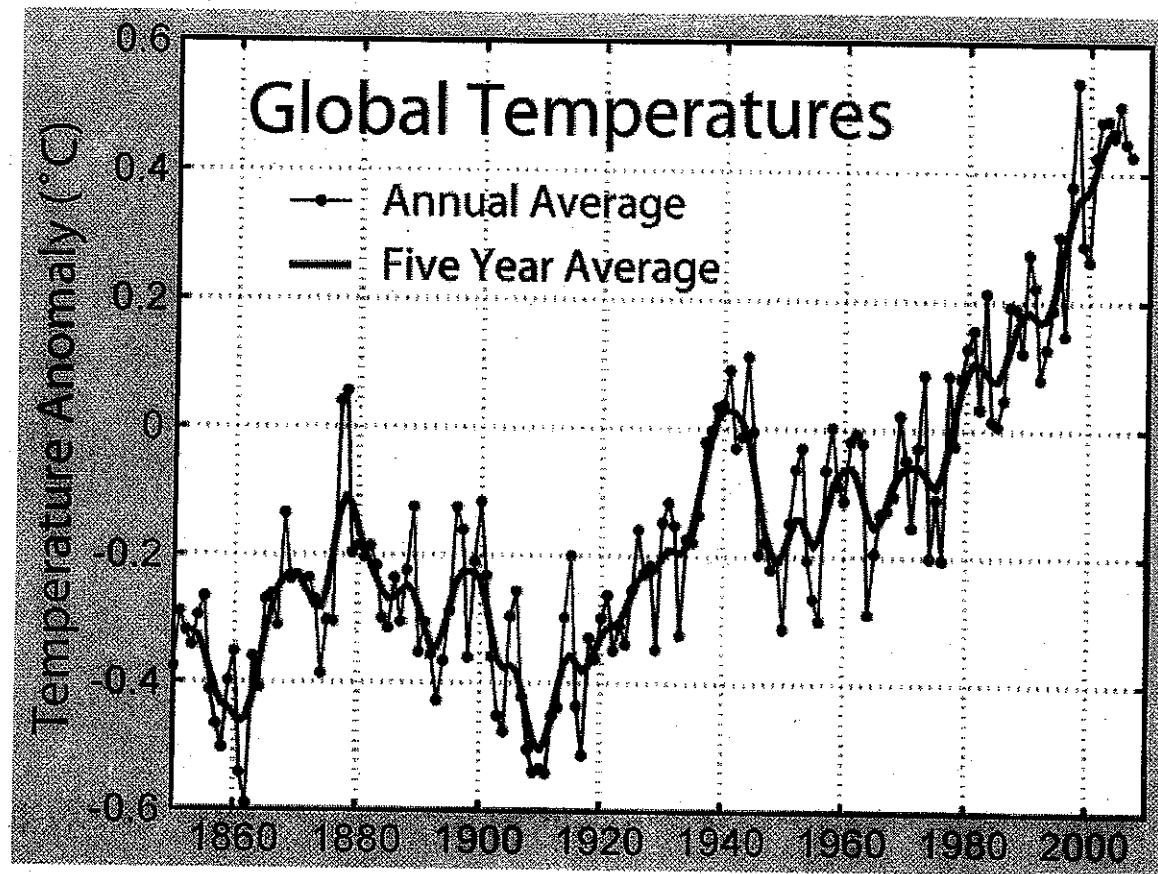
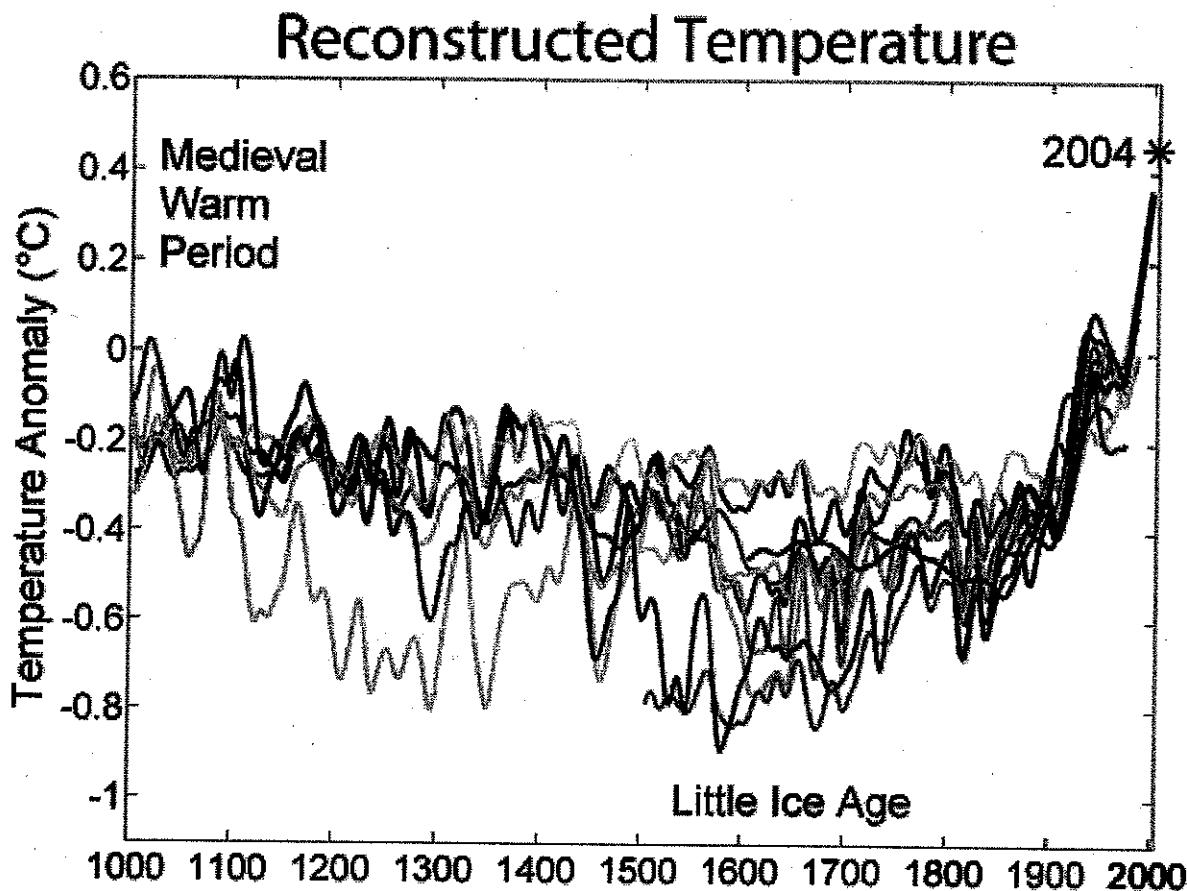


