

Math 1901
Freshman Seminar
Mathematical Climate Models

Fall 2024
1:00 - 2:15 Mondays and Wednesdays
Vincent Hall 213

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course website
<https://www-users.cse.umn.edu/~mcgehee/Course/Math1901/>

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Glacial Cycles

What Causes Glacial Cycles?

Widely Accepted Hypothesis

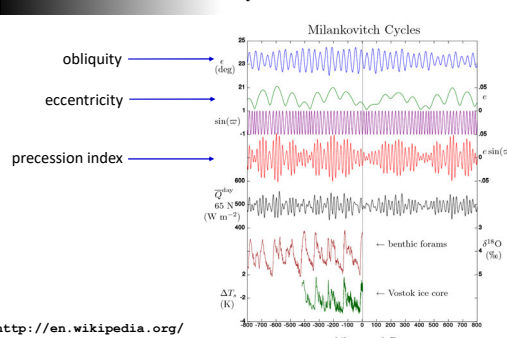
The glacial cycles are driven by the variations in the Earth's orbit (**Milankovitch Cycles**), causing a variation in incoming solar radiation (insolation).

This hypothesis is widely accepted, but also widely regarded as insufficient to explain the observations.

The additional hypothesis is that there are feedback mechanisms and/or triggering mechanisms that amplify the Milankovitch cycles. What these feedbacks are and how they work are not fully understood.

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http://en.wikipedia.org/wiki/Milankovitch_cycles

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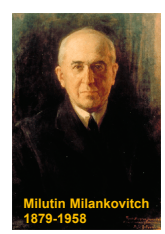
Who was Milankovitch?

Milutin Milankovitch was a Serbian mathematician and professor at the University of Belgrade.

In 1920 he published his seminal work on the relation between insolation and the Earth's orbital parameters.

In 1941 he published a book explaining his entire theory.


His work was not fully accepted until 1976.



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What happened in 1976?

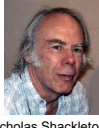


John Imbrie

Hays, Imbrie, and Shackleton, "Variations in the Earth's Orbit: Pacemaker of the Ice Ages," *Science* **194**, 10 December 1976.



James D. Hays



Nicholas Shackleton

"It is concluded that changes in the earth's orbital geometry are the fundamental cause of the succession of Quaternary ice ages."

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Hays, et al, Summary

- 1) Three indices of global climate have been monitored in the record of the past 450,000 years in Southern Hemisphere ocean-floor sediments.
- 2) ... climatic variance of these records is concentrated in three discrete spectral peaks at periods of 23,000, 42,000, and approximately 100,000 years. These peaks correspond to the dominant periods of the earth's solar orbit, and contain respectively about 10, 25, and 50 percent of the climatic variance.

Hays, et al, *Science* **194** (1976), p. 1125

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Hays, et al, Summary

3) The 42,000-year climatic component has the same period as variations in the obliquity of the earth's axis and retains a constant phase relationship with it.

4) The 23,000-year portion of the variance displays the same periods (about 23,000 and 19,000 years) as the quasiperiodic precession index.

5) The dominant, 100,000-year climatic component has an average period close to, and is in phase with, orbital eccentricity. Unlike the correlations between climate and the higher-frequency orbital variations (which can be explained on the assumption that the climate system responds linearly to orbital forcing), **an explanation of the correlation between climate and eccentricity probably requires an assumption of nonlinearity.**

Hays, et al, *Science* **194** (1976), p. 1125

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Hays, et al, Summary

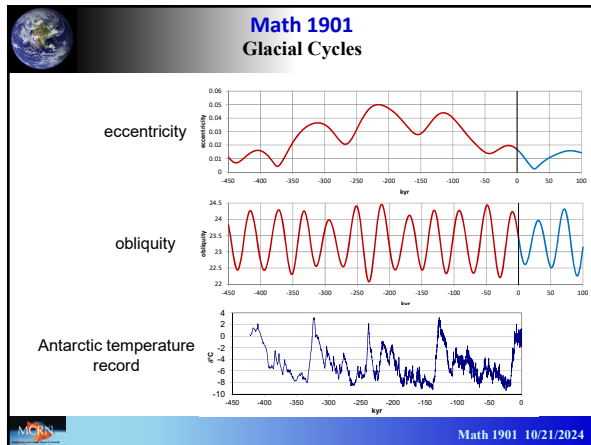
6) It is concluded that changes in the earth's orbital geometry are the fundamental cause of the succession of Quaternary ice ages.

