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

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

Climate in the News

https://www.wcax.com/content/news/Students-urge-UVM-to-divest-funds-from-fossil-fuels--563921001.html

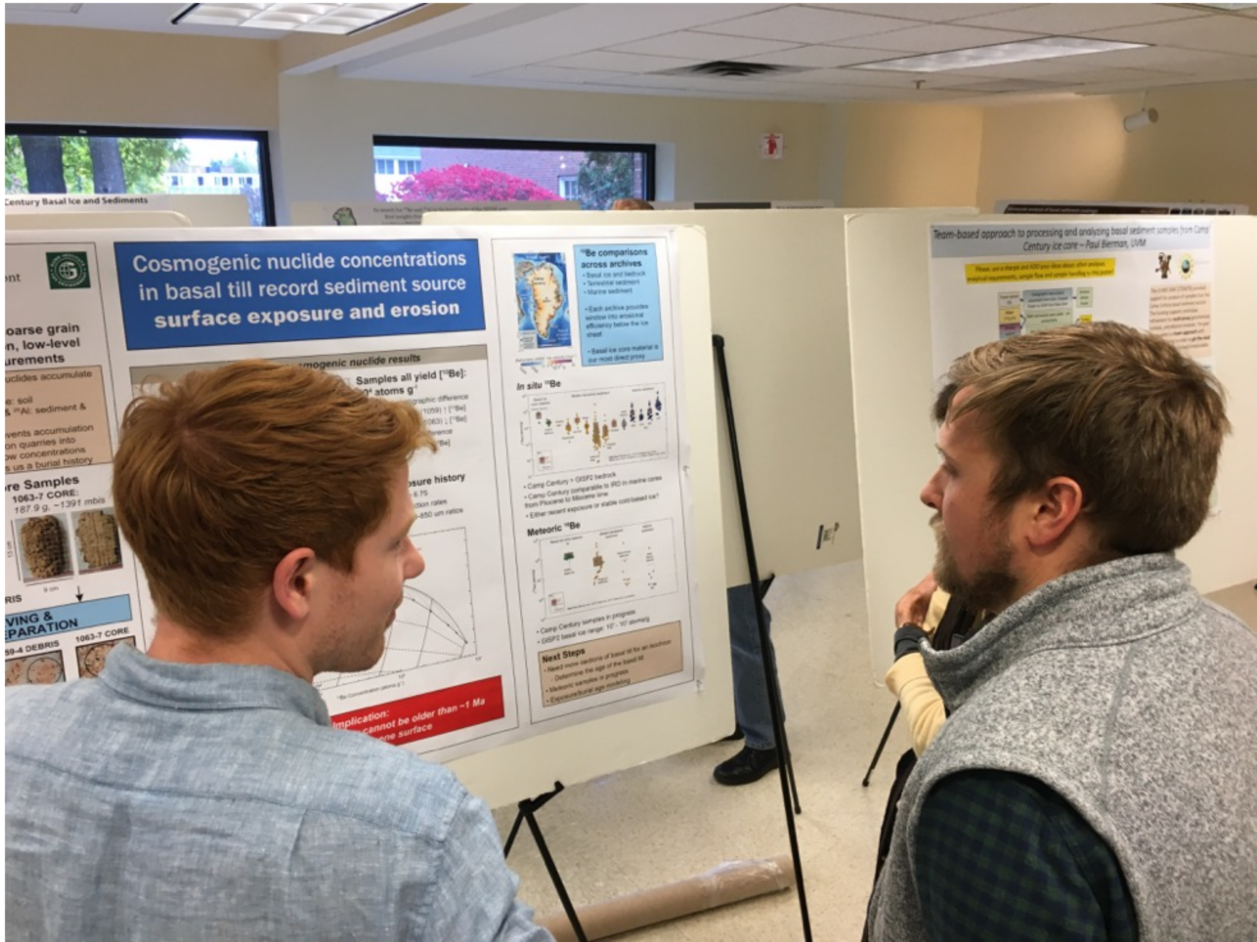
Greenland's Oldest Ice and Sediment

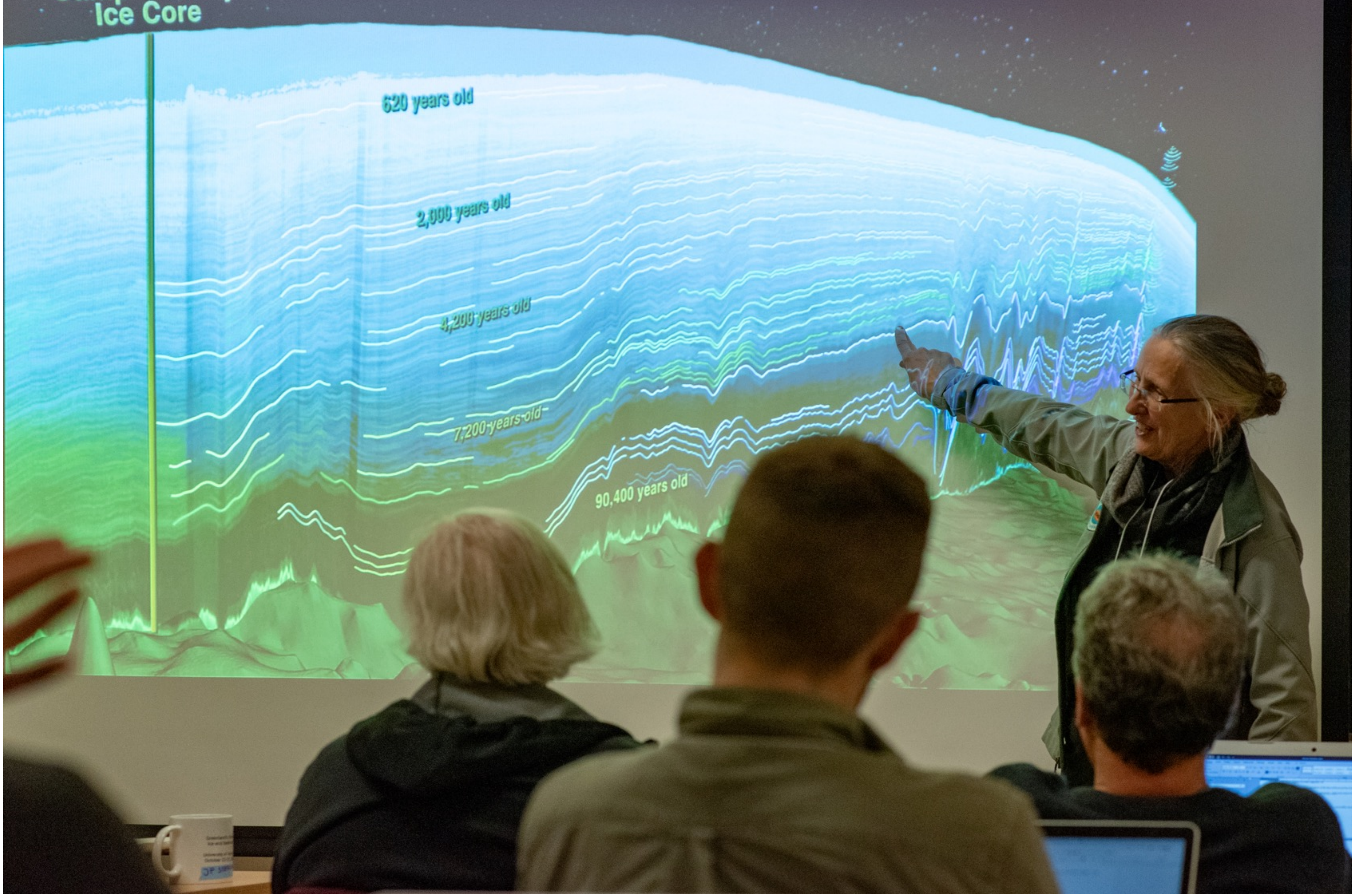
University of Vermont

October 22-25, 2019

31 people, 5 countries, 17 institutions


EXIT


Cosmogenic nuclide concentrations in basal till record sediment source surface exposure and erosion
Team-based approach to processing and analyzing basal sediment samples from Camp Century ice core – Paul Bierman, UVM
Next Steps


Ice Core
620 years old
2,000 years old
4,200 years old
7,200 years old
90,400 years old


Reserved

Dorothy Peteet, Lamont Doherty Earth Observatory, Columbia Univ.
Director of LDEO *Paleoecology Lab*

INTRODUCTION

Basal organics include woody debris, which give us clues as to the vegetation and climate of the environment prior to ice initiation.

METHODS

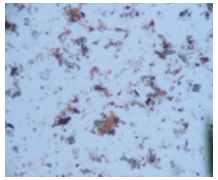
Pollen and Spores –
Acetolysis & screening
Counting 300 pollen grains per sample at 400X magnification or more.

Macrofossils –
Screening with distilled water between 500 and 150 microns, picking under 60X magnification.

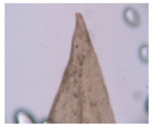
RESULTS

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

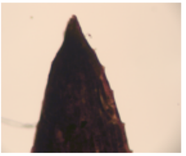
Macrofossils so far:



