[AV]Climate Sensitivity during the Phanerozoic: Lessons for the Future*

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Abstract

Understanding the link between the level of atmospheric CO_2 and global surface temperature is profoundly important. Almost all estimates of climate sensitivity (typically defined as the warming caused by a CO_2 doubling) have come from studying records spanning the last ~20 kyr Most of these studies find a modal climate sensitivity of ~3 °C, with a long probability tail at the high end. These studies have been vital for informing climate change issues, but a limitation is that they are calibrated to a present-day or cooler-than-present-day Earth; investigation of deep-time records (older than 2 Myr ago) are required to understand the dynamics of a globally warm Earth.

Ancient levels of CO_2 can be estimated from long-term carbon cycle models, which quantitatively track the major sources and sinks of atmospheric CO_2 over these timescales, or by proxy indicators. A synthesis of CO_2 estimates from carbon cycle models and from proxies shows a strong, first-order fit between CO_2 and geologic indicators of temperature: continental ice sheets are common when CO_2 drops below 500 ppm and absent when CO_2 exceeds 1000 ppm.

One parameter in most long-term carbon cycle models is climate sensitivity because the weathering of Ca and Mg-rich silicate rocks, which serves as a long-term sink for CO_2, is sensitive to temperature. Thus, it is possible to estimate long-term climate sensitivity by adjusting the climate sensitivity parameter in the long-term carbon cycle models until the model estimates of CO_2 best match the independent proxy estimates of CO_2. Over the past 420 Myr, the modal climate sensitivity is ~3 °C; a sensitivity of < 1.5 °C is highly improbable, while sensitivities of 6+ °C cannot be excluded. Deep-time climate sensitivity thus matches the present-day, despite the two approaches capturing fundamentally different carbon cycle processes; a climate sensitivity of around 3 °C appears to be a robust feature of the Earth system, independent of temporal scaling. The geologic record generally supports a positive link between CO_2 and temperature, and we should expect a climate sensitivity of 3 °C or more in the near future.

References

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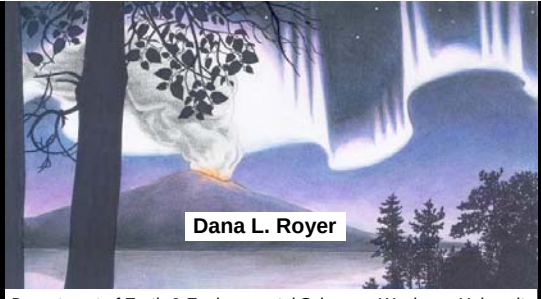
Climate sensitivity during the Phanerozoic: lessons for the future



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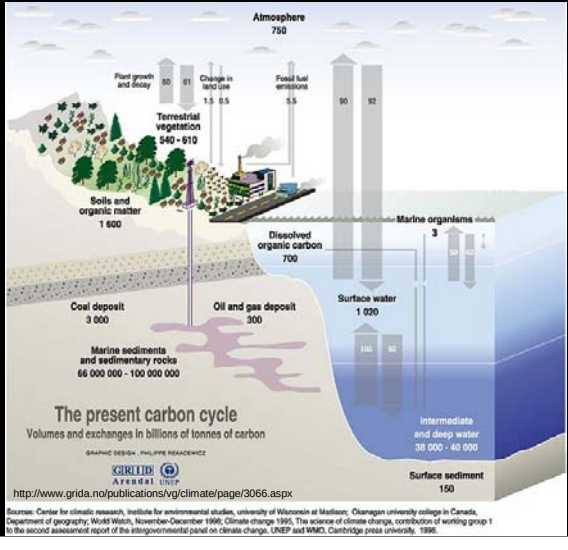
Artwork: Rebecca Horwitt

