



Evidence of Climate Change in Glacier Ice and Sea Ice

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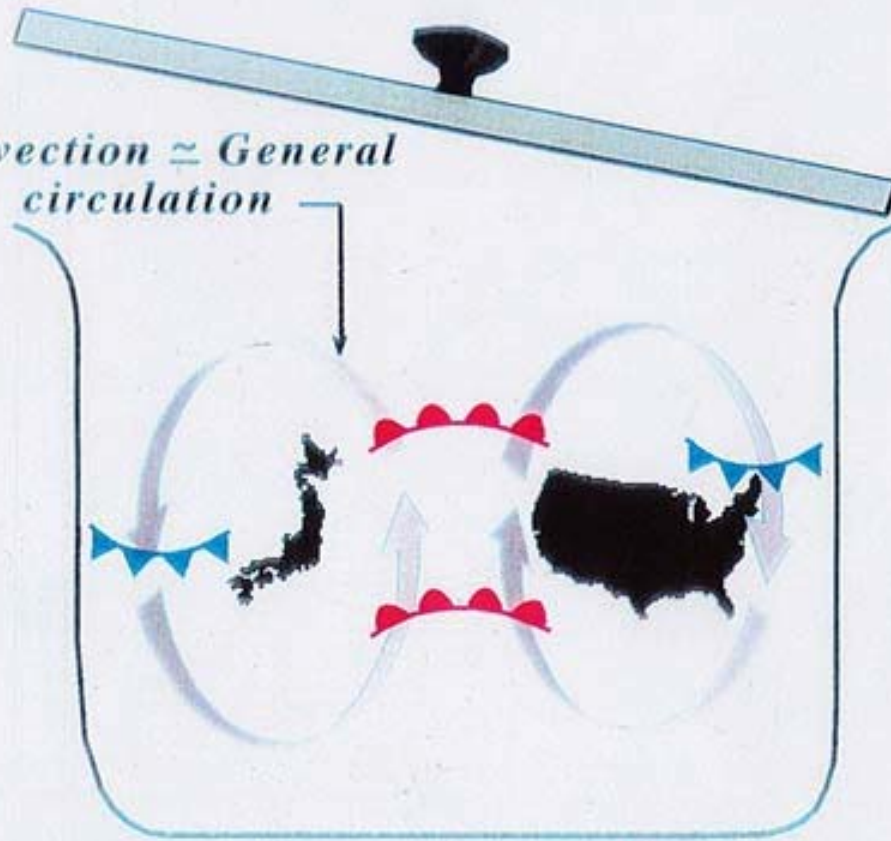
"I CAN REMEMBER WHEN EVERYONE
WAS SKEPTICAL ABOUT THE
GREENHOUSE EFFECT."