Cenococcum geophilum (fungus….**soil instability**

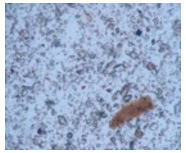


Tomenthypnum nitens?...calciphile or
Brachythecium – Ca or not



Polytrichum juniperinum
Dry environment
Woody debris

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



Adapted from Wilderness Inspire

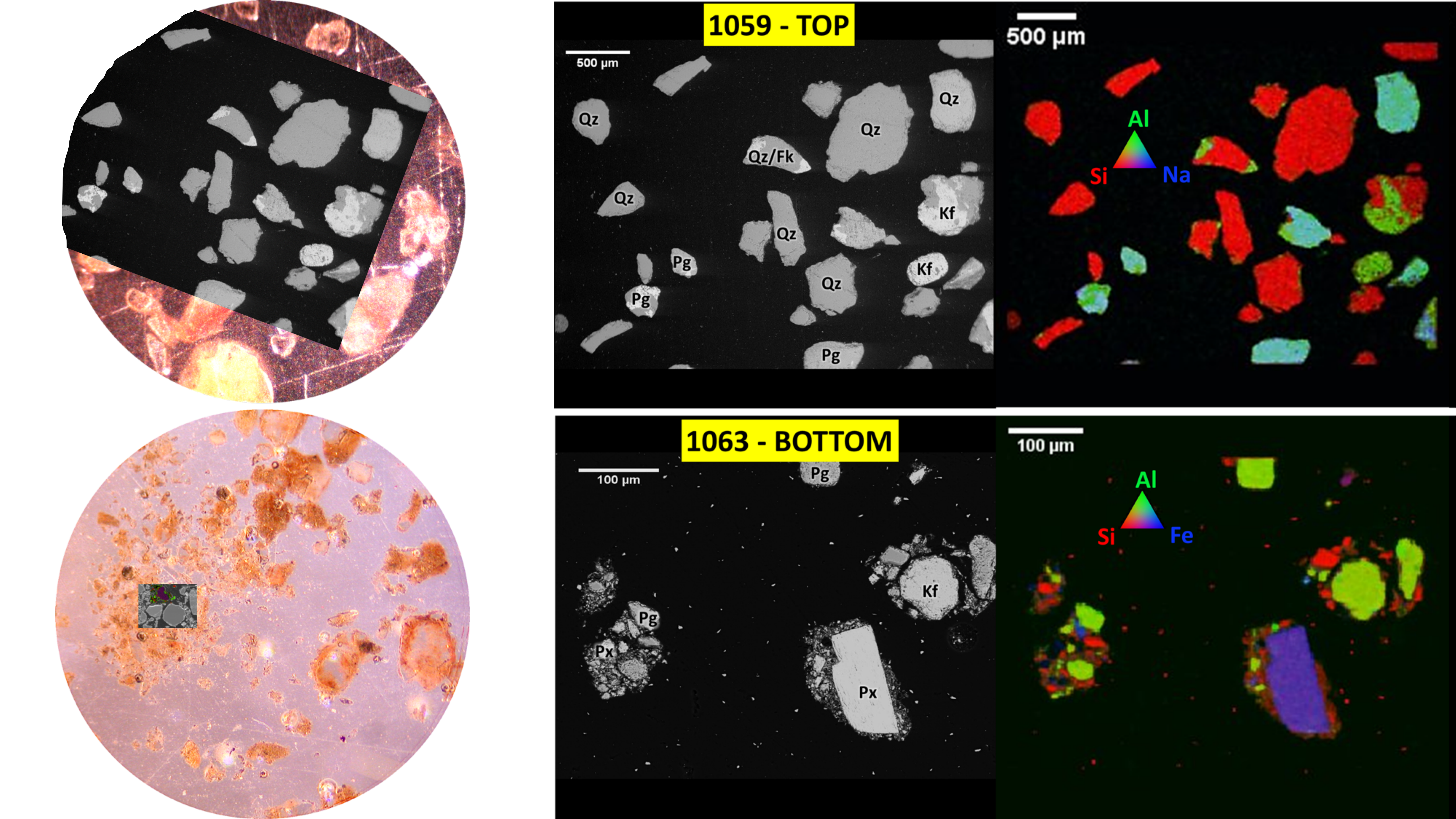
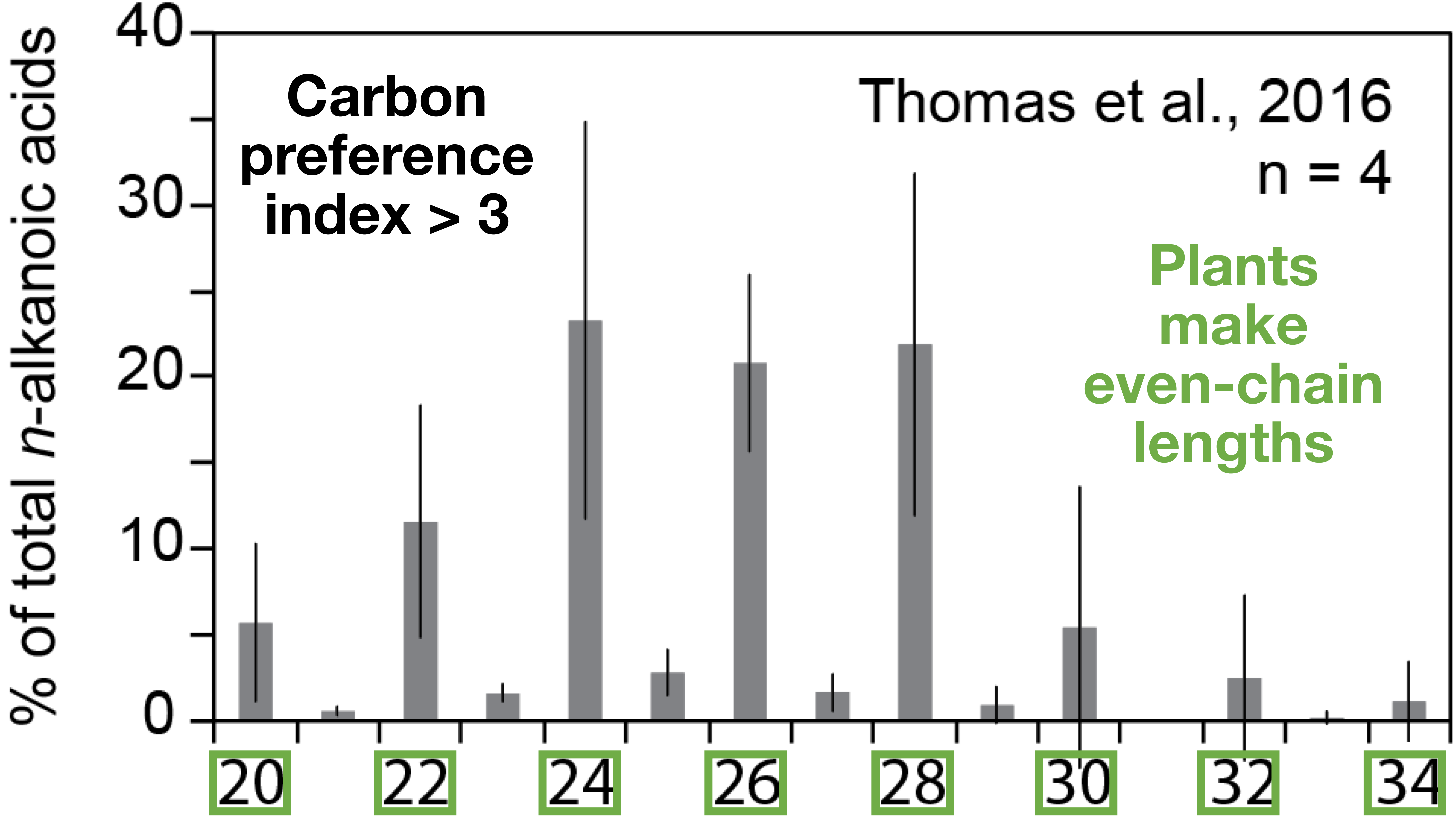
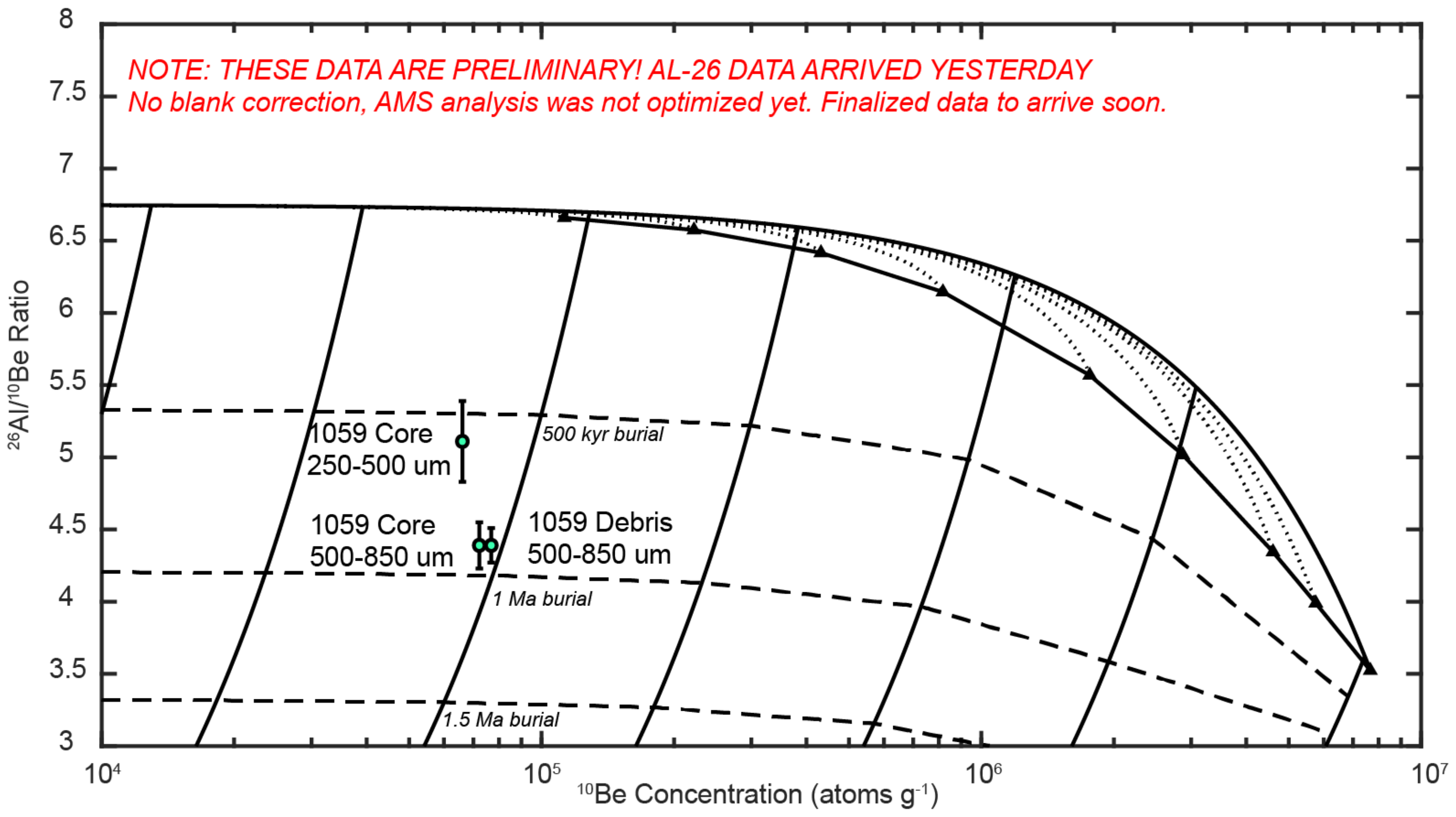

1059 - TOP
500 µm
Qz
Qz/Fk
Kf
Pg
500 µm
Al
Si
Na
1063 - BOTTOM
100 µm
Pg
Kf
Px
100 µm
Al
Si
Fe

Photo: I. Castañeda

Modern Greenland Shrubs



Camp Century basal till has a complex exposure history.



