Class 15: Climate Models
• What’s a climate model and how do they work?
• How robust are climate models and what are their limitations?
• Why are historical and paleoclimate data so important for model testing and validation?

Learning Objectives
• Understand the general components of climate models and how they are constructed
• Understand what is meant by ‘Model Calibration’ and ‘Model Validation’
• Understand the tradeoffs that climate modelers face when designing models at high resolution, over large areas, and over long time scales
• Explain how data about past climates are used for model validation

GEOLOGY 095, 195. Climate: past, present, future
Exam Report

- We have cross calibrated and developed a rubric
- Most people finished the exam on time and completed all the questions.
- Hope to have grading done this week
- Backlog of quizzes and attendance, will get loaded this week
Students urge UVM to divest funds from fossil fuels

Greenland’s Oldest Ice and Sediment
University of Vermont
October 22-25, 2019

31 people, 5 countries, 17 institutions
INTRODUCTION
Basal organics include woody debris, which give us clues as to the vegetation and climate of the environment prior to ice initiation.

METHODS
- Pollen and Spores – Acetolysis & screening
  - Counting 300 pollen grains per sample at 400X magnification or more.
- Macrofossils – Screening with distilled water between 500 and 150 microns, picking under 60X magnification.

RESULTS
- Pollen and spores – no pollen!! Filtering? Oxidation?
  - Macrofossils - 2 moss species, 1 fungus
  - Dry environment, possibly calciphile
- Looking for Dryas, Empetrum, Salix, Betula

**Macrofossils so far:**
- *Cenococcum geophilum* (fungus... soil instability)
- *Tomenthypnum nitens*... calciphile or *Brachythecium* – Ca or not
- *Polytrichum juniperinum*

**Pollen so far from Filters...NONE! (frustrating!)**
But
Several stomates, More samples...

Adapted from Wilderness Inspire
Modern Greenland Shrubs

Carbon preference index > 3

Plants make even-chain lengths

Thomas et al., 2016
n = 4

% of total $n$-alkanoic acids

20 22 24 26 28 30 32 34
Camp Century basal till has a complex exposure history.

Minimum limiting ages:
- Burial: 600-900 kyr
- Exposure: 20-30 kyr

Assuming production ratio: 6.75
Assuming sea level production rate

It’s old. The organic matter is C14 dead.
“Both samples are small and both are essentially right at background: I guess the reactor techs washed their hands before they handled the ice core sections...” – John Southon

Implication: ice cover at Camp Century cannot be older than ~1 Ma. Till is not pre-Pleistocene.
All about Climate Models

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The foundation for climate models is 100 years old
Climate models are computer simulations of reality – they are NOT reality

- They vary from simple to complex – all are simplifications of reality
- Complexity has evolved over time
- Some processes (such as clouds) are difficult to parameterize
- Increases in computing efficiency have increased model resolution
- Climate models are now coupled to ocean, ice sheet, and solid Earth models
- All of this is done mathematically
Think - pair – share: Given what you know about climate forcings and feedbacks, list 5 interactions that needs to go into a climate/ocean/ice model of Earth.
Forcings and Feedbacks in the Climate System

Schematic view of the components of the climate system, their processes and interactions.

Image credit: IPCC Assessment Report 4
Run simple climate model (3 knobs, no feedbacks)

https://scied.ucar.edu/simple-climate-model

You can VARY
CO₂ emission
Climate sensitivity
Ocean absorption

\[ T = T_0 + S \log_2 \left( \frac{C}{C_0} \right) \]

- \( T \) is the new/current temperature
- \( T_0 \) is the known temperature at some reference time (for example, 14.3°C in the year 2000)
- \( S \) is the "climate sensitivity" factor; we've been using 3°C (more on that below); the temperature rise as a result of CO₂ doubling
- \( C \) is the new/current atmospheric CO₂ concentration
- \( C_0 \) is the known atmospheric CO₂ concentration at some reference time (must be the same time as \( T_0 \); 368 ppm in 2000 would match the \( T_0 \) example mentioned above)
These four names are based off the IPCC report they were used in (‘FAR’ = First Assessment Report)

FAR = 1990
SAR = 1995
TAR = 2001
AR4 = 2007
A Climate Modeling Timeline
(When Various Components Became Commonly Used)

1890s Radiative Transfer
1960s Non-Linear Fluid Dynamics
1970s Sea Ice and Land Surface
1990s Atmospheric Chemistry
2000s Aerosols and Vegetation
2010s Biogeochemical Cycles and Carbon

Energy Balance Models
Atmosphere-Ocean General Circulation Models
Earth System Models
Climate models

For decades scientists have been using mathematical models to help us learn more about the Earth’s climate. Known as climate models, they are driven by the fundamental physics of the atmosphere and oceans, and the cycling of chemicals between living things and their environment. Over time they have increased in complexity, as separate components have merged to form coupled systems.

