

^{AV}What Is the Role of Carbon Dioxide in Climate Change during Earth History?*

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Abstract

Three distinct factors can alter the energy balance of the Earth system: (1) changes in the amount or distribution of incoming solar energy, (2) changes in the composition of the Earth's atmosphere influencing energy absorption or reflection, and (3) changes in the Earth's surface, independent of climate, that influence the Earth's albedo or reflectivity. These external factors (external to the climate system - e.g. solar variability, orbital changes, volcanism, plate tectonics, etc) are termed "forcing factors." In addition, the response of the Earth's climate system to external forcing may result in changes to the energy budget - the cooling associated with a decrease in solar energy could result in glaciation (a higher surface reflectivity) and decreased water vapor (a greenhouse gas) content in the atmosphere, thus amplifying the cooling. Such changes are termed "feedbacks." In Earth history, greenhouse gases such as carbon dioxide, have influenced climate both as a forcing factor and as a feedback. Changes in carbon dioxide can be a forcing factor if they involve the balance between inputs from the Earth's interior (volcanism) and continental weathering and burial of organic matter. On other time scales, climate change itself has a significant impact on plant productivity and burial of organic matter that then alters the carbon dioxide content of the atmosphere - a feedback process. The distinction is critical to understand the role of carbon dioxide in climate change. Interestingly, carbon dioxide, either as forcing agent or feedback, appears to have played a dominant role in climate throughout Earth history.

What is the role of carbon dioxide in climate change during Earth history?

Eric J. Barron

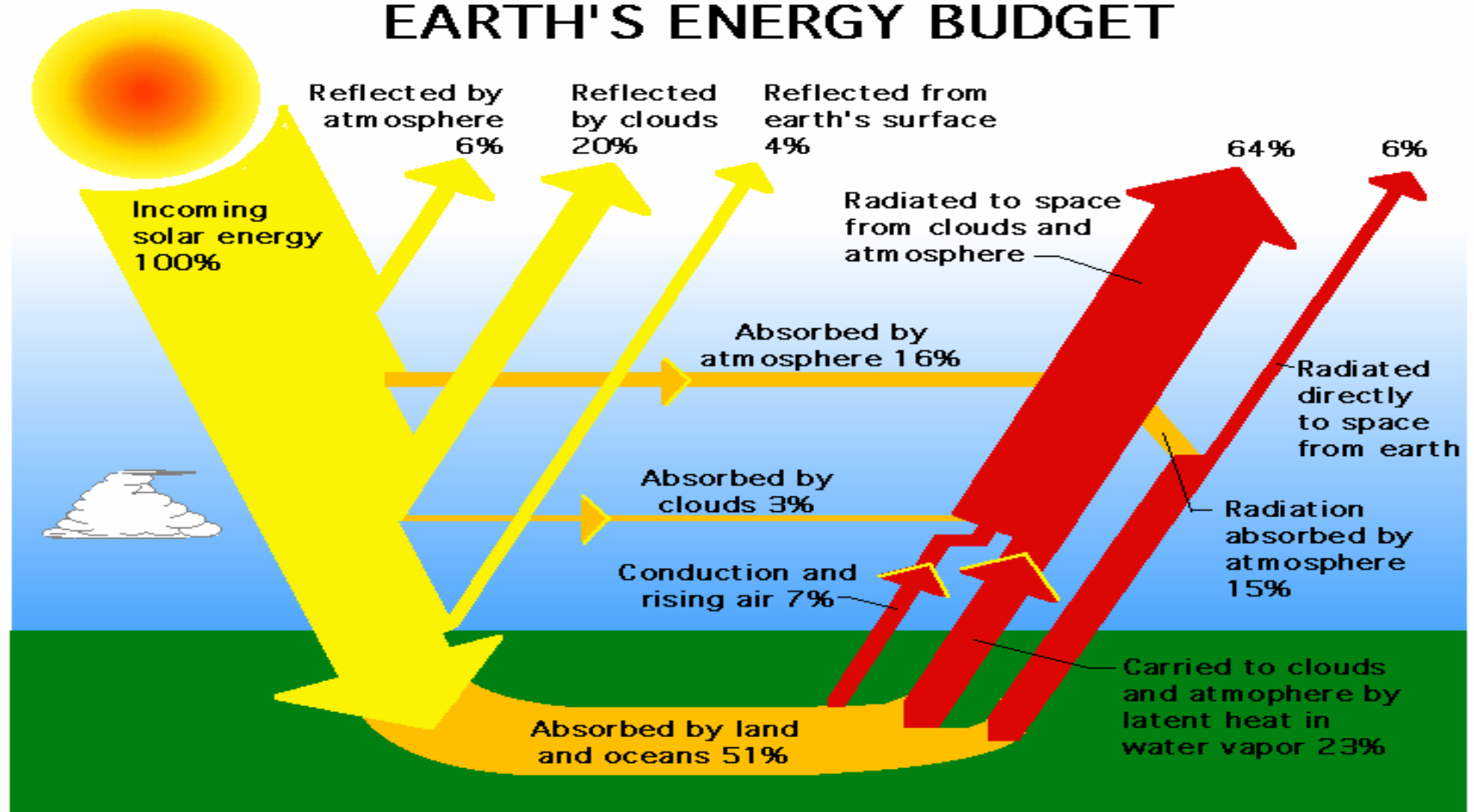
Jackson School of Geosciences

Why ask the question?