Minimum limiting ages:

Burial: 600-900 kyr

Assuming production ratio: 6.75

Exposure: 20-30 kyr

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

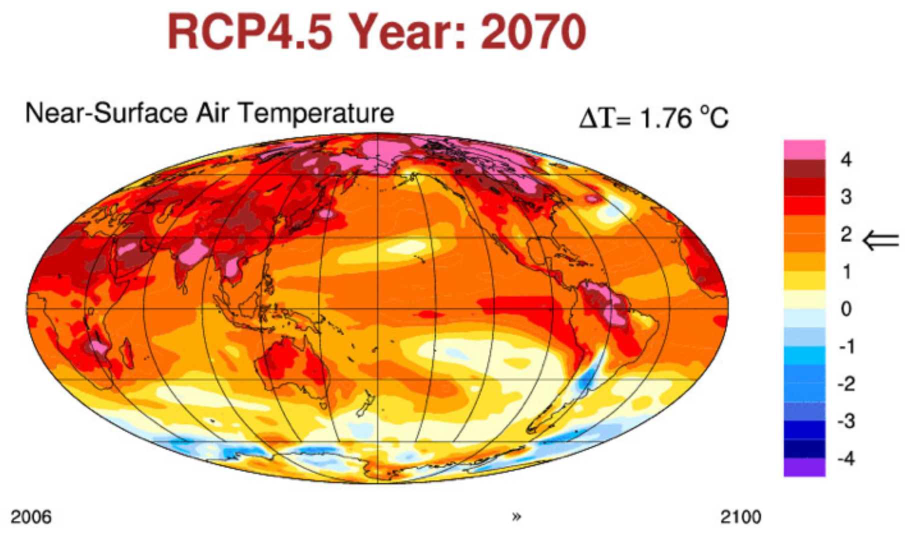
Implication: ice cover at Camp Century cannot be older than ~1 Ma. Till is *not* pre-Pleistocene.

All about Climate Models

- **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**

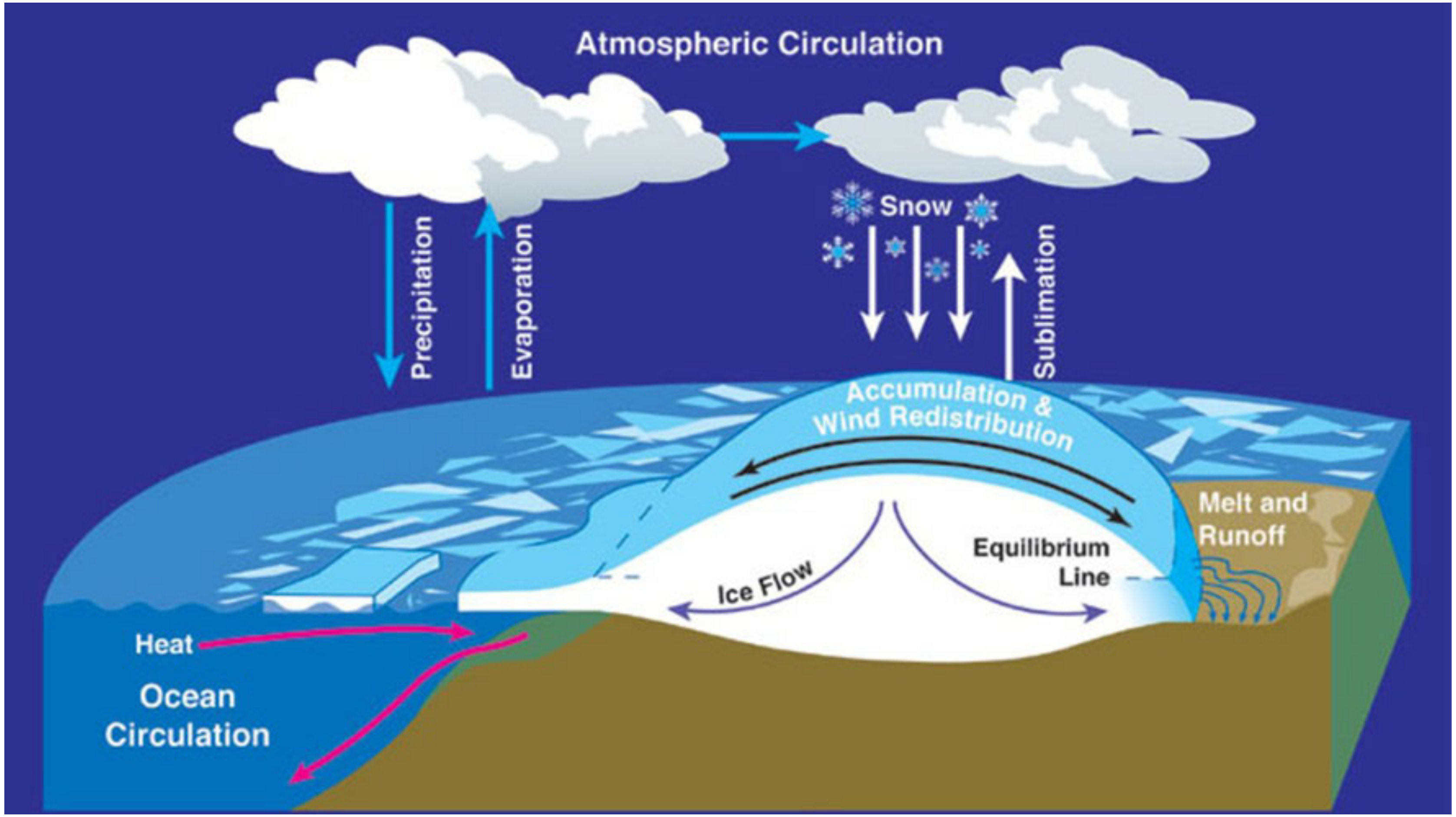
The foundation for climate models is 100 years old

Climate models are computer simulations of reality – they are NOT reality

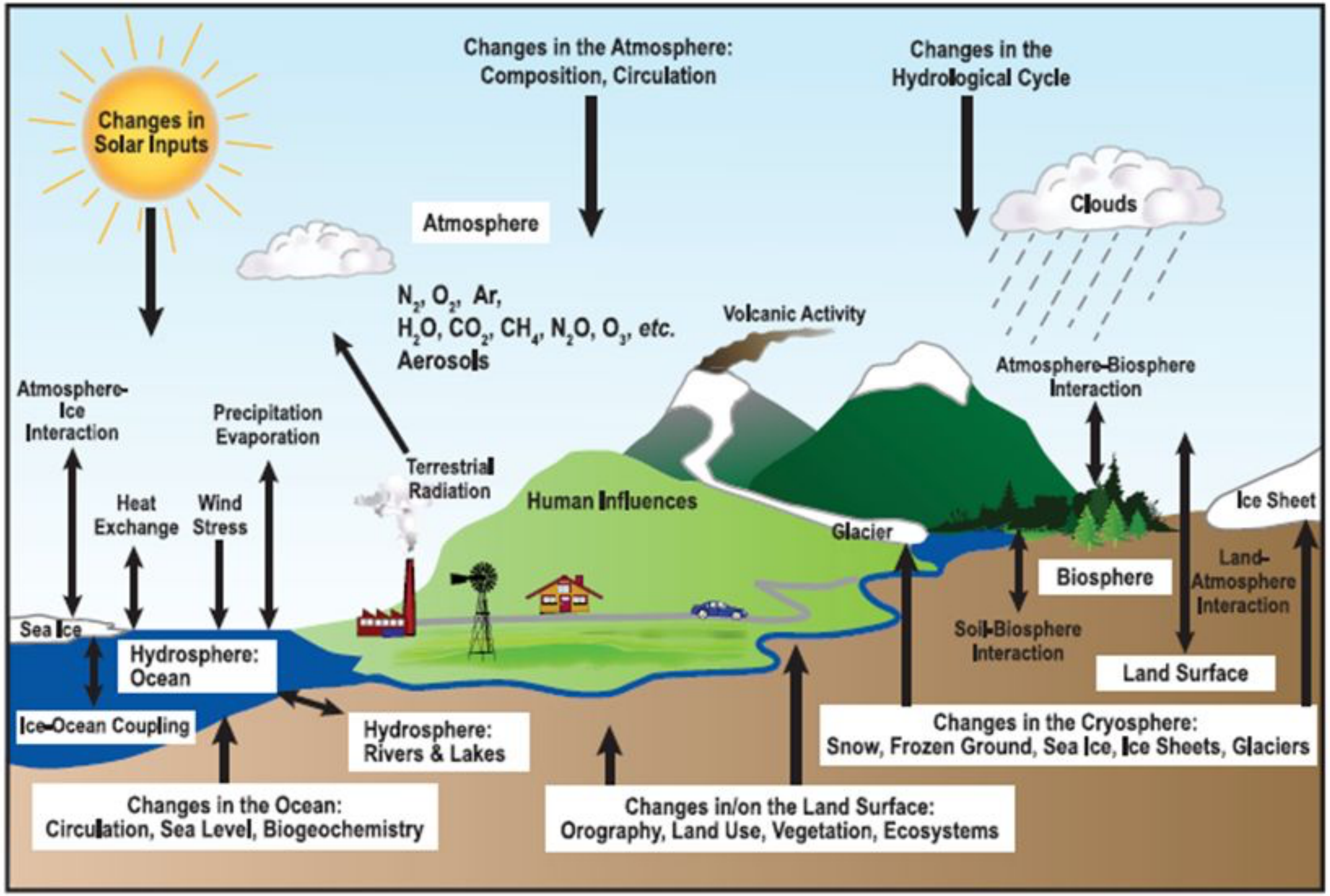


- They vary from simple to complex – all are simplifications of reality
- Complexity has evolved over time
- Some processes (such as clouds) are difficult to parameterize
- Increases in computing efficiency have increased model resolution
- Climate models are now coupled to ocean, ice sheet, and solid 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)

UCAR CENTER FOR SCIENCE EDUCATION

HOME TEACHERS STUDENTS LEARNING ZONE VISIT NCAR BLOG ABOUT

The Very, Very Simple Climate Model Activity

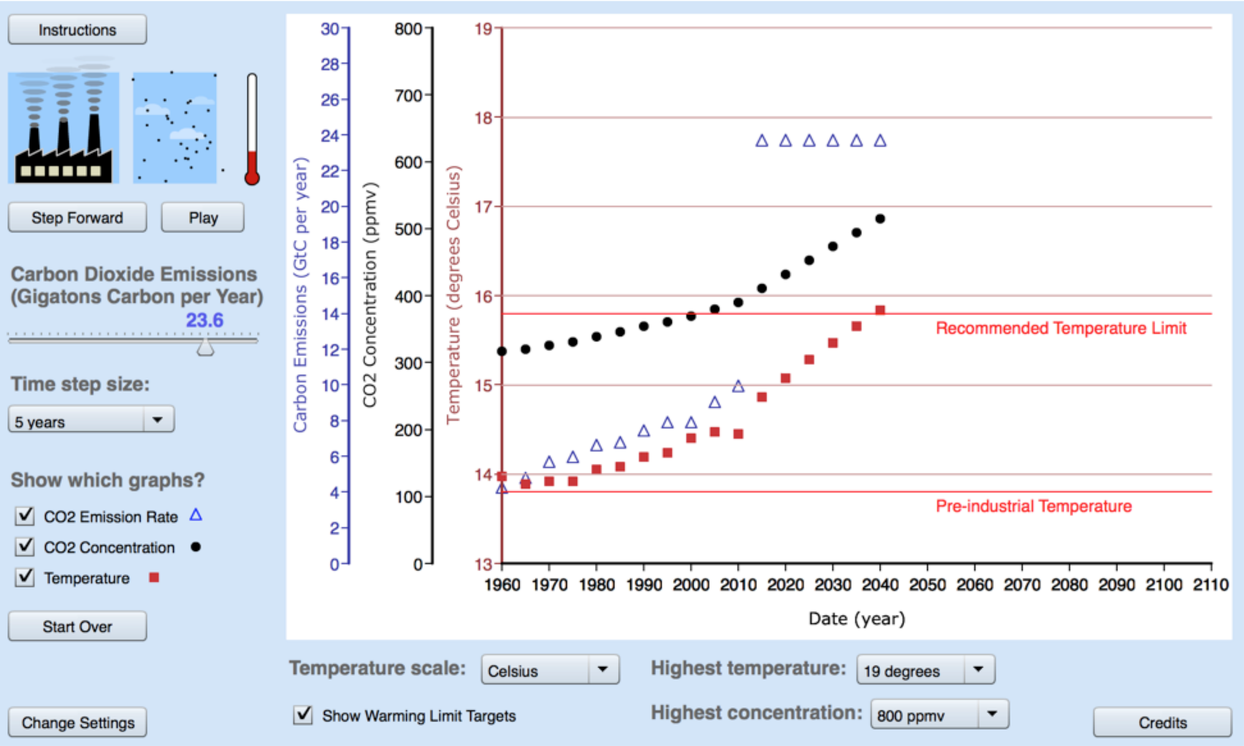
https://scied.ucar.edu/simple-climate-model

