



The Case for Anthropogenic Warming, I

Richard McGehee
School of Mathematics
University of Minnesota

Mathematics of Climate Seminar
September 10, 2019




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Anthropogenic Warming

Is the globe warming?
What determines the Earth's temperature?
What is the role of human activity?
How big is the problem?

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Anthropogenic Warming

Is the globe warming?

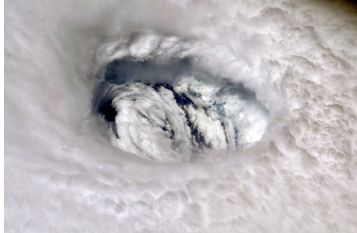
What determines the Earth's temperature?
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Anthropogenic Warming


The New York Times
How Has Climate Change Affected Hurricane Dorian?



Hurricane Dorian seen from the International Space Station on Monday.
Credit: NASA/EPA, via Shutterstock


<https://www.nytimes.com/2019/09/03/climate/hurricane-dorian-climate-change.html>

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Anthropogenic Warming


2017 Hurricanes



Harvey and Irma



Maria




Ophelia

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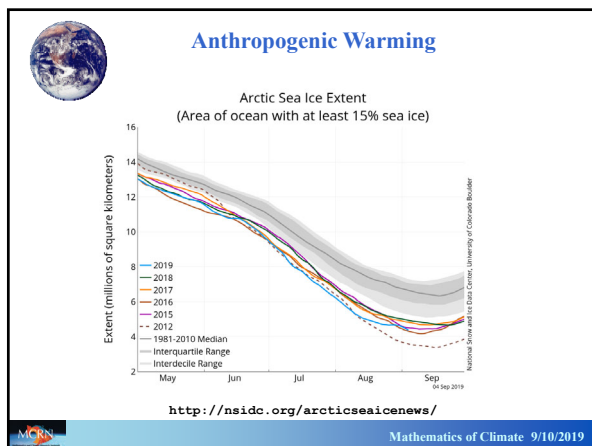
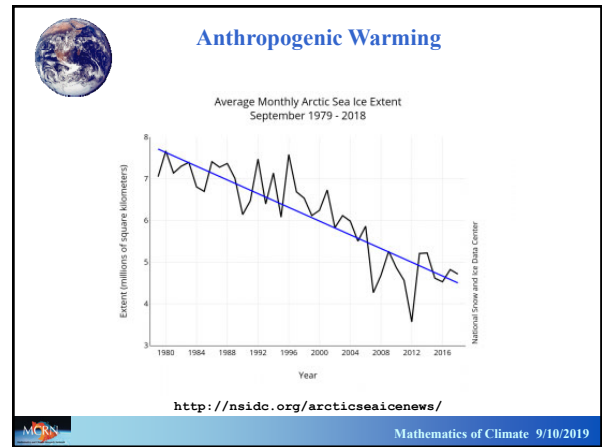
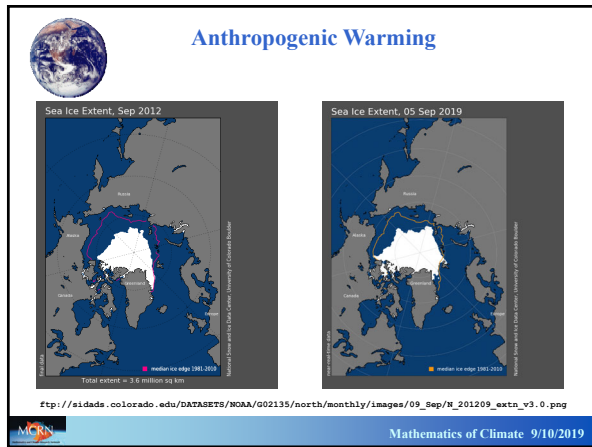
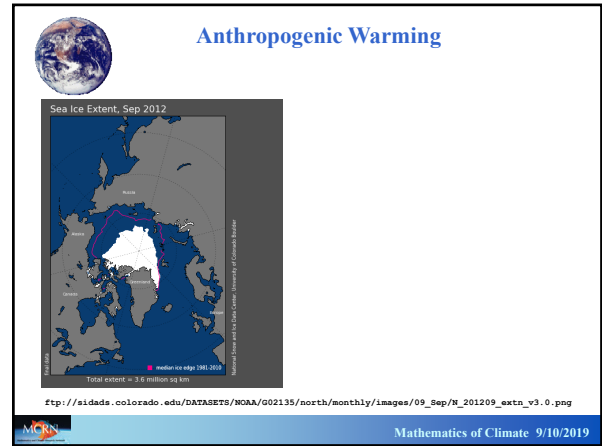
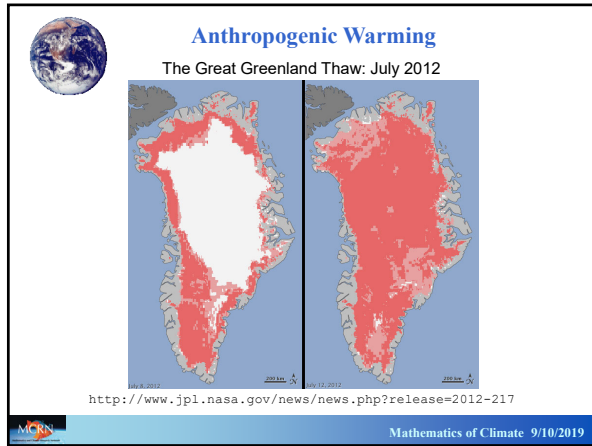
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Wildfires