- A re-occurring issue – if temperature leads carbon dioxide changes in Earth history (ice age example) does this cause us to rethink the link between current carbon dioxide increases and temperature (the role of humans)?
 - Equally important topic – can we demonstrate that carbon dioxide has been important in past climate change?
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Fundamental Constraint – the balance of energy

EARTH'S ENERGY BUDGET



Three “Players” can alter climate (External Forcing Factors)

- The amount and the distribution of incoming solar energy
 - (stellar evolution on the main sequence; solar variability; Earth’s orbit)
 - The role of the atmosphere in altering the transmission of incoming or outgoing energy
 - (particulates; selective absorbers like CO₂)
 - The role of the Earth’s surface
 - (distribution of the continents; orogeny; sea level – influencing circulation or the albedo)
-

Distinguishing between External Forcing Factors and Responses or Feedbacks

- *Forcing?* Biological innovation that covers the land with plants and alters the energy balance (yes)
 - *Forcing?* redistribution of plants in response to climate that alters the surface energy balance (no)
 - *Forcing?* Injection of massive amounts of carbon dioxide in the formation of flood basalts (yes)
 - *Forcing?* Higher water vapor content in the atmosphere in response to warming (no)
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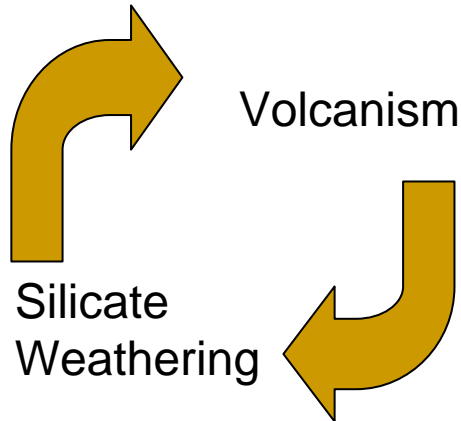
Role of Carbon Dioxide – Forcing or Feedback

- Importance is selective absorption at wavelengths of out-going long wave radiation
 - 13.5- 16.5 μm
 - 4.2 μm
 - 4.4 μm
 - 10.4, 9.4, 5.2, 2.7, 2.0, 1.6, 1.4 μm
 - Weaker bands at 0.78-1.24 μm
-

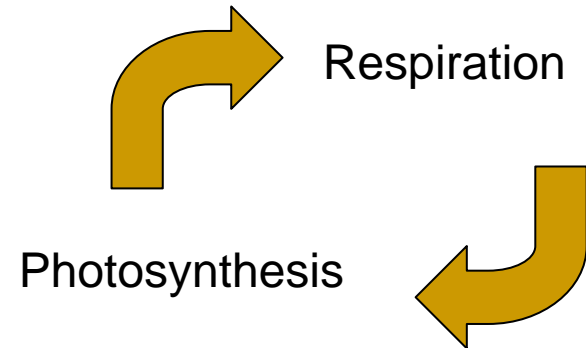
Carbon Dioxide: Forcing or Feedback?

