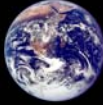



**A Climate Change Primer**  
**The Case for Anthropogenic Warming**

Richard McGehee



Seminar on the Mathematics of Climate Change  
 School of Mathematics  
 October 3, 2007

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**What's at Stake?**

- No ice fishing in Minnesota
- No polar bears in the Arctic
- No ice in Antarctica
- No Florida


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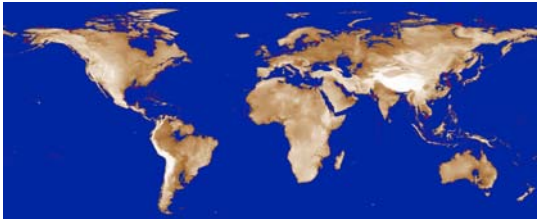
**The USA in the Ice Free Earth**  
 Computer Simulation, Clarence Lehman, Univ. Mn. 2006



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**The Modern Ice Free Earth**  
 Computer Simulation, Clarence Lehman, Univ. Mn. 2006




Sea level rises 63 meters.

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**Is the Globe Really Warming?**

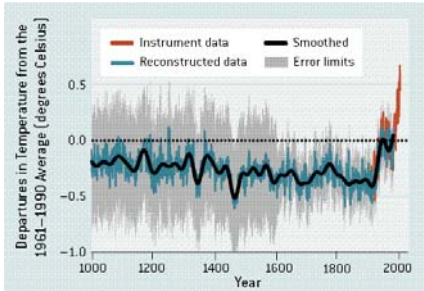
GREENLAND ICE SHEET MELT EXTENT



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**Is the Globe Really Warming?**



Gary Stix, *Scientific American* September 2006, pp.46-49

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**Is the Globe Really Warming?**

<http://www.ncdc.noaa.gov/paleo/globalwarming/paleolaet.html>

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**Is the Globe Really Warming?**

**Antarctic Temperature Data**

Petit, et al, *Nature* 399 (June 3 1999), pp.429-436

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**Is the Globe Really Warming?**

**Who is Steven Milloy?**

“Steven Milloy publishes JunkScience.com and CSRWatch.com. He is a junk science expert, and advocate of free enterprise and an adjunct scholar at the Competitive Enterprise Institute.”

<http://www.foxnews.com/story/0,2933,275267,00.html>



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**Is the Globe Really Warming?**

**What is the Competitive Enterprise Institute?**

“CEI relies on donations from individuals, foundations and corporations. The most generous sponsors of last year’s annual dinner at the Capital Hilton were the Alliance of Automobile Manufacturers, Exxon Mobil, the Pharmaceutical Research and Manufacturers of America, and Pfizer. Other contributors included General Motors, the American Petroleum Institute, the American Plastics Council, the Chlorine Chemistry Council and Arch Coal.”

Joel Achenbach, “The Tempest,” *The Washington Post*, Sunday, May 28, 2006, Page W08

<http://www.washingtonpost.com/wp-dyn/content/article/2006/05/23/AR2006052301305.html>



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**Is the Globe Really Warming?**

The temperature data indicate the globe is warming, but not dramatically compared to the last 10,000 years. Perhaps we are witnessing only a natural blip that has nothing to do with humans.



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**What Determines the Earth’s Temperature?**

$$T^4 = kS$$

where  $T$  = surface temperature (°K)

$S$  = solar influx ( $W/m^2$ )

$k$  = constant depending on reflectivity of the surface, emissivity of the surface, and the Stefan-Boltzmann constant.

For the current value of  $k$ ,  $T = 255^\circ K = -18^\circ C = 0^\circ F$

**Why isn’t the Earth a Snowball?**

C.Lorius, The ice-core record: climate sensitivity and future greenhouse warming, *Nature* 347 (1990), pp.139-145



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**Why isn’t the Earth a Snowball?**

**The Greenhouse Effect!**

Joseph Fourier, *Mémoires de l’Académie des Sciences de l’Institut de France*, t. vii. 1827.



Svante Arrhenius, "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground," *Philosophical Magazine and Journal of Science (Fifth Series)* 41, pp. 237-276, 1896.



