The Case for Anthropogenic Warming, II

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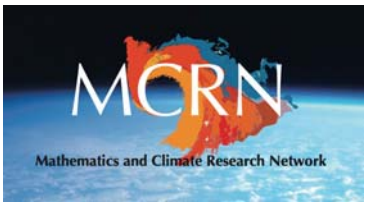
School of Mathematics
University of Minnesota

Mathematics of Climate Seminar
September 29, 2015



Anthropogenic Warming

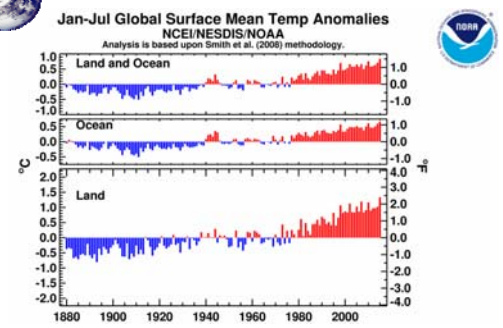
Is the globe warming?

What determines the Earth's temperature?

What is the role of human activity?

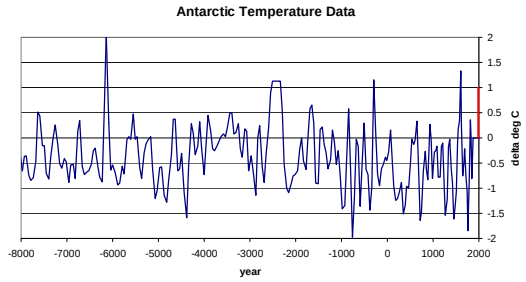
How big is the problem?

Anthropogenic Warming



https://www.ncdc.noaa.gov/sotc/service/global/glob/201501-201507.gif

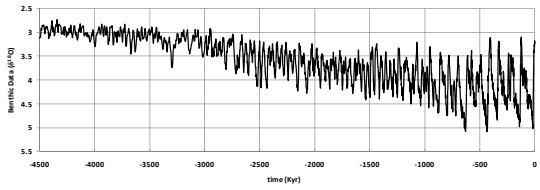
Anthropogenic Warming



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

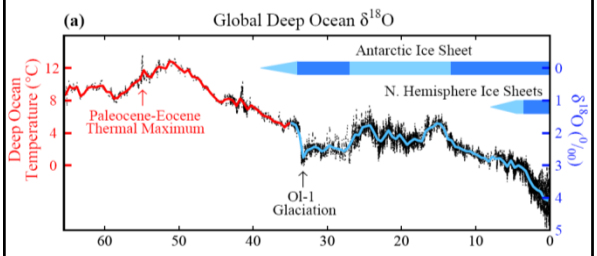
Anthropogenic Warming

Benthic ^{18}O Data



Lisiecki, L. E., and M. E. Raymo (2005), A Pliocene-Pleistocene stack of 57 globally distributed benthic d18O records, *Paleoceanography*,**20**, PA1003, doi:10.1029/2004PA001071.

Anthropogenic Warming



Hansen, et al, Target atmospheric CO2: Where should humanity aim? *Open Atmos. Sci. J.* **2** (2008)

Anthropogenic Warming

Is the globe warming?

Yes, but, from a geologic perspective, not so much.

What determines the Earth's temperature?

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Anthropogenic Warming

Heat Balance

outgoing (infrared) $\longrightarrow$ $\sigma T^4 = (1-\alpha)S$ $\longleftarrow$ solar incoming (visible)

where T = surface temperature (Kelvin)

S = solar influx (W/m^2)

α = albedo (reflectivity)

σ = the Stefan-Boltzmann constant

For current values , $T = 255K = -18°C = \boxed{0°F}$

Why isn't the Earth a Snowball?

Anthropogenic Warming

Why isn't the Earth a Snowball?

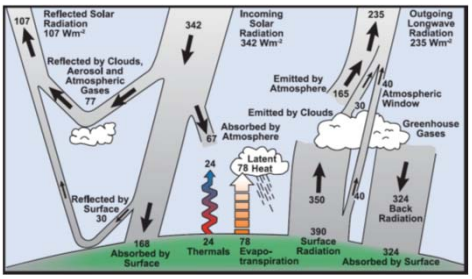
The Greenhouse Effect!

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.