Key is the Carbon Cycle

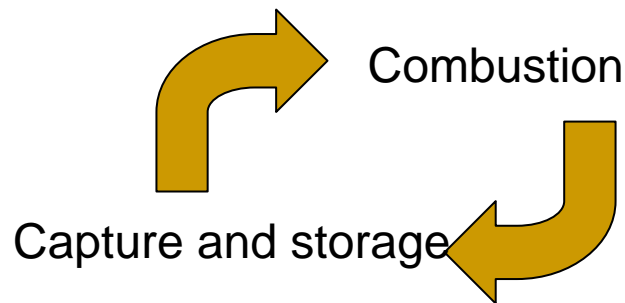
Geological Carbon Cycle



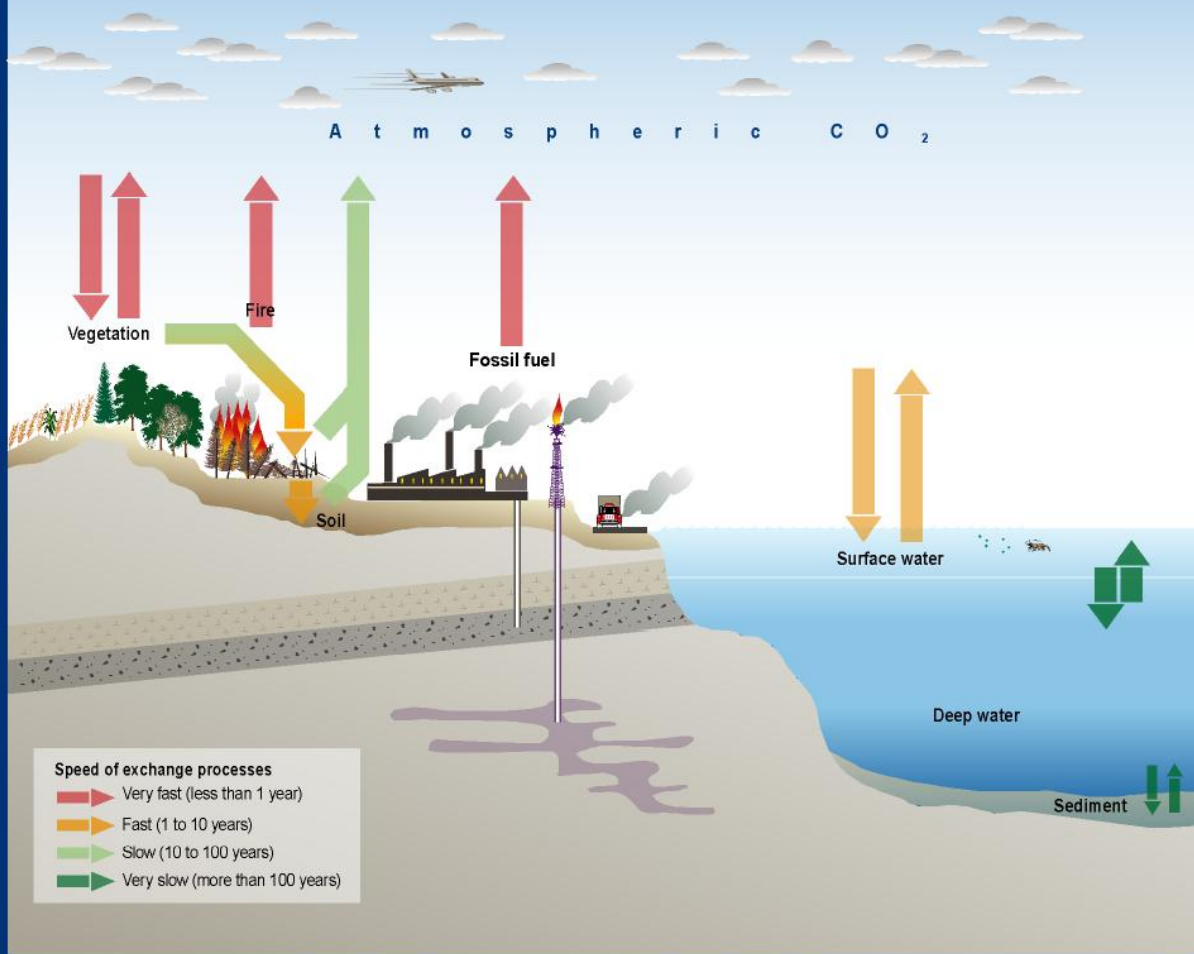
Biological Carbon Cycle



Human Carbon Cycle



Fast and slow processes in the carbon cycle

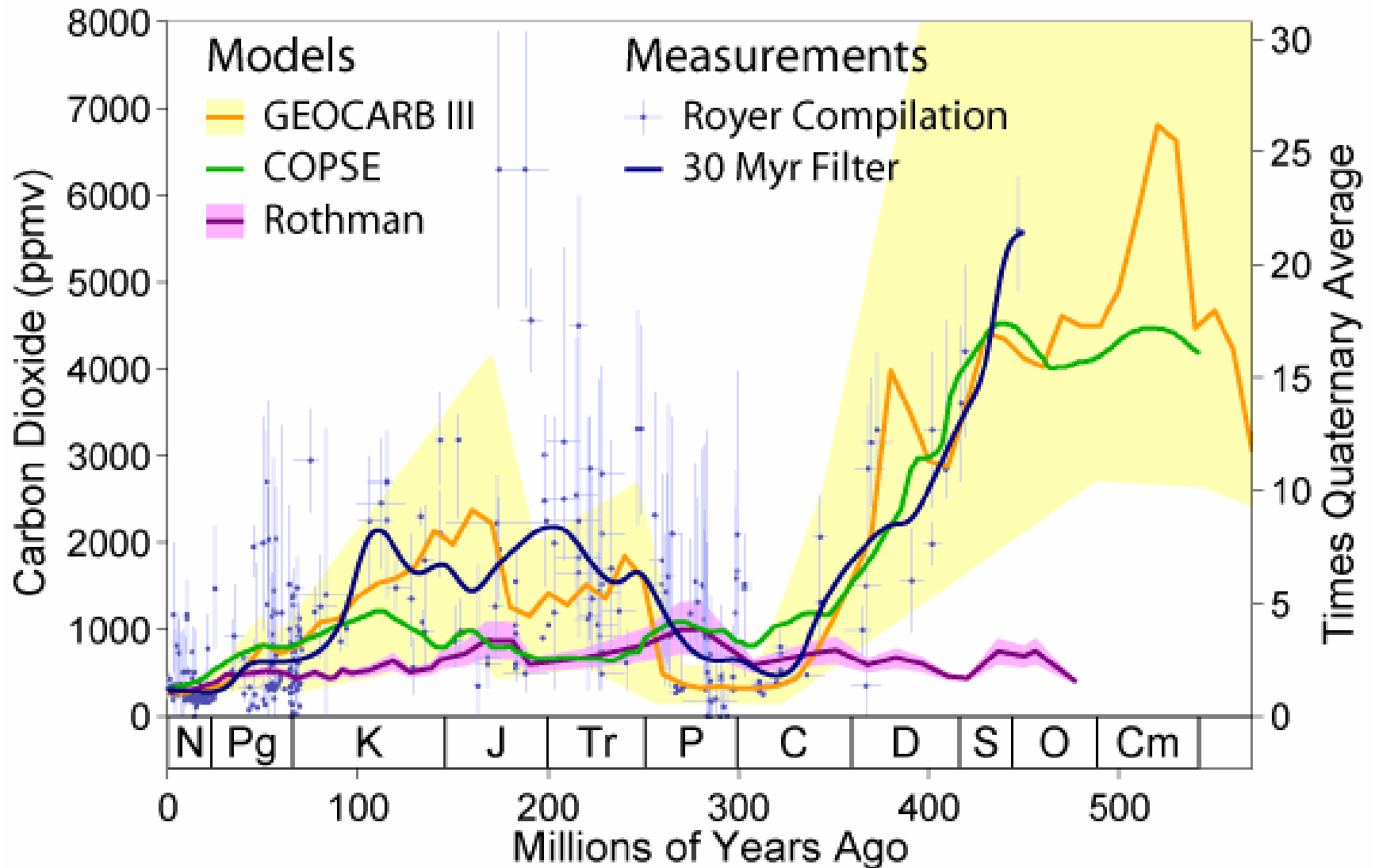


SYR - FIGURE 5-4

I. Carbon Dioxide – Perturbing the Geologic Carbon Cycle (very long time scales)

- Alter the balance of volcanism (carbon dioxide input) and the rates of weathering (carbon dioxide removal) - yields changes in atmospheric levels