Carr Fire, California, 2018

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Anthropogenic Warming

TIME

Record-Breaking Temperatures Around the World Are 'Almost Entirely' Due to Climate Change

July 2019 Was the Earth's Hottest Month Ever Recorded, NOAA Says
July 2019 was the hottest July and the hottest month on record globally since temperature records began

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<https://time.com/5652972/july-2019-hottest-month/>

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Global Average Temperature 1850 - 2018

Land data prepared by Berkeley Earth and combined with ocean data adapted from the UK Hadley Centre
Global temperature anomalies relative to 1951-1980 average
Vertical lines indicate 95% confidence intervals

http://berkeleyearth.org/wp-content/uploads/2019/01/GlobalAverage_2018.png

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0-2000 m Global Ocean Heat Content

— 3-Month average through Apr-Jun 2019
— Yearly average through 2018
— Pentadal average through 2014-2018

NOAA NESDIS/NOOC Ocean Climate Laboratory
Updated from Levitus et al. 2012

https://www.nodc.noaa.gov/OCS/3M_HEAT_CONTENT/

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Some energy comparisons:

- 1 megaton hydrogen bomb: 4×10^{15} Joules
- 1 day of an average hurricane: 5×10^{15} Joules
- Energy absorbed by the oceans since 1990: 25×10^{22} Joules
- = 5,000 hurricane-days
- = 60,000,000 H-bombs

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So, it has gotten a little hotter recently.
What about past climates?

Doesn't the climate always change?

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Lake Vostok

<http://svs.gsfc.nasa.gov/vis/a000000/a000900/a000996/index.html>

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Lake Vostok

Cored 2.2 miles

ANTARCTICA
South Pole
Lake Vostok

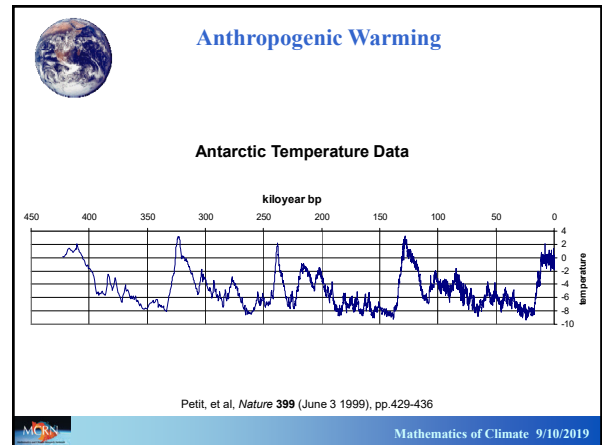
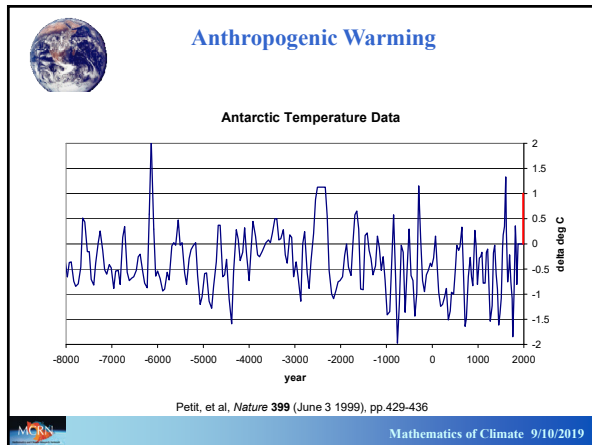
http://www.nsf.gov/news/mmg/media/images/lake_vostok_nsf_h.jpg

