Math 1901
Freshman Seminar
Mathematical Climate Models

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

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

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

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Why do we think that the increasing atmospheric CO_2 is the cause of the increasing temperature?

Why do we think that human activity is causing the increasing atmospheric CO_2?

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Why do we think that the increasing atmospheric CO_2 is the cause of the increasing temperature?

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.

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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Arguments from Climate Skeptics

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

Humans haven't been around very long in geologic time. They couldn't have been the cause of climate changes in the distant past.

Humans have been burning fossil fuels for only about two hundreds years. But the ice ages occurred long before that, so humans couldn't have been the cause of those climate changes.

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Earth's climate has changed many times in the past.

Paleoclimate

Paleoclimatology is the scientific study of climates predating the invention of meteorological instruments, when no direct measurement data were available. As instrumental records only span a tiny part of Earth's history, the reconstruction of ancient climate is important to understand natural variation and the evolution of the current climate.

https://en.wikipedia.org/wiki/Paleoclimatology

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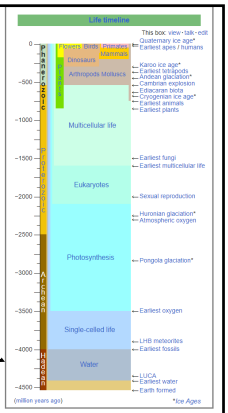
Four Geologic Eons

Phanerozoic

Proterozoic

Archean

Hadean



https://en.wikipedia.org/wiki/Phanerozoic

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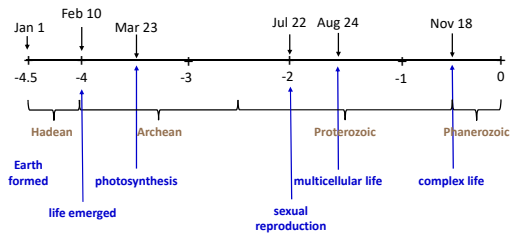
Earth Age Compressed to One Year



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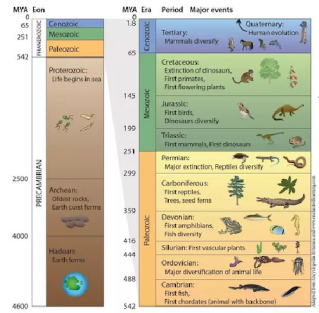

Three Eras of the Phanerozic

- Cenozoic
- Mesozoic
- Paleozoic

https://study.com/learn/lesson/phanerozoic-eon-era-facts.html

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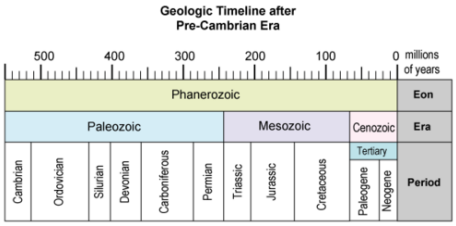
The Phanerozoic Eon



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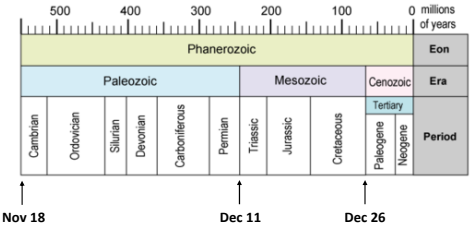
Geologic Timeline after Pre-Cambrian Era



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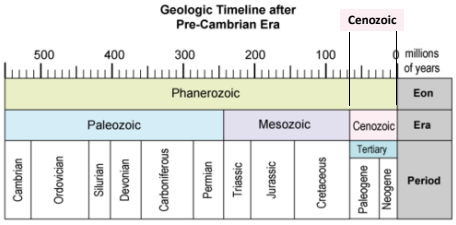
The Phanerozoic Eon



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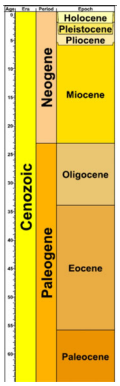
dinosaurs gone
mammals dominate

last ice age to now
last 12,000 years

glacial cycles starting
2.5 million years ago

Seven Epochs of the Cenzoic Era

- Holocene
- Pleistocene
- Pliocene
- Miocene
- Oligocene
- Eocene
- Paleocene



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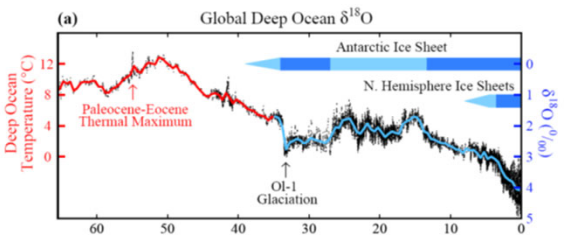
Temperatures in the Cenozoic Era
65 Myr - present