7) A model of future climate based on the observed orbital-climate relationships, **but ignoring anthropogenic effects**, predicts that the long-term trend over the next seven thousand years is toward **extensive Northern Hemisphere glaciation***.

*Quoted by George Will, Washington Post, February 5, 2009

Hays, et al, *Science* **194** (1976), p. 1125

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Glacial Cycles

Earth's climate has changed many times in the past.
Why do we think humans are responsible now?

Here's a reason.

The paleoclimate evidence points to the conclusion that the Earth should be entering a new ice age.

But we're not.

Instead, the Earth is warming and the ice sheets are melting.

The current climate is not following the pattern of the last million years.

Something has changed.

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Earth's climate has changed many times in the past.
Why do we think humans are responsible now?

First Reason

The 120 year old and increasingly relevant theory of greenhouse gasses.

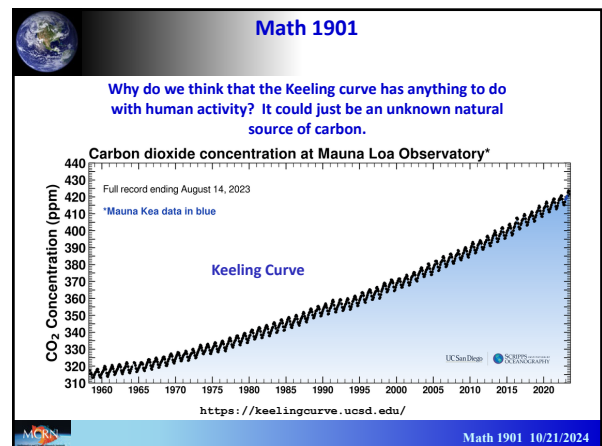
Second Reason

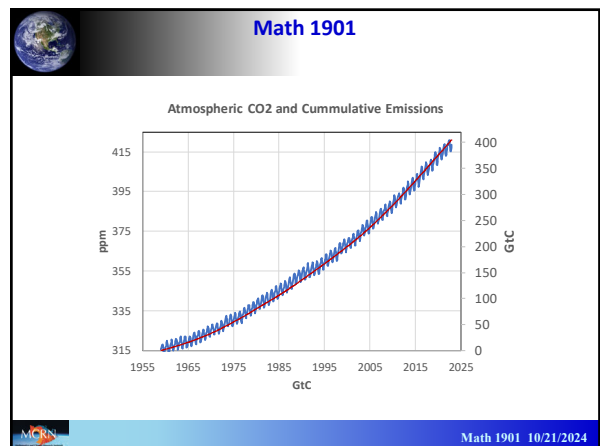
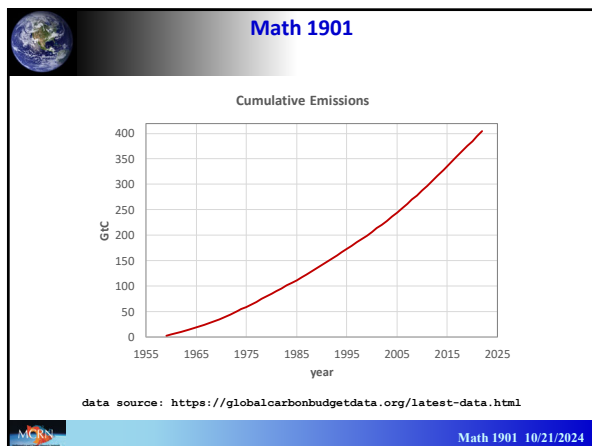
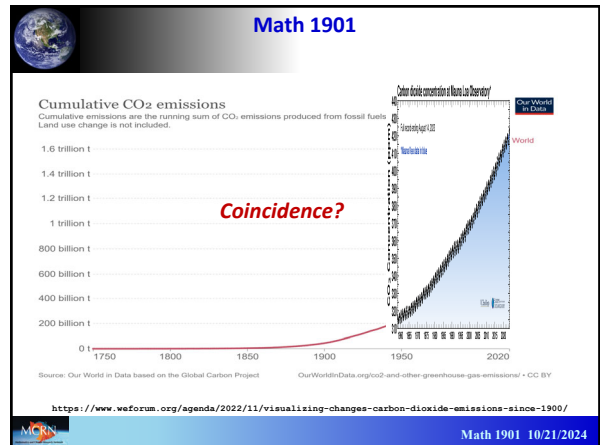
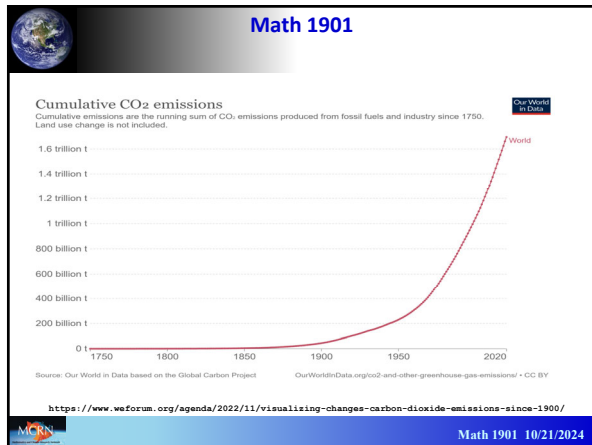
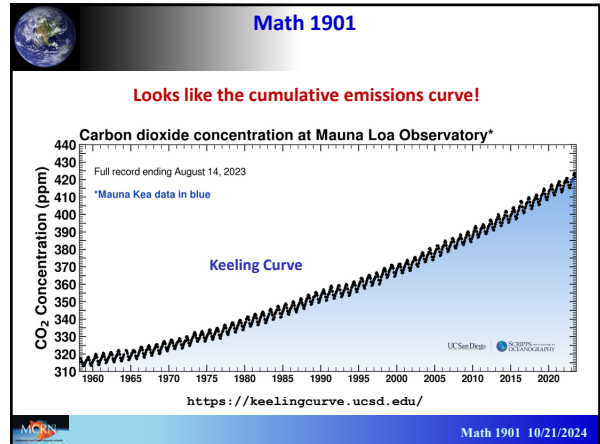
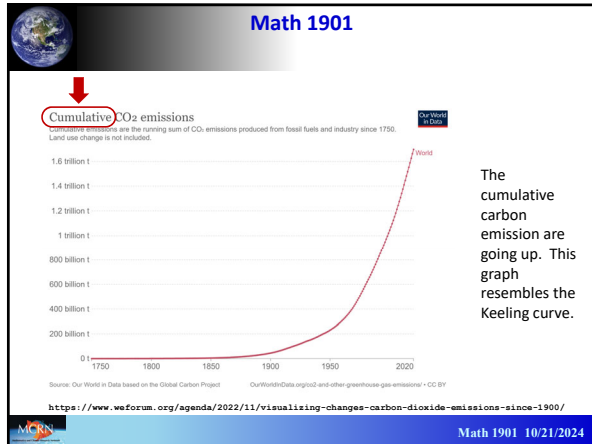
The climate is not following the glacial cycle pattern of the last million years.

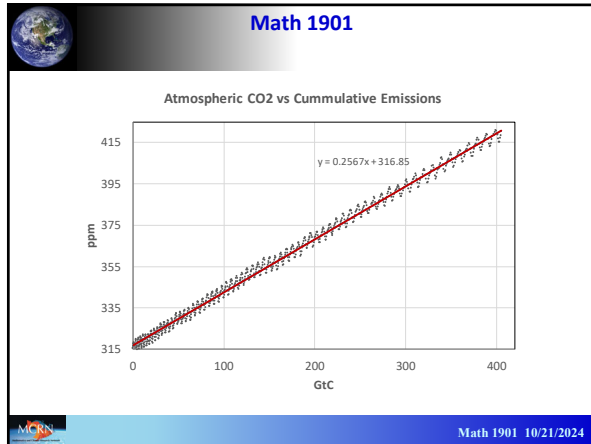
Third Reason

There is no other known culprit.