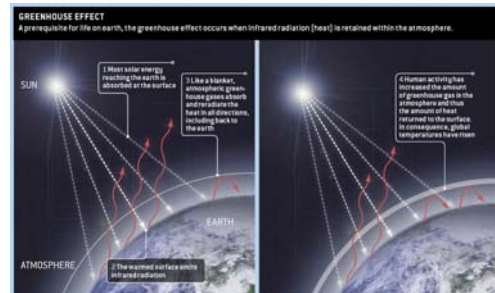
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**The Greenhouse Effect**

Greenhouse gases ( $CO_2$ ,  $H_2O$ ,  $CH_4$ ) are transparent to visible light, but opaque to infrared light. The energy from the sun passes through the atmosphere and heats the surface. The surface radiates energy at a lower temperature (infrared), which is absorbed by the atmosphere.



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The Carbon Cycle

What determines the level of CO<sub>2</sub> in the atmosphere?

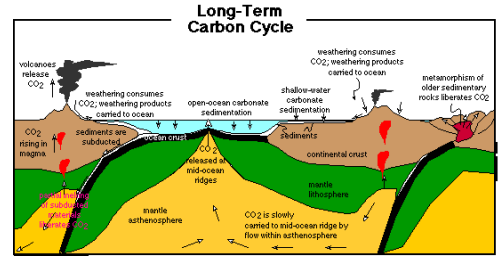
The Carbon Cycle

Short Term: Biology  
Intermediate Term: Oceans  
Long Term: Geology



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The Long-Term Carbon Cycle



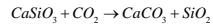
[http://www.carleton.edu/departments/geol/DaveSTELLA/Carbon/long\\_term\\_carbon.htm](http://www.carleton.edu/departments/geol/DaveSTELLA/Carbon/long_term_carbon.htm)



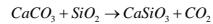
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Silicate Weathering

Rainwater containing dissolved CO<sub>2</sub> falling on silicate rocks replaces a silicon atom with a carbon atom, ultimately producing calcium carbonate (limestone) and silicon dioxide (quartz). For example, calcium silicate (Wollastonite):



Under volcanic conditions, the carbon atom is replaced by a silicon atom, completing the long term carbon cycle.



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The Earth's Long-Term Thermostat

The rate of silicate weathering is temperature dependent. The temperature is a function of the atmospheric CO<sub>2</sub>.

$$\frac{dx}{dt} = f(x) = a - b(T(x))x$$

where  $x$  = atmospheric CO<sub>2</sub> concentration  
 $T$  = surface temperature  
 $a$  = rate of CO<sub>2</sub> input from tectonics  
 $b$  = rate of silicate weathering



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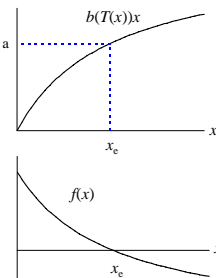
The Earth's Long-Term Thermostat

$T(x)$  is increasing  
 $b(T)$  is increasing  
 $b(T(x))$  is increasing  
 $b(T(x))x$  is increasing

