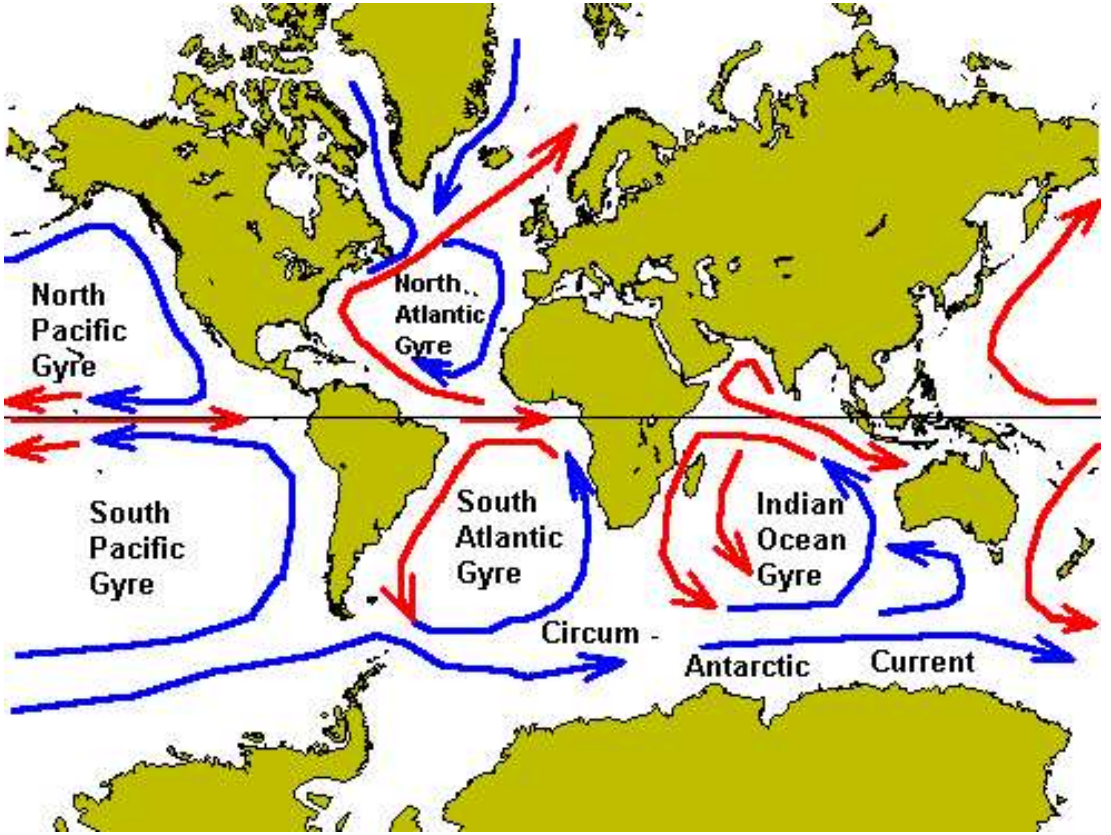
The Science of Climate Change

Last lecture....

- Laws of thermodynamics
  - First: Whenever heat is added to a system, it transforms to an equal amount of some other form of energy
  - Second: Heat never spontaneously flows from a cold substance to a hot substance
  - Third: No system can reach absolute zero
- Many substances expand when heated, so why does rubber contract when heated?

Water: An interesting material

- Water has a high specific heat capacity, i.e. it takes "a lot" of energy to warm water
- This property affects *our climate*



- At what temperature is water most dense?

Let's talk more about our climate

To do this we are going to talk about heat. How does heat flow?

