Class 11: Pleistocene (11.7 ka – 2.5 Ma) Climate Change

- What has climate done over the past ~2.5 million years?
- What mechanisms explain the observed climate change?

Learning Objectives

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4. Explain why orbital cycles cannot explain the last 100 years of climate change
The world needs a massive carbon tax in just 10 years to limit climate change, IMF says

The international organization suggests a cost of $75 per ton by 2030.

The group found that a global tax of $75 per ton by the year 2030 could limit the planet’s warming to 2 degrees Celsius (3.6 degrees Fahrenheit), or roughly double what it is now. That would greatly increase the price of fossil-fuel-based
If Power Shutoffs Are the New Normal in California, PG&E Needs to Do More than Provide Charging Stations

“What are we learning from this? Because this is crazy.”

MARISA ENDICOTT
Fellow
Bio

“I’m frustrated. I’m angry,” Joanie, who lives in the Oakland hills, tells me in the parking lot. “What are we learning from this? Because this is crazy.” She doesn’t completely trust PG&E’s stated reasons for shutting off the electricity, hinting it might have something to do with the financial losses it’s incurred due to fires and litigation. The company declared bankruptcy in January after its role in sparking recent wildfires led to lawsuits and major payouts.
Digital Petition

As climate change continues to accelerate, it is becoming increasingly urgent to ensure that we, as a university, are doing all that we can to minimize our contribution to the rising climate. This is why we— as students, staff, and faculty of this university— are demanding the University of Vermont to divest all holdings in the fossil fuel industry.
Temperatures of the Last 10,000 Years
(Ice core data from Crete site in central Greenland)

- Holocene Climate Optimum
- Roman Climate Optimum
- Medieval Warm Period
- Modern Warm Period
- Little Ice Age
- End of Last Ice Age

Daansgaard (1984), Avery (2009)
Review: Paleoclimate – Industrial & Holocene

The graph illustrates temperature variations from 1000 to 2000 AD, showing periods of Medieval climatic optimum and Little Ice Age. Temperature curves are presented for different regions:
- Northern Hemisphere (Full hemisphere, annual)
- Central England
- Northern Hemisphere (Extratropical, summer)
Scientists Measure Maya Drought With “Fossil Water”
Global-scale temperature patterns and climate forcing over the past six centuries

Michael E. Mann*, Raymond S. Bradley† & Malcolm K. Hughes†

* Department of Geosciences, University of Massachusetts, Amherst, Massachusetts 01003-5820, USA
† Laboratory of Tree Ring Research, University of Arizona, Tucson, Arizona 85721, USA

Spatially resolved global reconstructions of annual surface temperature patterns over the past six centuries are based on the multivariate calibration of widely distributed high-resolution proxy climate indicators. Time-dependent correlations of the reconstructions with time-series records representing changes in greenhouse-gas concentrations, solar irradiance, and volcanic aerosols suggest that each of these factors has contributed to the climate variability of the past 400 years, with greenhouse gases emerging as the dominant forcing during the twentieth century. Northern Hemisphere mean annual temperatures for three of the past eight years are warmer than any other year since (at least) AD 1400.
Today’s Class: Paleoclimate – The Pleistocene

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- Last Glacial Maximum to the Holocene
- The Last 150,000 Years
- The ‘Sawtooth’ Climate Pattern
- Pleistocene Comparisons to Present Climate
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Last Glacial Maximum to the Holocene

The Last 150,000 Years

The ‘Sawtooth’ Climate Pattern

Pleistocene Comparisons to Present Climate
Last Glacial Maximum (~29-20 ka) to the Holocene

- BIG changes once we look past the Holocene
- Big ice sheets over North America, Scandinavia, Eurasia at Last Glacial Maximum
- Sea level ~130 m lower than today
- Global temp ~3.5°C lower than today

Figure from Stokes (2017)
Last Glacial Maximum (~29-20 ka) to the Holocene

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Last Glacial Maximum (~29-20 ka) to the Holocene

- Global rise in temperature and CO$_2$ from LGM to Holocene
- Rising incoming solar radiation in key areas can explain some of the warming
- What about the weird ups and downs?
- What explains CO$_2$ rise?

Figure from Shakun et al. (2012)
Last Glacial Maximum (~29-20 ka) to the Holocene

Figure from Shakun et al. (2012)
• Global rise in temperature and CO\(_2\) from LGM to Holocene

• Rising incoming solar radiation in key areas can explain some of the warming

• What about the weird ups and downs?

• What explains CO\(_2\) rise?

Figure from Shakun et al. (2012)
Last Glacial Maximum (~29-20 ka) to the Holocene

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Last Glacial Maximum (~29-20 ka) to the Holocene

Figure from Muschitiello et al. (2019)
Last Glacial Maximum (~29-20 ka) to the Holocene

Figure from Ritz et al. (2013)
Last Glacial Maximum (~29-20 ka) to the Holocene

- Meltwater from melting ice sheets disrupted the AMOC
- Less heat transported into North Atlantic with weak AMOC
- Periods of abrupt cooling and warming in North Atlantic during deglaciation
Last Glacial Maximum (~29-20 ka) to the Holocene

Figure from Shakun et al. (2012)
Last Glacial Maximum (~29-20 ka) to the Holocene

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Figure from Shakun et al. (2012)
Global warming preceded by increasing carbon dioxide concentrations during the last deglaciation
Reminder: Southern Ocean Upwelling

Wind-driven currents cause upwelling off the coast of Antarctica.
Deglaciation Change in Upwelling