You can VARY

CO_2 emission

Climate sensitivity

Ocean absorption



$$T = T_0 + S \log_2 (C / C_0)$$

- T is the new/current temperature
- T_0 is the know 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 CO_2 doubling
- C is the new/current atmospheric CO_2 concentration
- C_0 is the known atmospheric CO_2 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)

The World in Global Climate Models

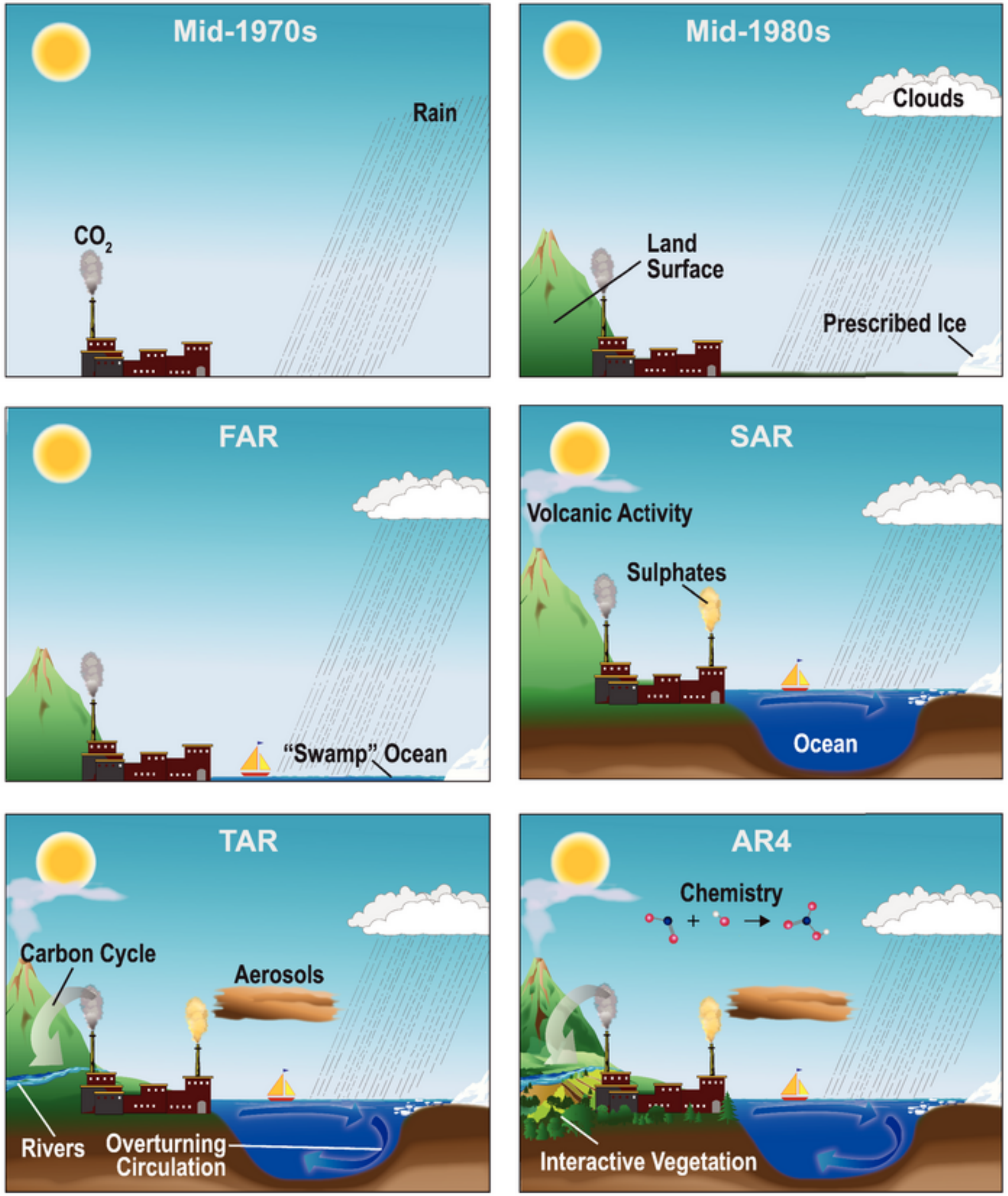
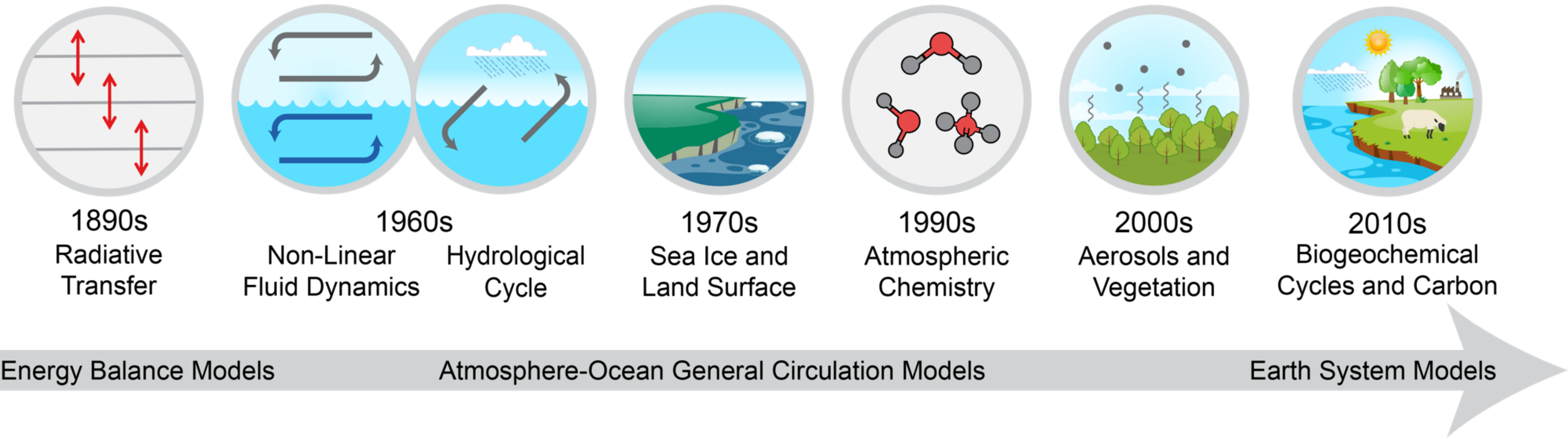


Figure from *CarbonBrief.org*

FAR = 1990
SAR = 1995
TAR = 2001
AR4 = 2007

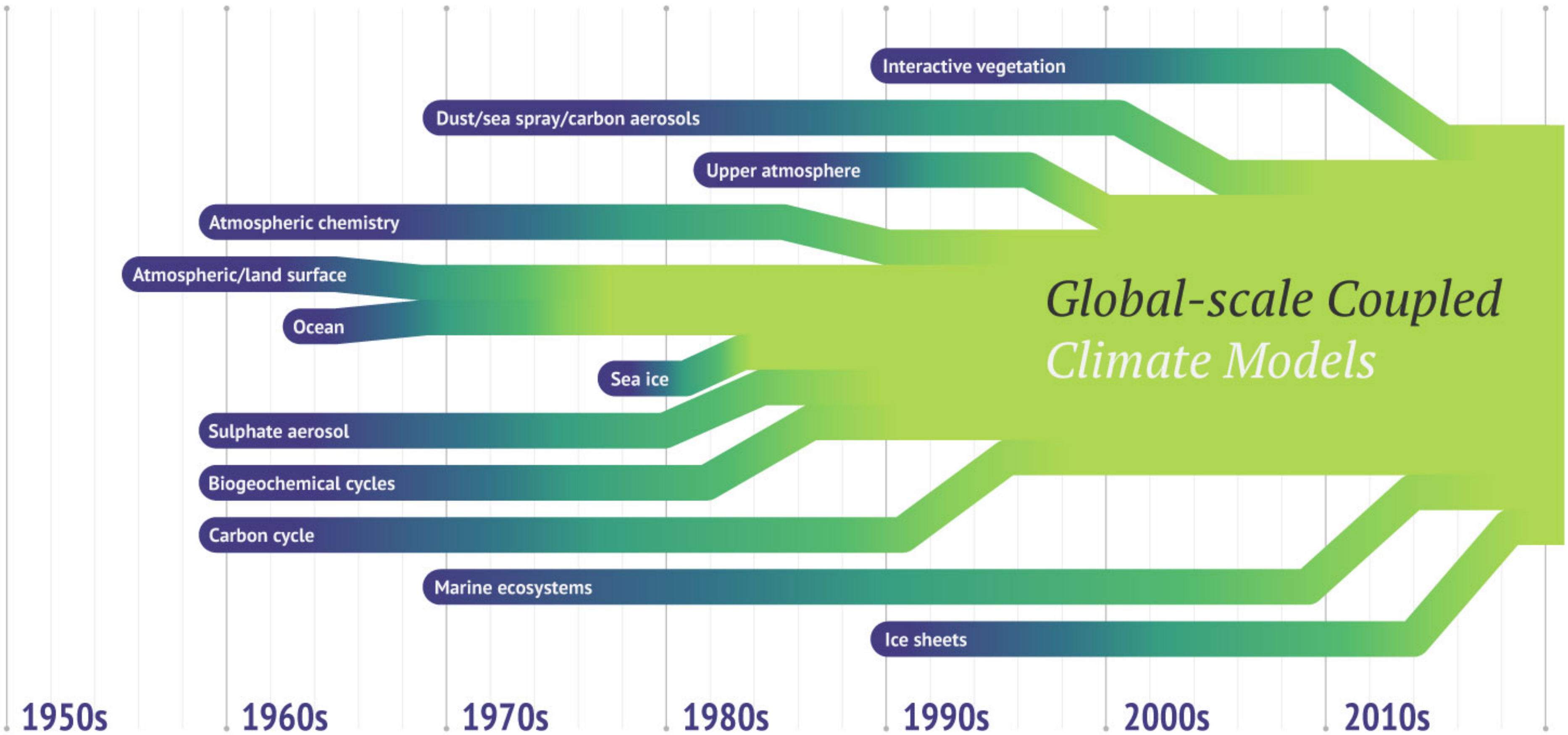
These four names are based off the IPCC report they were used in ('FAR' = First Assessment Report)

A Climate Modeling Timeline
(When Various Components Became Commonly Used)



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.

