


Math 5490
 Topics in Applied Mathematics
Introduction to the Mathematics of Climate

Fall 2023
1:25 - 3:20 Tuesdays and Thursdays
Amundson Hall 162

Richard McGehee, Instructor
 458 Vincent Hall
 mcgehee@umn.edu
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course website
www-users.cse.umn.edu/~mcgehee/teaching/Math5490/



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Math 5490
 Topics in Applied Mathematics
Introduction to the Mathematics of Climate


[Syllabus](#)



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 Topics in Applied Mathematics
Introduction to the Mathematics of Climate

Introductions




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Math 5490
Textbook




MATHEMATICS & Climate

Hans Kaper & Hans Engler
Mathematics & Climate
 SIAM 2013




<https://my.siam.org/Store/Product/viewproduct/?ProductId=24279328>

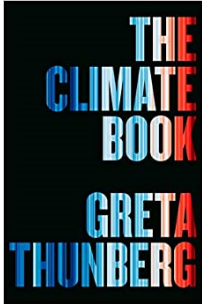


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Suggested Reading



Greta Thunberg
The Climate Book
 Penguin Press 2013



<https://www.penguinrandomhouse.com/books/709837/the-climate-book-by-greta-thunberg/>



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Greta Thunberg



2018




2023



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Greta Thunberg



PERSON of the YEAR
TIME

GRETA THUNBERG
THE POWER OF YOUTH

People are suffering. People are dying. Entire ecosystems are collapsing. We are in the beginning of a mass extinction, and all you can talk about is money and fairy tales of eternal economic growth.

Greta Thunberg, UN speech, September 23, 2019

Greta Thunberg, Person of the Year 2019

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Is there a climate emergency?

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Is there a climate emergency?


Floods
Droughts
Fires
Heat

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Math 5490
Is there a climate emergency? **Floods**

THE WALL STREET JOURNAL.

US
The Flooding in Vermont Is ‘Historic and Catastrophic,’ Governor Says



<https://www.cnn.com/2023/07/11/us/northeast-storms-flooding-excessive-rainfall-tuesday/index.html>

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Is there a climate emergency? **Droughts**

Hoover Dam, USA



www.escentral.com/story/opinion/op-ed/jonathan-hamby/2021/05/20/like-mead-1166131-tlee-2-shoutout-2022-impact-wat.com/7183341021/

Loire River, France

THE WALL STREET JOURNAL.

EUROPE
Europe’s Key Rivers Fall to Critical Levels, Aggravating Energy Crunch



www.wsj.com/articles/europe-key-rivers-fall-to-critical-levels-aggravating-energy-crunch-11660216554

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Is there a climate emergency? **Fires**

Canada



<http://www.nytimes.com/2023/08/04/podcasts/canada-wildfires-climate-change.html>

New York City



<https://www.cnn.com/us/live-news/canada-wildfires-us-air-quality-04-08-23/index.html>

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Heat

Is there a climate emergency?

The New York Times
Phoenix's Month in Hell: A 31-Day Streak of Record Heat Ends

A continuous stretch of days reaching or exceeding 110 degrees has filled emergency rooms. On Monday, the city hit 108 degrees, breaking the run, but setting a new, brutal record.



<https://www.ecowweather.com/en/weather-news/phoenix-heat-wave-could-be-the-most-intense-on-record-for-the-city/154752>

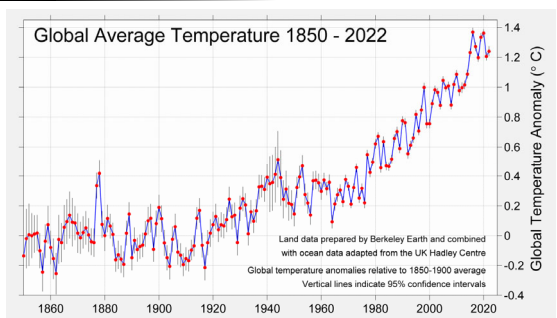


<https://www.capitaltimes.com/news/2023/04/04/study-phoenix-face-health-cries-12-beatwave-31-out-hit-at-same-time/>