Anthropogenic Warming

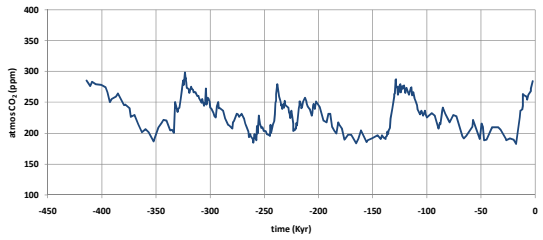
Heat Balance



Historical Overview of Climate Change Science, IPCC AR4, p.96
http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_CH01.pdf

Anthropogenic Warming

Atmospheric CO_2 (Vostok data)



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

Anthropogenic Warming

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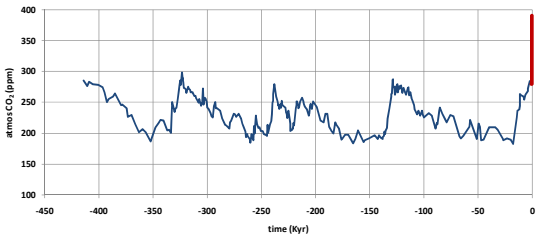
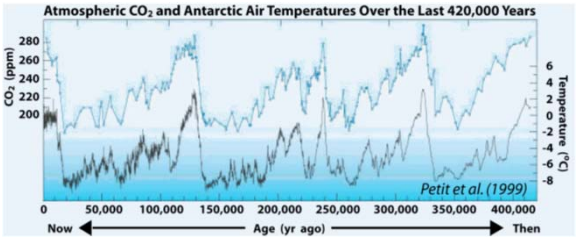


Petit, et al, *Nature* **399** (June 3 1999), pp.429-436

Anthropogenic Warming

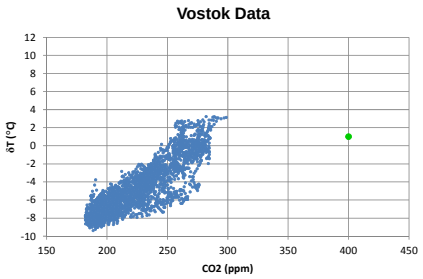
Atmospheric CO_2 & Temperature (Vostok data)



Pam Martin, University of Chicago, 2010

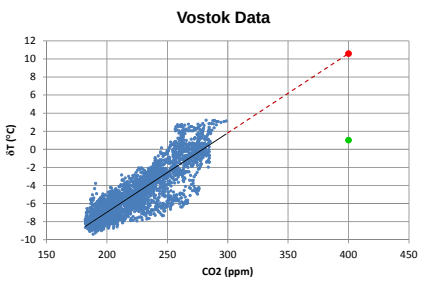
Anthropogenic Warming

Current conditions are well outside the range recorded in the ice core data.

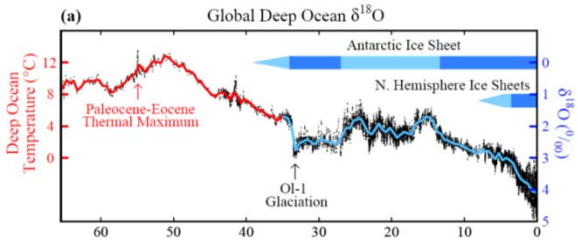


Anthropogenic Warming

Extrapolate linear regression to 400 ppm CO2.



Anthropogenic Warming



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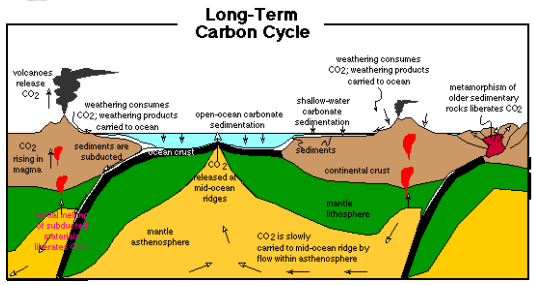
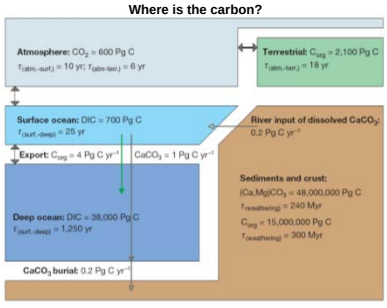
Anthropogenic Warming



http://www.carleton.edu/departments/geol/DaveSTELLA/Carbon/long_term_carbon.htm

Anthropogenic Warming

Where is the carbon?



Sigman & Boyle, *Nature* **207** (2000), p.860

Anthropogenic Warming

Silicate Weathering

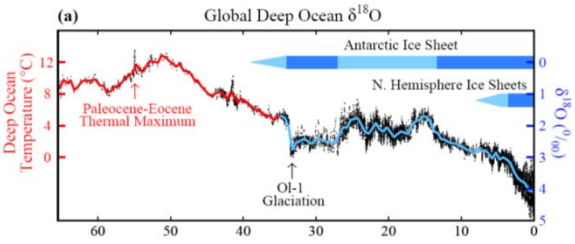
Rainwater containing dissolved CO_2 falling on silicate rocks replaces a silicon atom with a carbon atom, ultimately producing calcium carbonate (limestone) and silicon dioxide (quartz). For example, calcium silicate (Wollastonite):

$$CaSiO_3 + CO_2 \rightarrow CaCO_3 + SiO_2$$

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

$$CaCO_3 + SiO_2 \rightarrow CaSiO_3 + CO_2$$

Anthropogenic Warming



Hansen, et al, Target atmospheric CO2: Where should humanity aim? *Open Atmos. Sci. J.* **2** (2008)

Anthropogenic Warming

Is the globe warming?