 - Rate of sea floor spreading and subduction
 - Sea level – area of continent to weather
 - Topography and/or silicate exposure – rates of weathering
 - Analysis –
 - mass balance models based on weathering assessments (Sr isotopes), volcanism, carbonate deposition, sea level etc.,
 - carbonate character
 - stomatal density
-

Phanerozoic Carbon Dioxide



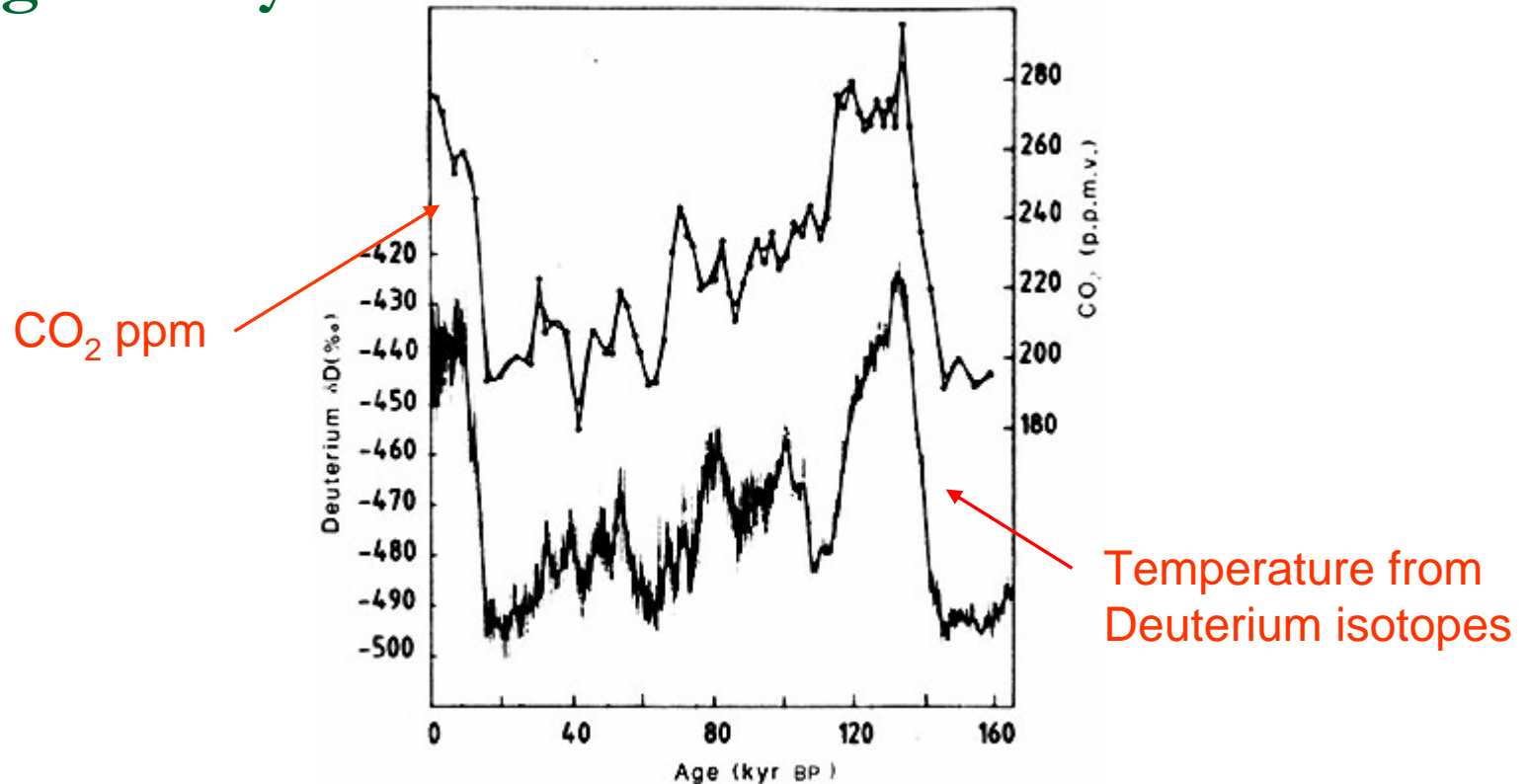
Is Carbon Dioxide the “external” driver for Phanerozoic climate change?