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Global Mean Temperature

Global Average Temperature 1850 - 2022



Land data prepared by Berkeley Earth and combined with ocean data adapted from the UK Hadley Centre
Global temperature anomalies relative to 1850-1900 average
Vertical lines indicate 95% confidence intervals

<https://berkeleyearth.org/global-temperature-report-for-2022/>

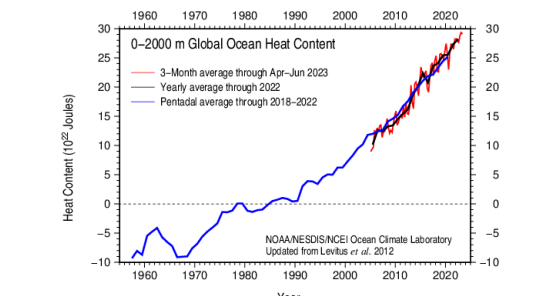
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Global Mean Temperature

climatereanalyzer.org

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Ocean Heat

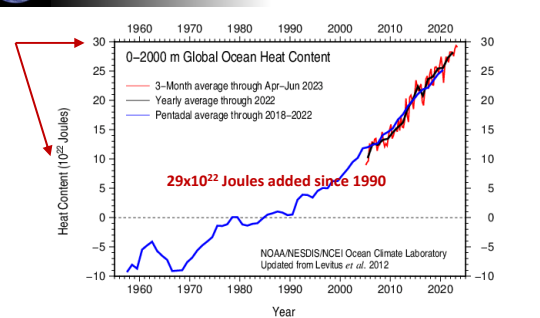


NOAA/NESDIS/NCEI Ocean Climate Laboratory
Updated from Levitus et al. 2012

<https://www.ncei.noaa.gov/access/global-ocean-heat-content/>

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Ocean Heat



29x10²² Joules added since 1990

NOAA/NESDIS/NCEI Ocean Climate Laboratory
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Ocean Heat

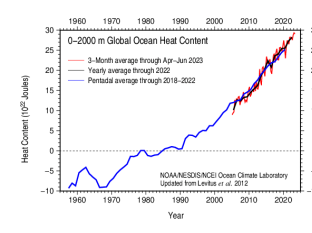
29x10²² Joules added since 1990

Some energy comparisons:

- 1 megaton hydrogen bomb: **4x10¹⁵ joules**
- 1 day of an average hurricane: **5x10¹⁹ joules**

Energy absorbed by the oceans since 1990:
29x10²² joules

- = 5,800 hurricane-days
- = 72,000,000 H-bombs



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

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Math 5490 Ocean Heat

29x10²² Joules added since 1990

Some energy comparisons:

- 1 megaton hydrogen bomb: **4x10¹⁵ joules**
- 1 day of an average hurricane: **5x10¹⁹ joules**
- annual global electricity generation: **1.04x10²⁰ joules**
- Energy absorbed by the oceans since 1990: **29x10²² Joules**
- = 2800 years of global electricity

NOMANS/SDS/NCEI Ocean Climate Laboratory Updated from Leifer et al. 2012

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Math 5490 Ocean Heat

29x10²² Joules added since 1990

Some energy comparisons:

- *Energy required to raise sea level by 1 meter: **15x10²² joules**
- 29x10²² J ↔ +6.3 feet**
- *Warm the atmosphere by 1°C: **0.26x10²² joules**
- 29x10²² J ↔ +111°C = +232°F**
- Phoenix in July: **110 + 232 = 342°F**

Moral: A lot of energy has been absorbed by the ocean.

*Hansen, et al, *Science* 308 (2005), p.1431

NOMANS/SDS/NCEI Ocean Climate Laboratory Updated from Leifer et al. 2012

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Math 5490 Ocean Heat

Where is all this extra energy coming from?

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Math 5490 Greenhouse Effect

Where is all this extra energy coming from?

