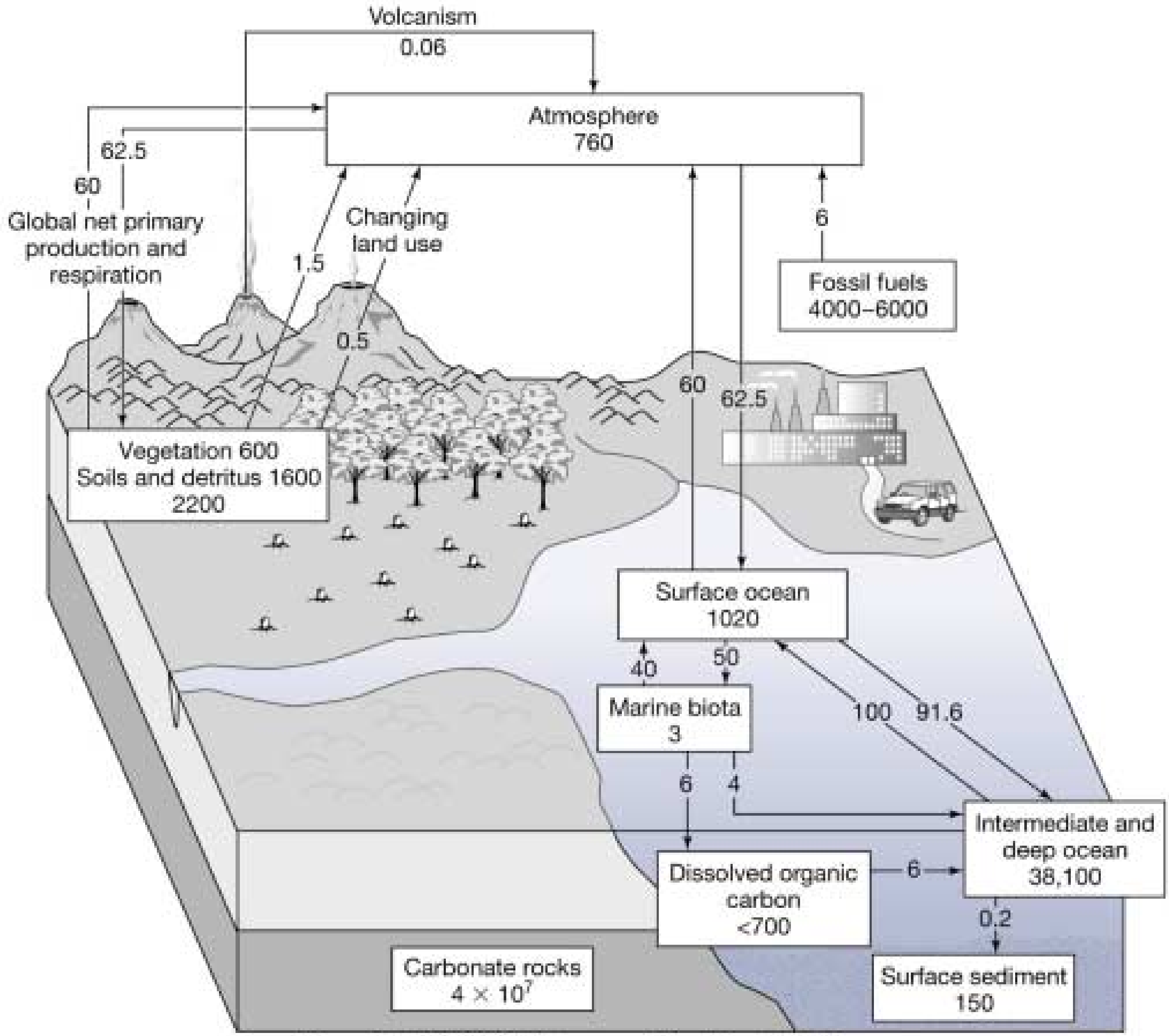
#2: burns it down and starts a farm

#3: logs it and replants with trees

Which one removes or adds the most CO_2 to the atmosphere?
(a) Immediate effect? (b) after 100 years?

Draw graphs to explain your answers.
Feel free to work in groups.

Global Carbon Cycle: Fig 13-1



Carbon cycle basics

Basic unit of measure:

Gton C: Gigatons of carbon atom

Gton = 10^9 metric tons (or 10^{15} g or 1 "petagram")

metric ton = 1000 kg ~ 2000 lbs or 1 English ton

Biological reservoirs

• land biomass is a large reservoir: ~2200 Gton C

• ocean biomass is a tiny reservoir: ~3 Gton C

Biological fluxes

• very large fluxes with atmosphere, but no net change in atmospheric CO2 unless...