GLOBAL WARMING MESSSES UP THE ICE FESTIVAL

Lid = Sea ice in the Arctic Ocean

*Convection \approx General
circulation*



*Polar
Region*

*Middle
latitude
belt*

*Equatorial
belt*



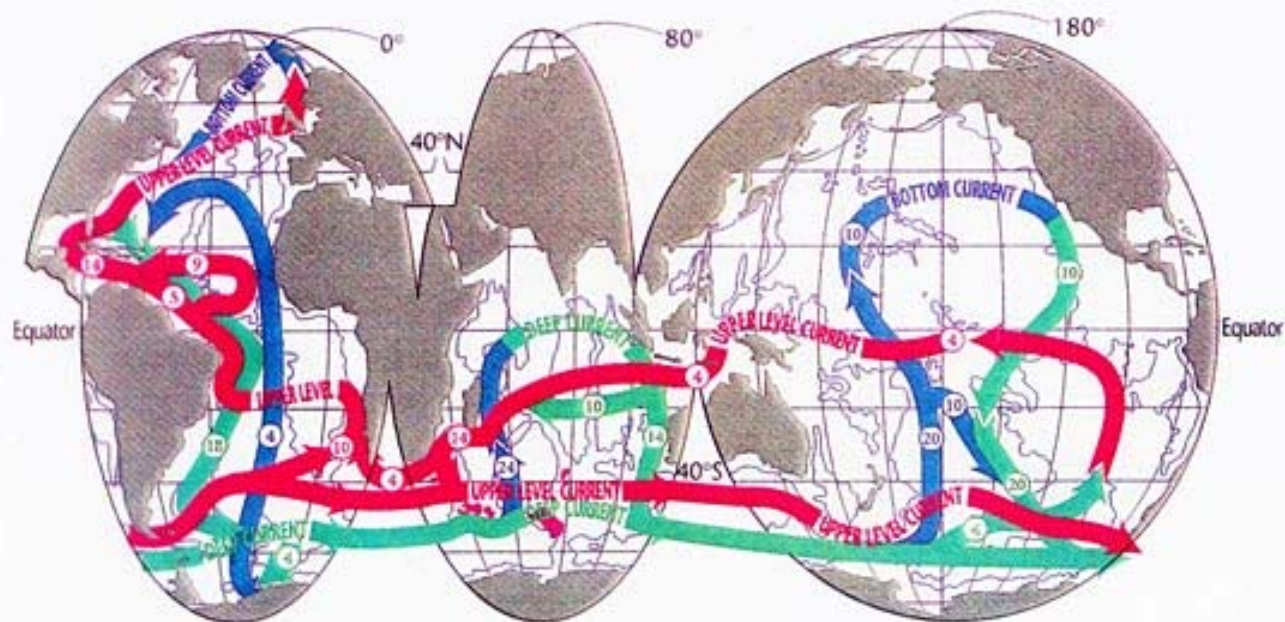
Heat Energy

**= Solar Energy
(constant)**

Reviews of Geophysics

AMERICAN GEOPHYSICAL UNION

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Evidence for warming of the Arctic



- Recent studies using a variety of methods and sources of information (sonar, remote sensing) indicate that sea ice in the northern hemisphere has decreased by about 7% to 14% over the past 40 years. The floating ice has also become about 40% thinner over the same period.

Evidence for warming of the Arctic



- The Greenland Ice Sheet is losing about two cubic miles of ice each year to the sea.
- Alaska is also losing an impressive amount of fresh water to the world's oceans.
 - Example: the Harding Ice Field has shrunk enough over the past 40 years to raise the Earth's sea level by 0.1 mm.

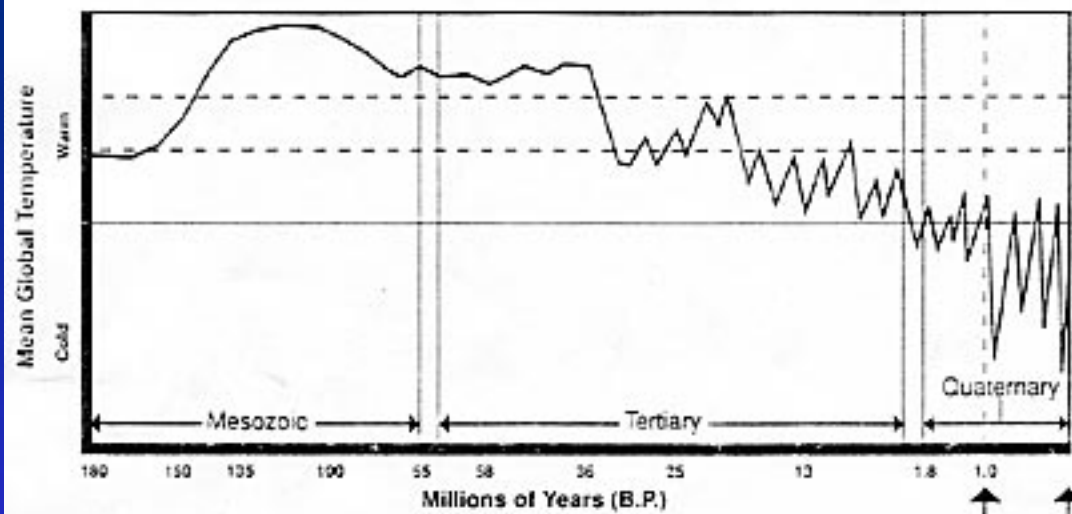
Evidence for warming of the Arctic

- Computer models suggest that melting is too severe to be created by natural causes alone and is probably related to human activity.
- Fresh melt water from the Arctic might slow the conveyor by diluting salty waters of the North, thus setting the stage for global cooling such as happened 15,000 and 12,000 years ago.