CarbonBrief
CLEAR ON CLIMATE

Climate models are computationally intensive – need massive computing power

The National Center for Atmospheric Research (NCAR) new supercomputer (called the ‘Cheyenne’)

It 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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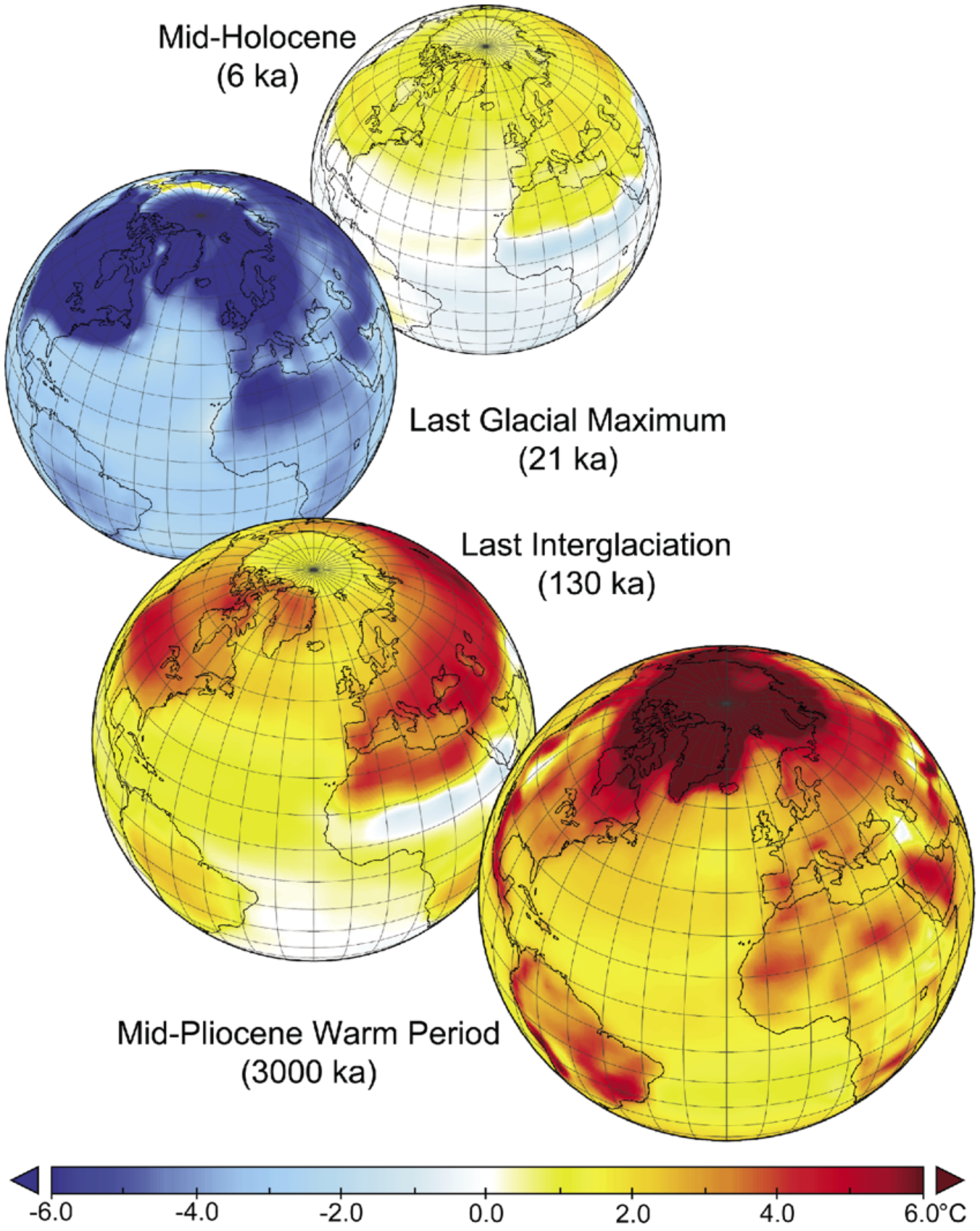
Model development and testing

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



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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.

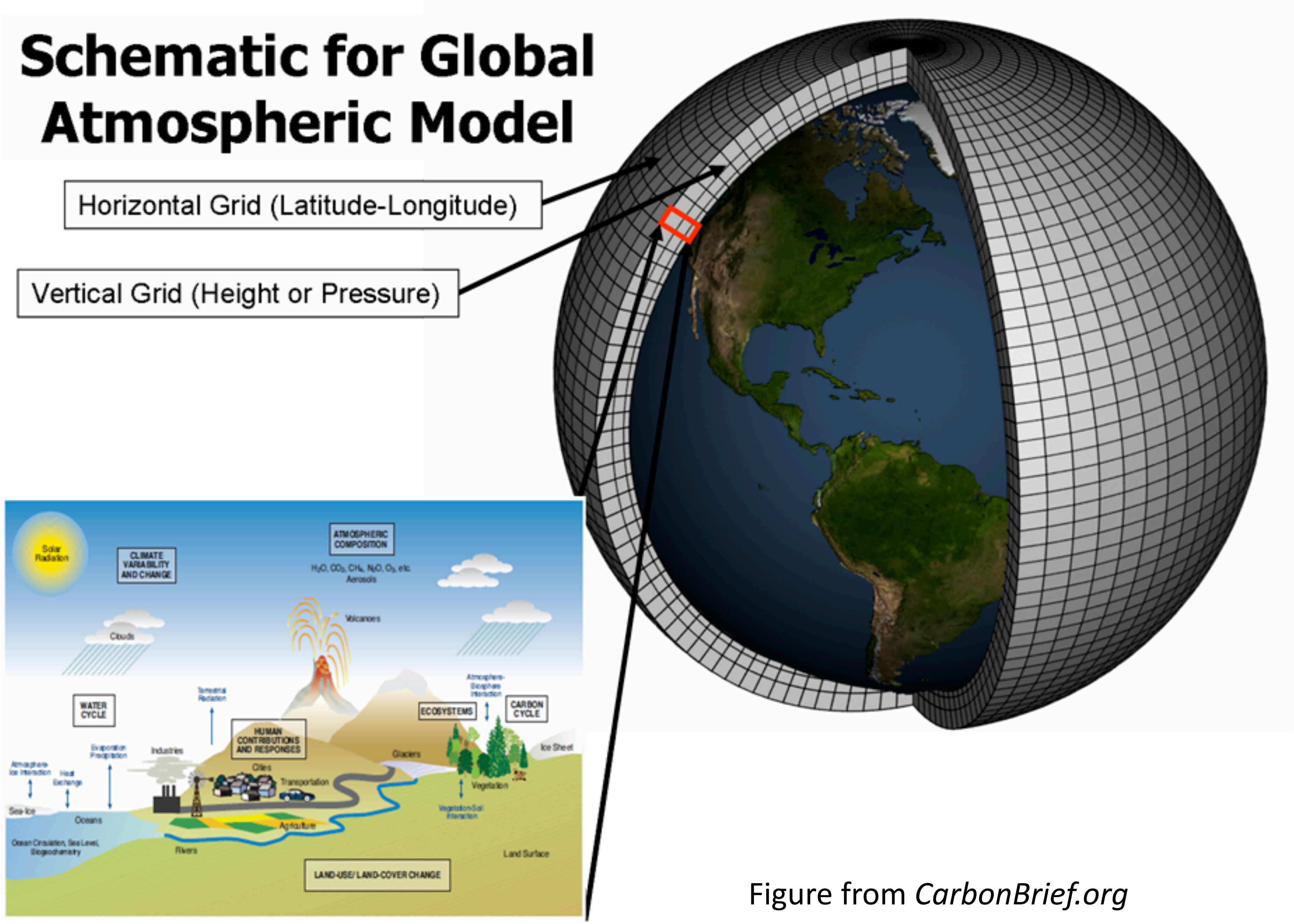
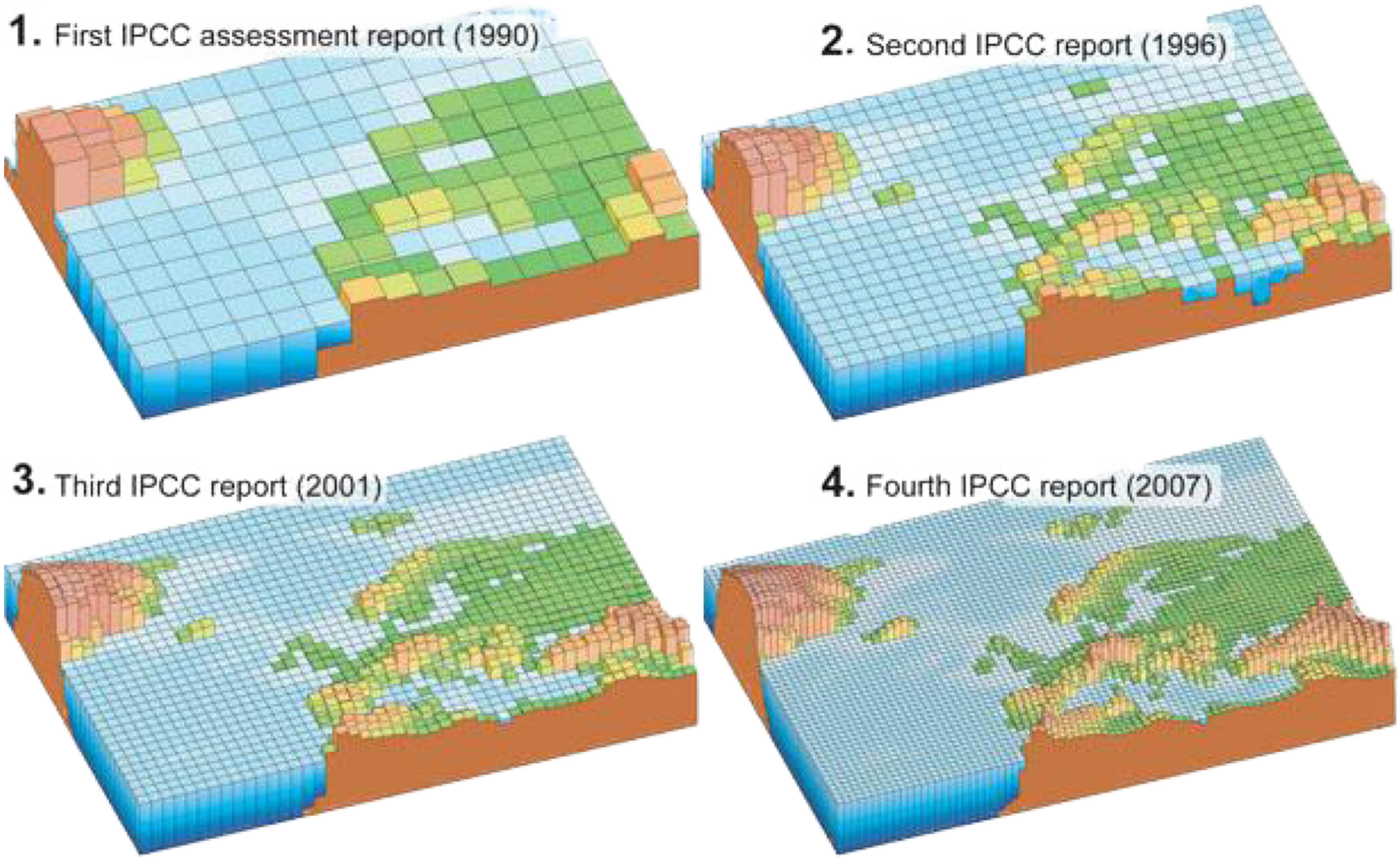