1. land biomass changes (fast, temporary)
2. ocean biological pump changes (fast, longer lasting)

• ocean biological pump is biomatter (hard shells) sinking to deep ocean or ocean bottom

Carbon cycle basics

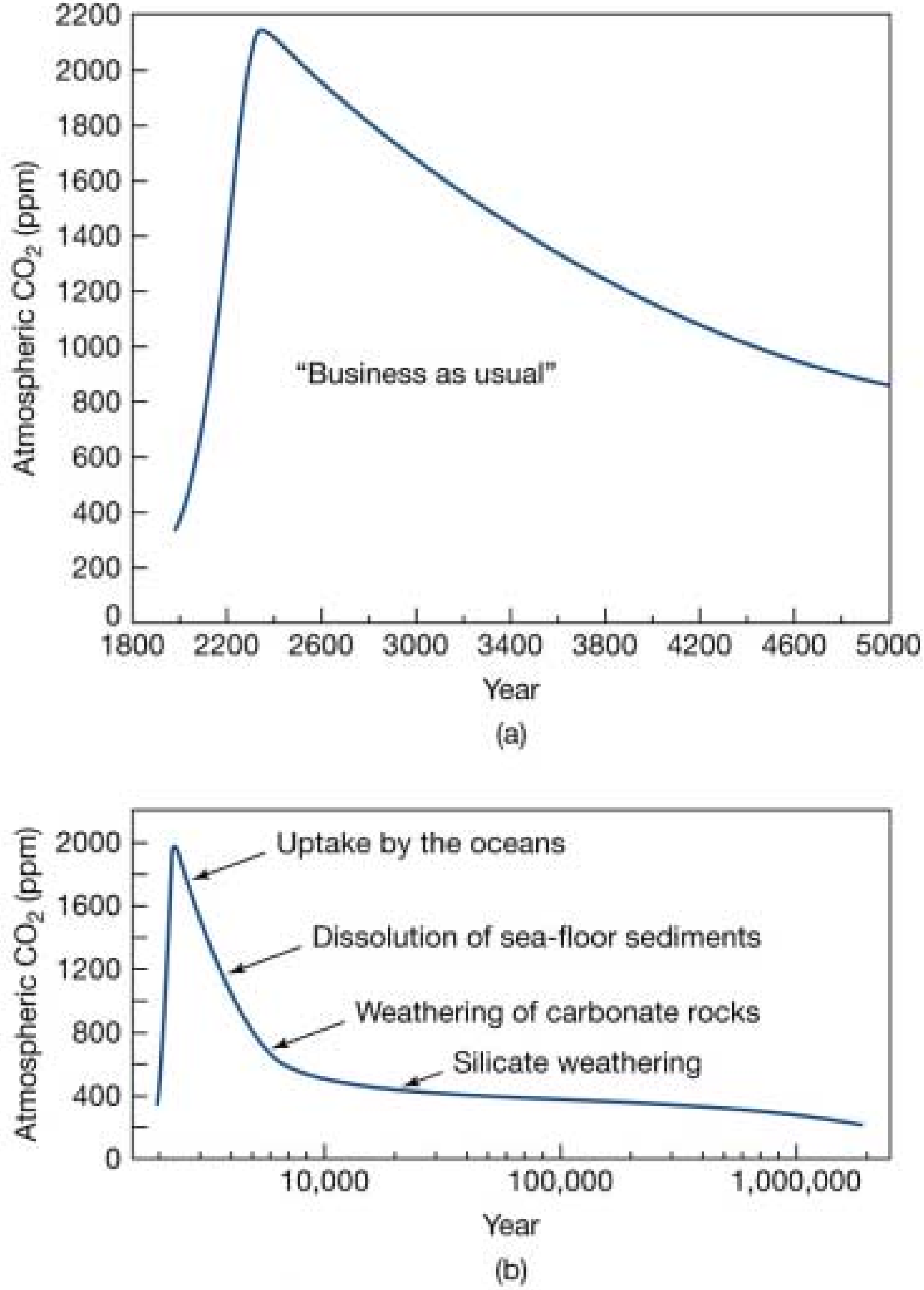
The land-ocean-atmosphere (LOA):

- atmosphere is a small reservoir (760 Gton) but tightly coupled to
  - land biota (2200 Gton) via photosynthesis and respiration/burning
  - surface ocean (1020 Gton) via dissolution
- thus, it is appropriate to consider the LOA as a single reservoir on timescales of a few years to a few decades

Removal from the atmosphere

- grow trees (building suburbs wont work!): temporary
- mix with deep ocean: 1000's of years (still temporary)
- [dissolve carbonate rocks, store as bicarbonate in deep ocean:
  10's to 100's of thousands of years (still temporary)]
- form new carbonate sediments via silicate weathering:
  PERMANENT (for our purposes)

Box Fig 13-2:
Long-term CO2
projections



Human perturbation

IPCC:

Intergovernmental Panel on Climate Change

SPM:

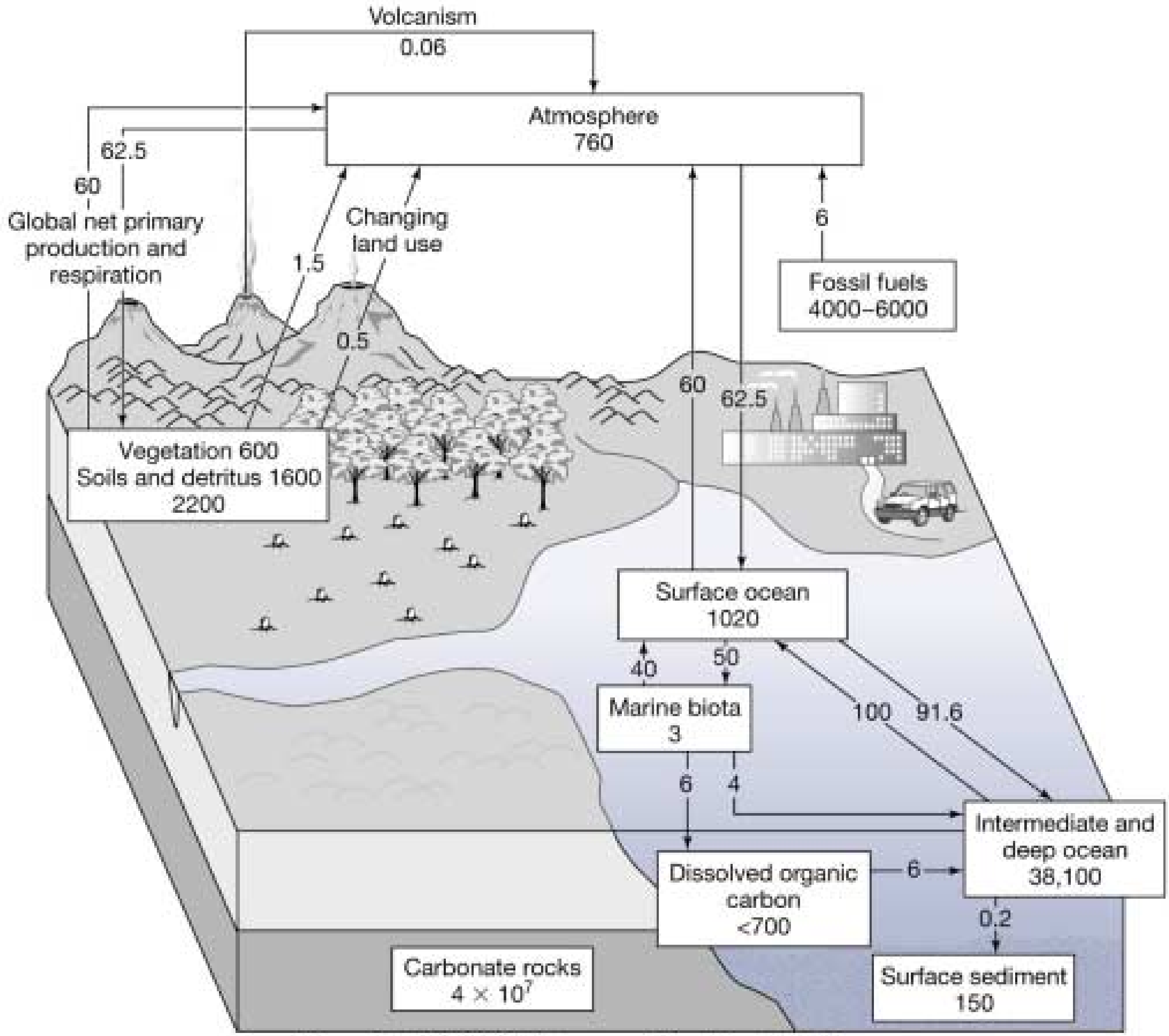
Summary for Policymakers (required reading!)

TABLE 13-1

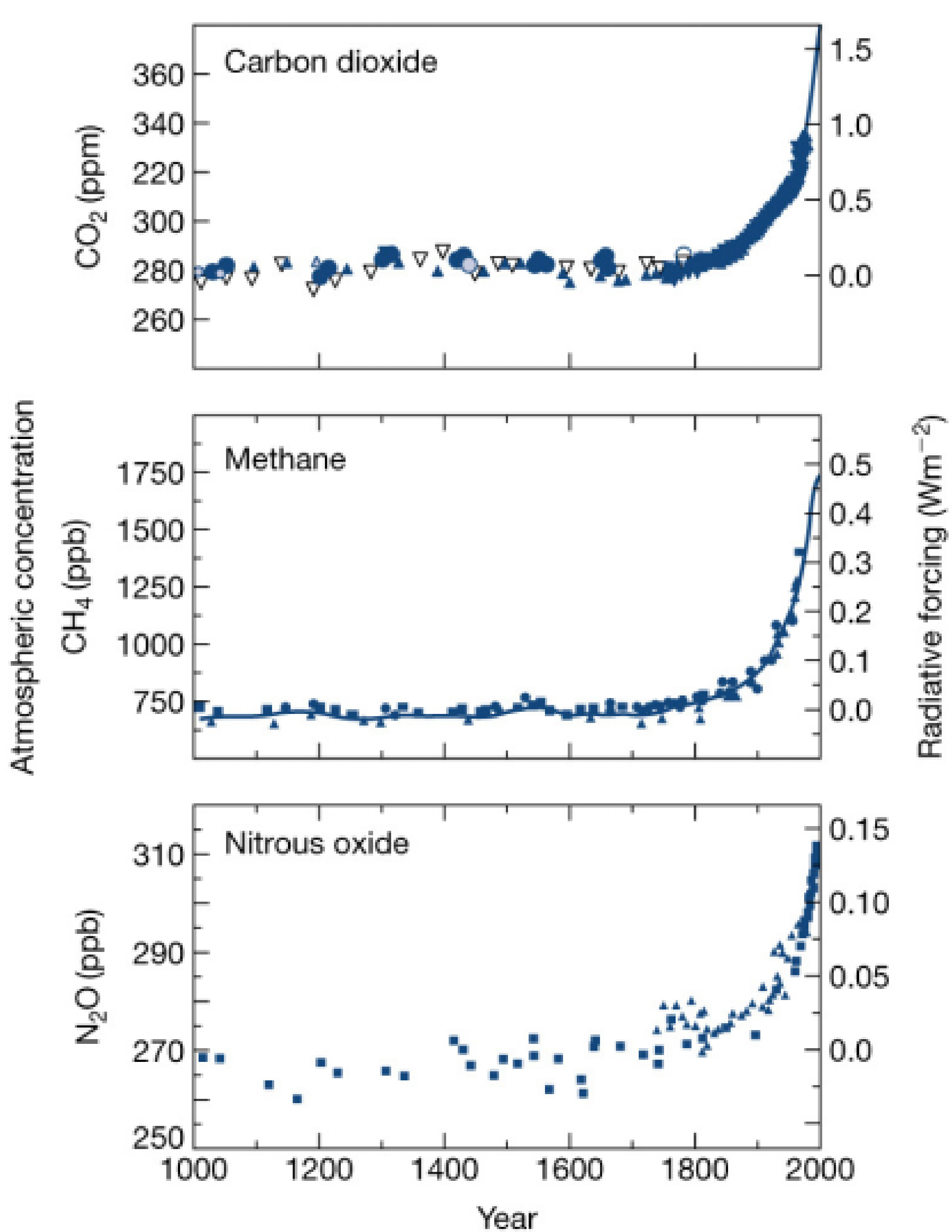
Fossil Fuel Reservoir Sizes and Burning Rates