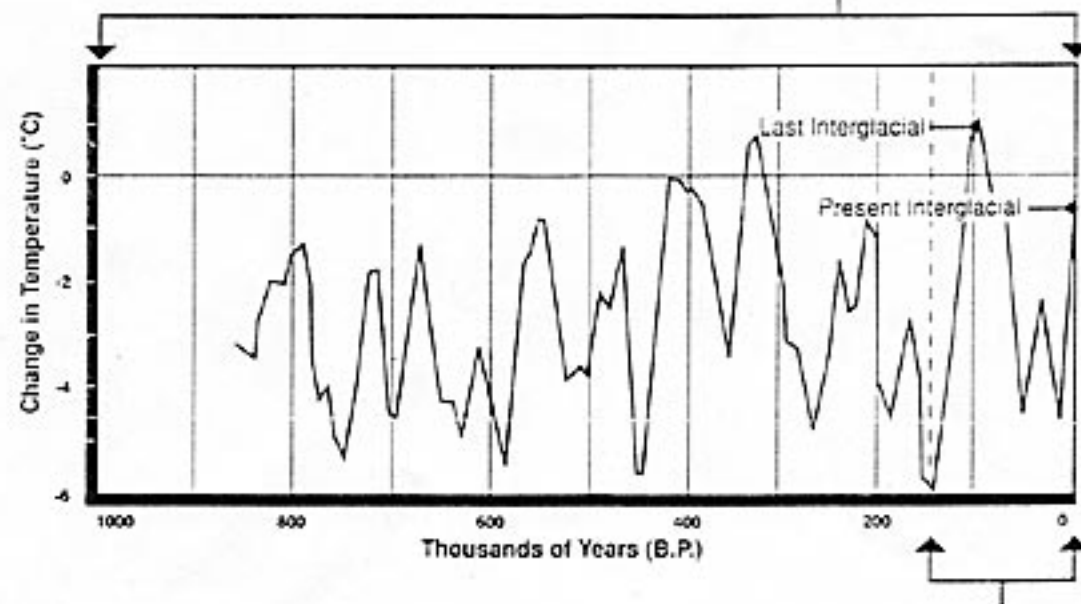
Is the climate changing?

A view to the past:

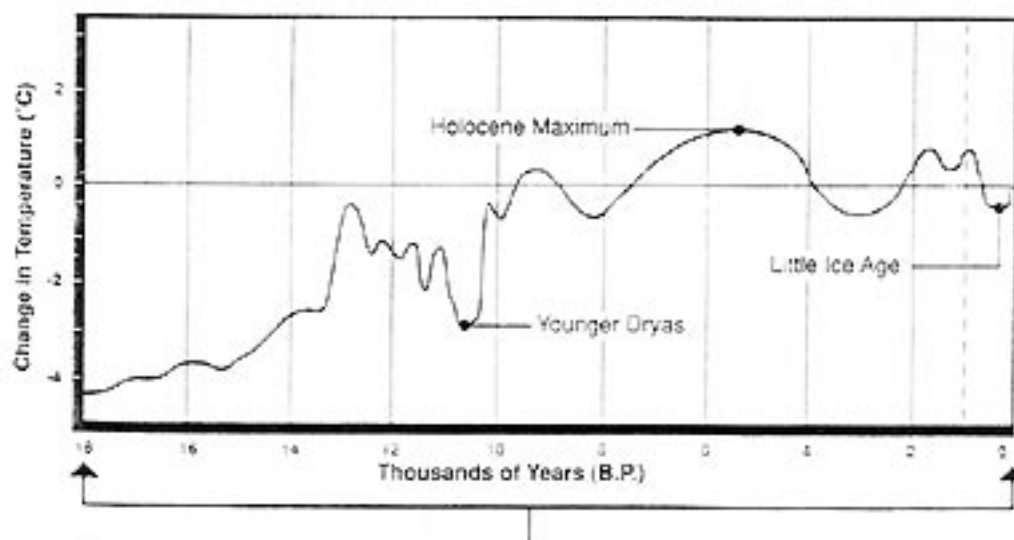
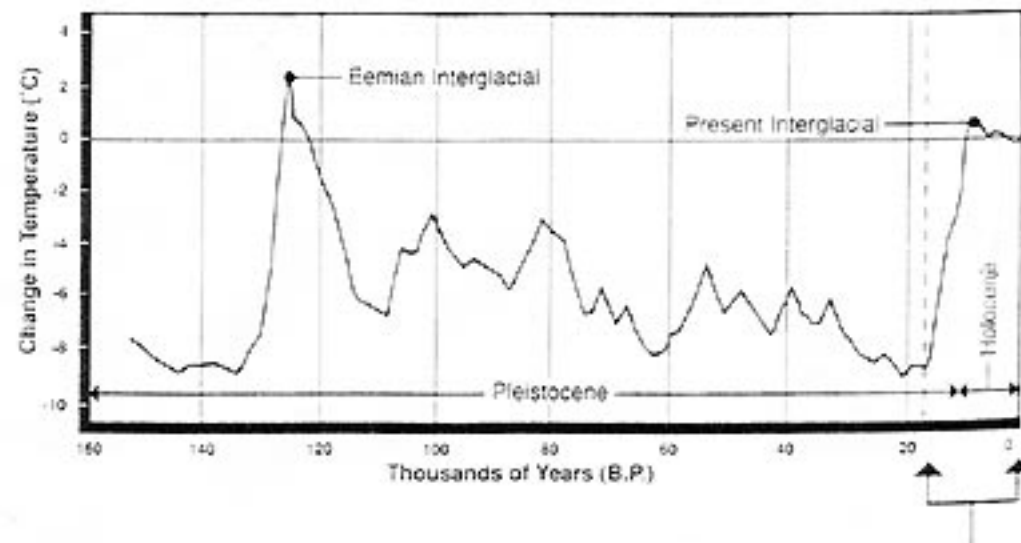
- There have been very large changes in the more distant past.
- The last million years have seen a succession of major ice ages interspersed with warmer periods.
- The last of these ice ages began to come to an end about 20,000 years ago. We are now in what is called an *interglacial period*.