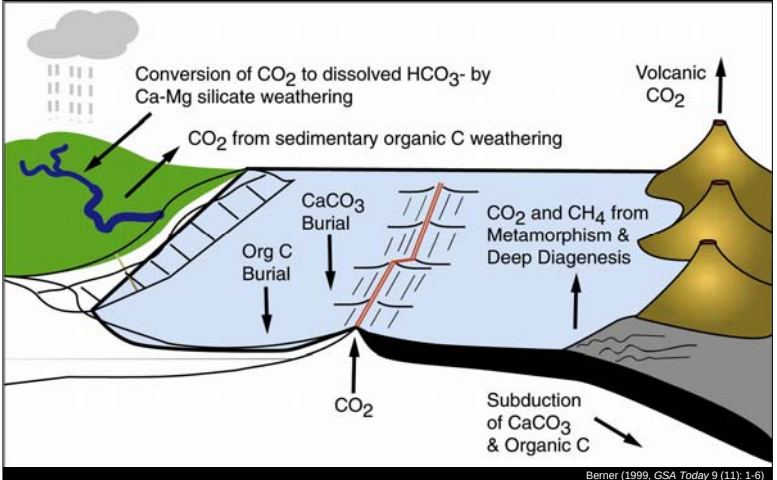
Short-term carbon cycle (<10,000 yr)



http://www.grida.no/publications/vg/climate/page/3066.aspx

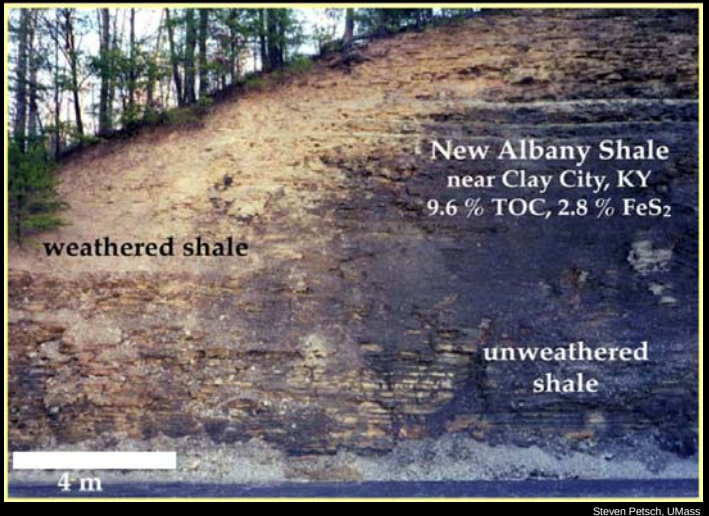
Sources: Center for climatic research, institute for environmental studies, university of Wisconsin at Madison; Okanagan university college in Canada, Department of geography; World Watch, November-December 1998; Climate change 1995, The science of climate change, contribution of working group 1 to the second assessment report of the intergovernmental panel on climate change. UNEP and WMO, Cambridge press university. 1996.

Long-term carbon cycle (>100,000 yr)



Berner (1999, *GSA Today* 9 (11): 1-6)

Weathering of organic carbon



Steven Petsch, UMass

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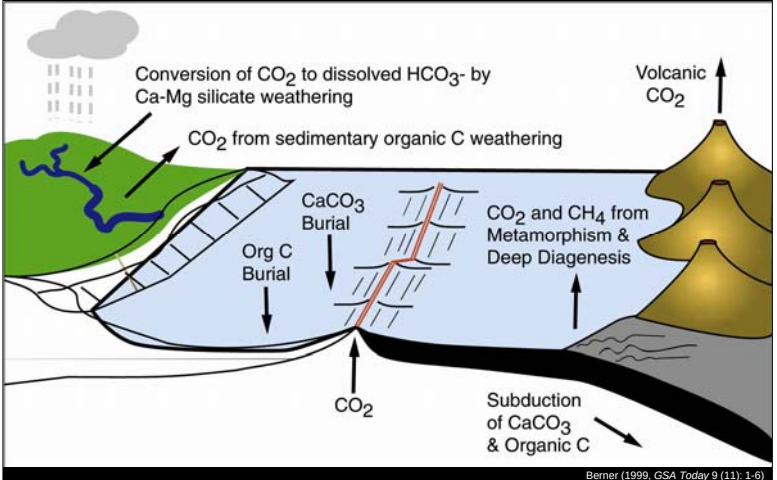
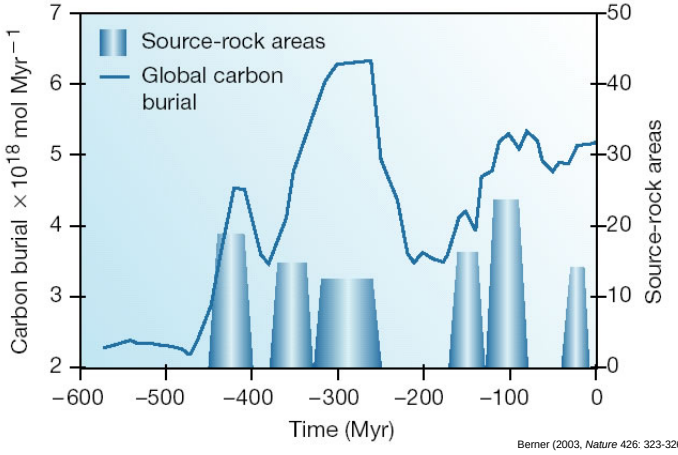