- Conduction
- Convection
- Radiation—no medium required for flow! Electromagnetic *waves*
  - A *wave* refers to any **traveling disturbance**
  - Examples: Rope under tension tugged from one side, surface of water disturbed from natural height
  - Light is an electromagnetic wave

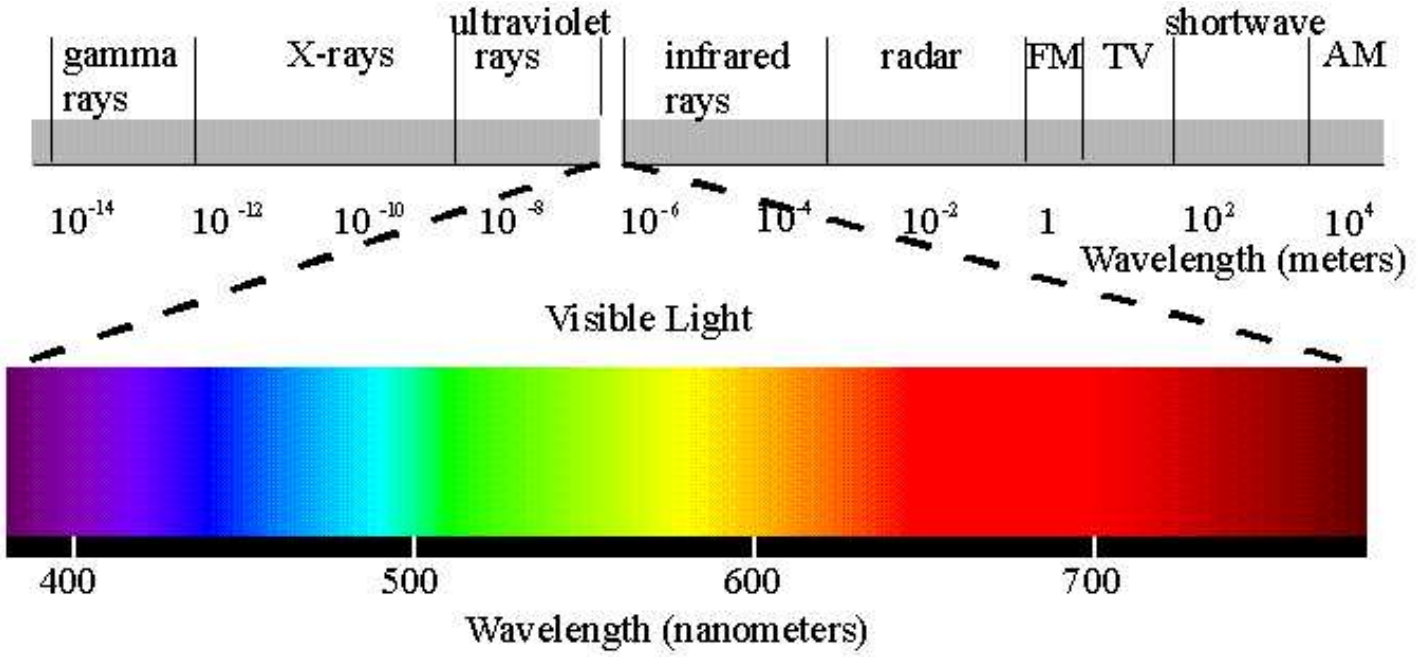
Wavelength and frequency

- When the disturbance is repetitive, one can measure the distance between "crests"—this is the *wavelength*, or λ
- As the disturbance travels, many crests pass by
- The number of crests per sec is the *frequency*, or ν
- The relationship between wavelength and frequency is

$$\lambda\nu = v_{wave} \tag{1}$$

where v_{wave} is the wave speed.

Wavelength of light



When an electromagnetic wave has a wavelength between 0.4×10^{-6} m and 0.7×10^{-6} m, it is visible to our eyes

Solar energy at the Earth

- Energy of fusion makes Sun hot $\rightarrow$ Sun's heat flows out in all directions via *radiation* of light $\rightarrow$ We receive that solar energy via sunlight
- If 1.4 kW of solar power strikes each sun-facing square meter of the Earth, or 1.7×10^{17} W, then why doesn't the Earth keep getting warmer?