(1)



- 1960 - 1990 arbitrary benchmark  
for deviations

- instrumental record only



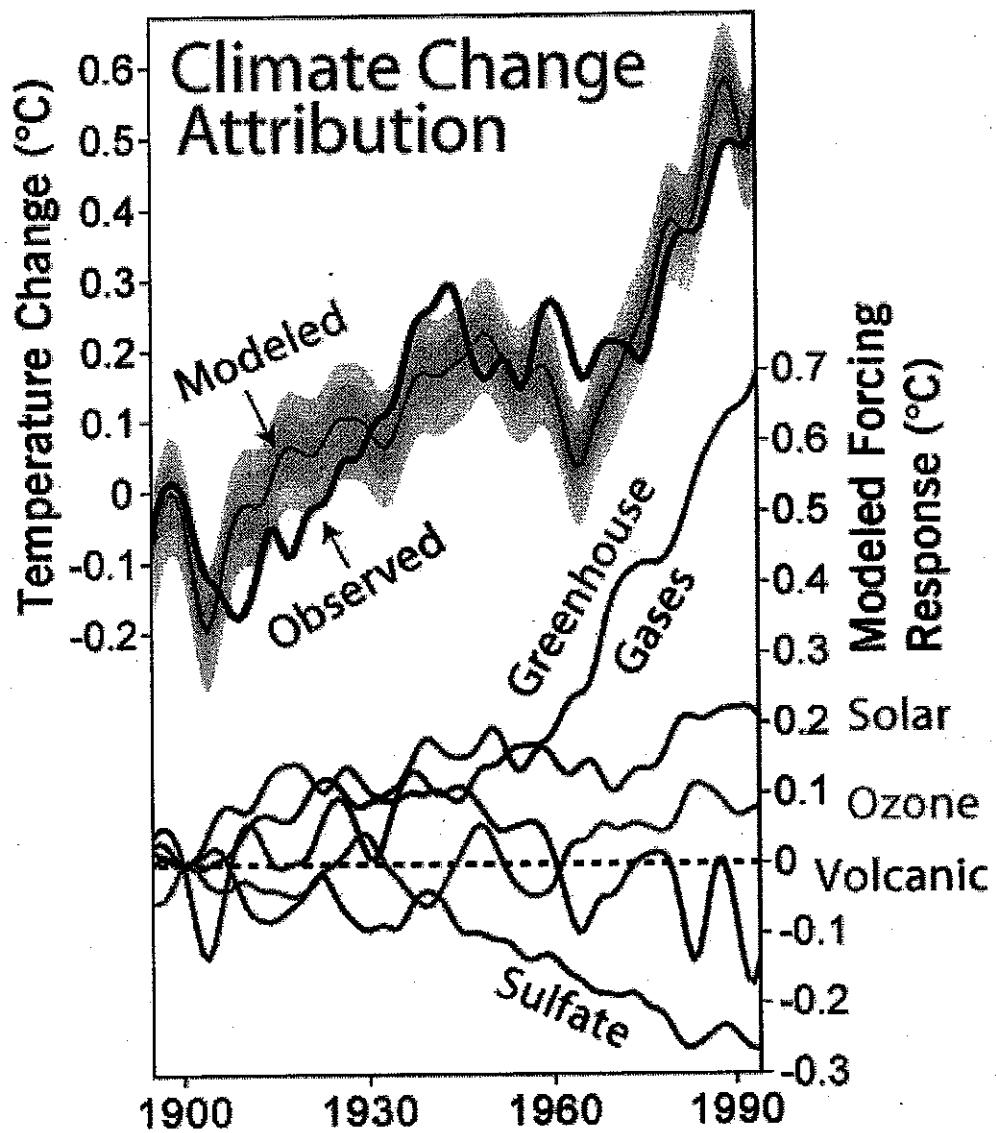
Instrumental  
tree rings

boreholes

Short, accurate +  
precise

longer, less precise,  
possibly less accurate

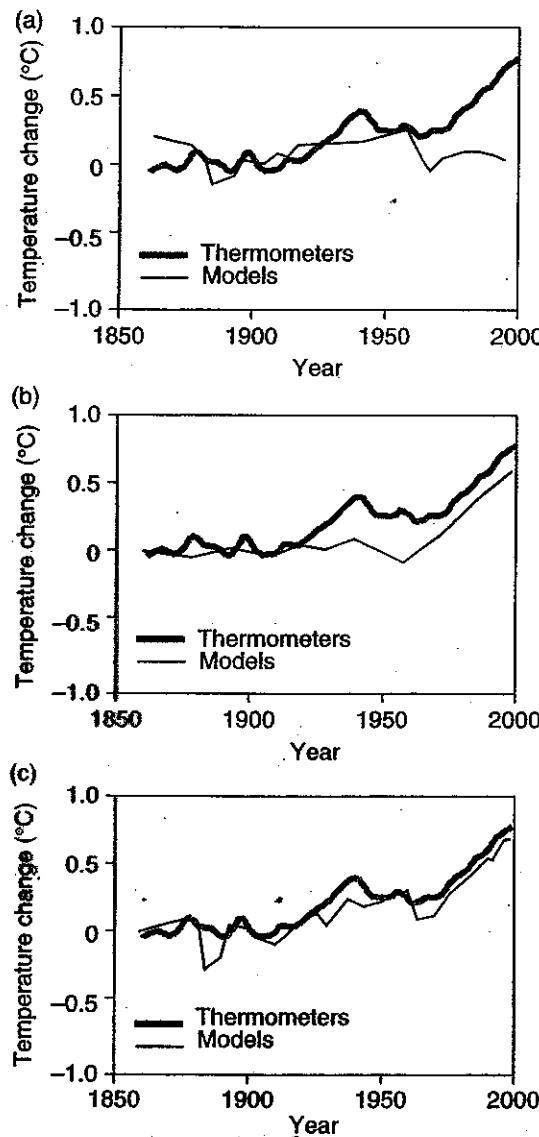
(3)