Yes, but, from a geologic perspective, not so much.

What determines the Earth's temperature?

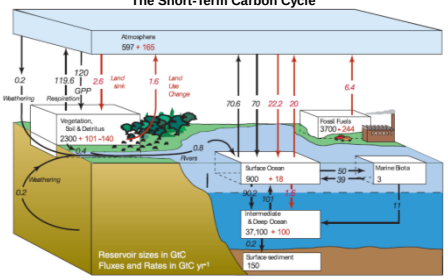
Physics! Solar heating plus the carbon cycle.

What is the role of human activity?

How big is the problem?

Anthropogenic Warming

The Short-Term Carbon Cycle



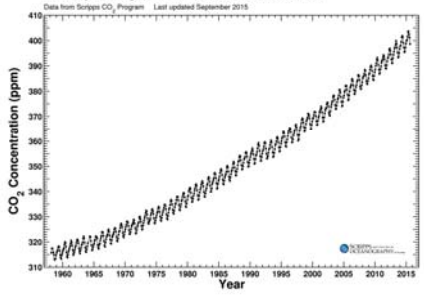
Couplings Between Changes in the Climate System and Biogeochemistry, IPCC AR4, p.513
http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_CH07.pdf

Anthropogenic Warming

http://www.climate.noaa.gov/images/about_climate/greenhouse_maunaloa.jpg

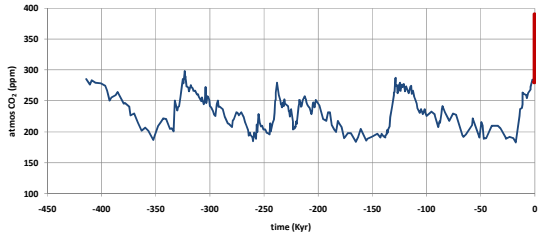
Anthropogenic Warming

Mauna Loa Observatory, Hawaii
Monthly Average Carbon Dioxide Concentration



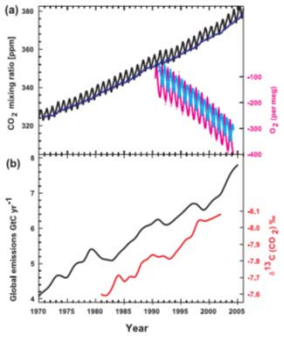
http://scrippsco2.ucsd.edu/graphics_gallery/mauna_loa_record/mauna_loa_record.html

Anthropogenic Warming



Anthropogenic Warming

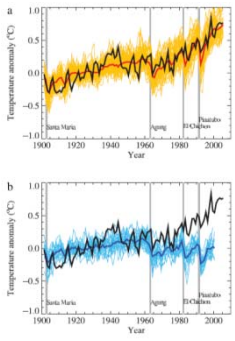
Carbon isotope ratios and atmospheric oxygen depletion indicate that the increase in atmospheric CO_2 comes from burning fossil fuels.



Changes in Atmospheric Constituents and in Radiative Forcing, IPCC AR4, Chap. 2, p.138
http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_CH02.pdf

Anthropogenic Warming

Models with and without human activity.



Understanding and Attributing Climate Change, IPCC AR4, Chap. 9, p.684
http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_Ch09.pdf

Anthropogenic Warming

Is the globe warming?
Yes, but, from a geologic perspective, not so much.

What determines the Earth's temperature?
Physics! Solar heating plus the carbon cycle.

What is the role of human activity?
We are adding CO_2 to the atmosphere.

How big is the problem?