$f(x) = a - b(T(x))x$  is decreasing

$x_e$  is a stable equilibrium for

$$\frac{dx}{dt} = f(x)$$



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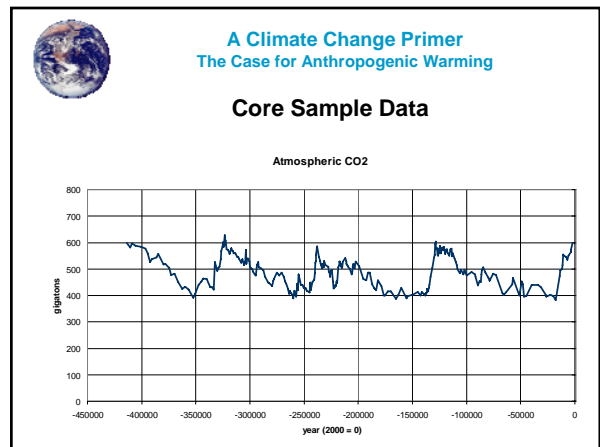
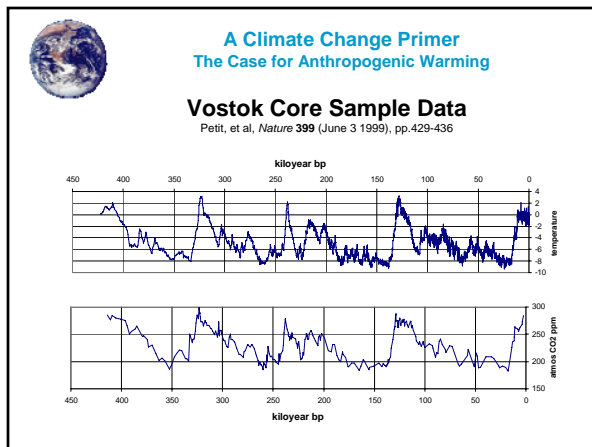
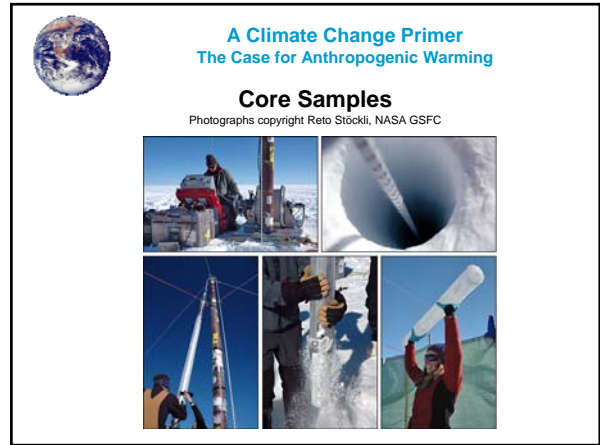
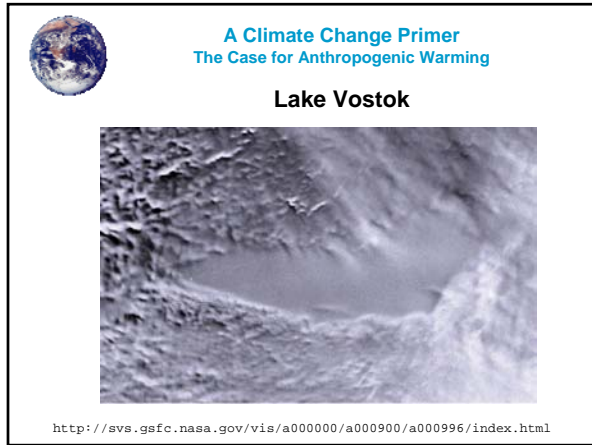
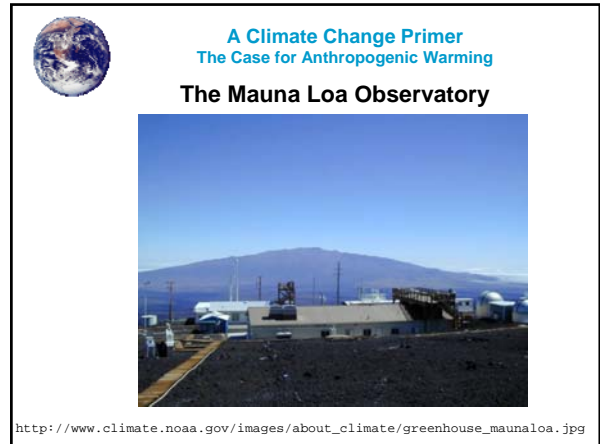
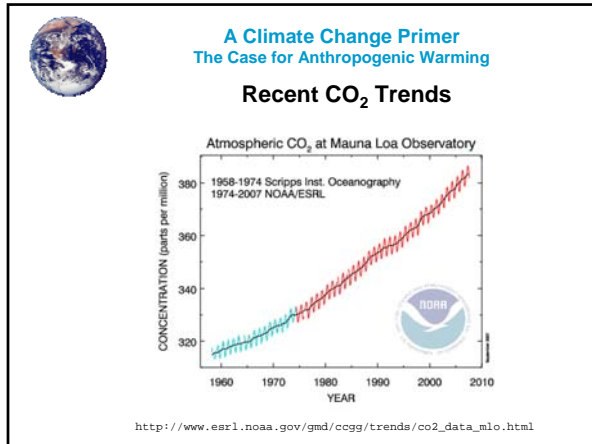
The Earth's Long-Term Thermostat