Reservoir	*Size, Gton(C)*	*Burning rate, Gton(C)yr*
Coal	4000	2.5
Oil	500	2.5
Natural gas	500	1.0
Total	5000	6.0

Global Carbon Cycle: Fig 13-1



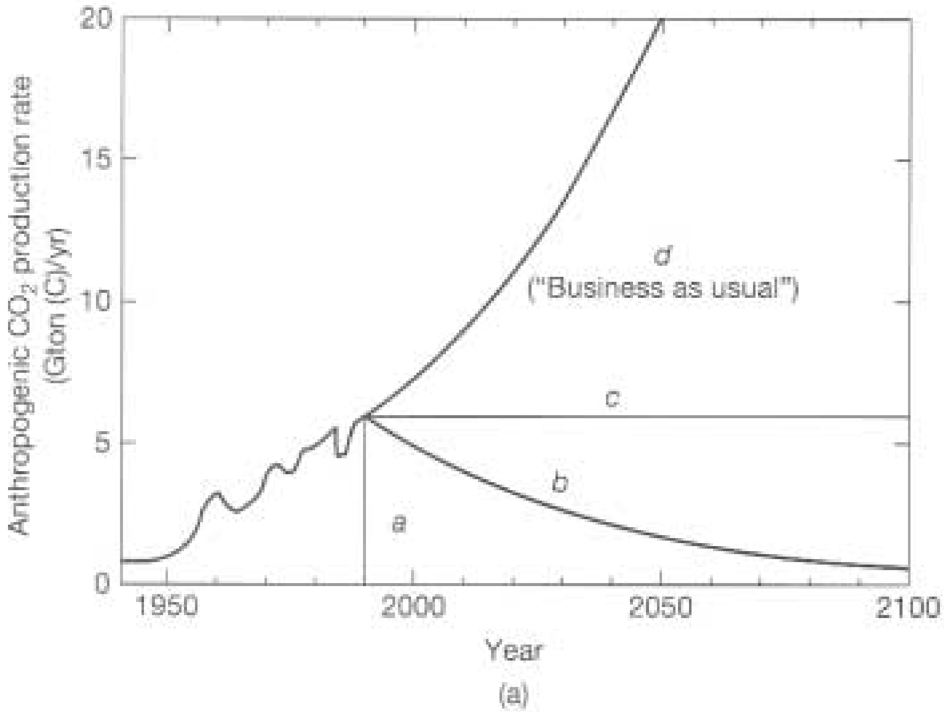
IPCC 2001, SPM
Fig 2: Industrial-era
GHG changes



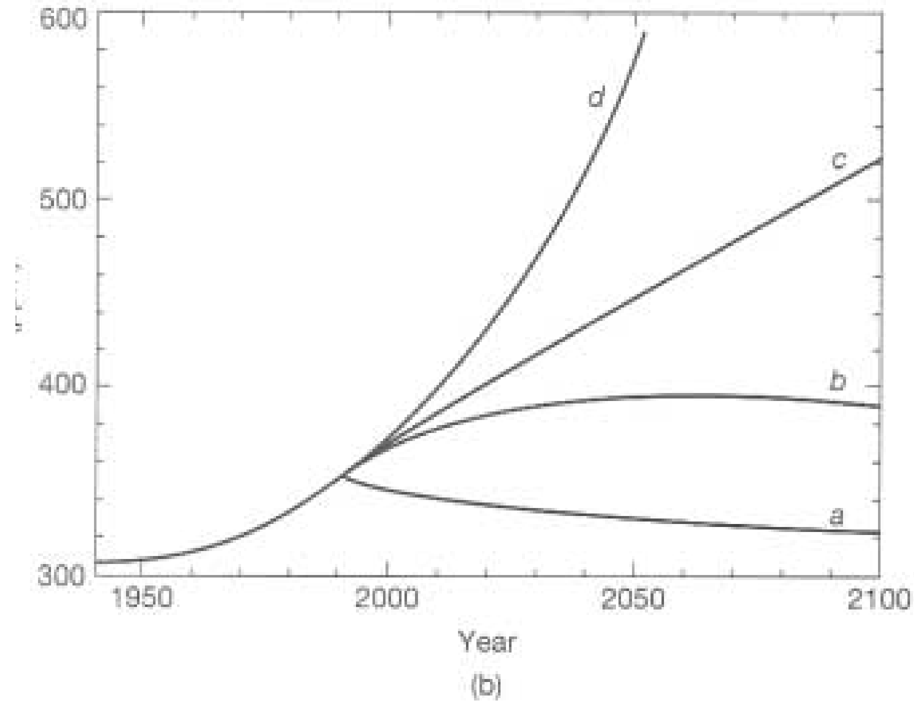
KKC Fig 13-4: simplified CO2 scenarios

Question: Which of these are realistic or feasible?