Note: There were some very simplified models before the dates mentioned.
Climate models are computationally intensive – need massive computing power

The National Center for Atmospheric Research (NCAR) new supercomputer (called the ‘Cheyenne’) is the 10th most powerful supercomputer in the world. It has the equivalent computing power of ~2,900 Playstation 4’s. It is used exclusively to model climate.
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Verification – Is the math right, does the model work?
Check equations and code

Calibration – adjusting coefficients to get the right answering
Use a “training” data set, part of the record

Validation – Does the model represent reality correctly?
Check against historical and paleoclimate data sets

Model development and testing
All about Climate Models

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Models much break the Earth into lots of little boxes and then solve equations for energy and mass transfer between the boxes.
Grid size, the size of the boxes, is key for accurate representation
See how the representation of North America changes with grid size

T42 – 200 by 300 km boxes
T85 – 100 by 150 km boxes
and so on....

As a general rule, increasing the resolution of a model by a factor of two means about ten times as much computing power will be needed (or that the model will take ten times as long to run on the same computer).
There is now ample evidence that an inadequate representation of clouds and moist convection, or more generally the coupling between atmospheric water and circulation, is the main limitation in current representations of the climate system.
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• Explain how data about past climates are used for model validation/tuning
Models can be tested against data and thus validated. They work pretty well at the global scale.
Bette Otto-Bliesner is a Senior Scientist at the National Center for Atmospheric Research (NCAR) in Boulder, Colorado, Deputy Director of the NCAR Climate and Global Dynamics Laboratory, and serves as head of NCAR's Paleoclimate Modeling Program. Born in Chicago, Illinois, Otto-Bliesner first became interested in Meteorology as a child watching P.J. Hoff, the CBS affiliate weatherman.

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**Simulating Arctic Climate Warmth and Icefield Retreat in the Last Interglaciation**

Bette L. Otto-Bliesner,1* Shawn J. Marshall,2 Jonathan T. Overpeck,3 Gifford H. Miller,4 Aixue Hu,3 CAPE Last Interglacial Project members

In the future, Arctic warming and the melting of polar glaciers will be considerable, but the magnitude of both is uncertain. We used a global climate model, a dynamic ice sheet model, and paleoclimatic data to evaluate Northern Hemisphere high-latitude warming and its impact on Arctic icefields during the Last Interglacial. Our simulated climate matches paleoclimatic observations of past warming, and the combination of physically based climate and ice-sheet modeling with ice-core constraints indicate that the Greenland Ice Sheet and other circum-Arctic ice fields likely contributed 2.2 to 3.4 meters of sea-level rise during the Last Interglacial.
Bette asks the question, using coupled atmosphere, ocean, ice sheet models – what happened to the Greenland Ice Sheet the last time climate was as warm as today?

DNA in ancient ice suggests boreal forests in Greenland but when?
Model forcing, LIG = Last Interglacial, 130-120,000 years ago

- Temperatures similar to today
- Sea-level meters higher
- Ice sheets retreated dramatically

Solar radiation INCREASED in Northern Hemisphere summer

Annual AVERAGE solar radiation steady

Excess (over average) solar radiation

Latitude

At 125,000 years ago
Comparing the model to paleoclimate data

The paleoclimate data

The model results

How well do they match?
Sensitivity tests of the model – let’s test things on the computer

Ice removed from Greenland – too warm, so ice sheet survived

Massive meltwater release slows AMOC and cools ocean
Bette’s model results for the last interglacial

THINK- PAIR – SHARE

How do models indicate that the Greenland Ice sheet changed during the last interglacial period?

After **2000 years** of warming and melting

After **3000 years** of warming and melting

- **2.2 meters** of sea level
- **3.4 meters** of sea level
Why coupled climate/atmosphere/ice models matter – effects of Greenland Ice Sheet meltwater

Sea-level rise due to polar ice-sheet mass loss during past warm periods

A. Dutton¹, A. E. Carlson², A. J. Long³, G. A. Milne⁴, P. U. Clark⁵, R. DeConto⁶, B. P. Horton⁶,⁷, S. Rahmstorf⁸, M. E. Ray…
Sea level 125,000 years ago was +6-9 m; this is Boston at +2 m.
Next time - Projections I : Temperature, weather, sea level

Make sure to READ:

Mann, Chapter 3
Ruddiman, Chapter 20
Webpage: What Are Climate Models and How Accurate Are They?

QUIZ 3
Important points

- Advances in computing power have allowed climate models to include more physical processes and resolve dynamics at finer resolutions
  - There will always be some limitations (although they’ll get better with time):
    - **Tradeoff between model resolution, scale, and runtime**
      - Running a global-scale climate model at higher resolutions (small gridboxes) can take multiple years to simulate climate change until 2100
      - Using a lower resolution can allow much faster runtimes, allowing more simulations to be run with different parameters/settings
      - To resolve small-scale dynamics like clouds, we have to use models that only cover a small spatial area
        - For bigger models (global scale), we can’t resolve clouds and have to just assign a ‘cloud value’ (parameterization)
  - **Another limitation in models is our understanding of the climate system**
    - The strength of forcings and feedbacks are difficult to predict
      - Climate sensitivity to changing atmospheric carbon dioxide levels is still a big uncertainty
    - Predicting how parts of the climate system will change in the future requires knowledge of how they’ve changed during past periods of climate change
  - Climate models are often ‘tuned’ by simulating past periods of climate change and comparing the model outputs to paleoclimate data