- The amount and the distribution of incoming solar energy
 - Stellar evolution on the main sequence –e.g. Cretaceous about 1% less than today
- The role of the atmosphere in altering the transmission of incoming or outgoing energy
 - Selective absorbers like CO₂
- The nature of the Earth’s surface
 - Distribution of the continents; orogeny, sea level – influencing circulation or the albedo

II. Carbon Dioxide – Intersection of the Geologic and Biologic Carbon Cycle (intermediate time scales)

- Can temperature (ice age) perturb (lead) the carbon balance
 - More ice – lower sea level – sediment flux with nutrients changes ocean productivity and CO₂ draw down
 - More ice – more wind transported dust – more ocean fertilization – greater CO₂ draw down
 - More wind – more intense circulation – greater upwelling (nutrients) – greater productivity and CO₂ draw down
 - Cold temperatures of the ocean – increased gas solubility – deep water carbon dioxide reservoir grows
 - Cold temperatures and more ice – decreased plant and soil reservoir for carbon – atmospheric reservoir source declines
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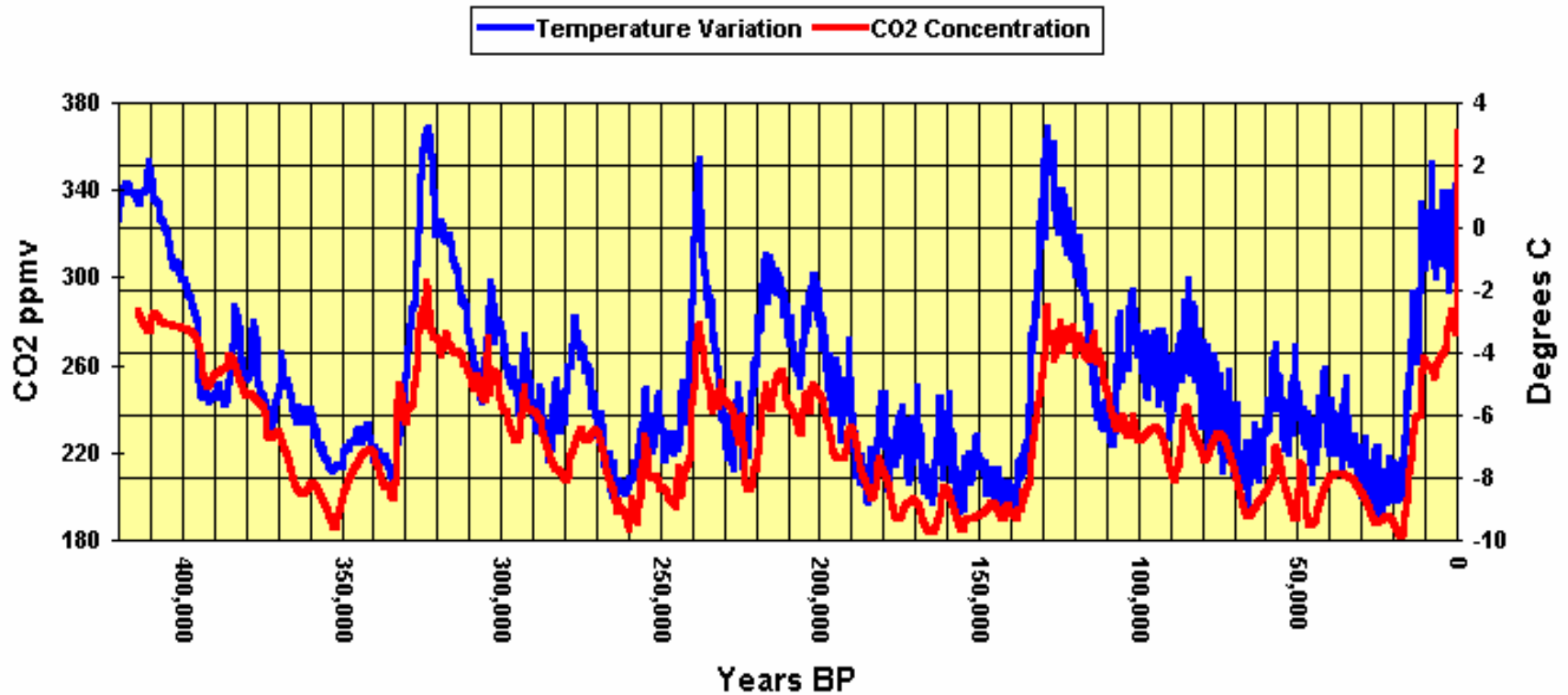
The Vostok core demonstrating the close link between carbon dioxide and temperature through the last glacial cycle.