Climate "forcings"

# COMPARING MODELS + DATA → HINDCASTING

(4)



Data vs.  
natural  
forcings

vs.  
anthropogenic  
forcings

vs  
DN

Fig. 11.8 Hadley Centre model simulation of the climate of the last 140 years using (a) natural forcings only, (b) anthropogenic forcings only, and (c) all forcings. Replotted from IPCC (2001).

(5)

# Forecasting

## Global Warming Projections

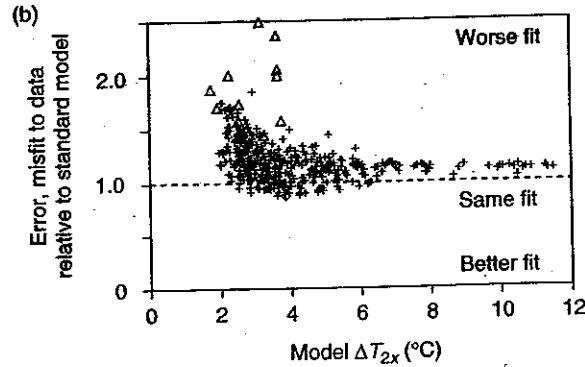
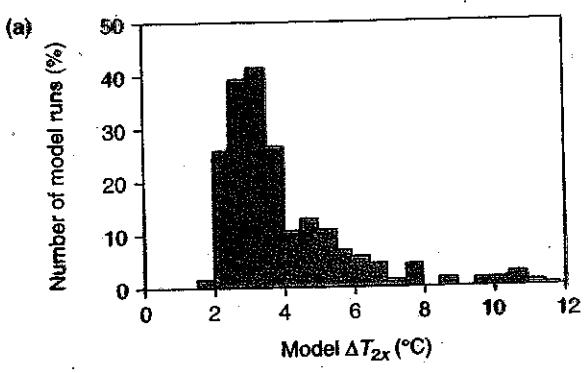
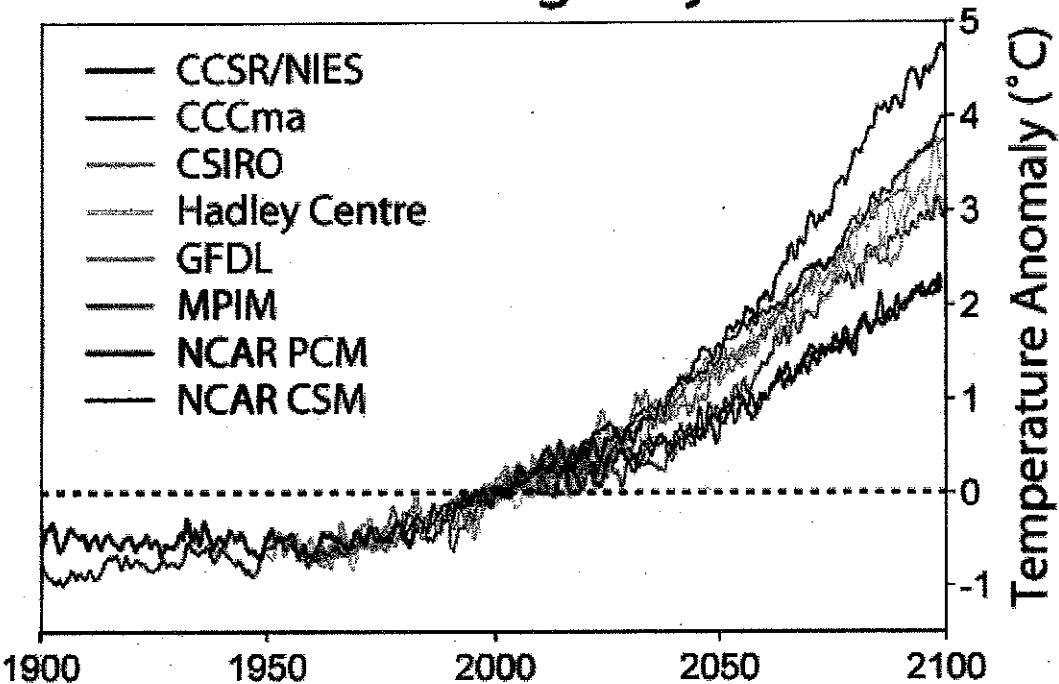


Fig. 12.1 Results from ClimatePrediction.net. (a) Distribution of the climate sensitivity,  $\Delta T_{2x}$ , of different model configurations. (b) Error in predicting the real climate, relative to the error of a hand-tuned model = 1.0.