Figure from Wu et al. (2018)
Deglaciation ‘Story’

1. Increasing insolation causes Northern Hemisphere ice sheets to begin shrinking
2. Meltwater into North Atlantic slows AMOC
3. North Atlantic cools, South Atlantic warms
4. Reduced Antarctic sea ice leads to increased upwelling (increasing carbon flux to atmosphere)
5. AMOC eventually recovers, causing more ice sheet melt
6. Repeat…
Jeremy Shakun is a paleoclimatologist based out of Boston College. His research focuses on how the cryosphere has influenced and responded to climate change in Earth’s past. He has had several important publications including the Deglacial CO$_2$ – Temperature relationship and a recent paper on the long-term stability of the East Antarctic Ice Sheet.
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Last Glacial Maximum to the Holocene

The Last 150,000 Years

The ‘Sawtooth’ Climate Pattern

Pleistocene Comparisons to Present Climate
The Last 150,000 Years

- Build-up to maximum glacial conditions (LGM)
- Climate changes driven by orbital forcing and feedbacks within the global climate system
- Example: expanding Antarctic sea ice reducing ocean-atmosphere carbon exchange, leading to further cooling

Figure from Kohfield and Chase (2017)
Revisiting Orbital Cycles

- Eccentricity
- Obliquity/Tilt
- Precession

100,000 years
41,000 years
23,000 years

Graph showing pCO2 (ppmv) and Antarctic relative temperature change over time (Age in ka).
Another feedback:
• Orbital-induced cooling causes ice to form around North Atlantic
• This means more water is being exported out of the Atlantic and staying on land
• This makes the North Atlantic saltier, enhancing downwelling
• This leads to more carbon being sequestered in the deep ocean, reducing atmospheric concentration
• Which leads to more cooling...

Figure from Kohfield and Chase (2017)
The Last 150,000 Years

- Ice sheets grow best when summer and winter are both mild
  - Less melting in summer, more precipitation in winter

- The last 150,000 years shows a full eccentricity cycle, with precessional swings getting milder and milder

- Periods of glacial buildup and retreat, but overall increase in glacial volume up to Last Glacial Maximum

Figure from Kohfield and Chase (2017)
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Long periods of glacial build-up (~80-100 kyr)

Rapid deglaciation (~10 kyr)

Product of both orbital forcing and internal climate feedbacks

Figure from Shulz and Zeebe (2006)
Sawtooth pattern was in ~41 kyr cycles until 1.1 – 0.9 million years ago, then it transitioned into ~100 kyr cycles.
Mystery: Mid-Pleistocene Transition

Hypothesis:

- At beginning of Pleistocene, lots of soft sediment (regolith) overlying North America

- Ice sheets forming on soft sediment were thinner, more mobile

- Ice sheets at this time more susceptible to changes in obliquity, deglaciation every ~41 kyr

Figure from Roy et al. (2004)
Hypothesis:

- After ~1 million years of repeated glaciations, soft sediment scraped off continents
- Ice sheets now forming on hard bedrock. Due to friction, ice sheets less mobile, grow thicker
- Ice sheets now could survive through obliquity changes, only deglaciate every ~100 kyr

Figure from Roy et al. (2004)
Sawtooth pattern was in ~41 kyr cycles until 1.1 – 0.9 million years ago, then it transitioned into ~100 kyr cycles.
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Question:

• Is the present global warming due to orbital cycles and/or natural climate system feedbacks?

• Peak insolation for 65°N summer was around 10,000 years ago

• According to our understanding of the Pleistocene, we should be entering into a glacial build-up period

• Our carbon emissions are pushing us in the other direction

Figure from Ganopolski et al. (2016)
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The Pleistocene...

- is characterized by glacial/interglacial cycles,
- that follow a regular pattern (the ‘sawtooth’),
- that are caused by both orbital forcing changes and natural feedbacks,
- which provide critical information about how Earth’s climate system work,
- and that confirm that natural forcings do not explain current warming.
Exam 1

• All three of us graded a series of 5 exams to calibrate and develop a key
  • Chris and Mae Kate graded most exams
• We created rubric with points for partial credit
  • Most people answered all questions
  • Essays were strong
Median = 80%, a bit low (I aim for 83-84)

163/172 passed (>60%)

Most in B range

Our bad, The exam was 1 question too long
Strategies for next exam

• Even though open book/open note, you need to study for several hours – not enough time to look things up in exam (by design)
• Make note sheets as you study and have them at exam
• Don’t lift sentences/phrases from web sites and the book; this is plagiarism. “Use quotation marks and a citation” (Halsted, 2019).
• Read all questions before answering; answer the ones you know well first and quickly; return later to those you know less well
• Put some answer down for every question.
• Follow length suggestions
If you would like to improve your score....

• You may **rewrite one of the short answer questions**
• You must submit your rewrite on blackboard **by Friday October 18 at midnight** – no extensions
• We will regrade whatever question you submit and **add it to your exam grade**
• **You are on your honor,** this must be your own work
If you don’t agree with how your exam was graded...

- Submit a written statement to Paul by email by Friday October 18, Midnight. Late statements not accepted.
- Comments must be stated by question number.
- In your statement for each question, explain exactly what it was that you don’t think was properly graded. If you have issues for more than one question, write a statement for each question.
- I will review your explanation(s) and then regrade each question you called out. Your grade may go up or it may go down on each question and on the exam.
Please come see us and others if you need help with study hints, accommodation, more time on tests.

https://www.uvm.edu/academicsuccess/student_accessibility_services

Student Accessibility Services