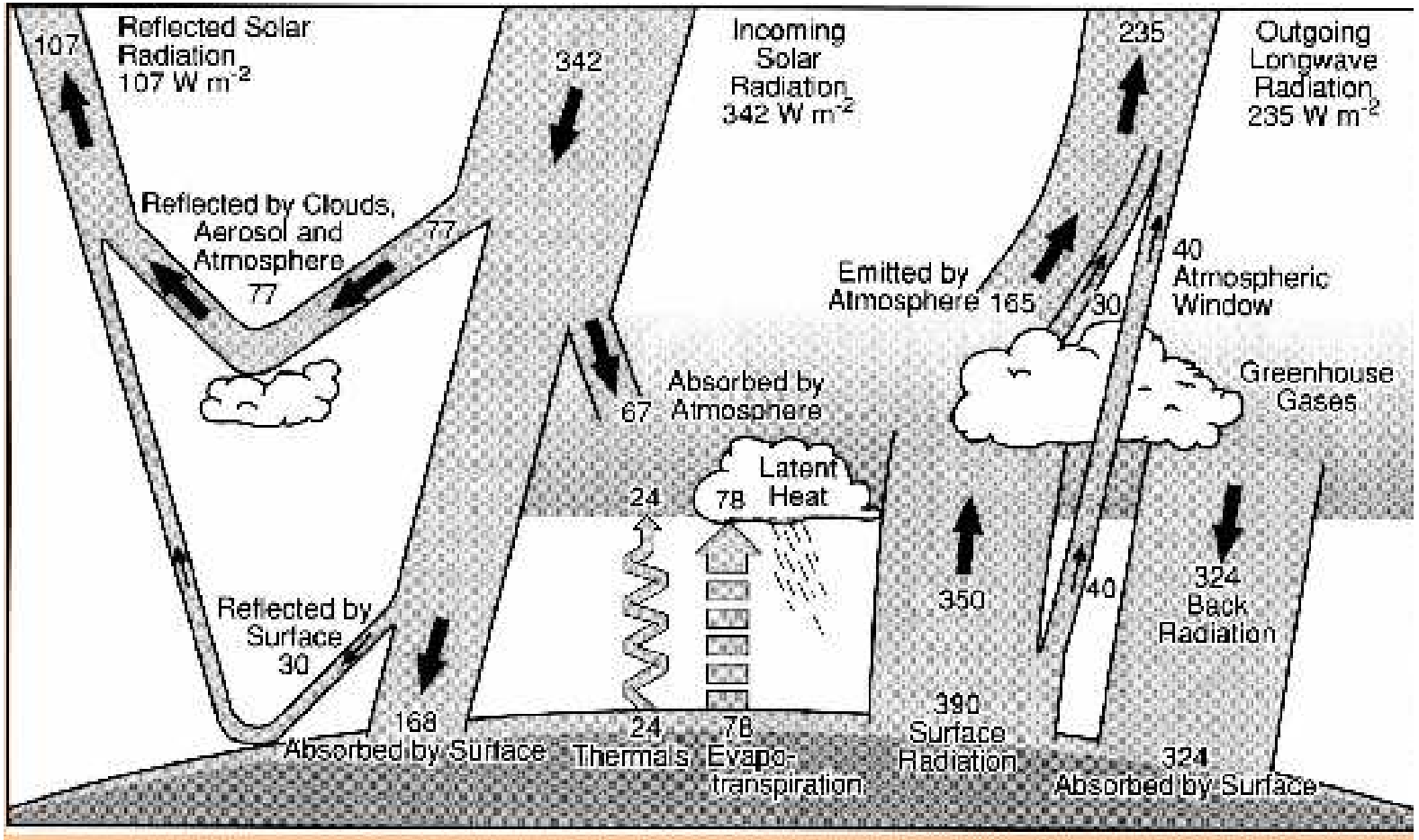
Simple version of energy balance

- Sunlight heats the Earth
- Earth warms up and radiates infrared light
- When Earth has warmed enough:
  Power out as infrared = Power in from sunlight
- PROBLEM: This model predicts that the Earth's surface temp. is -20 degree C! That's cold!

Effect of Earth's atmosphere

- Some materials are transparent to visible light, but opaque to infrared light, like glass, CO_2, water vapor
- Greenhouse—visible light passes through glass walls, warming interior, but interior infrared radiation is trapped, keeping heat in
- Atmosphere has similar effect on the Earth so that the surface temp. is 20 degrees C! Not so cold!