Barnola et al., 1987, Nature©NPG used with permission

Updated Barnola et al. Ice Record

Antarctic Ice Core Data 1



Is Carbon Dioxide the “external” driver for the Ice Ages?

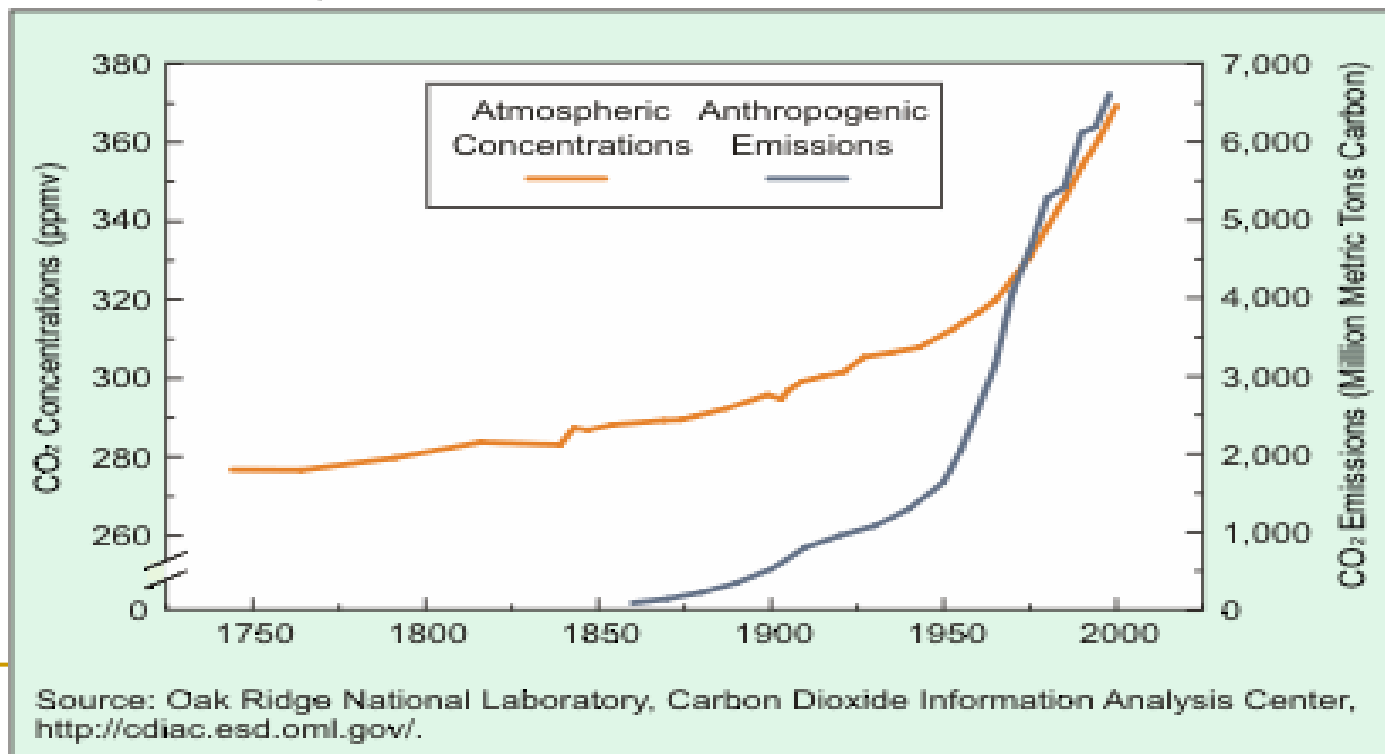
- The amount and the distribution of incoming solar energy
 - Earth's orbit
 - The role of the atmosphere in altering the transmission of incoming or outgoing energy
 - Selective absorbers like CO₂
 - The nature of the Earth's surface
 - Ice distribution, vegetation
-

Carbon Dioxide – So, how significant is the lead or lag with temperature?