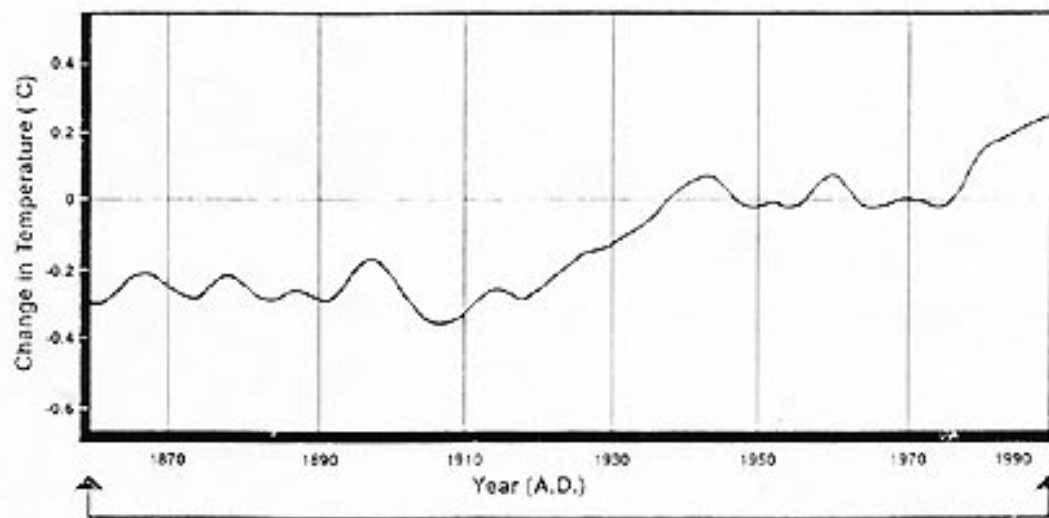
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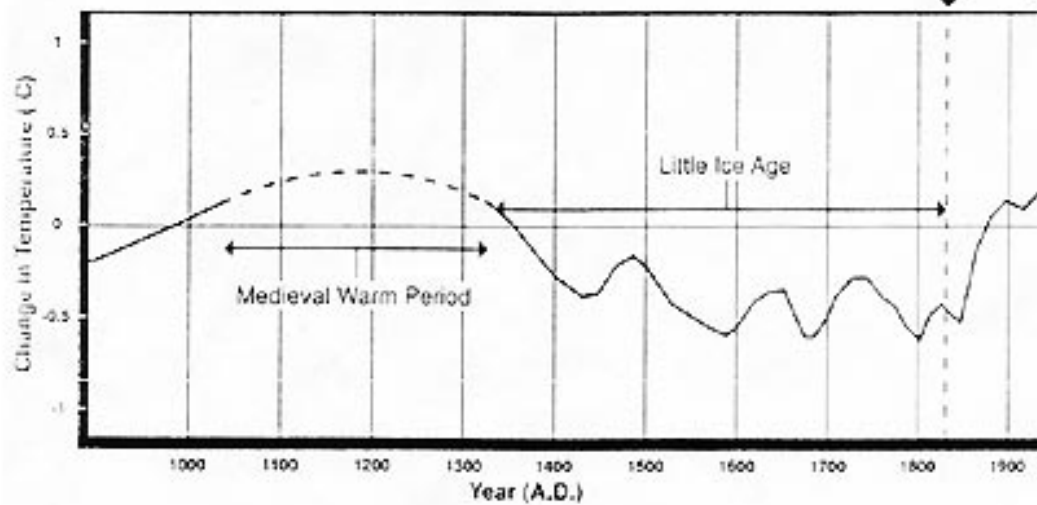
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