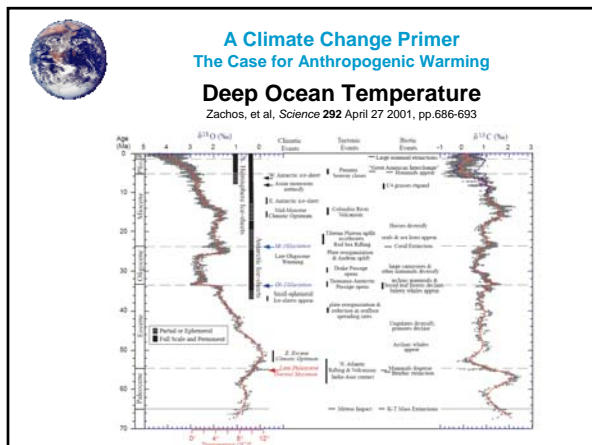
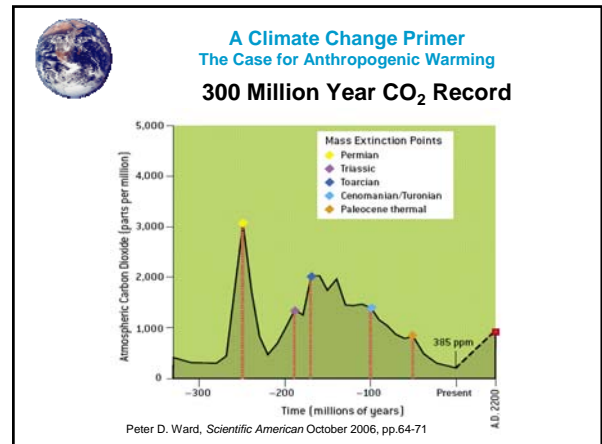
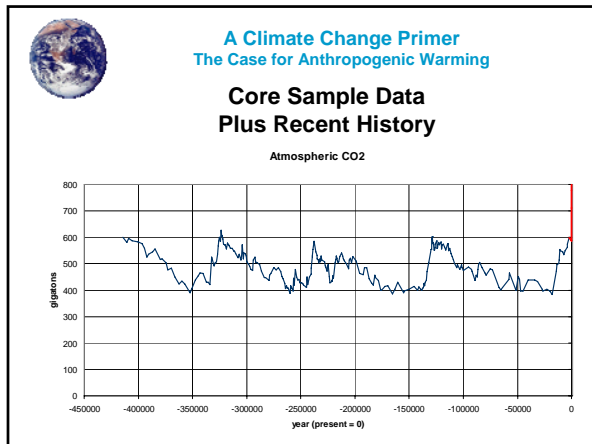
$$\frac{dx}{dt} = a - b(T(x))x$$

This model illustrates why the Earth's temperature is relatively constant.

Limitations:

Perhaps  $a$  is a delayed function of  $x$ .  
Perhaps  $b$  is also a function of exposed silicate rocks and hence is a function of ice cover.





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**Summary**

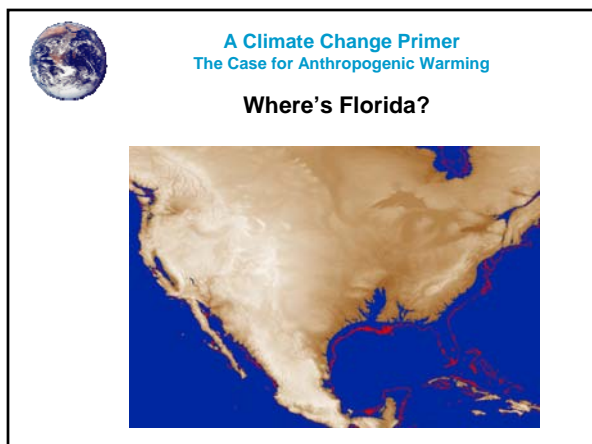
There is a scientifically sound theory of the greenhouse effect.

There is a growing body of data linking CO<sub>2</sub> and temperature.

Human activity has produced huge amounts of CO<sub>2</sub>.

The atmospheric CO<sub>2</sub> levels are heading for Eocene levels in the coming centuries.

The Eocene Earth was ice free.



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**But there's hope ...**

What about the oceans? They cannot absorb the CO<sub>2</sub> as fast as we are now producing it. But if we stop, can they return the atmospheric CO<sub>2</sub> to preindustrial levels?

Will we pass a threshold? Are we resetting the Earth's thermostat to a higher temperature?

Can technology save us?

*Come back next week for the continuing drama.*