- ??? Dating difficulties - it is still unknown whether CO₂ concentration leads or lags temperature during the ice ages (may be different depending on the length of the ice period).
 - There are ample mechanisms by which CO₂ concentration could follow temperature (ice formation changing deep water temperature changing the reservoir for carbon)
 - More strongly, *we expect CO₂ to respond to climate given the right time scales*
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III. Carbon Dioxide – the Human Perturbation (short time scales)

- Human source term that is recognized (and larger than the increase in the atmospheric reservoir)

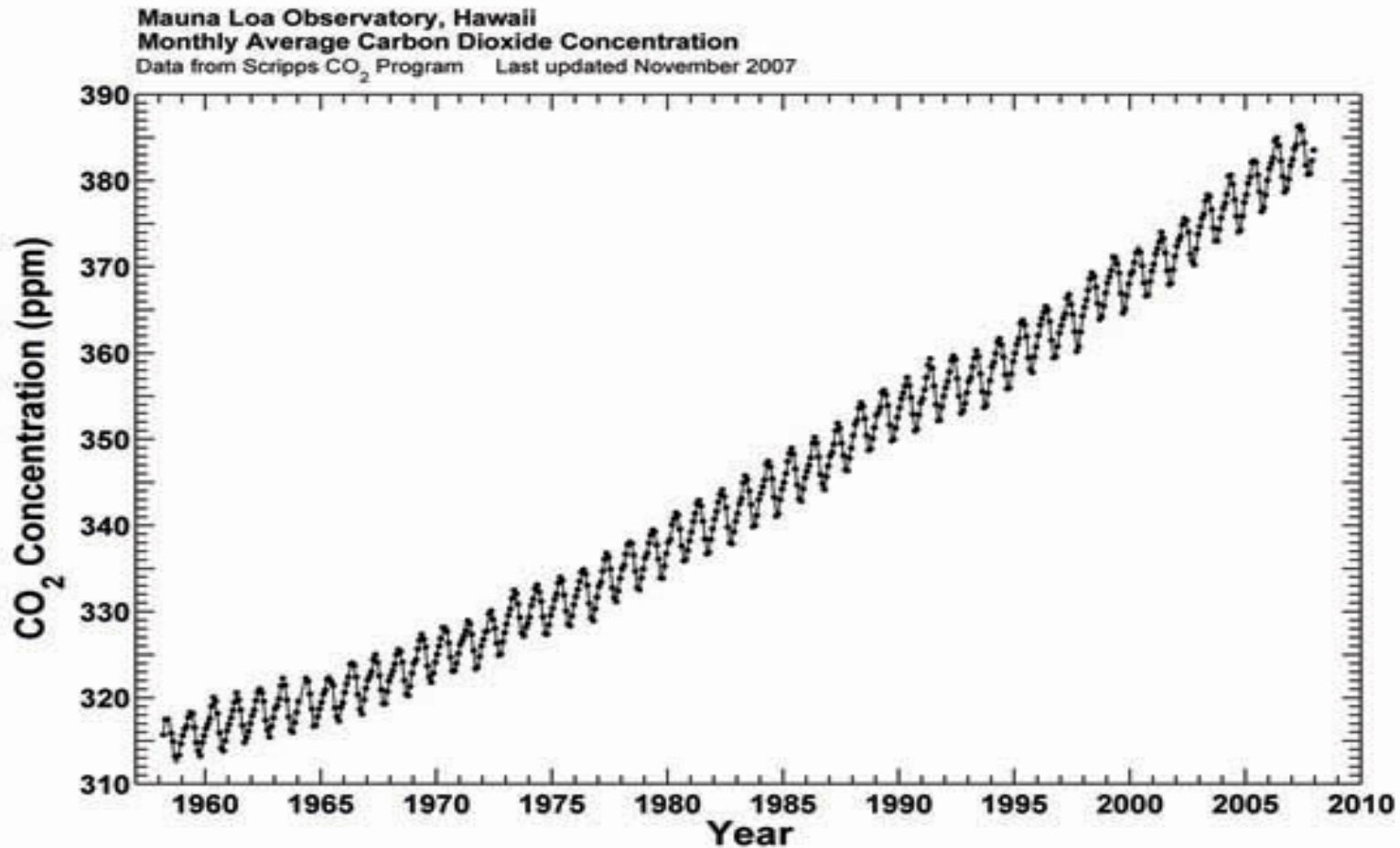


Carbon Dioxide – the Human Perturbation (short time scales)