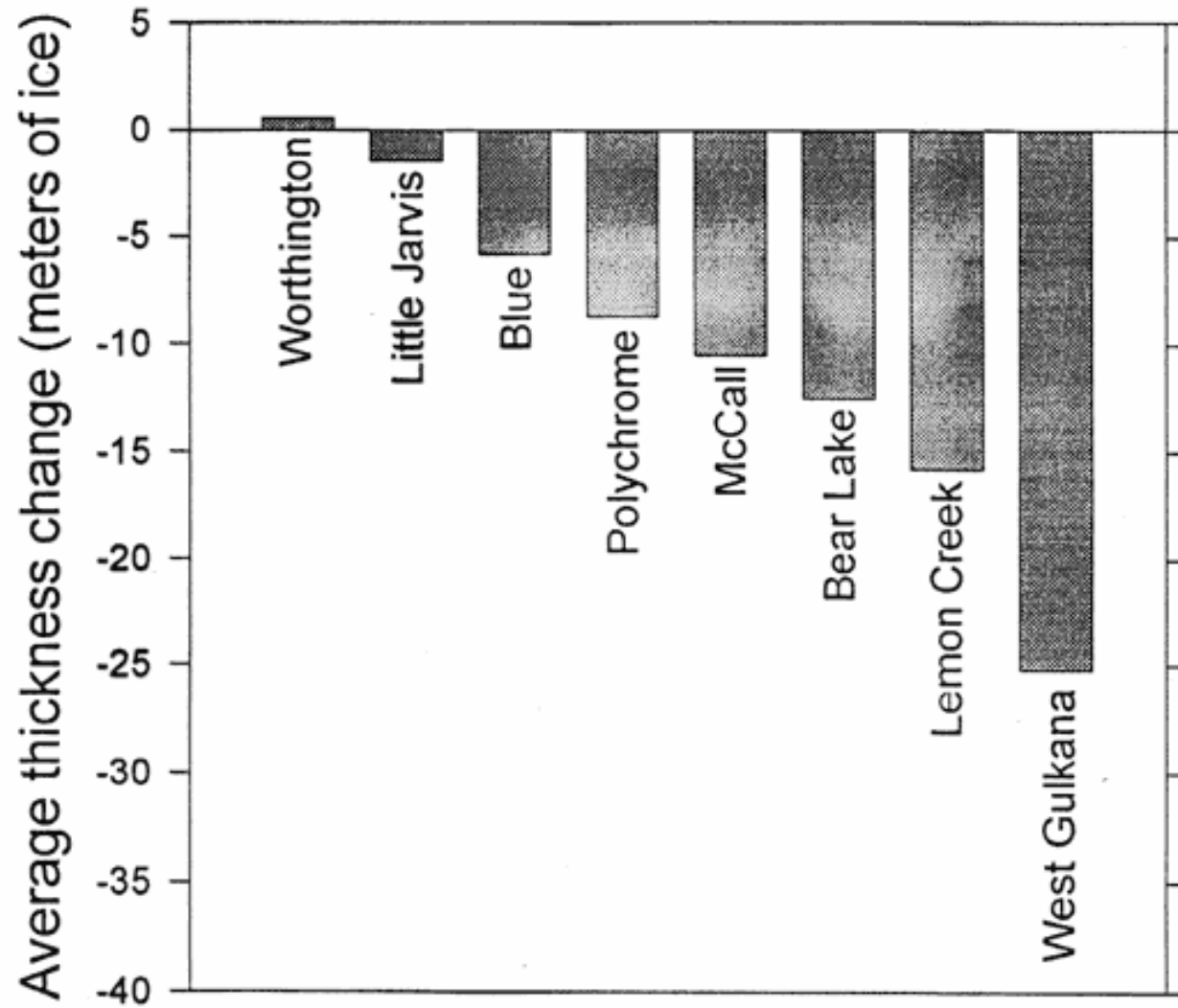
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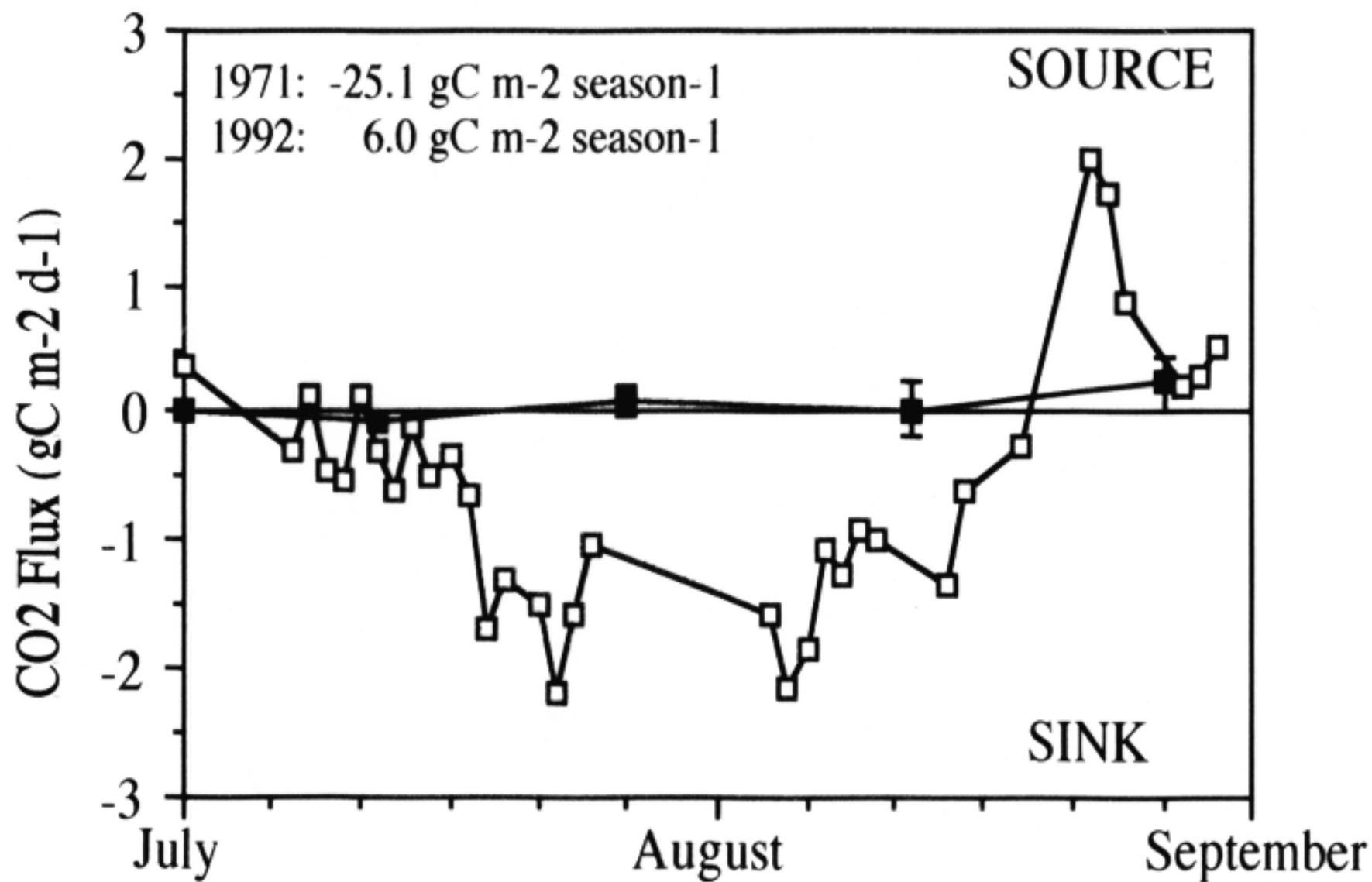
Decade-to-century scale climate variability