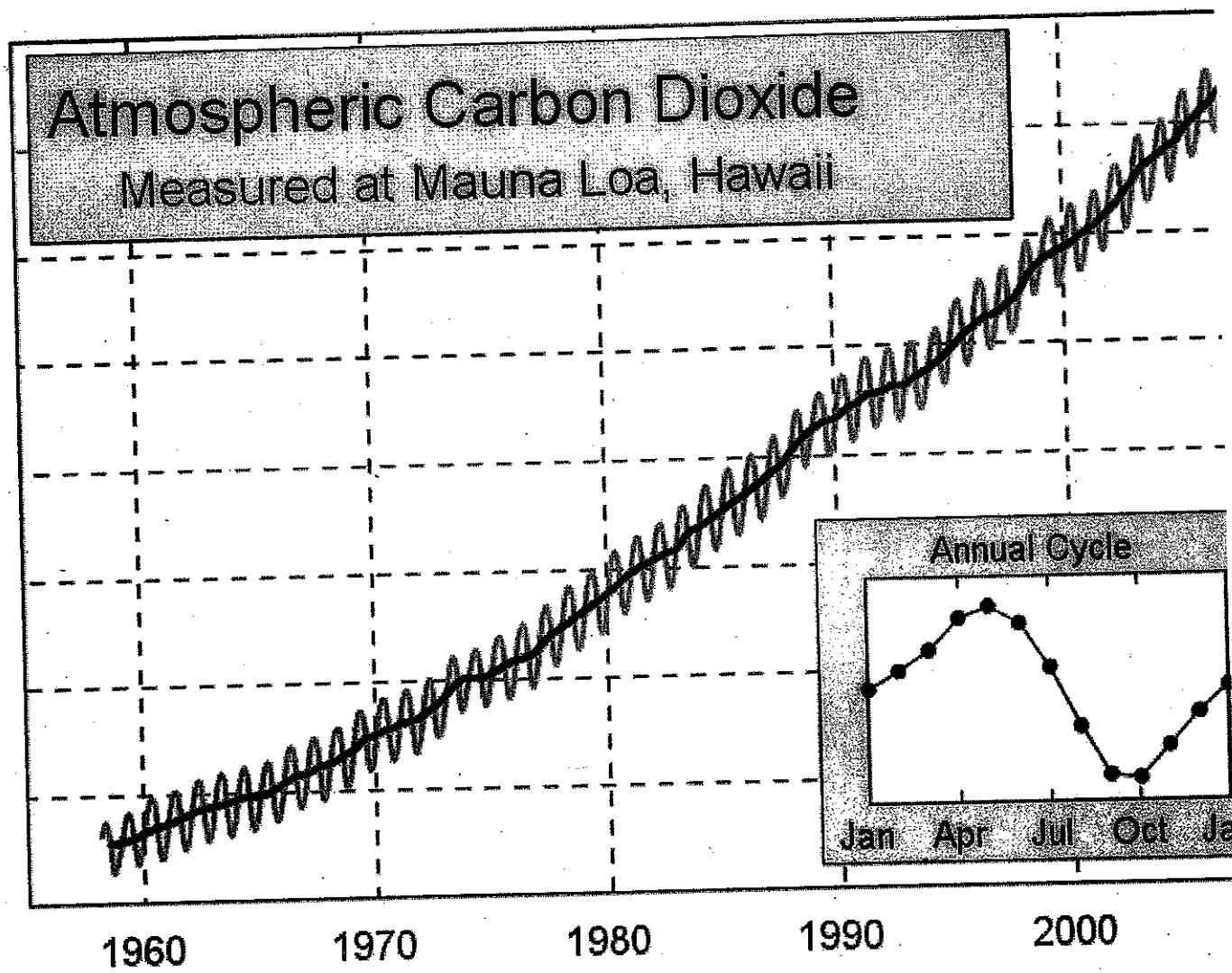
⑥

2.7

Fast Carbon Cycle

Terrestrial organic  $\longleftrightarrow$  atmosphere

Can be seen clearly in Keeling Curve



# Relationships of atm CO<sub>2</sub> + Temperature...

2.1

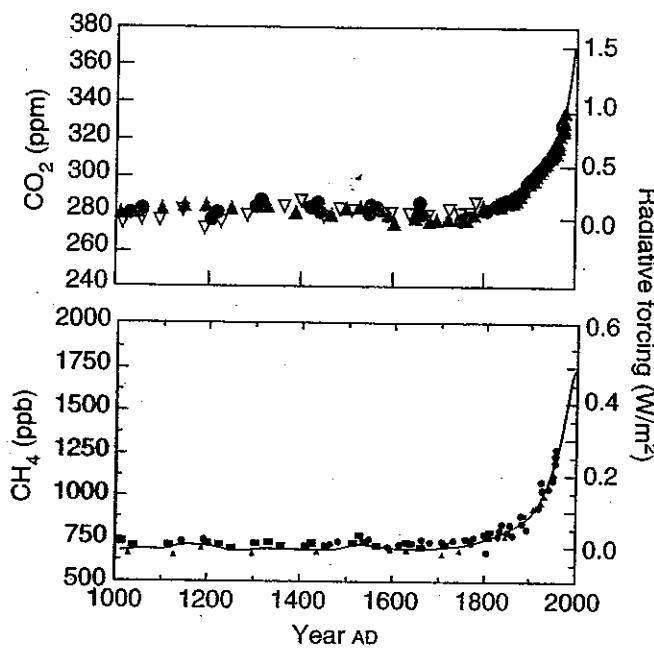