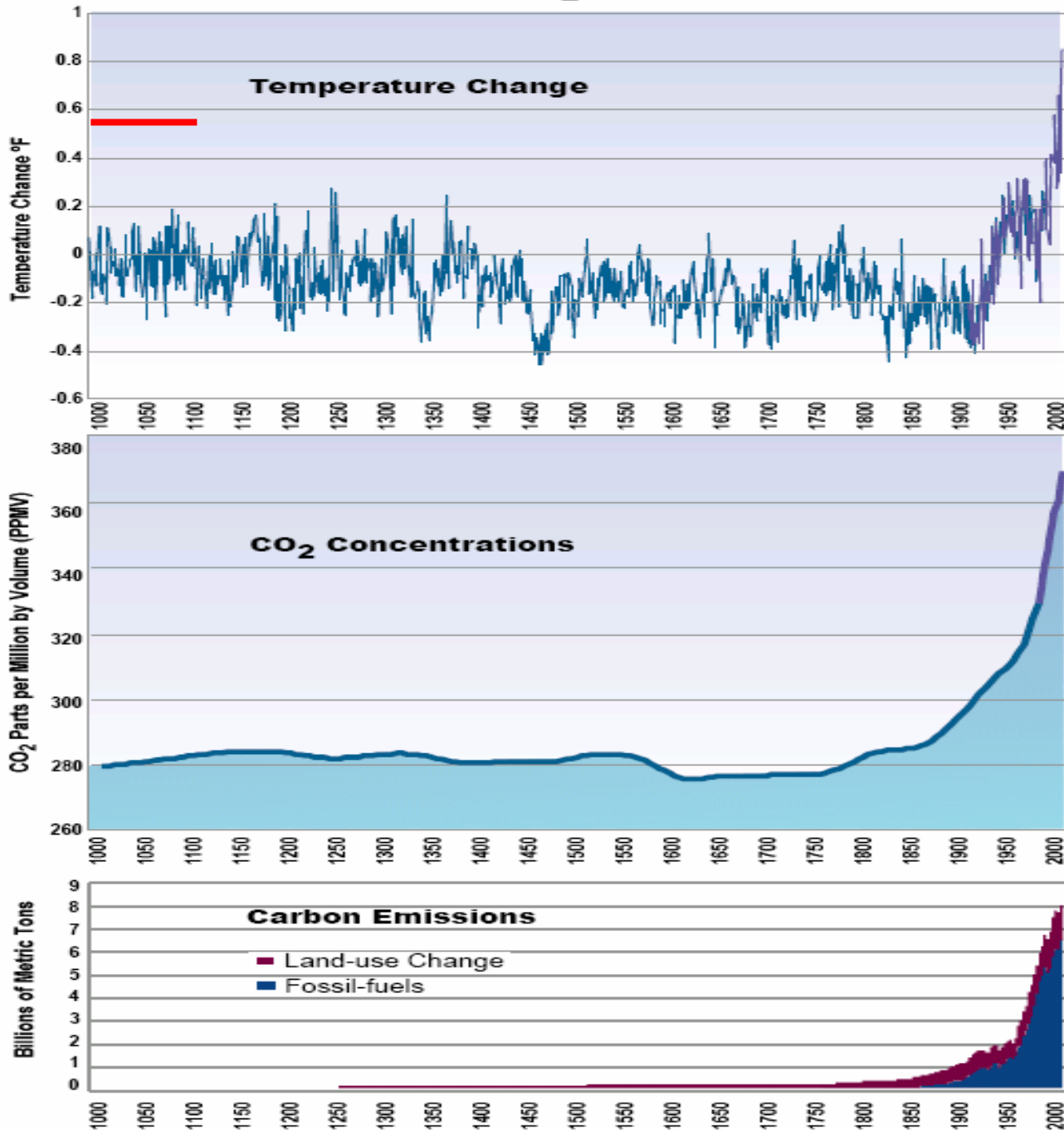
- Inability of the system to compensate fully on the time scales of decades (ocean uptake, biosphere response)
 - Carbon isotopic signature of fossil carbon
-

Level of CO₂ in the atmosphere, 1958-2007

Scripps CO₂ program



1000 Years of Global CO₂ and Temperature Change



Carbon Dioxide as a human-induced forcing factor for the last century

Is Carbon Dioxide the “external” driver for the current warming?

- The amount and the distribution of incoming solar energy
 - Solar variability
 - The role of the atmosphere in altering the transmission of incoming or outgoing energy
 - Particulates; selective absorbers like CO₂
 - The nature of the Earth’s surface
 - Future changes
-

Returning to the question?

- A re-occurring issue – if temperature leads carbon dioxide changes in Earth history (ice age example) does this cause us to rethink the link between current carbon dioxide increases and temperature (the role of humans)?

No, actually it would be a surprise if carbon dioxide had a simple relationship to temperature, especially on different time scales

- Equally important topic – can we demonstrate that carbon dioxide has been important in past climate change?

Yes, in fact, perhaps involved as forcing or feedback in every climate change

References

- Barnola, J.M., D. Raynaud, Y.S. Korotkevitch, C. Lorius, 1987, Vostok ice core provides 160,000 y record of atmosphere CO₂: Nature, v. 329, p. 408-414.
 - Intergovernmental Panel on Climate Change (IPCC), 2001, Climate change 2001; Synthesis report of the IPCC third assessment report: p. 184.
 - Rohde, R.A., Phanerozoic carbon dioxide chart, http://www.globalwarmingart.com/wiki/Image:Phanerozoic_Carbon_Dioxide_png.
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