- Volcanic aerosols
- Solar variability
- Greenhouse gasses
- Atmosphere/ocean dynamics

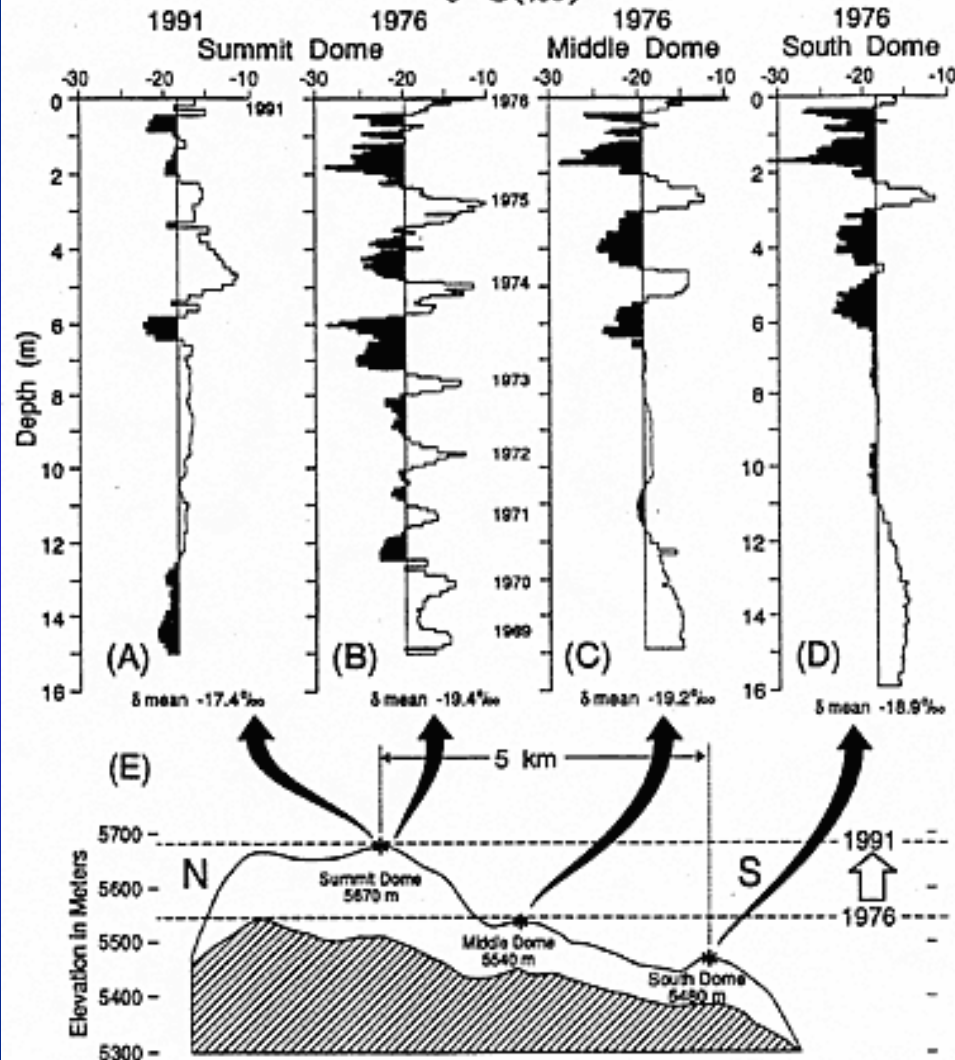
GLACIER CHANGES IN WESTERN NORTH AMERICA, 1957 TO MID 1990'S





Quelccaya Ice Cap, Peru

$\delta^{18}\text{O}(\text{‰})$



All of the known tropical glaciers and ice caps are retreating. The rate of retreat is accelerating. Note that the 1991 $\delta^{18}\text{O}$ values are enriched by 2‰ and that annual variations are no longer preserved at this site.

Reasons for scientific uncertainty

Incomplete understanding of:

- *Sources and sinks of greenhouse gases* (e.g., CO₂, CH₄, N₂O, CFC), which affect predictions of future concentrations;
- *clouds*, which strongly influence the magnitude of climate change;
- *oceans*, which influence the timing and patterns of climate change;
- *polar ice sheets*, which affect predictions of sea level rise.

The complexity of the system means that we cannot rule out surprises

温故知新

**BY STUDYING THE OLD,
WE LEARN SOMETHING NEW**

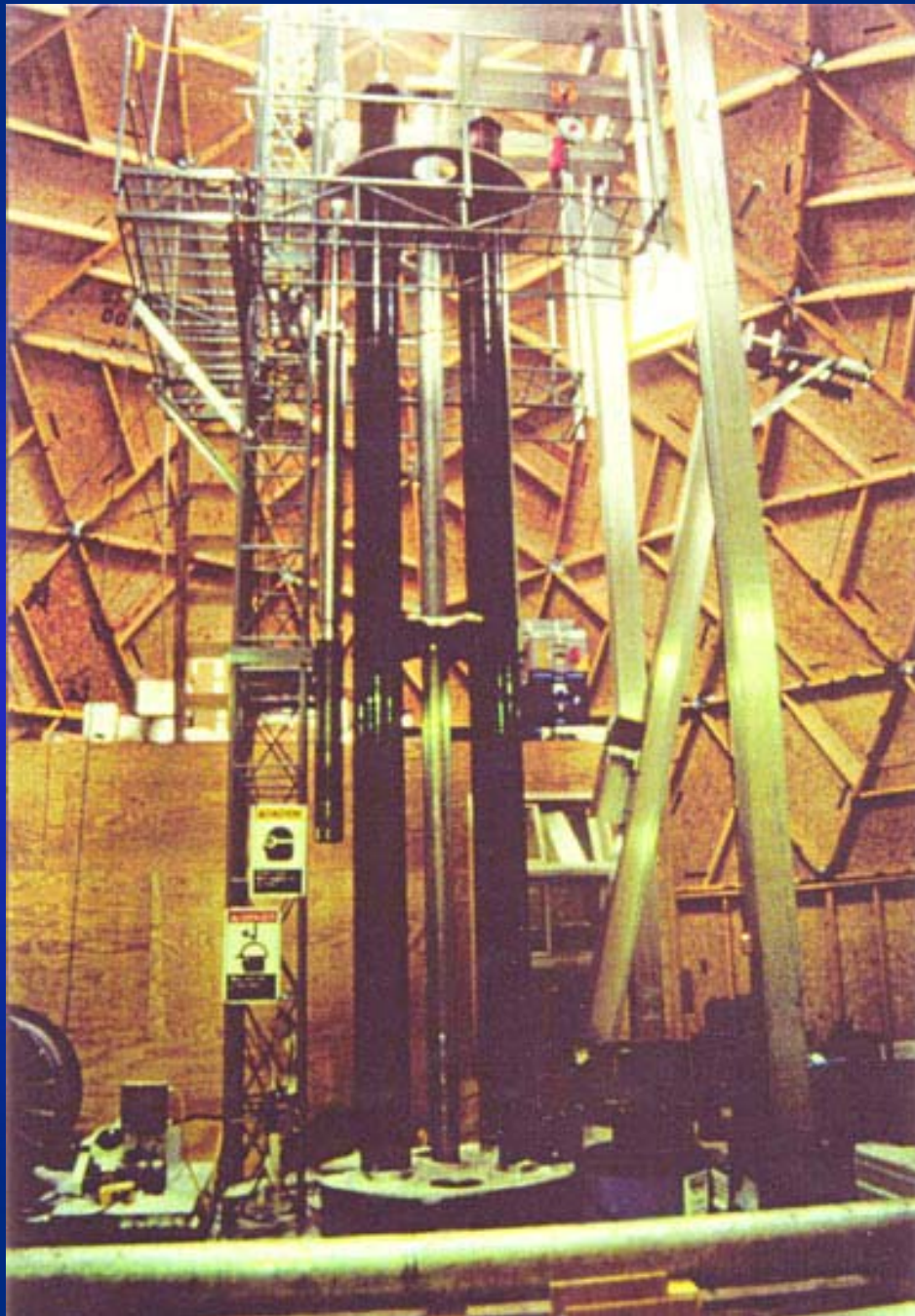
*Contributed by Yasuko and Ray Fields
Mombetsu, Hokkaido, Japan*