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

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Math 5490 Greenhouse Effect

Earth's Heat Balance

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

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Math 5490 Greenhouse Effect

The Greenhouse Effect

Greenhouse gases (CO₂, H₂O, CH₄) 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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Greenhouse Effect

The Greenhouse Effect

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Who discovered the greenhouse effect?

1. A meteorologist
2. A physicist
3. A chemist
4. A mathematician
5. Al Gore

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Greenhouse Effect


The Greenhouse Effect

Greenhouse gases (CO₂, H₂O, CH₄) 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?

A mathematician!

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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Greenhouse Effect

The Greenhouse Effect!

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



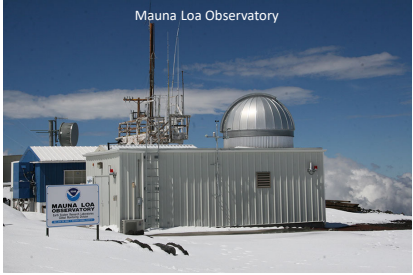
Svante Arrhenius, "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground," *Philosophical Magazine and Journal of Science (Fifth Series)* 41, pp. 237-276, 1896.



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Math 5490
Greenhouse Effect

Can we measure greenhouse gasses?



Mauna Loa Observatory

https://research.noaa.gov/Portals/0/EasyDRNews/1502/200600p587EDNmain10061mlc_sign_miller.jpg

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Greenhouse Effect

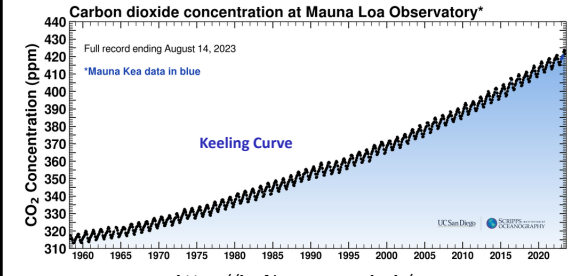
Can we measure greenhouse gasses?

<https://keelingcurve.ucsd.edu/>

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Math 5490
Greenhouse Effect

Can we measure greenhouse gasses?