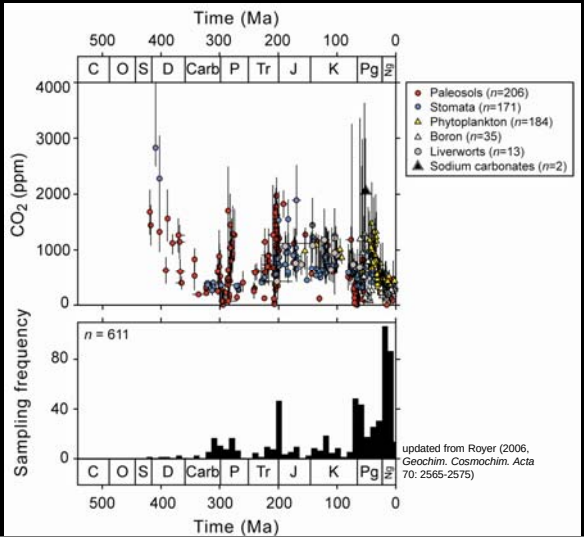
Berner (1999, *GSA Today* 9 (11): 1-6)

Burial of organic carbon



Berner (2003, *Nature* 426: 323-326)

Phanerozoic record of CO_2



updated from Royer (2006, *Geochim. Cosmochim. Acta* 70: 2565-2575)

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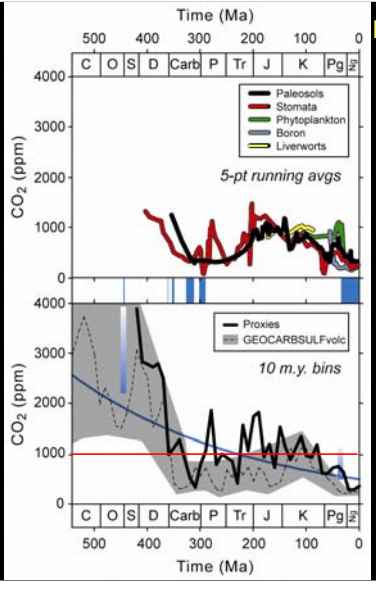