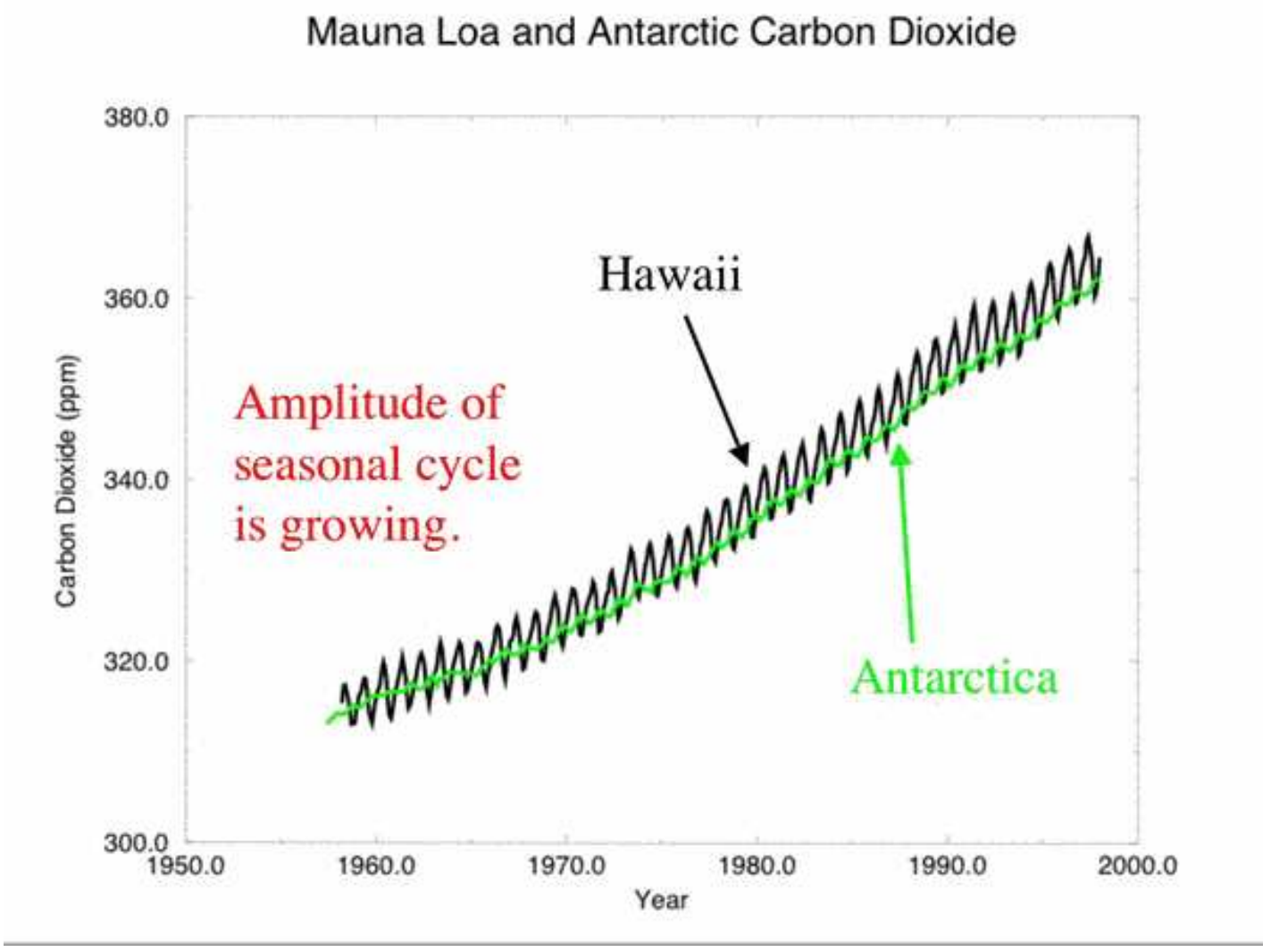
Realistic energy balance



(figure from *Climate Change 1995: The Science of Climate Change*)