Carbon dioxide concentration at Mauna Loa Observatory*

Full record ending August 14, 2023

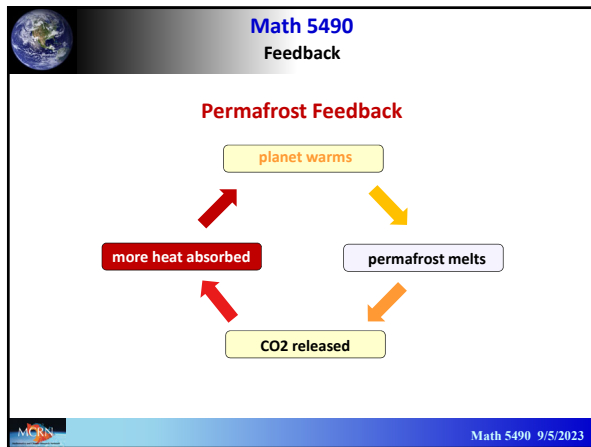
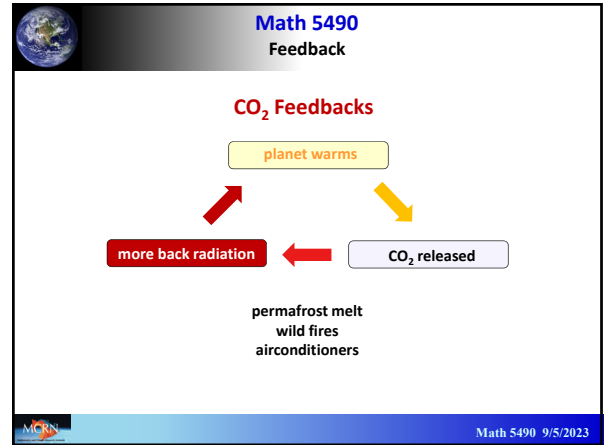
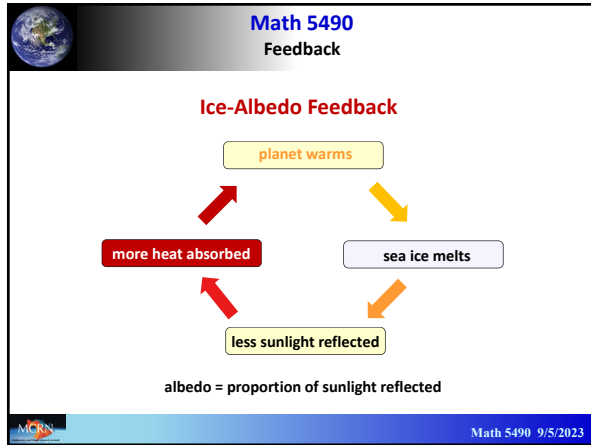
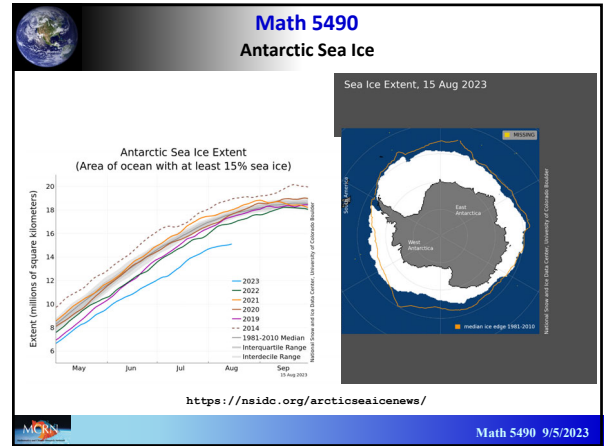
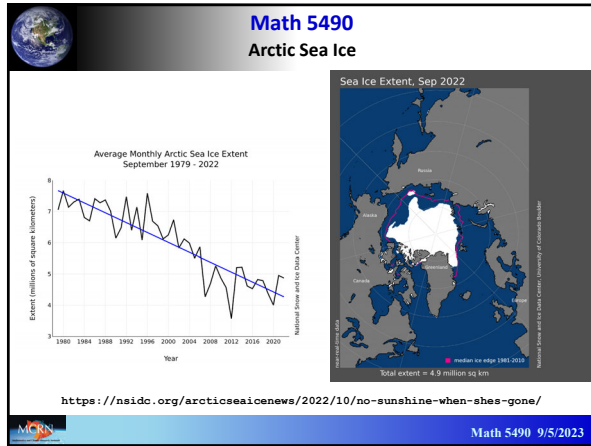
Mauna Kea data in blue

Keeling Curve

UC San Diego Scripps Institution of Oceanography

<https://keelingcurve.ucsd.edu/>

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Math 5490 Permafrost

The National Snow and Ice Data Center estimates that there are **1400** Gigatonnes of carbon (GtC) stored in the permafrost.