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Core Samples
Photographs copyright Reto Stöckli, NASA GSFC

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Anthropogenic Warming

Every hundred thousand years or so the Earth gets a little hotter, but mostly it has been pretty cold.

What happened before that?

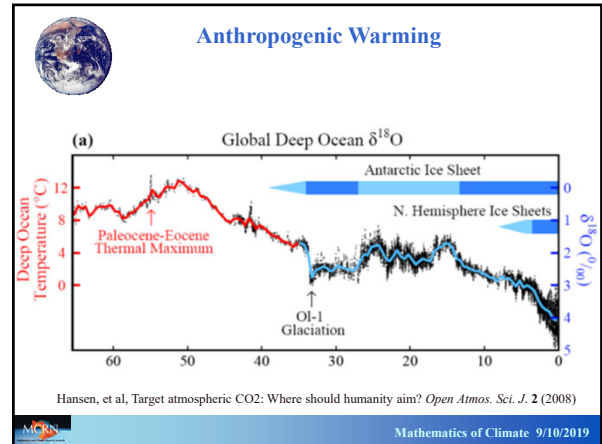
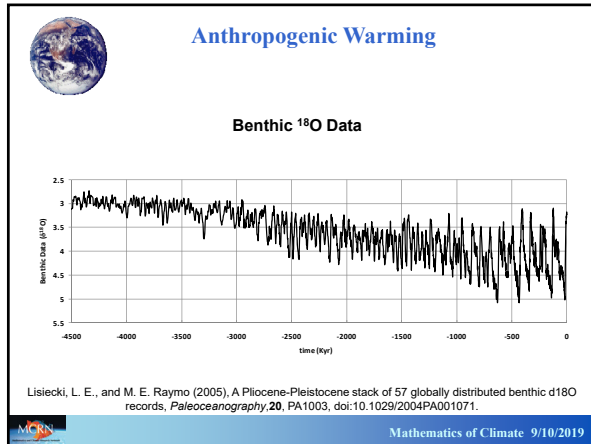
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Ocean Sediment Cores

http://eo.ucar.edu/staff/russell/climate/paleoclimate/sediment_proxy_records.html

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Anthropogenic Warming

Is the globe warming?

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

What determines the Earth's temperature?

What is the role of human activity?

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Anthropogenic Warming

Heat Balance

outgoing (infrared) $\rightarrow \sigma T^4 = (1 - \alpha)S \leftarrow$ 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, $T = 255\text{K} = -18^{\circ}\text{C} = 0^{\circ}\text{F}$

Why isn't the Earth a Snowball?

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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.

Who discovered the greenhouse effect?

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Anthropogenic Warming

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Who discovered the greenhouse effect?

Joseph Fourier (1827), *Mémoire sur les Températures du Globe Terrestre et des Espaces Planétaires*, *Mémoires de l'Académie Royale des Sciences*, t. vii., p. 569.




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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.

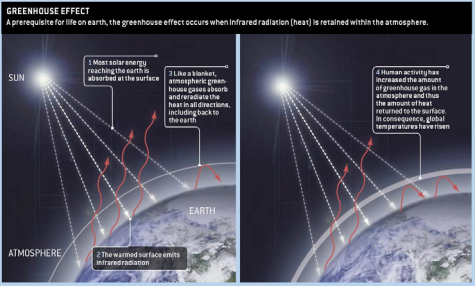


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GREENHOUSE EFFECT

A prerequisite for life on earth, the greenhouse effect occurs when infrared radiation (heat) is retained within the atmosphere.



1 Most solar energy reaching the earth is absorbed at the surface.

2 Like a blanket, atmospheric greenhouse gases absorb and re-emit the heat in all directions, including back to the earth.

