Today’s Climate in Perspective: Paleoclimate Evidence

Hendrick Avercamp (1585-1634)
~1608; Rijksmuseum, Amsterdam
Observations

**Paleoclimate**: climate conditions that occurred prior to the instrumental record.
Why study paleoclimate?

- There is a need to reconstruct *pre-anthropogenic climate change*, to understand underlying forcings and their effect on the climate system.

- Only paleo data can define the envelope of natural climate variability (including the record of forcing).

- Such data can be used to test the ability of models to simulate changes in the past; without such verification, confidence in models of the future will be limited...
IPCC AR4 WG1 – The Physical Science Basis

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Palaeoclimate

Coordinating Lead Authors:
Eyvind Jansen (Norway), Jonathon Overpeck (USA)

Lead Authors:
Keith R. Briffa (UK), Jean-Claude Duplessy (France), Fortunat Joos (Switzerland), Valerie Masson-Delmotte (France), Daniel Olago (Kenya), Dottie Otto-Bliesner (USA), W. Richard Peltier (Canada), Stefan Rahmstorf (Germany), Niranjan Ramach (India), Dominique Raynauld (France), David Rind (USA), Olga Solomina (Russian Federation), Ricardo Villalba (Argentina), De’er Zhong (China)

Contributing Authors:
J.-M. Barnola (France), E. Bauer (Germany), E. Brady (USA), M. Chandler (USA), J. Cole (USA), E. Cook (USA), E. Cortejo (France), T. Ducharne (Norway), D. Fl tner (Switzerland), M. Geyh (France), M. Kayser (France), M. Khodri (France), A. Kishi (France), D. Levermann (Germany), O. Lie (Norway), M.-F. Lootte (Belgium), K. Matsumoto (USA), E. Mornin (Switzerland), F. Nylen-Thompson (USA), D. Mote (USA), R. Muciker (USA), T. Nakamura (UK), O. Pascana (Norway), F. Parnin (France), G.-K. Plattner (Switzerland), H. Plassack (USA), R. Spahni (Switzerland), L.D. Stott (USA), L. Thompson (USA), G. Waebroeck (France), G. Wise (USA), J. Zachos (USA), G. Zhengteng (China)

Review Editors:
Jean Inezel (France), John Mitchell (UK)

This chapter should be cited as:
Earliest instrumental records on land
Sources of Paleoclimate Data

- Tree rings* (width, density)
- Ice cores* (isotopes, melt layers, net accumulation, glaciochemistry)
- Corals* (isotopes, geochemistry, growth rate)
- Lake and marine sediments* (varve thickness, sedimentology, geochemistry, biological content)
- Speleothems* (isotopes)
- Historical records*
- Geomorphic evidence
- Macrofossils
- Loess and Peat
- Boreholes

* Climate archives that may contain annual-to-decadal resolution
Sources of Paleoclimate Data

Varved sediments

Banded corals

Tree rings

Historical documents

Speleothems (stalagmites)


Source: NOAA WDC-A for Paleoclimatology

(Zurich daily weather diary from 1573)

Source: Pfister 1990

Source: S. Burns
Reality check!

- Proxy records register climate *as well as other factors*....
- Not all regions have useful proxy records (*there may not be any where you want them*...)
- Processing the data may remove or degrade climatic information
- Not all reconstructions are the same
Examples......

Source: NOAA ESRL/GMD
Modern coral $\delta^{18}O$ anomalies (red)

Sea surface temperatures (black)

Source: Cobb et al., 2003
Climatological Database for the World’s Oceans (CLIWOC): observations from 1750-1850

Source: http://www.knmi.nl/~koek/cliwoc.htm
Documentary evidence:

Ice Breaking Date: River Tornio, Finland

May 25--

May 5--

1690 1790 1890 1990
A speleothem record from southern Oman

Source: S. Burns et al., 2002
Greenland Summit (GISP2): Holocene ice core volcanic sulfate record

Source: Zielinski et al., 1995
Questions to consider:

1. What drives climate change on long time scales (1 ka, 10 ka, 100 ka etc.)?

2. How stable is the climate system?

3. How have earth systems (cryosphere, biosphere, atmosphere, ocean) responded to these changes?
High Resolution Reconstructions

The last 1,000 years

(Mann et al., 1999)
Uncertainty (Jansen et al., 2007 – IPCC AR4 Ch 6)
The last 1,000 years

(Jansen et al., 2007 – IPCC AR4 Ch 6)
Anthropogenic Increase: Records Over the Last Millennium

Source: Raynaud et al., 2003
Medieval Time

Sensu lato

Solar activity LOW*

*....&/or geomagnetic field strength low!