CO2 emissions



resulting
CO2 concentrations



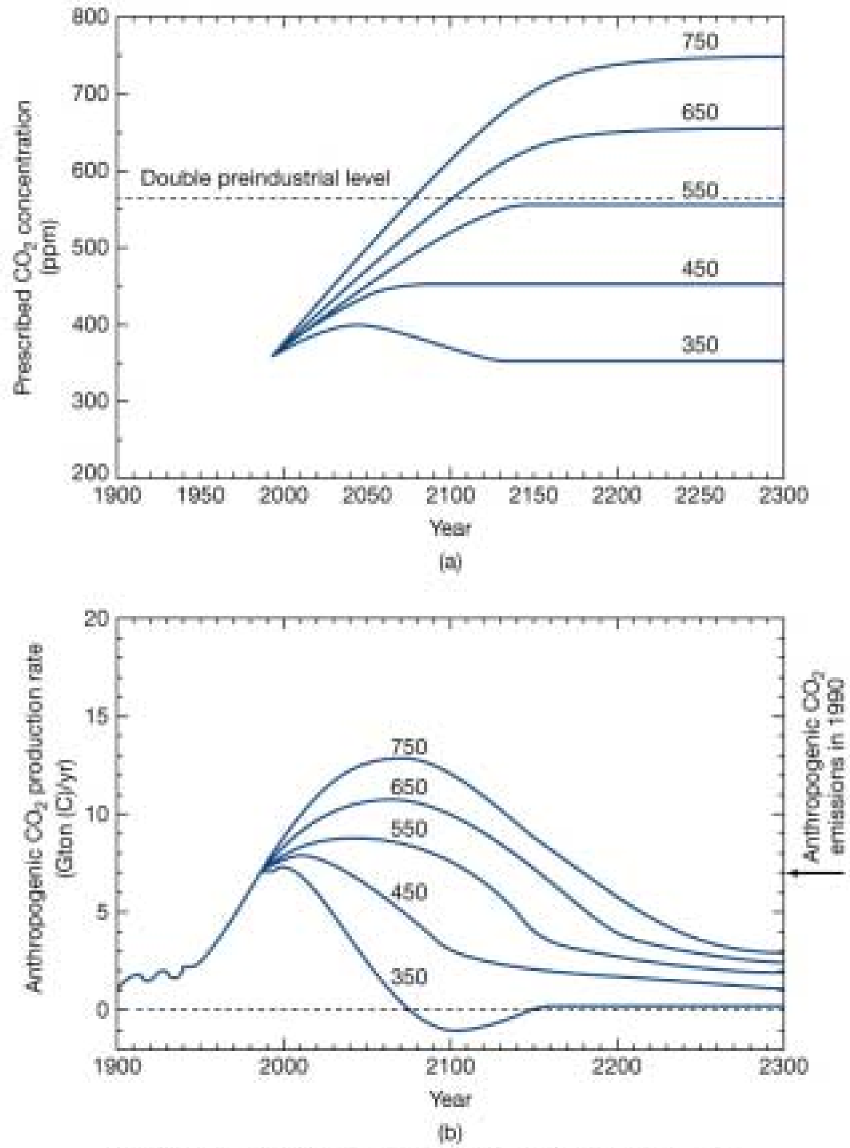
a. stop all emissions immediately
b. begin emissions reduction immediately
c. freeze at 1990 emissions (Kyoto Protocol for entire world)
d. business-as-usual

Fig 13_5: paths to CO2 stabilization

<u>Question 1:</u> What level of CO2 constitutes "dangerous interference with the climate system"?