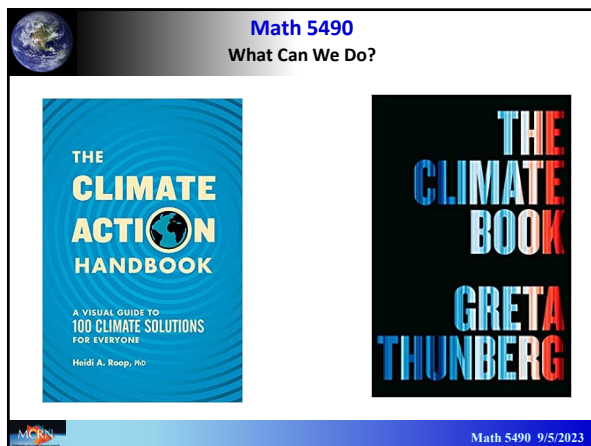
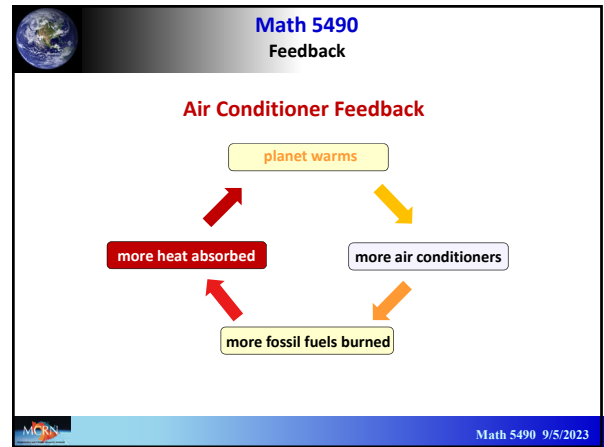
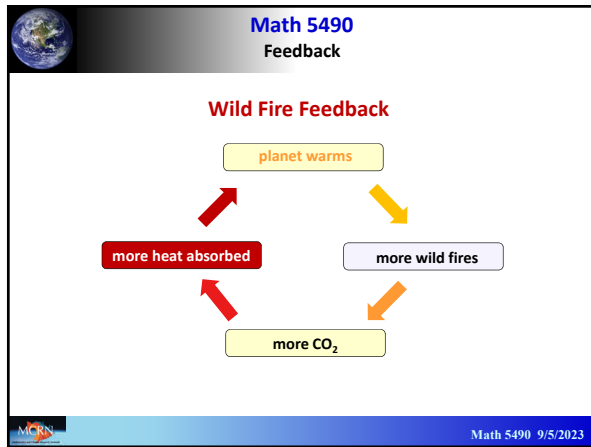
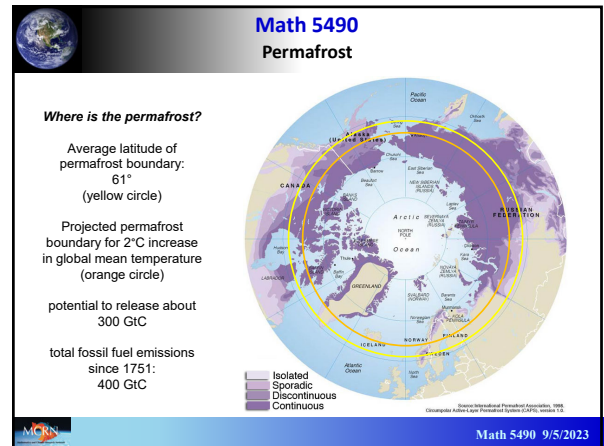
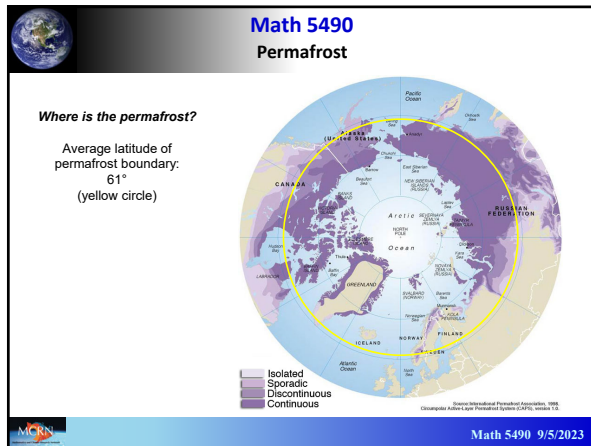
By comparison, the atmosphere currently holds about **890** GtC.

permafrost = permanently frozen soil

http://alaska.usgs.gov/science/interdisciplinary_science/cse/arctic_coastal_plain.php

<https://www.nps.gov/gaaz/learn/nature/permafrost.htm>

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Coming Attraction

Mathematics begins on Thursday
Energy Balance
temperature change ~ energy in – energy out

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