BOTTOM LINE: Energy out = Energy in

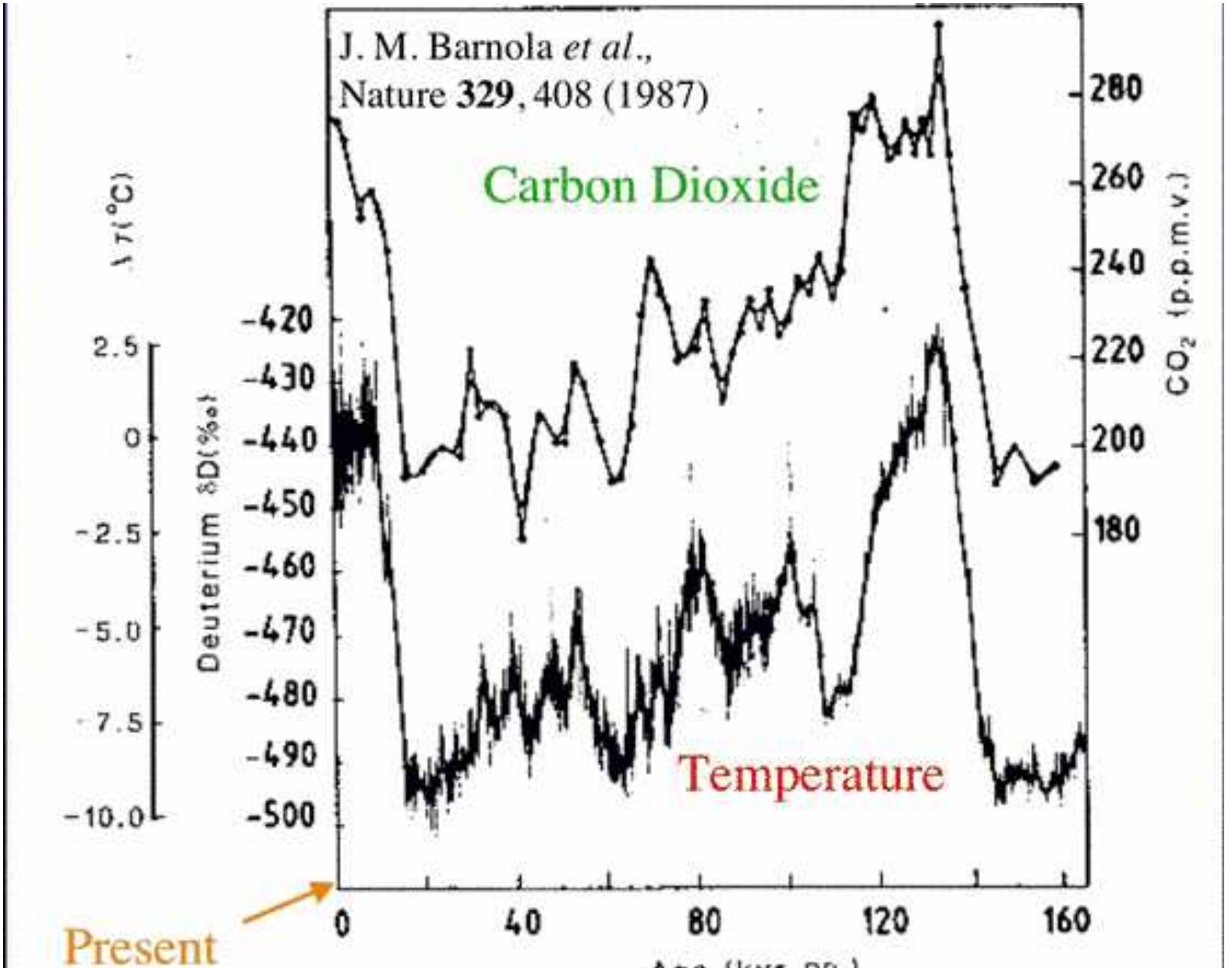