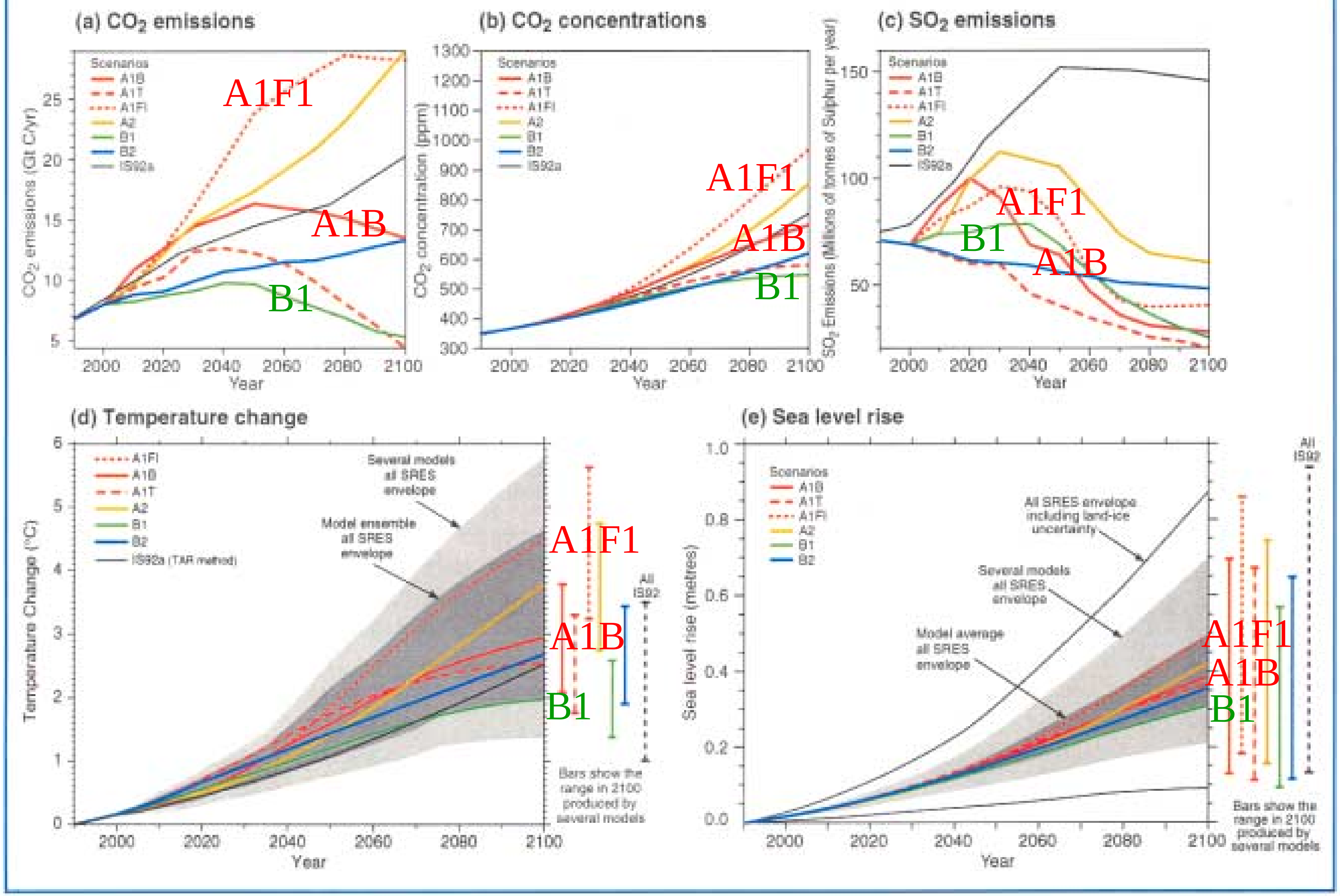
<u>Question 2:</u> What emission pathway keeps us below that level?

<u>Note:</u> Question 1 is far more difficult for science to answer.



IPCC SPM Fig 5: scenarios and projections

A1F1, A1B, B1: Scenarios from Homework



IPCC SPM, Emission Scenario descriptions

The Emission Scenarios of the Special Report on Emission Scenarios (SRES)

A1. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies).

A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

B1. The B1 storyline and scenario family describes a convergent world with the same global population, that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

B2. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with continuously increasing global population, at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

An illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A2, B1 and B2. All should be considered equally sound.

The SRES scenarios do not include additional climate initiatives, which means that no scenarios are included that explicitly assume implementation of the United Nations Framework Convention on Climate Change or the emissions targets of the Kyoto Protocol.

Wed Nov 26

Upcoming talks/events:

Today

ATG 310 12:30

Dr Nathan Gillett, "Ozone depletion and climate in Southern Hemisphere"

Monday, Dec 1

Smith Hall 115 3:30 (refreshments) 4:00 (talk)

Prof John Magee?, "Climate modeling in the US 1955-2004"

Tues, Dec 2

ATG 310 3:00 undergraduate program in Atmospheric Sciences, information meeting and social

Announcements:

10 more hard copies of IPCC report are available

Tad's homework... 2nd half review sheet coming (hopefully Monday)

Today:

- IPCC presentation (lead with effect)
- Probability exercise
- Non-CO2 forcing agents
- Climate sensitivity
- Regional changes, consequences, sea-level change

IPCC SPM: order of presentation... skewed?

page 1, bullet 1: begin with EFFECT

An increasing body of observations gives a collective picture of a warming world and other changes in the climate system.

finally, on page 5, CAUSE is mentioned

Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate.

IPCC probability definitions

Throughout the IPCC report, knowledge is expressed in terms of probability, using terms such as "likely" or "very likely". These terms are not used in a casual sense, but reflect a careful assessment of confidence in scientific understanding.