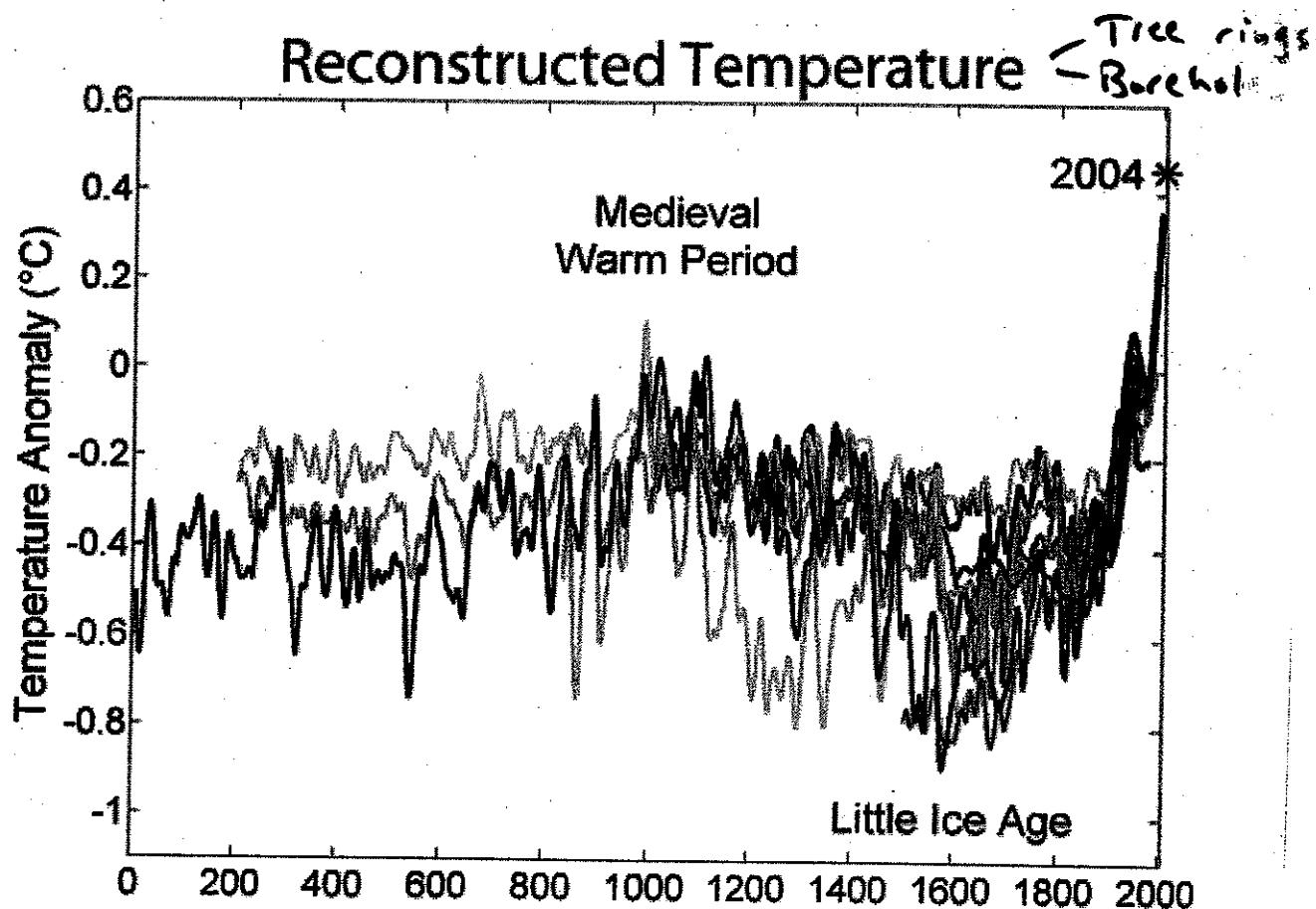


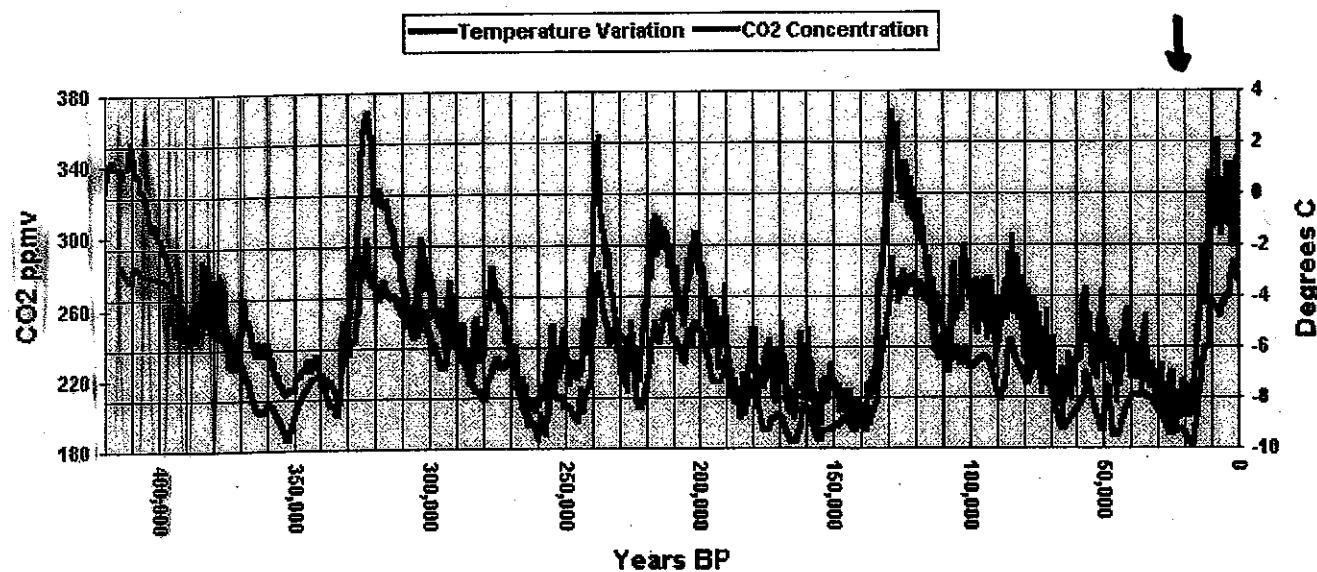
Fig. 10.1 History of CO<sub>2</sub> and CH<sub>4</sub> concentrations in the atmosphere, from ice cores (symbols) and atmospheric measurements (solid lines). Replotted from IPCC (2001).