Keeling Plot



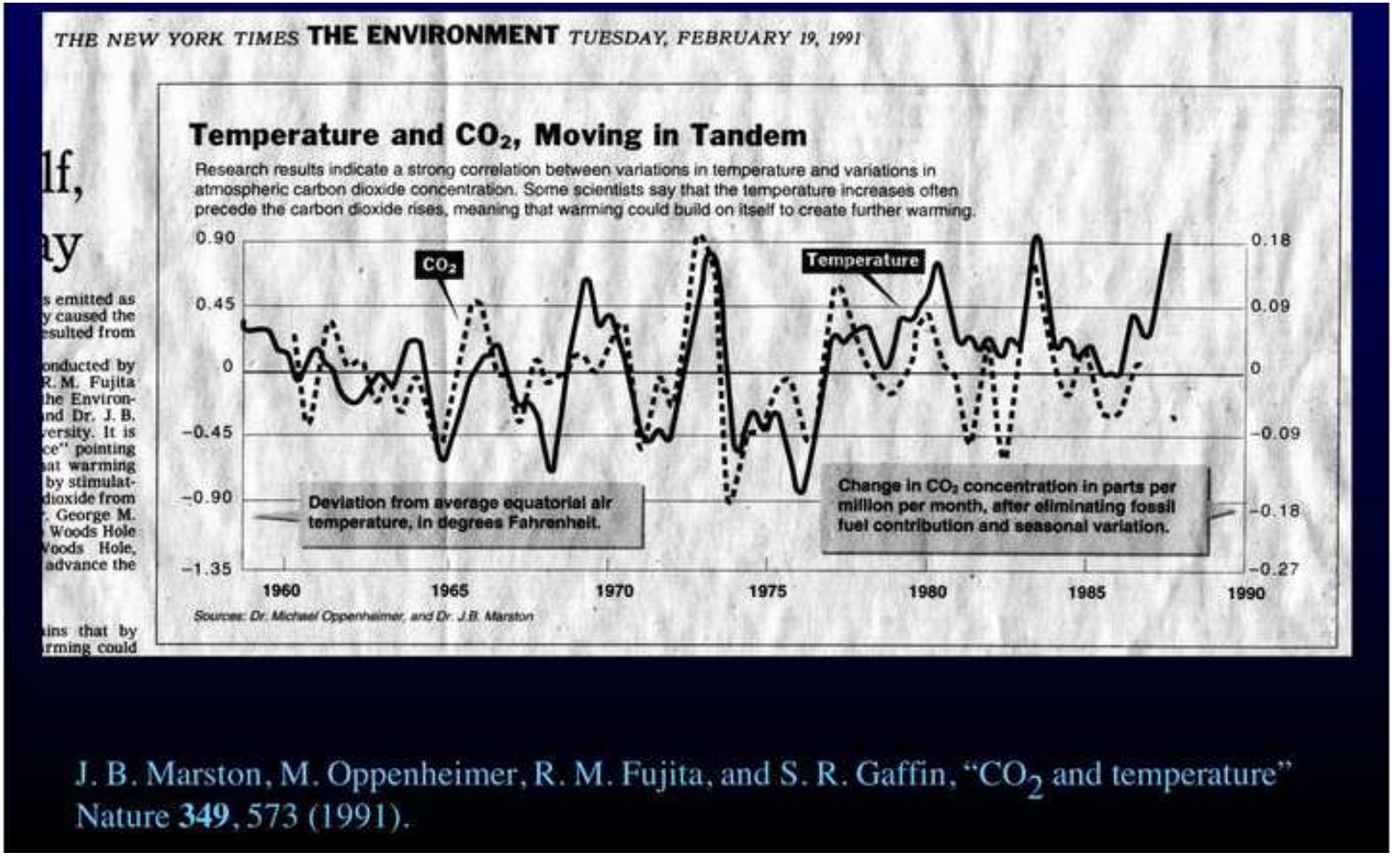
From:

http://online.itp.ucsb.edu/online/colloq/marston2

Keeling Plot/Temperature Plot



Keeling Plot/Temperature Plot



THE NEW YORK TIMES **THE ENVIRONMENT** TUESDAY, FEBRUARY 19, 1991

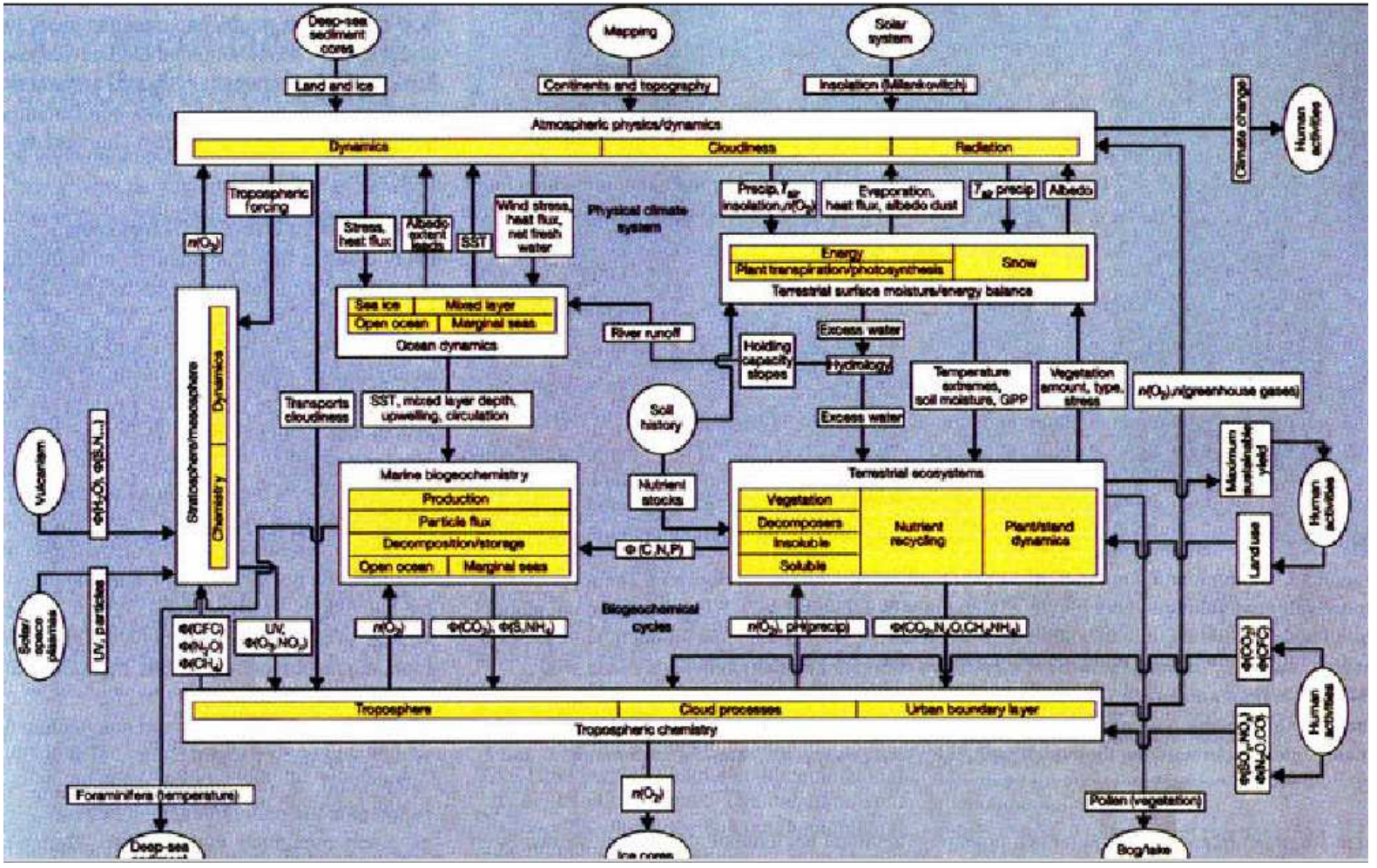
Temperature and CO_2, Moving in Tandem

Research results indicate a strong correlation between variations in temperature and variations in atmospheric carbon dioxide concentration. Some scientists say that the temperature increases often precede the carbon dioxide rises, meaning that warming could build on itself to create further warming.

Sources: Dr. Michael Oppenheimer, and Dr. J.B. Marston

J. B. Marston, M. Oppenheimer, R. M. Fujita, and S. R. Gaffin, "CO_2 and temperature" Nature **349**, 573 (1991).

Can we understand these possible correlations?



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Effects on ecosystem