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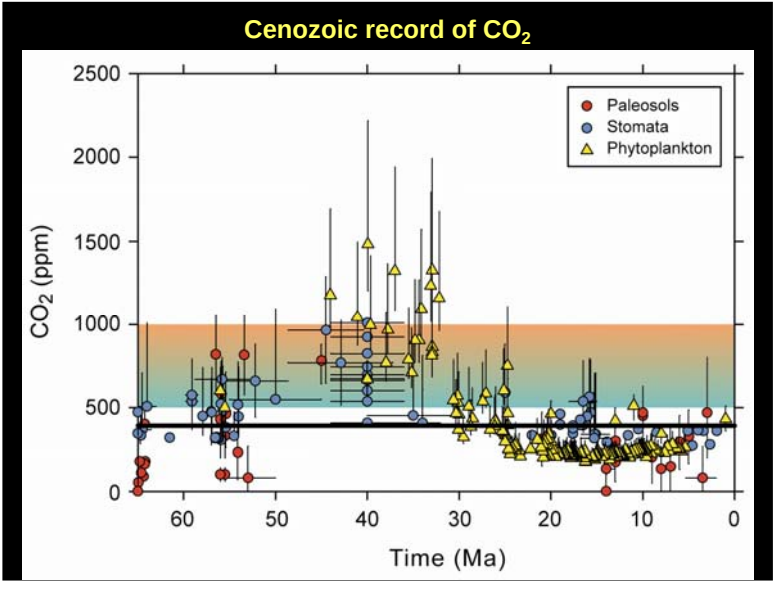
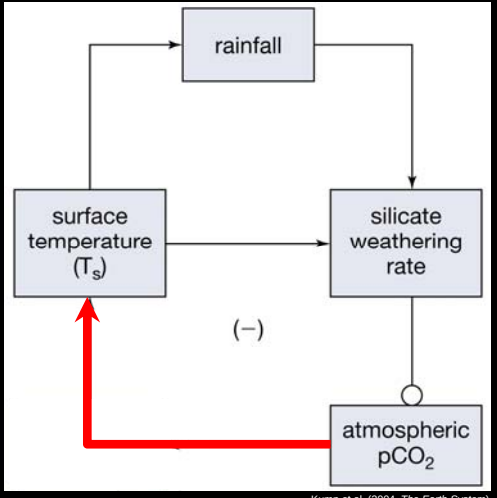
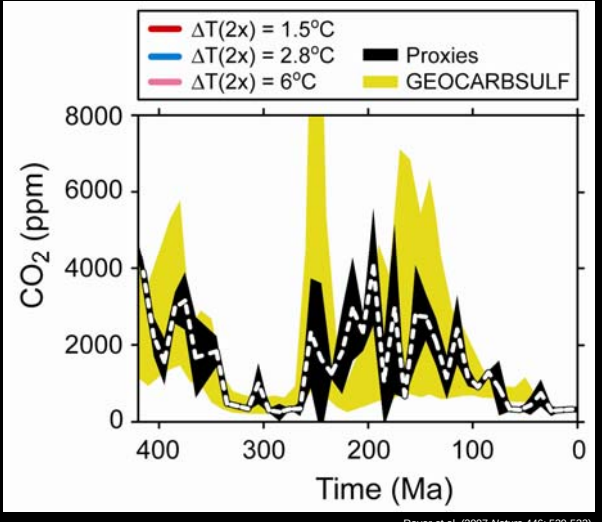

Cenozoic record of CO_2
Paleosols
Stomata
Phytoplankton
CO_2 (ppm)
2500
2000
1500
1000
500
0
60
50
40
30
20
10
0
Time (Ma)

Silicate weathering negative feedback loop



Kump et al. (2004, *The Earth System*)

Geologic constraints on climate sensitivity



Royer et al. (2007 *Nature* 446: 530-532)

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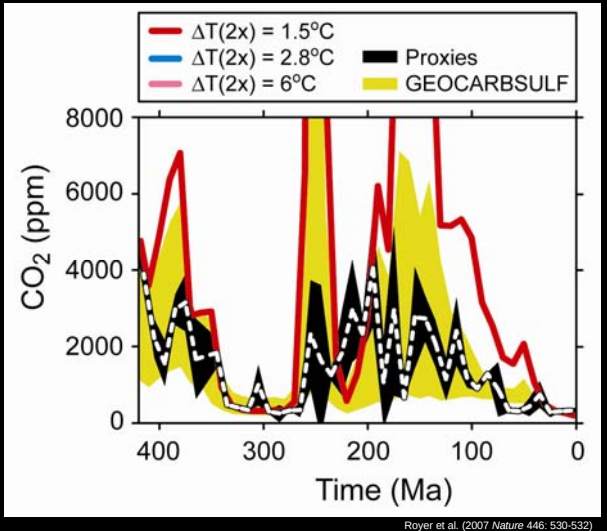