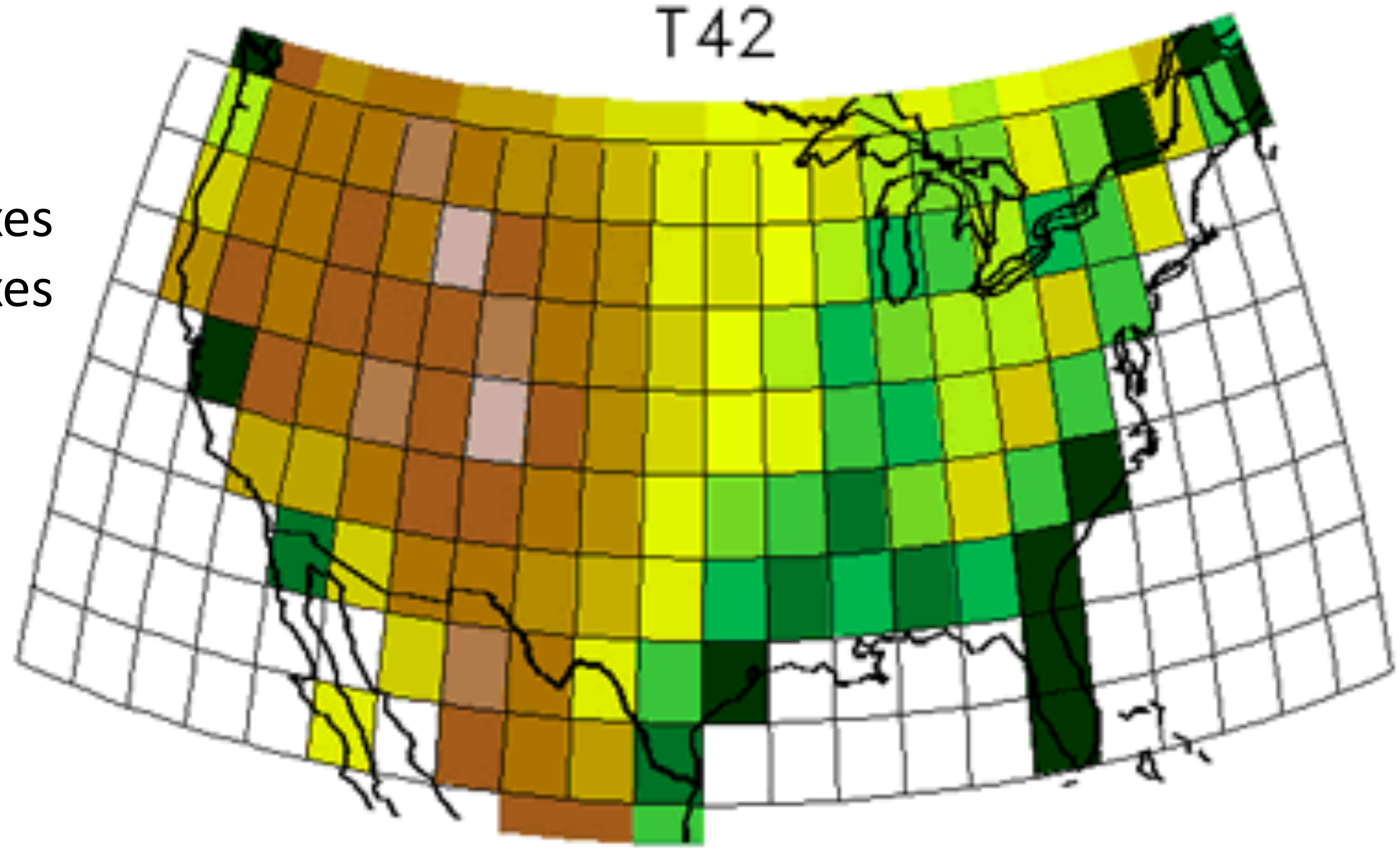
Figure from *CarbonBrief.org*

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).

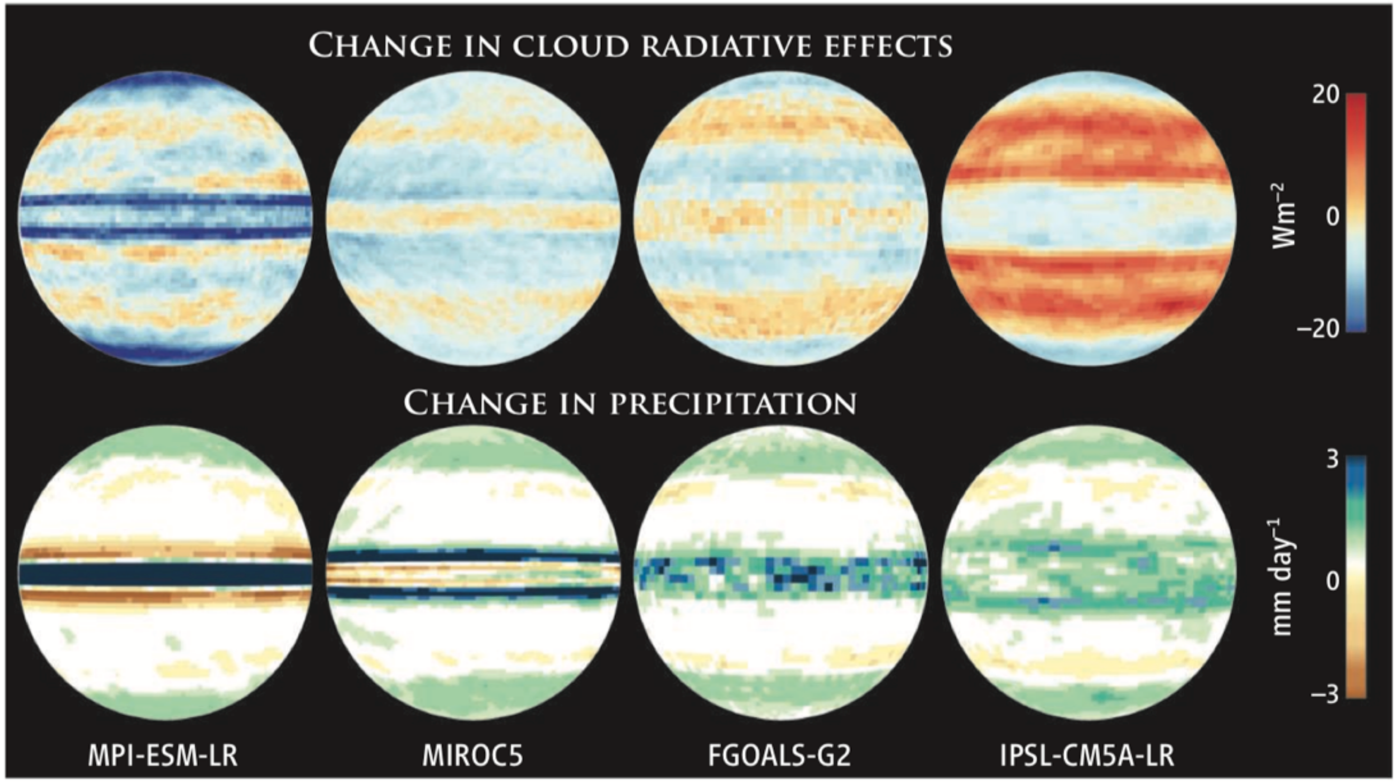
CLIMATE CHANGE

What Are Climate Models Missing?

A better representation of the coupling between atmospheric water and circulation is necessary to reduce imprecision in climate model projections.

Bjorn Stevens[1] and Sandrine Bony[2]

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.



Wide variation. The response patterns of clouds and precipitation to warming vary dramatically depending on the climate model, even in the simplest model configuration. Shown are changes in the radiative effects of clouds and in precipitation accompanying a uniform warming (4°C) predicted by four models from Phase 5 of the Coupled Model Intercomparison Project (CMIP5) for a water planet with prescribed surface temperatures.

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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 – Paleo climate/ice sheet modeler

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,[1] CAPE Last Interglacial Project members