- note agreement



20K YBP

## Antarctic Ice Core Data

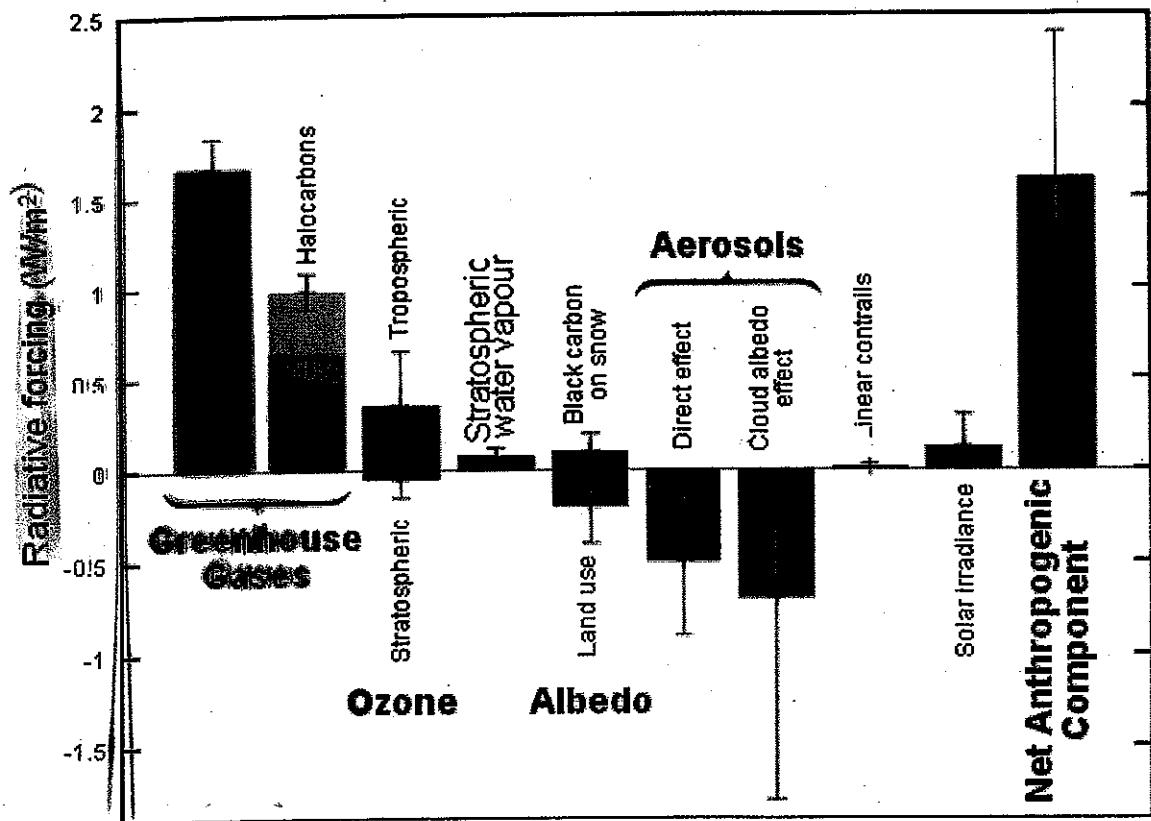


*CO<sub>2</sub> is the 1° driver*

*time-series approach*

*mechanistic approach*

## Radiative Forcing Components

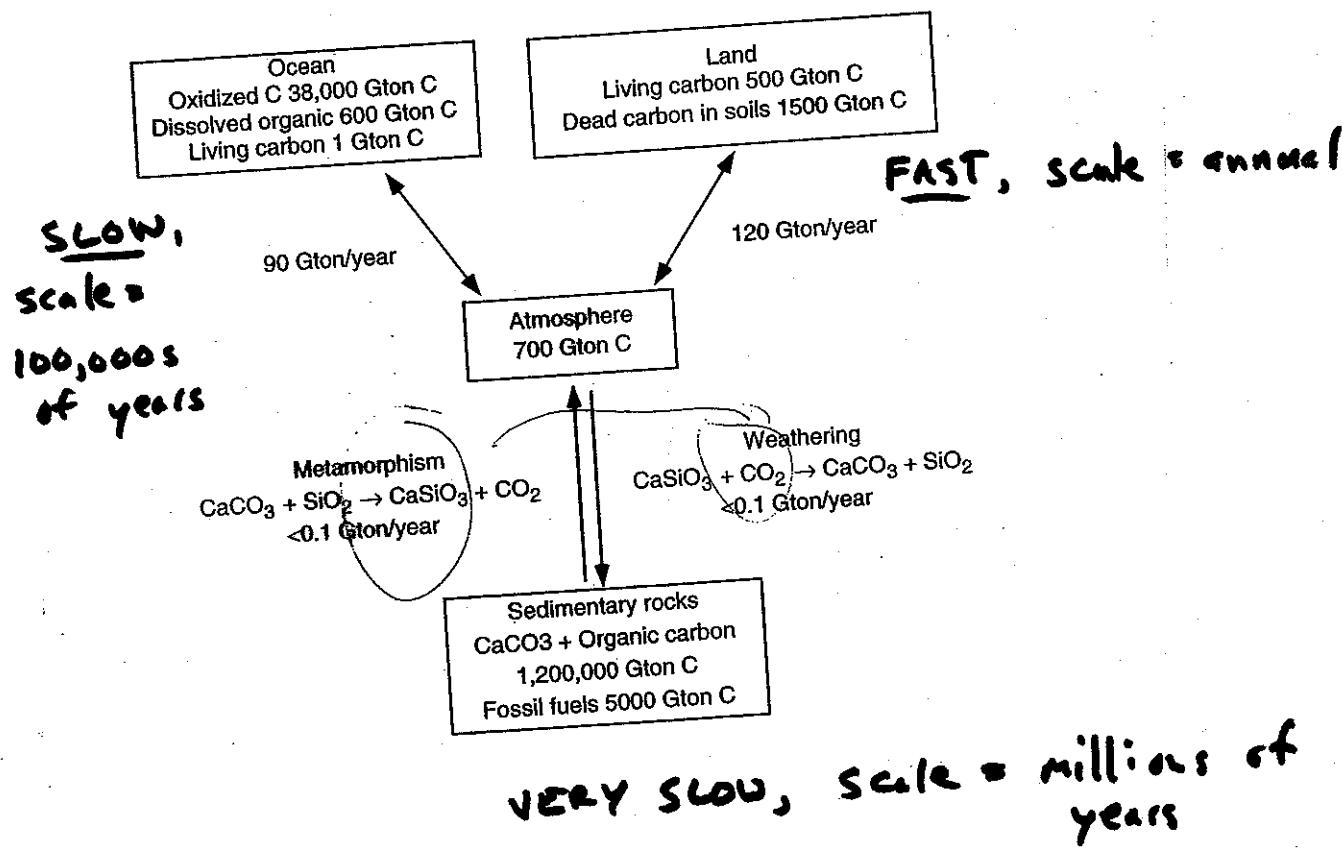


(9)

2.6

# CARBON CYCLES

□ pools  
↔ fluxes



→ Note relative sizes of the CO<sub>2</sub> pools or 'stocks'

→ Anthropogenic fluxes can △ the equilibrium

# Greenhouse gasses

(10)

4.1

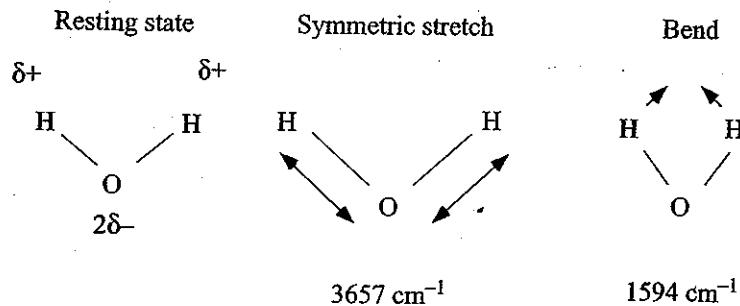


Fig. 4.1 Vibrational modes of a water molecule that interact with IR light in the atmosphere.

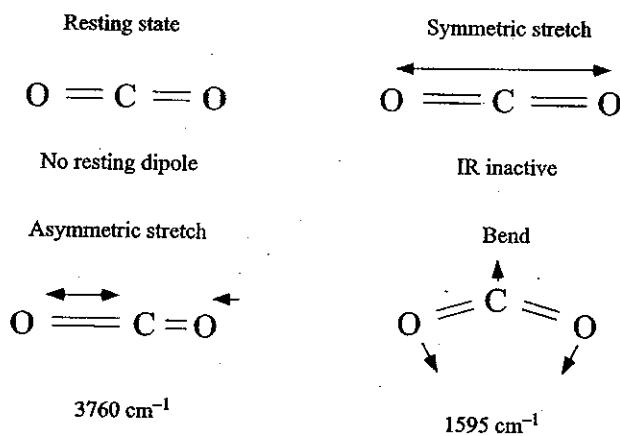