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

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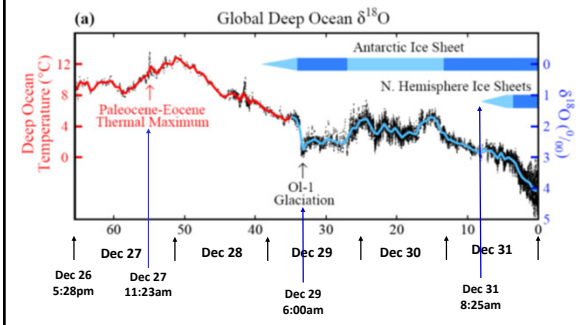

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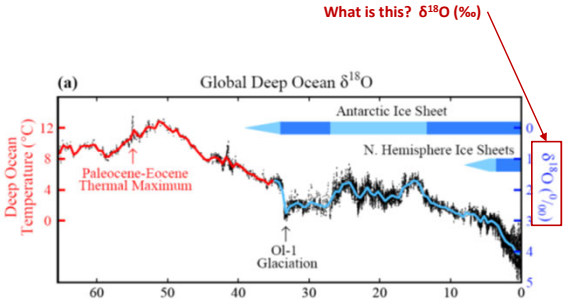

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Ocean Sediment Cores

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

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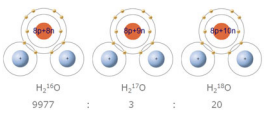
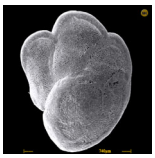
^{18}O as a Climate Proxy



The isotope ^{16}O preferentially evaporates from the ocean and is sequestered in glaciers, leaving the heavier isotope ^{18}O more highly concentrated in the ocean. Thus oceanic concentration of the isotope ^{18}O is higher during glacial periods.

Foraminifera absorb more ^{18}O into their skeletons when the water temperature is lower and when more ^{18}O is in the water.

Thus higher concentrations of ^{18}O in foraminifera fossils indicate lower ocean temperatures and higher glacier volume.



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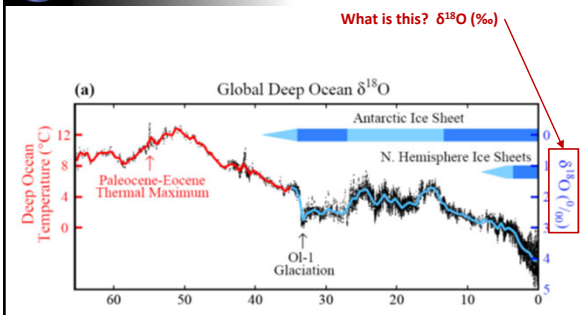

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What is this? $\delta^{18}O$ (‰)

‰ : "per mil," "per thousand"
1000‰ = 100% = 1
10‰ = 1% = 0.01
1‰ = 0.1% = 0.001

^{18}O: Oxygen 18: 8 protons 8 electrons 10 neutrons
^{17}O: Oxygen 17: 8 protons 8 electrons 9 neutrons
^{16}O: Oxygen 16: 8 protons 8 electrons 8 neutrons
Most of the oxygen atoms on Earth are ^{16}O.
About 1 in 500 atoms is ^{18}O. About 1 in 2500 is ^{17}O.
There are other oxygen isotopes, but they are unstable.

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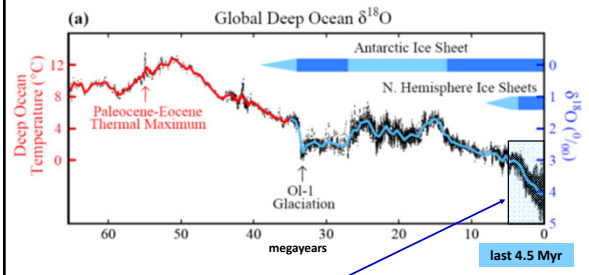

The Last 4.5 Million Years

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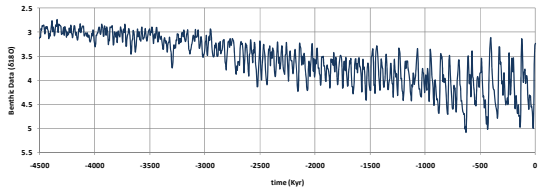
^{18}O in Foraminifera Fossils During the Past 4.5 Myr



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.

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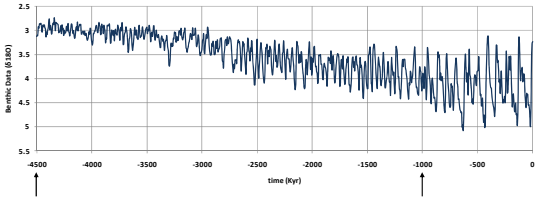
^{18}O in Foraminifera Fossils During the Past 4.5 Myr



Dec 31
3:15pm

Dec 31
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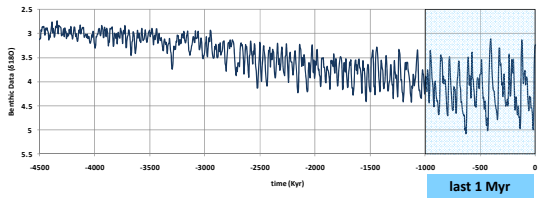
^{18}O in Foraminifera Fossils During the Past 4.5 Myr