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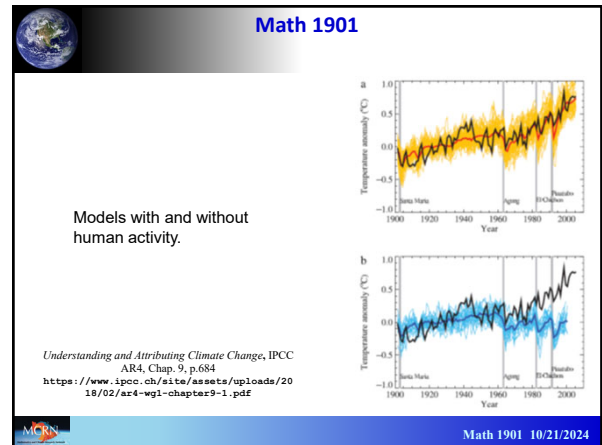
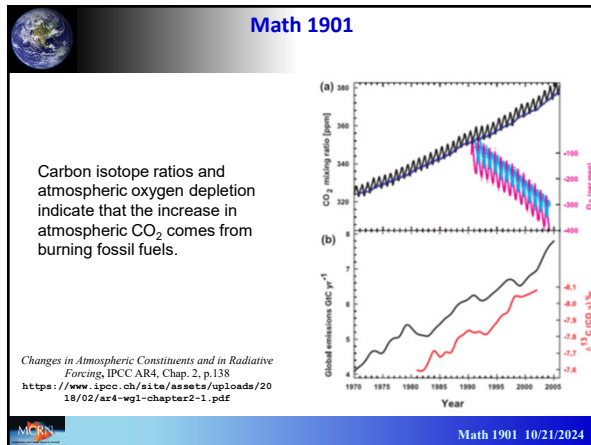
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No big deal. Both the accumulated emissions and the atmospheric CO₂ are increasing. Circumstantial evidence.

Is that all you got?

Nope.

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Scientific Conclusion

The scientific data are consistent with the hypothesis that the burning of fossil fuels is causing changes in the Earth's climate.

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Scientific Conclusion

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Reasonable Human Reaction

We gotta stop burning fossil fuels!

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https://www.lemonde.fr/en/environment/article/2023/01/01/uk-climate-group-extinction-rebellion-suspends-public-disruption-tactics_609966_114.html

<https://newrepublic.com/article/166821/climate-delay-discourse-denial>

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Measuring Atmospheric Carbon

ppm: parts per million
 GtC: gigatonnes carbon
 GtCO₂: gigatonnes carbon dioxide

tonne: metric ton = 1000 kilograms = 10⁶ grams
 ≈ 1.10 tons

gigatonne = 10⁹ tonnes = 10¹⁵ grams = petagram

atmospheric carbon:
 1 ppm ≈ 2.13 GtC

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What is the weight of the carbon in the atmosphere at 420 ppm?

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atmospheric carbon:
 1 ppm ≈ 2.13 GtC

What is the weight of the carbon in the atmosphere at 420 ppm?

2.13 × 420 ≈ 895 Gt

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Measuring Atmospheric Carbon

carbon atomic weight ≈ 12
 oxygen atomic weight ≈ 16
 carbon dioxide molecular weight ≈ 12 + 2×16 = 44

1 GtC = (44/12) GtCO₂ ≈ 3.67 GtCO₂

1 GtCO₂ = (12/44) GtC ≈ 0.273 GtC

How much carbon is in 1.6 trillion tons of carbon dioxide?

1.6 trillion tons of CO₂ = 1600 GtCO₂ = 0.273 × 1600 GtC ≈ 436 GtC

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