The terms are defined as follows:

virtually certain	>99% chance of being true
very likely	90 - 99%
likely	66 - 90%
medium likelihood	33 - 66%
unlikely	10 - 33%
very unlikely	1 - 10%
exceptionally unlikely	<1%

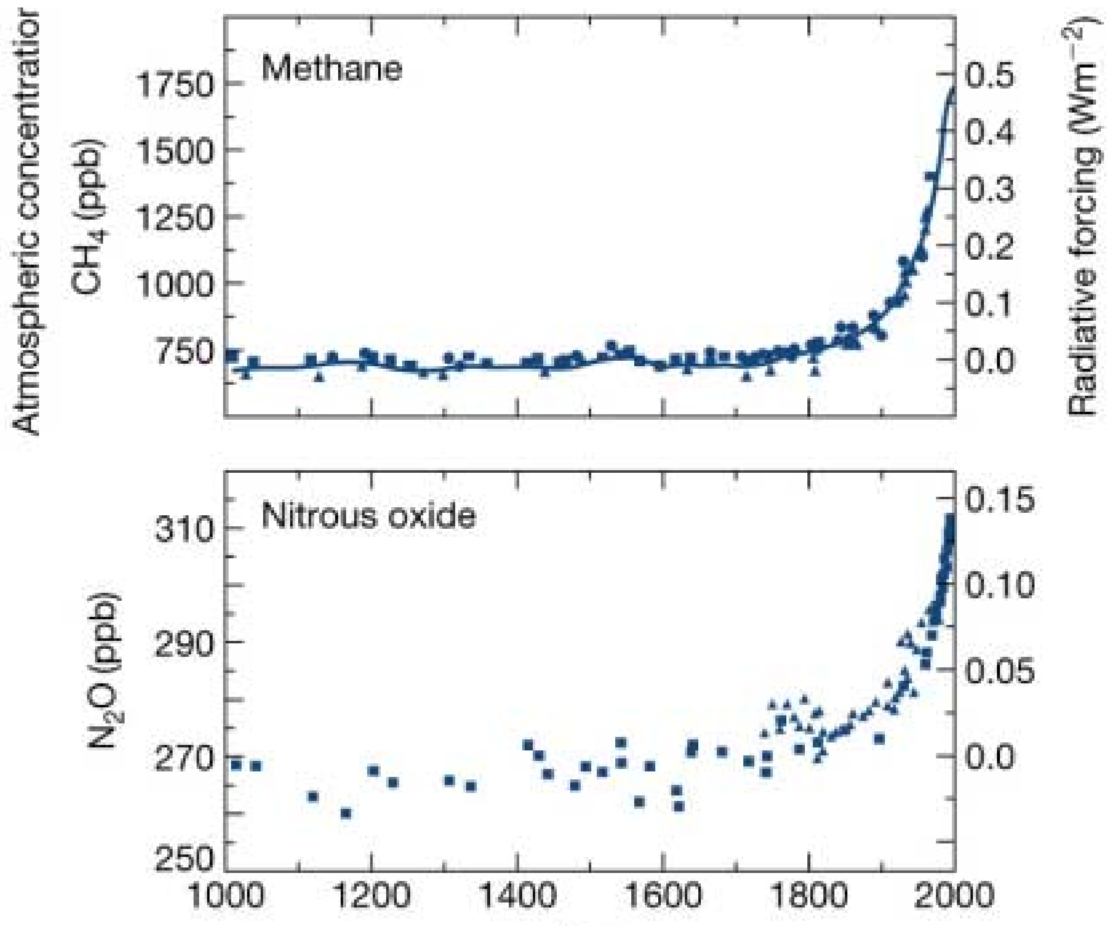
Exercise: Give examples from your own experience that illustrate at least three of these categories.

non-CO2 forcings: other GHGs

CO_2 is up ~30% for a forcing of 1.5 W/m^2

<u>other greenhouse gases:</u>

- CH_4 (methane) — rice patties, cow belches, termites
- N_2O (nitrous oxide) — nitrogen fixation, nitrate fertilizers
- Halocarbons (CFCs and halons) — refrigerants, blowing agents, etc



non-CO2 forcings: aerosols

CO_2 is up ~30% for a forcing of 1.5 W/m^2

<u>aerosols:</u>

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

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

- Specifically, this gave modelers much greater confidence that the "signal" of anthropogenic influence on climate had been detected.

  1990: "generally consistent"