3 The warmed surface emits infrared radiation.

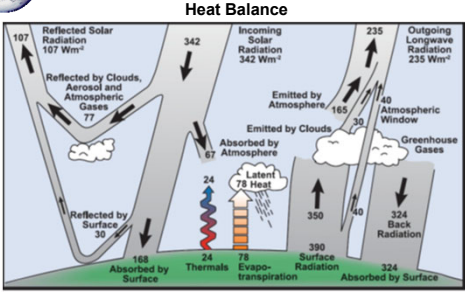
4 Human activity has increased the amount of greenhouse gas in the atmosphere and thus the amount of heat returned to the surface. In consequence, global temperatures have risen.

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

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Heat Balance



107 Reflected Solar Radiation 107 Wm^{-2}

342 Incoming Solar Radiation 342 Wm^{-2}

235 Outgoing Longwave Radiation 235 Wm^{-2}

Reflected by Clouds, Aerosol and Atmospheric Gases 77

Reflected by Surface 30

Absorbed by Surface 168

24 Thermals

78 Latent Heat

76 Evapo-transpiration

390 Surface Radiation

324 Absorbed by Surface

Emitted by Atmosphere 165

30 Atmospheric Window

Greenhouse Gases

Emitted by Clouds 40

40

Historical Overview of Climate Change Science, IPCC AR4, p.96
http://ipcc-wg1.ucar.edu/wg1/Report/AR4WG1_Print_CN01.pdf

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Okay, the greenhouse gases are important.

What do you know about them?

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Anthropogenic Warming

Remember Lake Vostok?