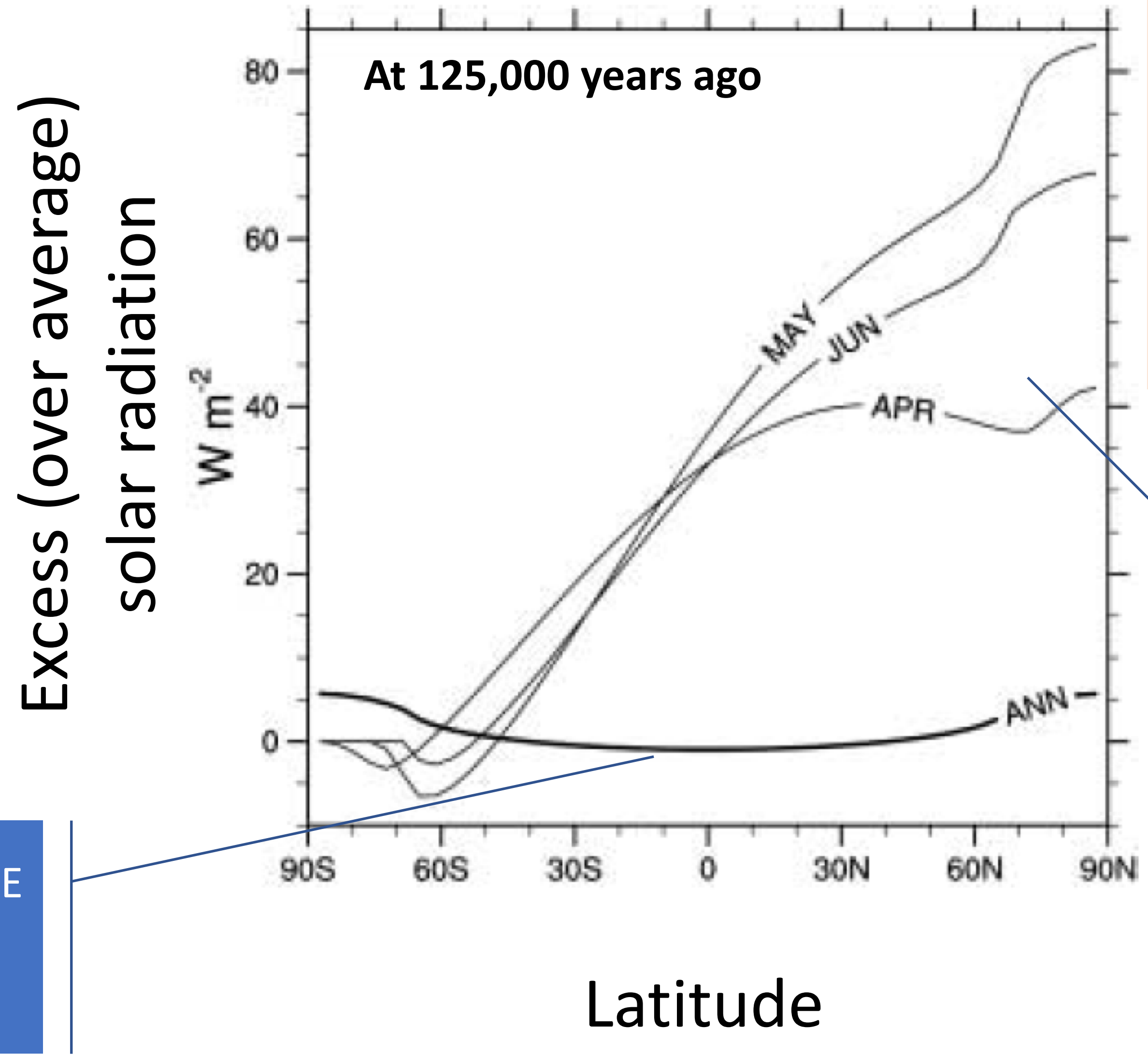
In the future, Arctic warming and the melting of polar glaciers will be considerable, but the magnitude of both is uncertain. We used a global climate model, a dynamic ice sheet model, and paleoclimatic data to evaluate Northern Hemisphere high-latitude warming and its impact on Arctic icefields during the Last Interglaciation. 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 Interglaciation.

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.

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**

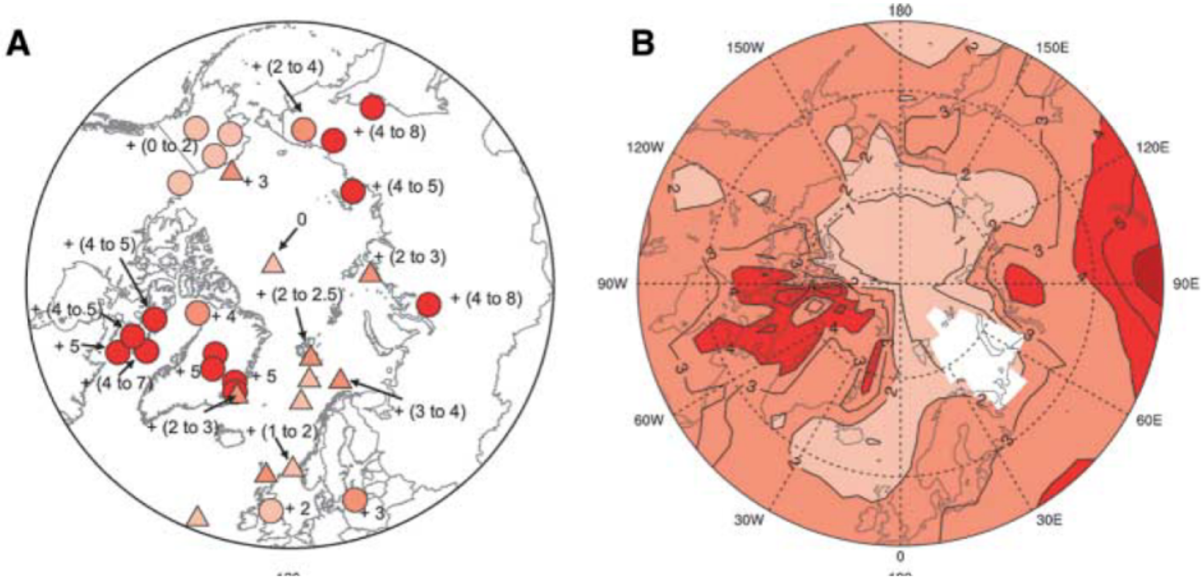
Annual AVERAGE solar radiation steady

Solar radiation INCREASED in Northern Hemisphere summer

Comparing the model to paleoclimate data

The paleoclimate data

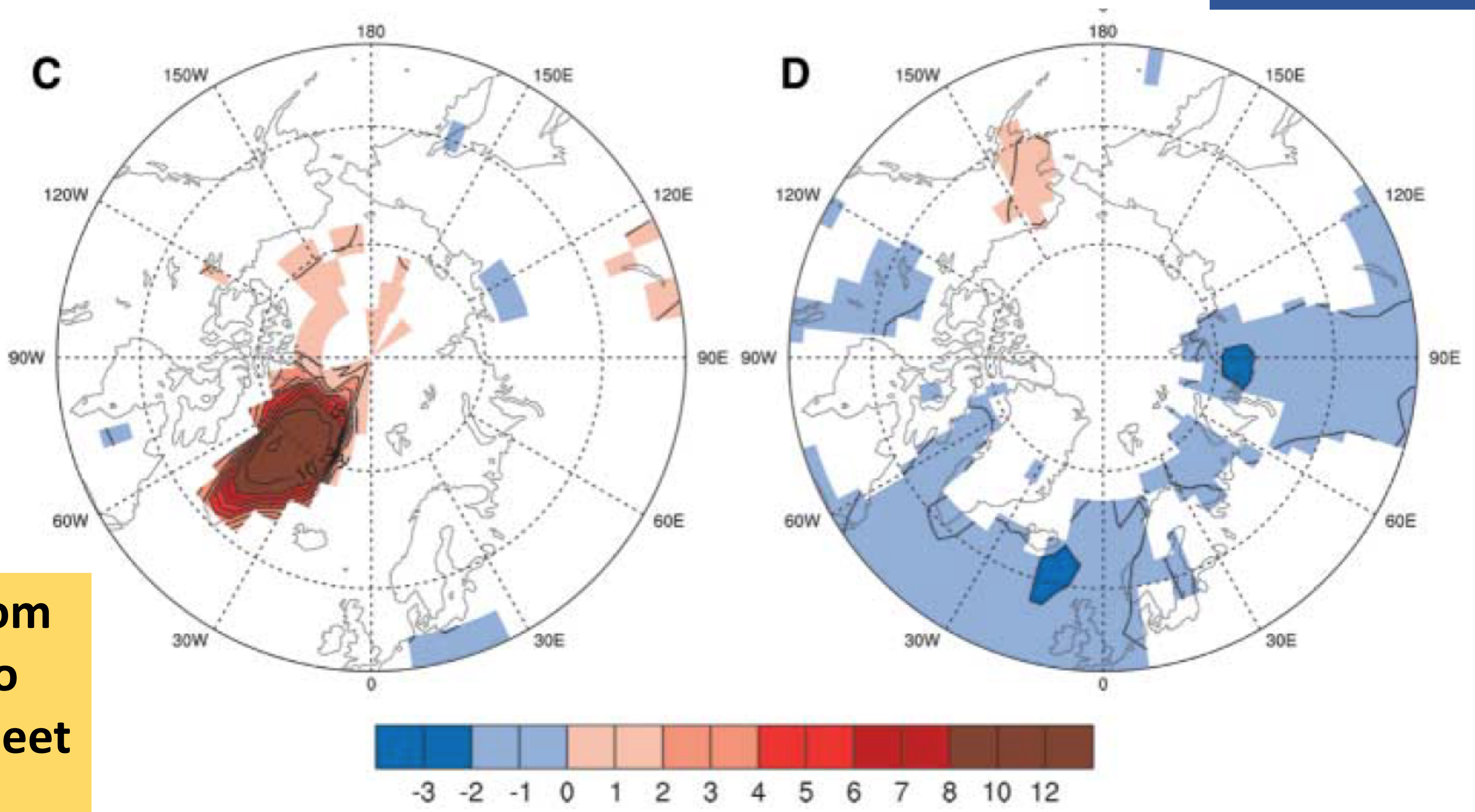
The model results



How well do they match?

Sensitivity tests of the model – let's test things on the computer

Massive meltwater release slows AMOC and cools ocean



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

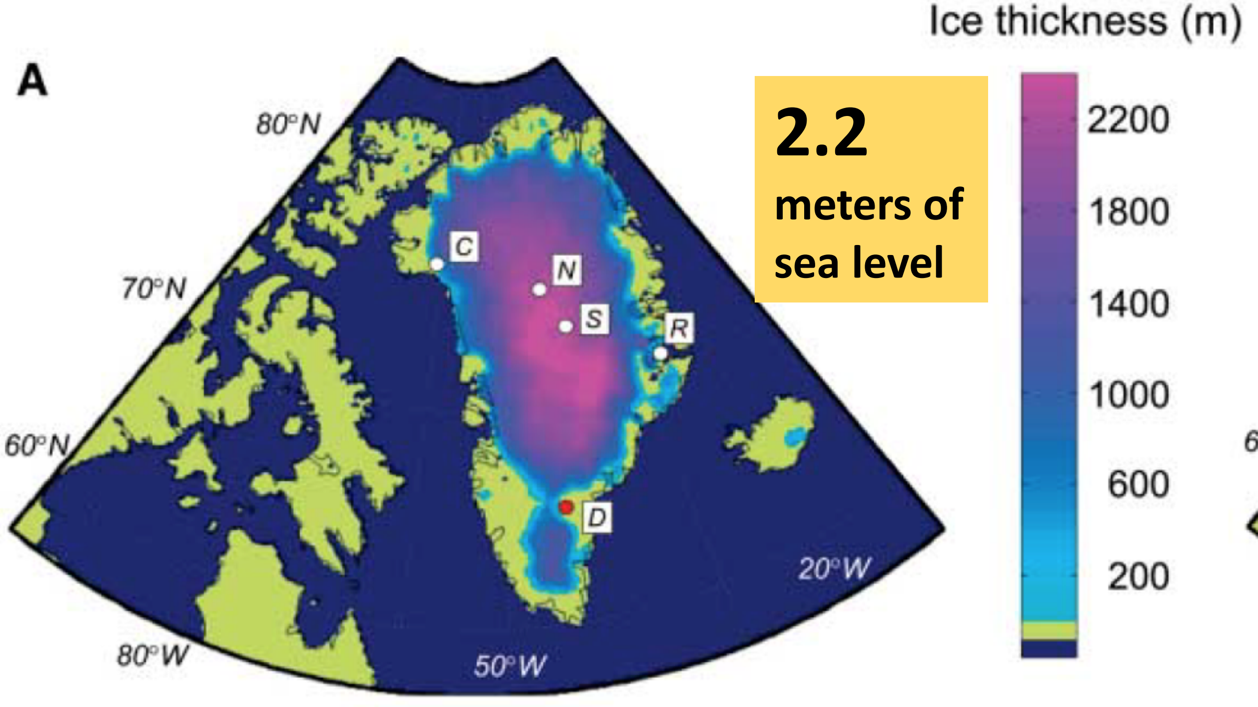
Bette's model results for the last interglacial