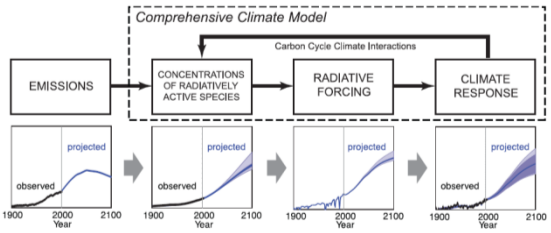
Anthropogenic Warming

The IPCC Fourth Assessment Report

http://nobelprize.org/nobel_prizes/peace/laureates/2007/

Anthropogenic Warming

Prediction Methodology

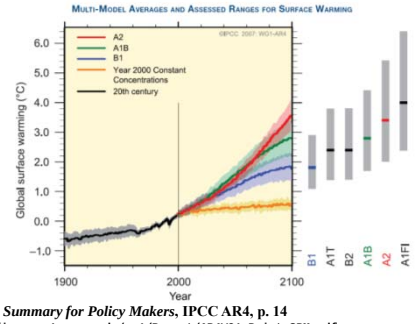


***Global Climate Projections*, IPCC AR4, p.753**
http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_CH10.pdf

Anthropogenic Warming

The IPCC Fourth Assessment Report

Global Mean Temperature Predictions

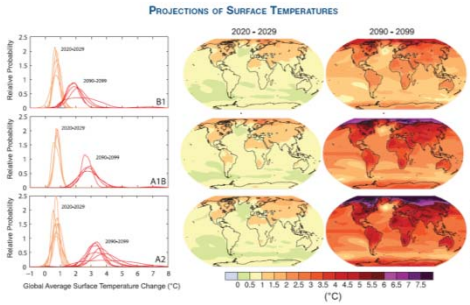


Summary for Policy Makers, IPCC AR4, p. 14
http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_SPM.pdf

Anthropogenic Warming

The IPCC Fourth Assessment Report

Surface Temperature Predictions



Technical Summary, IPCC AR4, p. 72
http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_SPM.pdf

Anthropogenic Warming

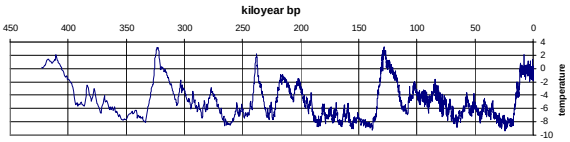
The Last Interglacial Period

Global average sea level was likely between 4 and 6 m higher during the last interglacial period, about 125,000 years ago, than during the 20th century, mainly due to the retreat of polar ice. Ice core data suggest that the Greenland Summit region was ice-covered during this period, but reductions in the ice sheet extent are indicated in parts of southern Greenland. Ice core data also indicate that average polar temperatures at that time were 3°C to 5°C warmer than the 20th century because of differences in the Earth's orbit. The Greenland Ice Sheet and other arctic ice fields likely contributed no more than 4 m of the observed sea level rise, implying that there may also have been a contribution from Antarctica.

Technical Summary, IPCC AR4, p. 58
http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_SPM.pdf

Anthropogenic Warming

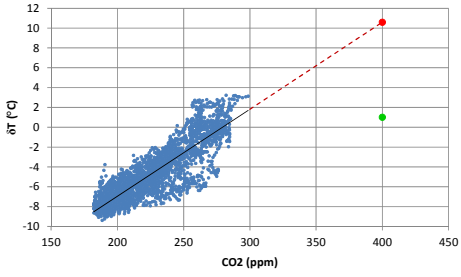
Antarctic Temperature Data



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

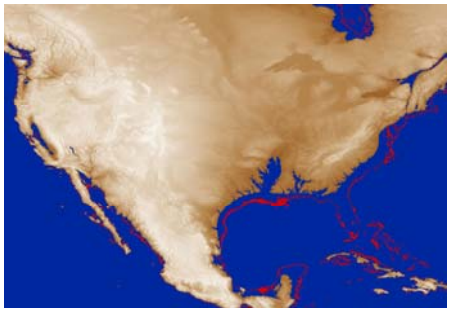
Anthropogenic Warming

Vostok Data



Anthropogenic Warming

USA in the Ice Free Earth

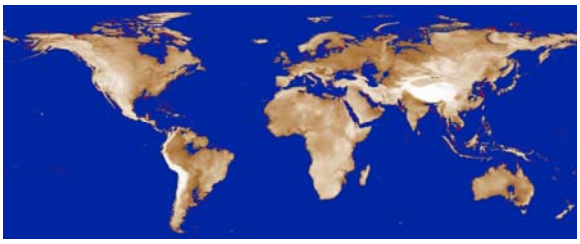


Clarence Lehman, University of Minnesota, 2006

Anthropogenic Warming

The Modern Ice Free Earth

Sea level rises 63 meters.



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Anthropogenic Warming

Summary

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Yes, but, from a geologic perspective, not so much.

What determines the Earth's temperature?
Physics! Solar heating plus the carbon cycle.

What is the role of human activity?
We are adding CO_2 to the atmosphere.

How big is the problem?
Not big. Yet. ...

Anthropogenic Warming

What can mathematicians do?

Models
Minimal complexity, aka "conceptual", "simple", "toy"
Intermediate complexity
Maximal complexity, aka "GCM"

Data
Parameter estimation (statistics)
Data assimilation

Quantification
Uncertainty
Resilience

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