Ice Sheet Forensics:
Putting Current Climate Change in Context of the Past

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Outline

- Where is most of the surface fresh water on Earth?
- The Earth is a system of moving components that interact.
- How is evidence of past climate archived in the ice sheets?
- What is some evidence that the climate can change abruptly, in less than 10 years?
- What is the evidence that CO$_2$ levels are higher now than in at least 600,000 years?
- See science in action - a PolarPalooza podcast
Ice sheets

- huge continental snow & ice masses, covering over 50,000 km²
- 2 exist on Earth: Greenland and Antarctica
- Together they contain 95% of Earth’s glacial ice.
- If totally melted, they would raise sea level 70m.
The Earth is a system of systems
The Earth acts as a system.

What we experience on land is due to the sun’s energy and resulting interactions between the atmosphere and the oceans.

NASA

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The atmosphere circulates on a global scale
The ocean circulates on a global scale

Salty, cold ocean water in the north Atlantic sinks, driving circulation for the oceanic conveyor belt.
Changes in one part of the earth system affect other parts
Atmospheric transport brings evidence of environmental conditions to ice sheets
Polar ice cores are the highest-resolution natural archive of evidence of past climate
Snow on polar ice sheets contains evidence that, over time, becomes part of the ice core climate record.

Precipitation

Surface snow

Firn

Pore close-off

Ice with bubbles

Core

~ 1/2 meter

~ 80 meters

~ 300 meters

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Snow exhibits profound changes in characteristics due to changes in the environment.

A buried former surface wind crust

The nature of the surface greatly affects exchange processes (and visa versa).
The physical structure of snow is an indicator of environmental conditions.
Below the surface, there is *physical evidence* of years past:

The layers create evidence of weather.

Summer surface frost formation and light snowfalls create the light bands.

Strong winds and very cold temperatures leave the wind packed snow of winter, appearing as darker layers.

These layers are still visible in the ice core!

Albert, 2007

Albert for NSTA 2008
Ice cores provide evidence of recent and distant past
Evidence in the ice: layering and accumulation rate indicate past precipitation. Volcanic horizons help as definitive time markers.

Snow **layering and volcanic ash** layers are both visible in the core. This **evidence helps determine the age of the ice** at depths down through the ice core.
Evidence in the ice:

Oxygen isotopes provide evidence of the air temperature at the time the snow was deposited.

Water contains isotopes of oxygen, $^{18}\text{O}$ or $^{16}\text{O}$. Ocean water evaporates into the atmosphere. The atmosphere cools toward the poles. Colder air holds less vapor; heavier isotopes tend to drop out more than lighter isotopes. The more heavy isotopes in the snow on the glacier, the warmer the atmosphere was.

after Dansgaard 1973

Albert for NSTA 2008
What have Greenland ice cores told us about climate, based on evidence of accumulation rate and temperature?
Ice core isotopes show temperature cooling in the little ice age that drove human settlements out of Greenland.
But those changes were small compared to the climate change before that! Climate can change in less than 10 years!!

Cuffey and Clow reconstructions, 1994
Abrupt climate change resulted from melting of the Laurentide ice sheet – the increase in fresh water on the ocean surface shut down the ocean “conveyor belt” circulation.

When the ocean conveyor belt of heat stops, there are large changes in temperature and precipitation patterns on the land and sea.

Albert for NSTA 2008
Bubbles in ice cores contain evidence of gases in ancient atmospheres
What does evidence in the pore space in ice sheets tell us about climate?

- Precipitation
- Surface snow
- Firn
- Pore close-off
- Ice with bubbles

Core:
- ~ 1/2 meter
- ~ 80 meters
- ~ 3000 meters

Albert, 2007

Albert for NSTA 2008
Evidence of climate in the pore space:
Air in the pore space and in bubbles in the ice core hold gases. This provides evidence about past atmospheric composition, for example greenhouse gases like carbon dioxide and methane.
What does the Antarctic ice sheet tell us about climate from evidence in pore space and bubbles?

Albert for NSTA 2008
Ice cores have shown that for the last 600,000 years, temperature and CO$_2$ have been very closely linked.
Recent measurements of atmospheric CO₂ in Hawaii show currently increasing trends in atmospheric CO₂.
CO$_2$ levels in the atmosphere are now the highest they have been in at least many hundreds of thousands of years!
Greenhouse warming is melting large masses of ice in the Arctic now, changing North Atlantic ocean salinity. There might not be enough ice in the Arctic now to shut down the conveyor belt this time.

Subpolar seas bordering the North Atlantic have become noticeably less salty since the mid-1960s, especially in the last decade.

This is the largest and most dramatic oceanic change ever measured in the era of modern instruments.

B. Dickson, et. al., Nature, April 2002
• The Earth’s land-ocean-atmosphere form a linked system. Changes in one part affect other parts.

• Evidence of climate in the ice of an ice sheet includes volcanic dust for time-markers, isotopes for temperature, accumulation rate for precipitation, etc.

• Evidence of climate in the pore space & bubbles in an ice sheet reflects past atmospheric composition, including greenhouse gases like CO₂, CH₄, and other gases.

• Ice cores provide the highest-resolution natural archive of past climate on the planet.
Summary part 2

• Ice cores have provided the discovery that abrupt climate change can occur in less than 10 years.

• Ice cores have provided the discovery that temperature and CO₂ are linked, and that the current CO₂ level of the atmosphere is the highest it has been in at least 600,000 years.

• Ice coring science enables us to understand the Earth’s linked systems, and helps to put current environmental changes in the earth system in perspective.
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