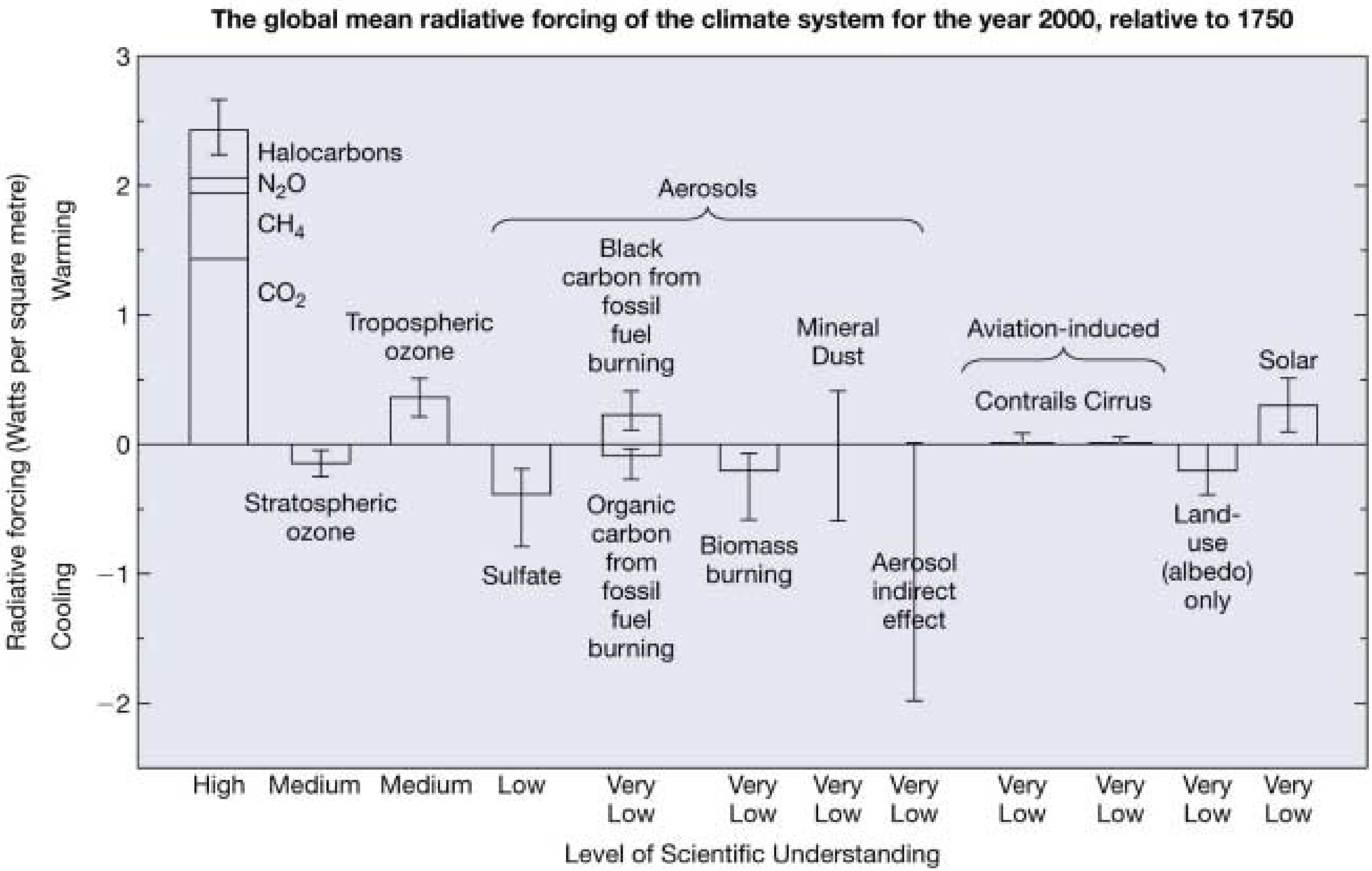
  1995: "a discernable influence"

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

  (see overheads)

- Problem: forcing estimates are 0 to -3 W/m^2 (!!!)

IPCC 2001, SPM, Fig 3: Forcings



Non-CO_2 Forcings

Basic Global Warming Forecast Equation

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

small difference

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

- The current best guess is that non-CO_2 forcings (positive GHGs and negative aerosols) add up to a net forcing close to zero.
- Also, this is expected to remain approximately true in the future.
- Thus, the question of forcing is primarily a question of CO_2 concentration.

- BUT... there is enormous uncertainty regarding the aerosol forcings. More on that next week.

Climate sensitivity

Basic Global Warming Forecast Equation

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

Table 1: Climate sensitivity

$\Delta T(2xCO_2)$ (K)	λ $(K/(W/m^2))$	Notes
1.2	0.3	Stefan-Boltzmann Law (no feedback case)
1.5	0.4	IPCC low
3.0	0.8	IPCC medium
4.5	1.2	IPCC high

Climate sensitivity

Basic Global Warming Forecast Equation

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

<u>National Research Council, 1979:</u>
"We estimate the most probable global warming for a doubling of CO_2 to be near 3 degrees C, with a probable error of plus or minus 1.5 degrees."

<u>IPCC, 2001:</u>
"Climate sensitivity [to CO_2 doubling] is likely to be in the range 1.5 to 4.5C."

This is mostly based on climate models. But recall that Lorius et al. got a value within this ranged based on empirical analysis of ice-ages.

The problem is, this range is awfully large (factor of three!) Is it even useful for policy-making purposes?

IPCC SPM Extreme events table

Table 1: Estimates of confidence in observed and projected changes in extreme weather and climate events.

Confidence in observed changes (latter half of the 20th century)	Changes in Phenomenon	Confidence in projected changes (during the 21st century)
Likely[7]	**Higher maximum temperatures and more hot days over nearly all land areas**	Very likely[7]
Very likely[7]	**Higher minimum temperatures, fewer cold days and frost days over nearly all land areas**	Very likely[7]
Very likely[7]	**Reduced diurnal temperature range over most land areas**	Very likely[7]
Likely[7], over many areas	**Increase of heat index[12] over land areas**	Very likely[7], over most areas
Likely[7], over many Northern Hemisphere mid- to high latitude land areas	**More intense precipitation events[b]**	Very likely[7], over many areas
Likely[7], in a few areas	**Increased summer continental drying and associated risk of drought**	Likely[7], over most mid-latitude continental interiors. (Lack of consistent projections in other areas)
Not observed in the few analyses available	**Increase in tropical cyclone peak wind intensities[c]**	Likely[7], over some areas
Insufficient data for assessment	**Increase in tropical cyclone mean and peak precipitation intensities[c]**	Likely[7], over some areas

regional effects and sea level change

see KKC figures: 13-9, 13-10, 13-12 and accompanying text

- Climate change in a specific region is what we really care about...
- but, regional changes are much harder to predict than global-mean changes

- Sea-level change depends not only on temperature change (simple thermal expansion of water) but also on the balance between snowfall and melting (net decrease of ice-sheets over the land would raise sea level). Thus, sea-level change forecasts have very large uncertainty.