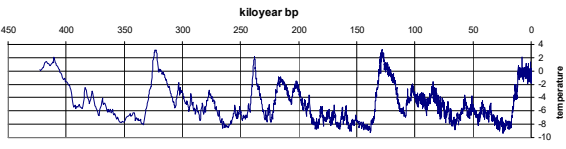


<http://svs.gsfc.nasa.gov/vis/a000000/a000900/a000996/index.html>

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Antarctic Temperature Data



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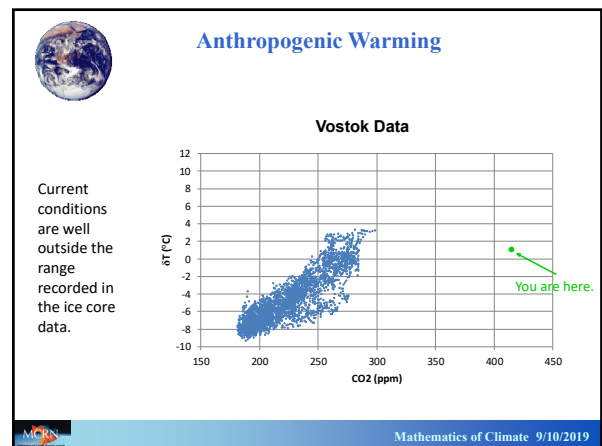
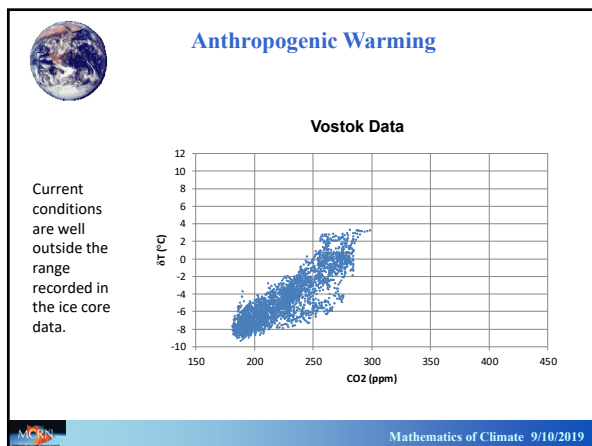
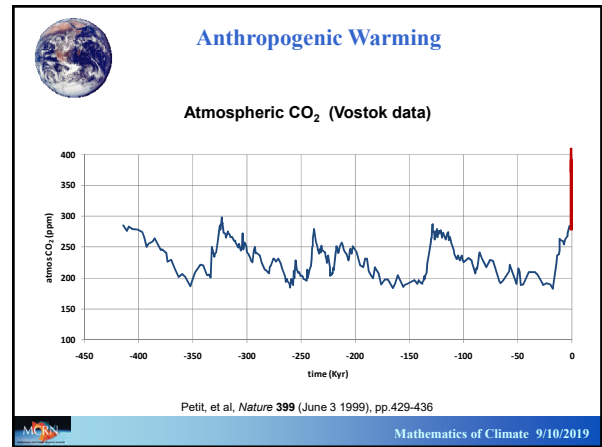
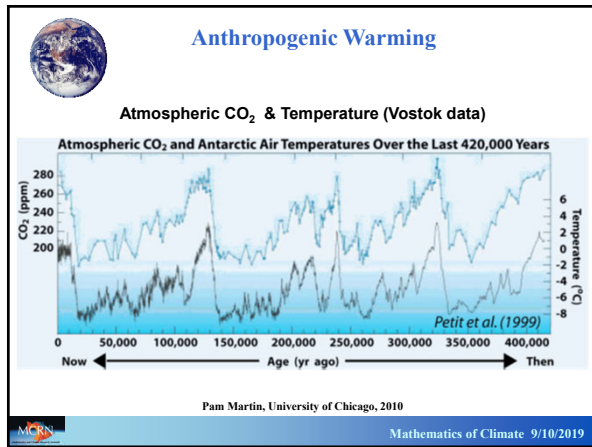
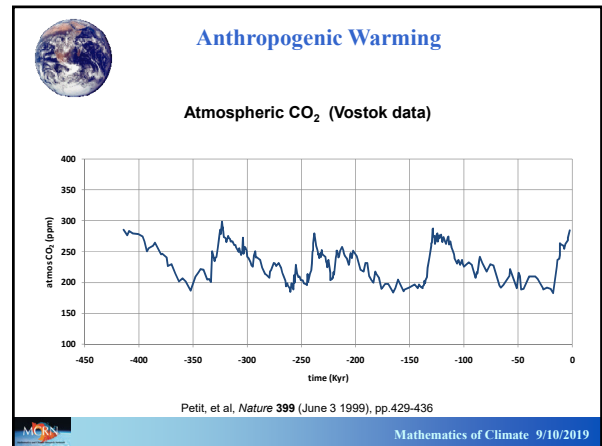
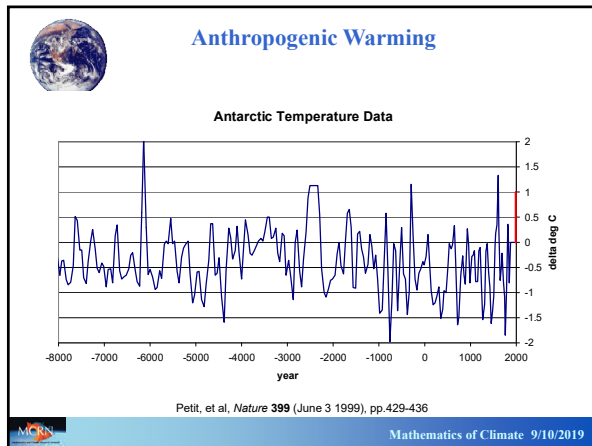
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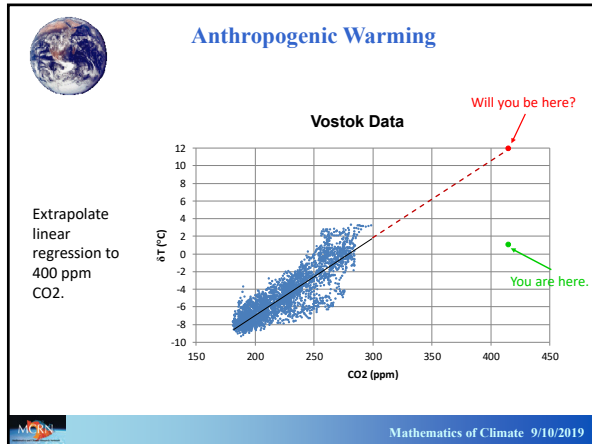
4
2
0
-2
-4
-6
-8
-10

temperature

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

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

What determines the Earth's temperature?

There's more. Stay tuned.

What is the role of human activity?

How big is the problem?

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