Solar activity HIGH

Age (yr BP)

\[ \Delta^{14}C \ (\%) \]
Glacial-Interglacial Timescales

The last ~100,000 years

source: Petit, et al., 1999
Marine sediments tell us about changes in global ice volume

$\text{H}_2\text{O}$ $\rightarrow$ $\text{CaCO}_3$ $\rightarrow$ $^{18}\text{O}/^{16}\text{O}$
Source: Petit-Maire et al., 1999
Laurentide Ice Sheet extent at 18ka ($^{14}$C) B.P.
Laurentide Ice Sheet extent at 12.5ka ($^{14}$C) B.P.
Laurentide Ice Sheet extent at 8ka (14C) B.P.
Laurentide Ice Sheet extent at 5ka (14C) B.P.
Oxygen isotopes of marine organisms are used to estimate global ice volume.
Global Sea-level changes

(+15-20m in MIS11?)

Source: Waelbroeck et al., 2001
Eustatic sea-level change since 14,000 years B.P.

Source: Lambeck et al., 2004 [QSR]
What drives climate change on glacial-interglacial timescales?
Insolation cycles:

- Eccentricity = 100 kyr
- Obliquity = 41 kyr
- Precession = 23 kyr
Perihelion in NH winter

Perihelion in NH summer

JUNE 21
MAR. 20
DEC. 21
SEPT. 22
MAR. 20
DEC. 21
JUNE 21
SEPT. 22
DEC. 21
JUNE 21

TODAY
5500 yr ago
11,500 yr ago
Precession
19, 22, 24 kyr

Obliquity
41 kyr

Eccentricity
95, 125, 400 kyr

Solar Forcing
65°N Summer

Hot

Stages of Glaciation

Cold
Milankovitch theory

Ice sheet growth/decay controlled by Northern Hemisphere summer insolation

![Graph showing June 65°N insolation and δ18O(‰) vs age (kyr).](image-url)
What mechanisms in Earth’s system could amplify small changes in solar radiative forcing?
Compare changes in ice volume to CO$_2$ concentrations in ice core records

ICE VOLUME

ATMOSPHERIC CO$_2$

[Graph showing ice volume and atmospheric CO$_2$ concentrations over time]
Dome C Antarctica (EPICA site)
(75°06’S, 123°21’E, 3233 m asl)
TODAY!

CO₂ (ppmv)

δD ice Temp

Methane (ppbv)

200
300
400
500
600
700
800

0 100,000 200,000 300,000 400,000 500,000 600,000
Age (yr BP)
Pre-Quaternary Climate

Source: Zachos et al., 2008
Source: Zachos et al., 2001
Earth’s Thermostat? – C cycling between rocks and atmosphere
Today’s Climate in Perspective: Paleoclimate Evidence

I. Paleoclimatology (importance, types of records, uncertainties)

II. Climate change on different timescales
   - Last 2,000 years
   - Glacial-Interglacials (last 650,000 years)
   - Pre-Quaternary (last 65 million years)

III. Abrupt climate change

Additional: IPCC AR4 Chapter 6
What caused the Ice Ages and other important climate changes before the Industrial Era?

Global climate is determined by the Earth’s radiation balance, which can change by:

1. changes in incoming solar radiation
2. amount of solar radiation that is reflected
3. amount of long wave energy radiated back to space
4. locally, by how heat is distributed
What caused the Ice Ages and other important climate changes before the Industrial Era?

2,000 years

Glacial-interglacial (last 2.5 million years)

Pre-Quaternary (last 65 million years)
What caused the Ice Ages and other important climate changes before the Industrial Era?

**Climate forcings on different timescales:**

**Tectonic**

**Orbital**
Milankovich Cycles (eccentricity/obliquity/precession)
~100,000; 40,000; 23,000/19,000 years

**Millennial to centennial**
solar irradiance
thermohaline oscillations (“internal” variability?)

**Decadal-to-interannual**
volcanic
ENSO/NAO/PDO (“internal” variability?)

**Feedbacks:** snow/sea-ice cover (albedo), greenhouse, etc.
The last 1,000 years

(Jansen et al., 2007 – IPCC AR4 Ch 6)
Medieval Time
Sensu lato

Solar activity LOW*

Solar activity HIGH

*....&/or geomagnetic field strength low!
orbital parameters

Eccentricity Cycle (100 k.y.)