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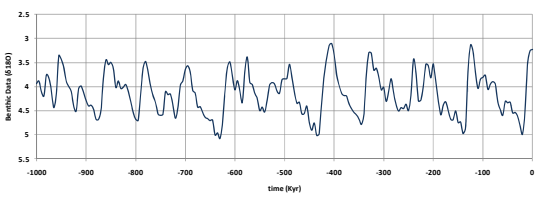
^{18}O in Foraminifera Fossils During the Past 1.0 Myr



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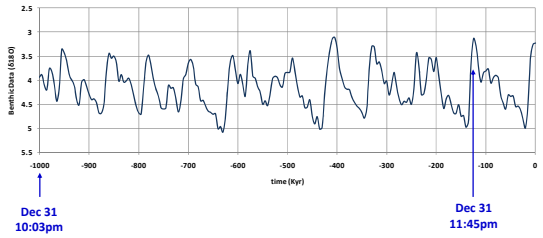
^{18}O in Foraminifera Fossils During the Past 1.0 Myr



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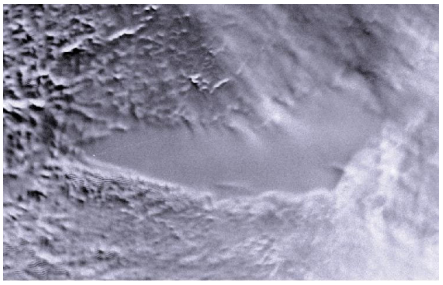
Lake Vostok



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

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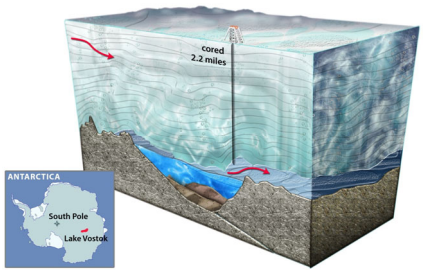
Lake Vostok



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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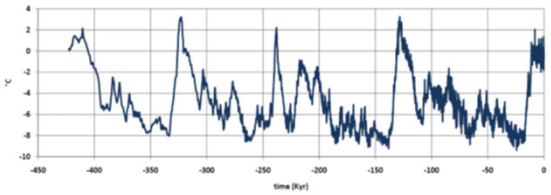
Recent (last 400 Kyr) Temperature Cycles
Vostok Ice Core Data



J.R. Petit, *et al* (1999) Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica, *Nature* 399, 429-436.

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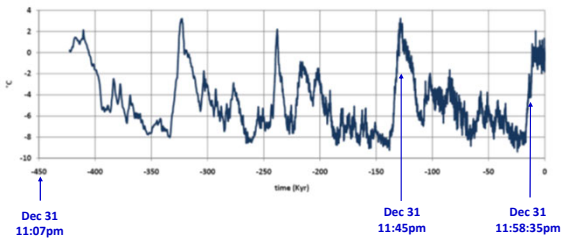
Recent (last 400 Kyr) Temperature Cycles
Vostok Ice Core Data



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event	years before present	Earth age = 1 year
end of last ice age	12,000 ybp	- 84 seconds
First Egyptian pyramid	4,800 ybp	-34 seconds
First Chinese dynasty	4,000 ybp	-28 seconds
0 AD	2,024 ybp	-14 seconds
Norman Conquest	956 ybp	-7 seconds
Declaration of Indepedence	248 ybp	-1740 milliseconds
Industrialization (280ppm)	163 ybp	-1140 milliseconds
Atomic Age	79 ybp	-550 milliseconds
Mauna Loa (315ppm)	66 ybp	-460 milliseconds
350 ppm	37 ybp	-260 milliseconds
400 ppm	8 ybp	-56 milliseconds

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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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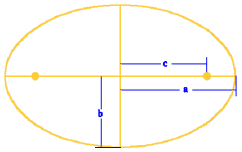
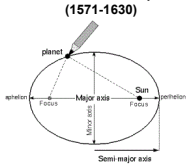
Earth's Orbit

Kepler's First Law: The orbit of every planet is an ellipse with the Sun at one of the two foci.



Eccentricity = c/a

Johannes Kepler (1571-1630)



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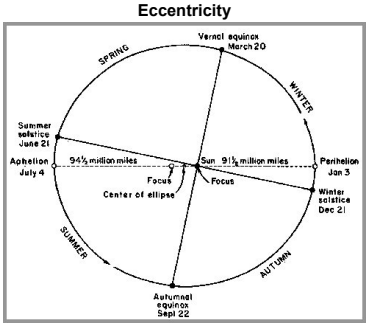
Eccentricity



John Imbrie & Katherine Palmer Imbrie, *Ice Ages: Solving the Mystery,* Harvard Univ. Press, 1979.