Fig. 4.2 Vibrational modes of a CO<sub>2</sub> molecule that interact with IR light in the atmosphere.

usually  $\geq 2$  bonds  $\rightarrow$  greenhouse

one bond, symmetric  $\rightarrow$  not IR active

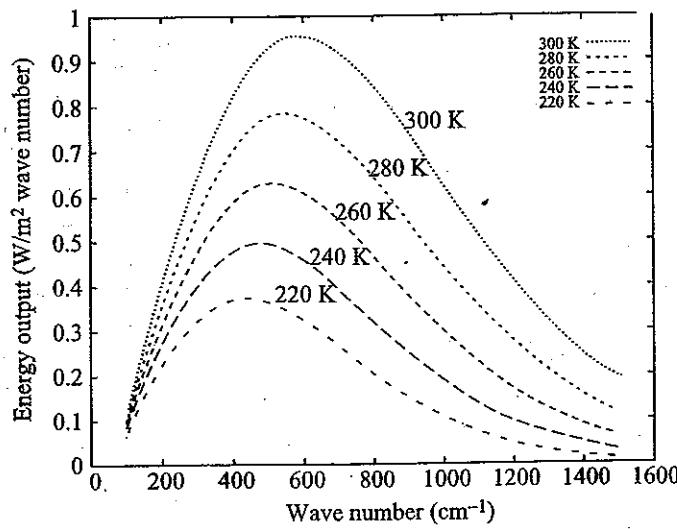
N<sub>2</sub>, O<sub>2</sub>

vs  
N<sub>2</sub>O<sub>3</sub> - Br... - O<sub>2</sub>

# Radiation Spectra

4.2

(11)



Ideal  
Blackbody

Fig. 2.4 The intensity of light emitted from a blackbody as a function of light wave number, for different blackbody objects of different temperatures in kelvins. A warmer object emits more radiation than a cooler one.