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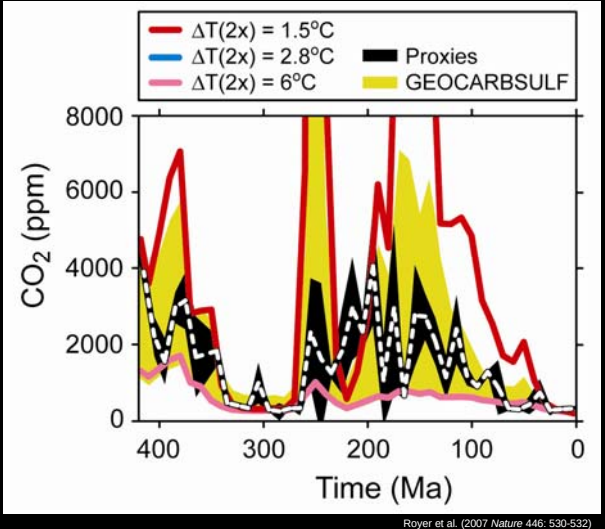

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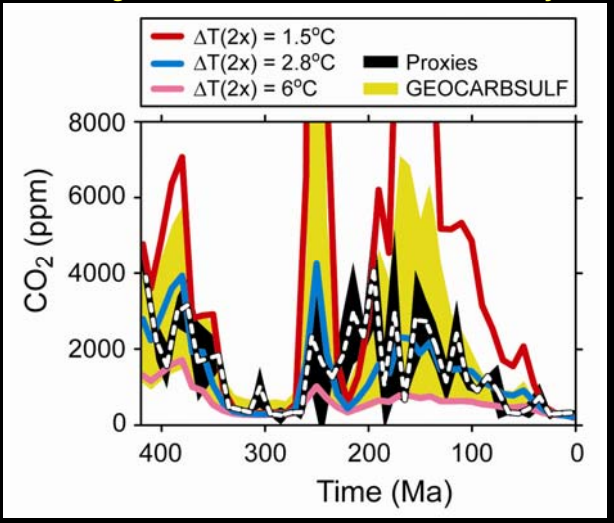

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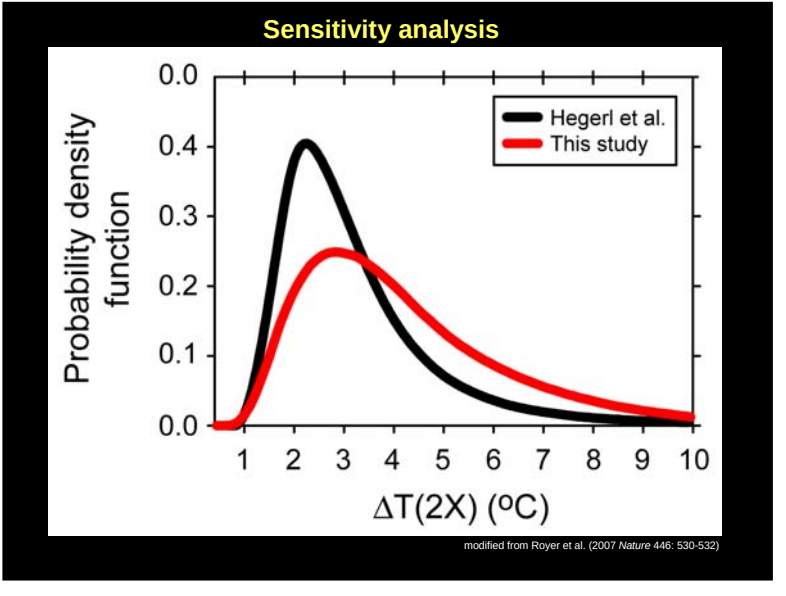


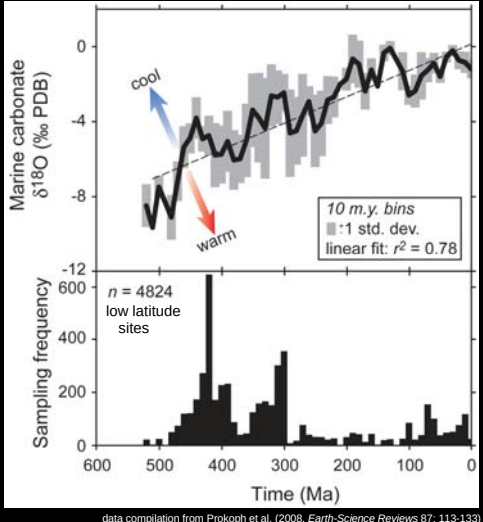
Presenter's Notes: Residual variance: thick blue line = standard run; thin black line = varying the four factors simultaneously
Where to next—time slices through time (do icy times have a higher DT(2x)?)