THINK- PAIR – SHARE

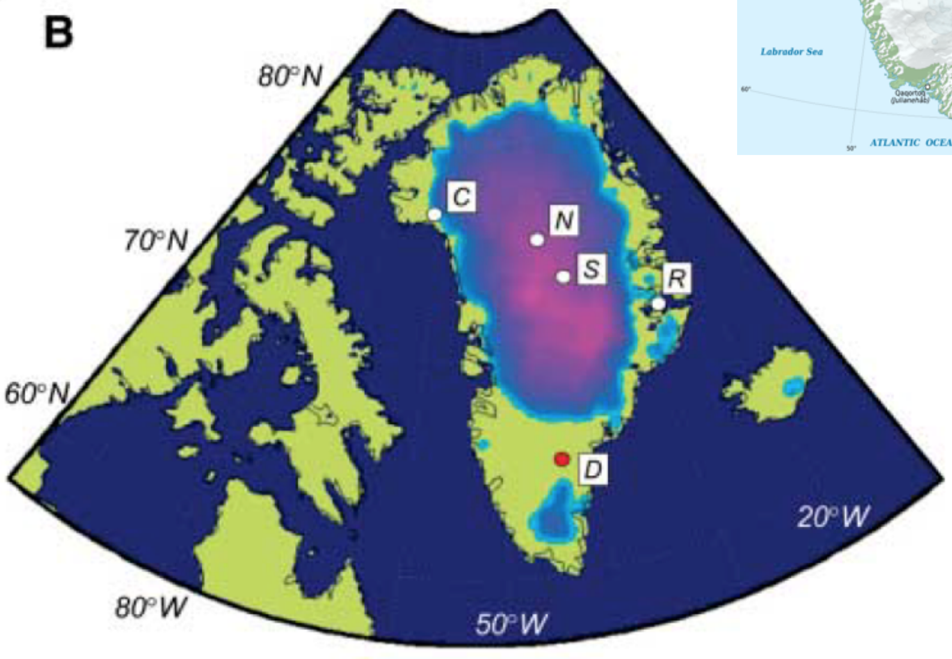
How do models indicate that the Greenland Ice sheet changed during the last interglacial period?

After **2000 years** of warming and melting

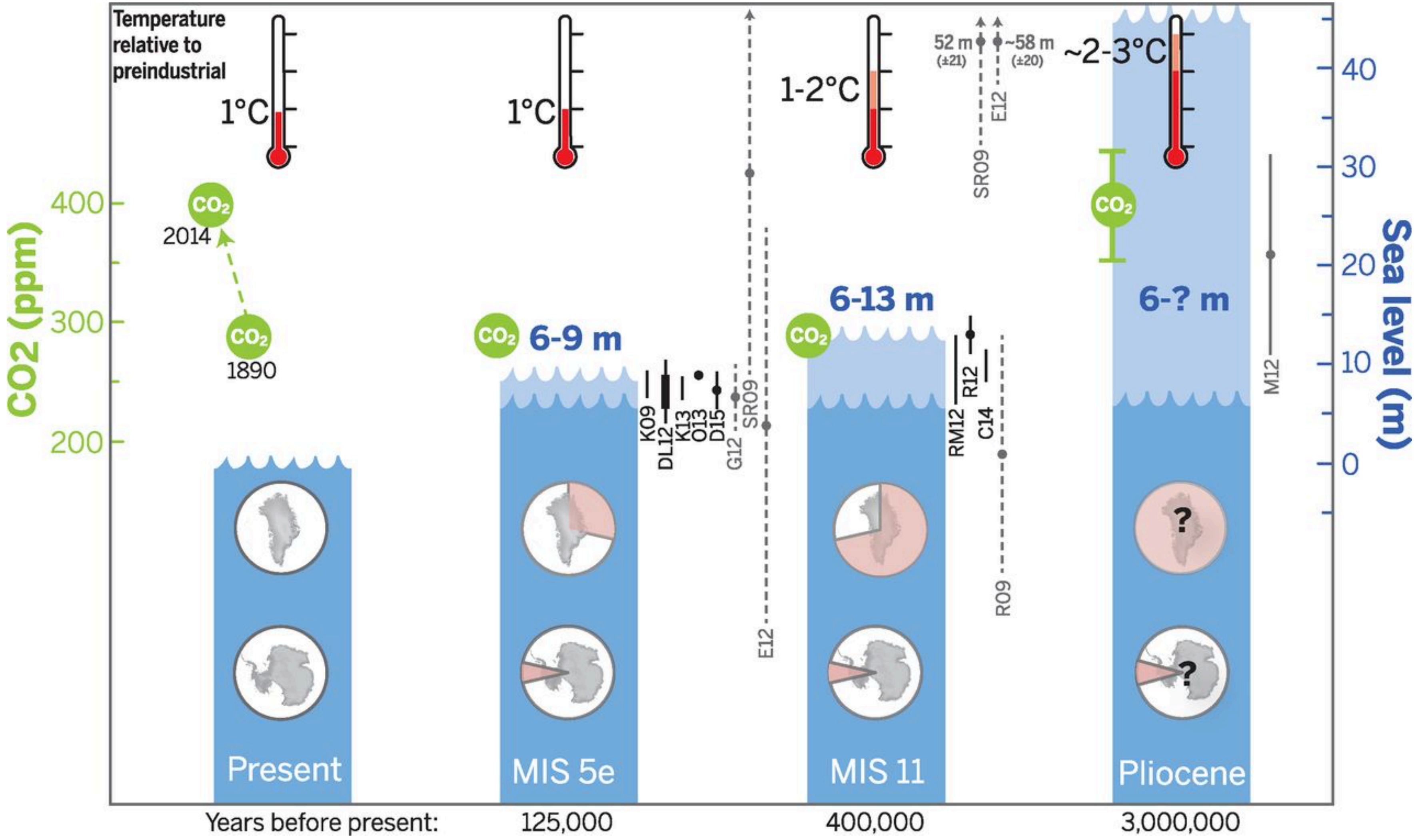
After **3000 years** of warming and melting



2.2
meters of sea level



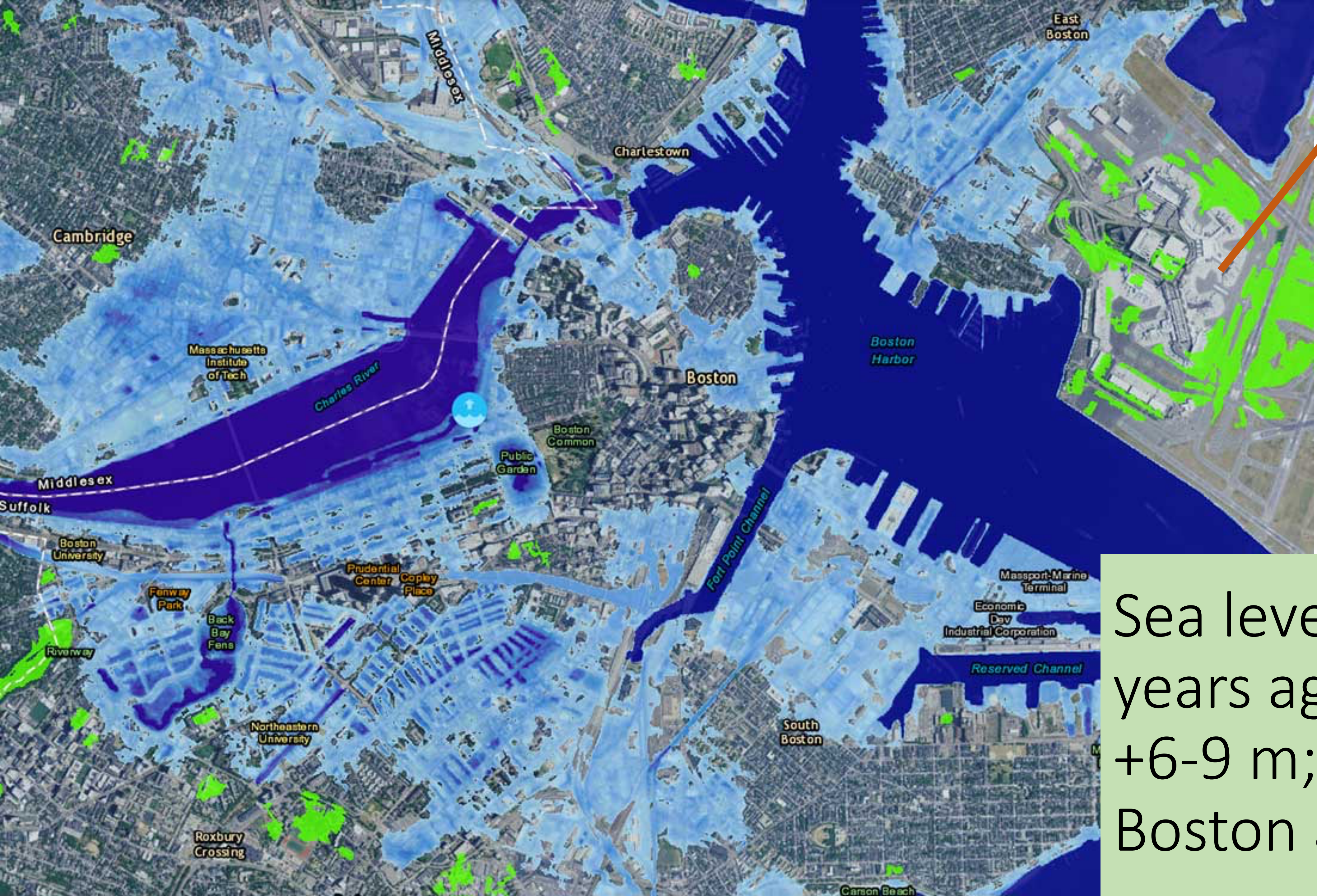
3.4
meters of sea level



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

A. Dutton[1,*], A. E. Carlson[2], A. J. Long[3], G. A. Milne[4], P. U. Clark[2], R. DeConto[5], B. P. Horton[6,7], S. Rahmstorf[8], M. E. Ray...

Why coupled climate/atmosphere/ice models matter – effects of Greenland Ice Sheet meltwater



Take a sea plane from Logan?

Models matter for planning

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