- More ice ↔ Less ice
- Colder temperature ↔ Warmer temperature
- δ18O (%)

100,000-year cycles dominant

Transition interval

100,000 years

Obliquity Cycle (41 k.y.)

- 41,000-year cycles dominant (smaller 23,000-year cycles)
- Normal to Ecliptic

Precession of the Equinoxes (19 and 23 k.y.)

- Northern Hemisphere tilted away from the sun at aphelion.
- Northern hemisphere tilted toward the sun at aphelion.

Slow drift in trend

First ice rafting 2.75 Myr ago

Myr ago

0.5
1.0
1.5
2.0
2.5
3.0
3.5
Comparing Current Climate Change to Earlier Changes in Earth’s History

- Identify the variable of comparison
- Local vs. global changes
- Differences in timescales

Examples: temperature & CO₂
Comparing Current Climate Change to Earlier Changes in Earth’s History

Example: \( \text{CO}_2 \)

- Varied between 180 ppm and 300 ppm over last 650,000 years

  *Present concentration is about 380 ppm*

- Rate of rise at end of ice ages of 80 ppm took \( \sim \) 5,000 years

- Higher levels have existed many millions of years ago
TODAY!

CO2 (ppmv)

Methane (ppbv)

δD ice ~ Temp

0 100,000 200,000 300,000 400,000 500,000 600,000

Age (yr BP)

200 300 400 500 600 700 800

200 C

300 C

400 C

440 C

-360

-400

-420

-440
<table>
<thead>
<tr>
<th>Comparing Current Climate Change to Earlier Changes in Earth’s History</th>
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<tbody>
<tr>
<td>Example: Temperature</td>
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<tr>
<td>- More difficult to reconstruct because of high spatial variability</td>
</tr>
<tr>
<td>Local temperature variations can be high (a few °C)</td>
</tr>
<tr>
<td>Global temperature variability is smaller</td>
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<tr>
<td>(global warming signal of past century of 0.7°C)</td>
</tr>
<tr>
<td>- Global temperature reconstructions only go back 2,000 years</td>
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<tr>
<td>- Rate of past temperature change:</td>
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<tr>
<td>4-7°C from glacial to interglacial over 5,000 years</td>
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<tr>
<td>- Projections of the rate of future temp change exceed that</td>
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<tr>
<td>seen in last 50 million years</td>
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Abrupt Climate Change

Greenland Summit oxygen isotopes
Abrupt Climate Change
**CROSSING THE THRESHOLD**

Global warming alters ambient conditions little by little. But even this kind of slow, steady change can push climate drivers, such as well-established ocean currents or patterns of rainfall, to a critical point at which they lurch abruptly into a new and different state. That switch brings with it an associated shift in climate—with potentially challenging consequences to people and societies. Once a climate driver crosses its so-called threshold, the changes that ensue could persist for millennia. Many thresholds may still await discovery; here are three that scientists have identified:

<table>
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<tr>
<th>CLIMATE DRIVER</th>
<th>THRESHOLD CROSSING</th>
<th>RESULTING CLIMATE SHIFT</th>
<th>SOCIAL CONSEQUENCES</th>
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<tr>
<td>Ocean currents in the North Atlantic carry warmth northward from tropics, keeping western Europe’s winters mild [see box on opposite page].</td>
<td>Freshening of surface waters in the far north slows down these currents, possibly stopping them altogether.</td>
<td>Temperatures plummet in the region, and climate in Europe and the eastern U.S. becomes more like Alaska’s.</td>
<td>Agriculture suffers in regions around the world, and key navigation routes become clogged with ice.</td>
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<td>Rainwater that is recycled through plants (absorbed by their roots and returned to the air through evaporation from their leaves) provides much of the precipitation in the world’s grain belts.</td>
<td>A minor dry spell wilts or kills too many plants, and recycled rainfall disappears, reinforcing the drying in a vicious cycle.</td>
<td>A potentially mild dry spell is enhanced and prolonged into a severe drought.</td>
<td>Parched land can no longer support crops; famine strikes those who cannot trade for the remaining grain in the world market.</td>
</tr>
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<td>Currents in the Pacific Ocean determine major patterns of sea-surface temperature, which in turn control regional weather patterns.</td>
<td>Natural phenomena, such as El Niño, cause subtle changes in sea-surface temperatures, although scientists are still not sure why.</td>
<td>Weather patterns on adjacent continents shift, triggering severe storms or droughts where they typically do not occur.</td>
<td>Some croplands dry up while other places incur damage from intense storms.</td>
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Abrupt Climate Change

The role of ocean circulation