Summary

- There is a strong CO_2-temperature coupling for much of the Phanerozoic. There is a threshold for nucleating ice sheets at the equivalent radiative forcing of ~500 ppmv (adjusted for changing luminosity through time). Above this CO_2 threshold, large continental ice sheets are typically absent.

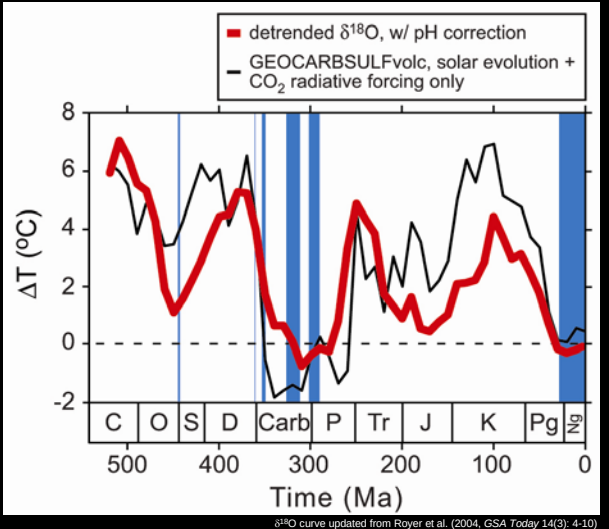
- A model-data comparison for paleo-CO_2 indicates an average climate sensitivity of ~3 °C throughout the Phanerozoic; this calculated sensitivity is similar to calculations for the present-day, implying that an ~3 °C sensitivity is a robust feature of the Earth system.

Phanerozoic $\delta^{18}O$ shallow marine carbonate record



data compilation from Prokoph et al. (2008, *Earth-Science Reviews* 87: 113-133)

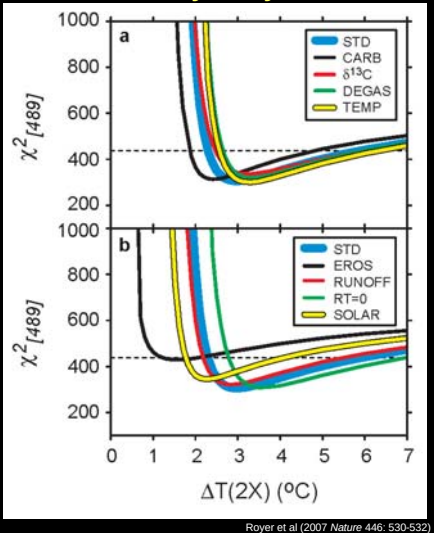
General link between CO_2 and temperature



δ18O curve updated from Royer et al. (2004, *GSA Today* 14(3): 4-10)

Presenter's Notes: DT(2x) = 2.3 ºC

Sensitivity analysis



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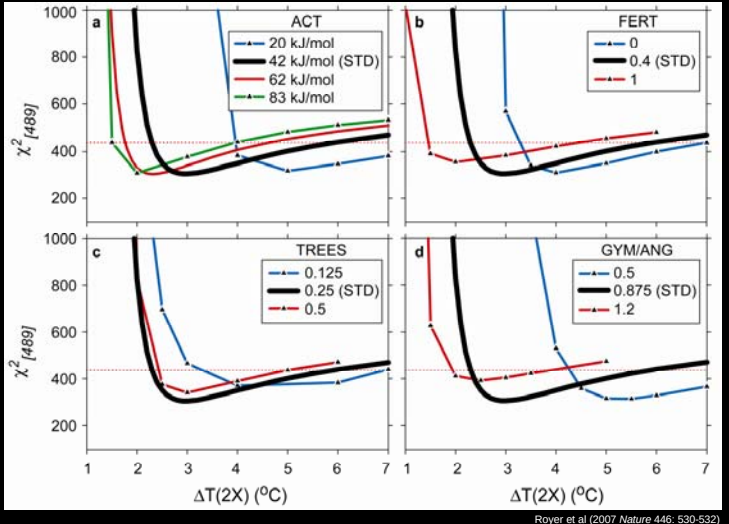

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