Earth's  
Atmosphere

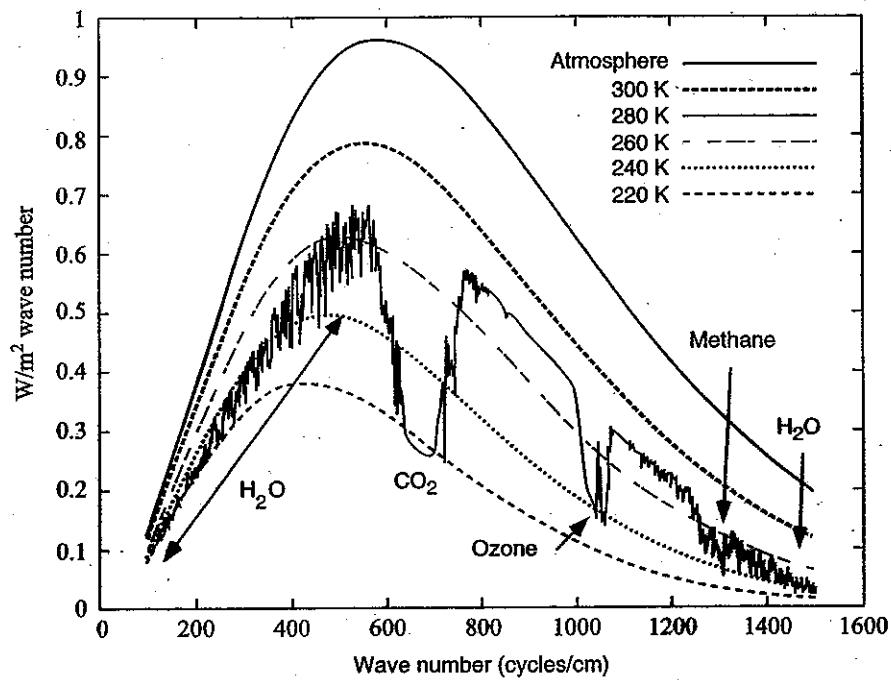


Fig. 4.3 The solid line is a model-generated spectrum of the IR light escaping to space at the top of the atmosphere. For comparison, the broken lines are blackbody spectra at different temperatures. If the Earth had no atmosphere, the outgoing spectrum would look like a blackbody spectrum for 270 K, between the 260 and 280 K spectra shown. The atmospheric window is between about 900 and 1000 cm⁻¹, where no gases absorb or emit IR light. CO₂, water vapor, ozone, and methane absorb IR light emitted from the ground and emit lower-intensity IR from high altitudes where the air is colder than at the surface.

# The greenhouse effect in a nutshell 4.5

(12)

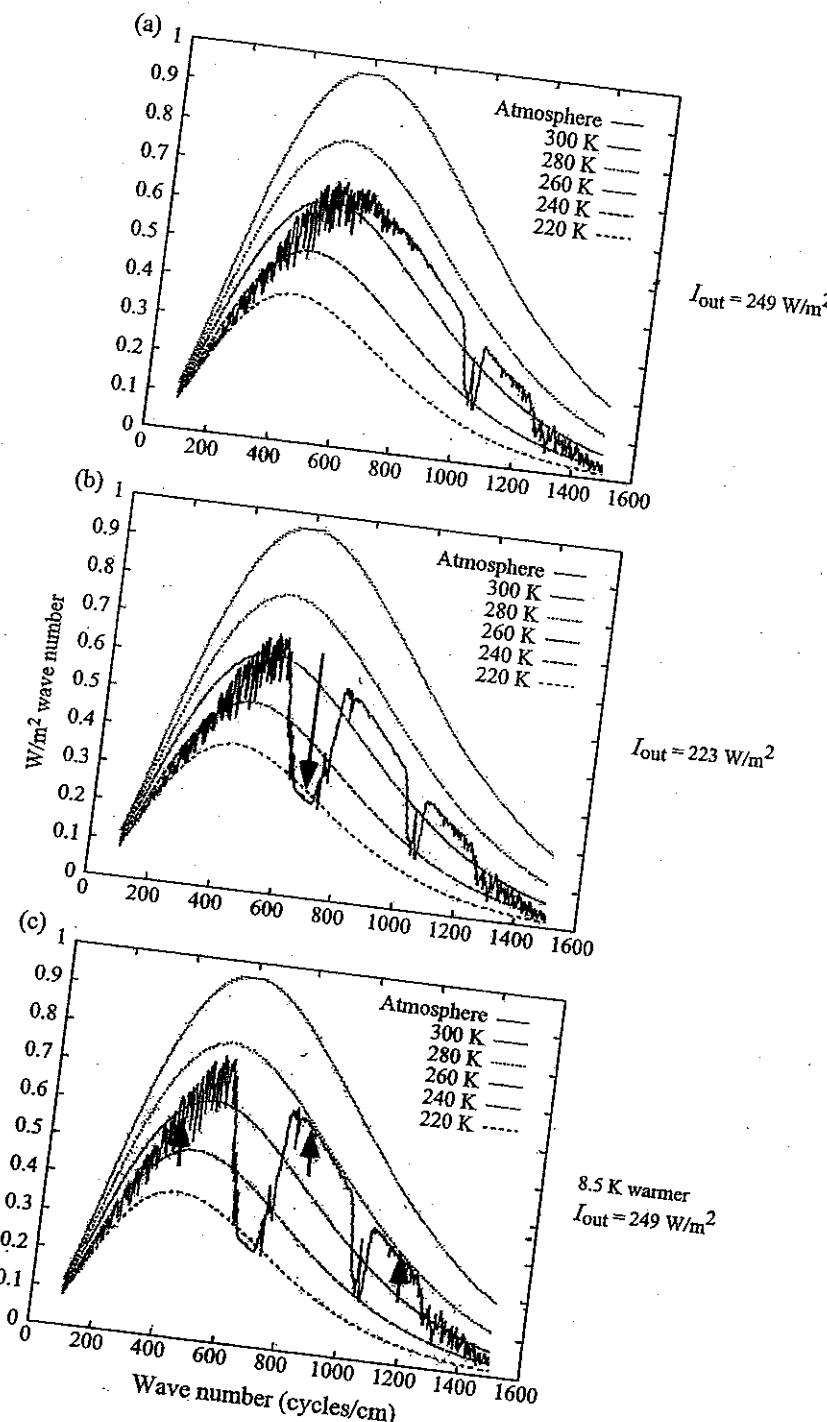


Fig. 4.8 A demonstration of the greenhouse effect of CO<sub>2</sub>. (a) We begin with no CO<sub>2</sub>. Let's assume that the energy budget of the Earth was in balance at a ground temperature of 270 K. In (b) we add 1000 ppm CO<sub>2</sub>, decreasing the outgoing energy flux. (c) The ground and the atmosphere above it respond by warming up to 8.5 K. The total outgoing energy flux is restored to its initial value. The total energy flux is proportional to the area under the curves. CO<sub>2</sub> takes a bite out of (a) to generate (b), but (c) bulks up everywhere to compensate.