Why Greenland? — GISP



- Thickest ice in North America
- Sustained through interglacial period
- Simple flow
- High accumulation: about 20 cm/yr.
- Almost no melting
- Broad plateau
- Basal ice is below pressure melting point (e.g., -2.4°C at 3,100 m)
- Mean annual temperature of -31°C





GISP II ice coring
drill located on
Greenland ice cap.

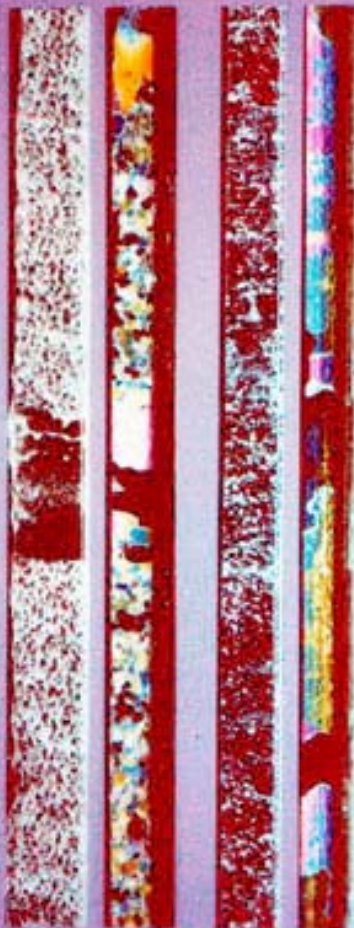
Acquired a core
3050m to bedrock
including a section
of basal rock
(granite).

PICO/UAF 1989–94

ICE CORE ANALYTICAL SYSTEM

Thin Sections

Greenland Guliya, China



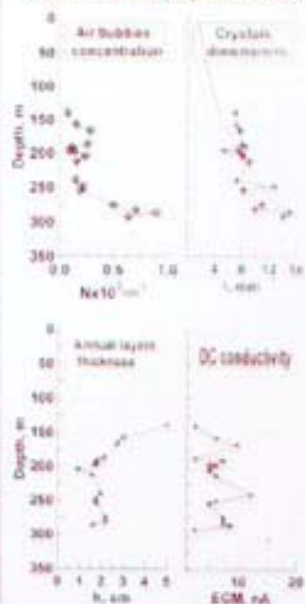
Schematic of the Ice Core Analytical System

101 Surface Potential Output 102 Interferential (IR) Output
103 Laser Scattering Output 104 Photo Scattering



The Guliya ice core site is located in the eastern part of the Tibetan Plateau, at an altitude of 5200 m. The ice core was drilled in 1992 by the Chinese Academy of Sciences. The ice core is 305 m long and contains a record of the climate over the last 2500 years. The ice core is currently being analyzed by the Ice Core Analytical System.

GULIYA ICE CORE (CHINA 1992)



Acknowledgements

1. Department of Polar Science, Chinese Academy of Sciences

2. Department of Polar Science, Chinese Academy of Sciences

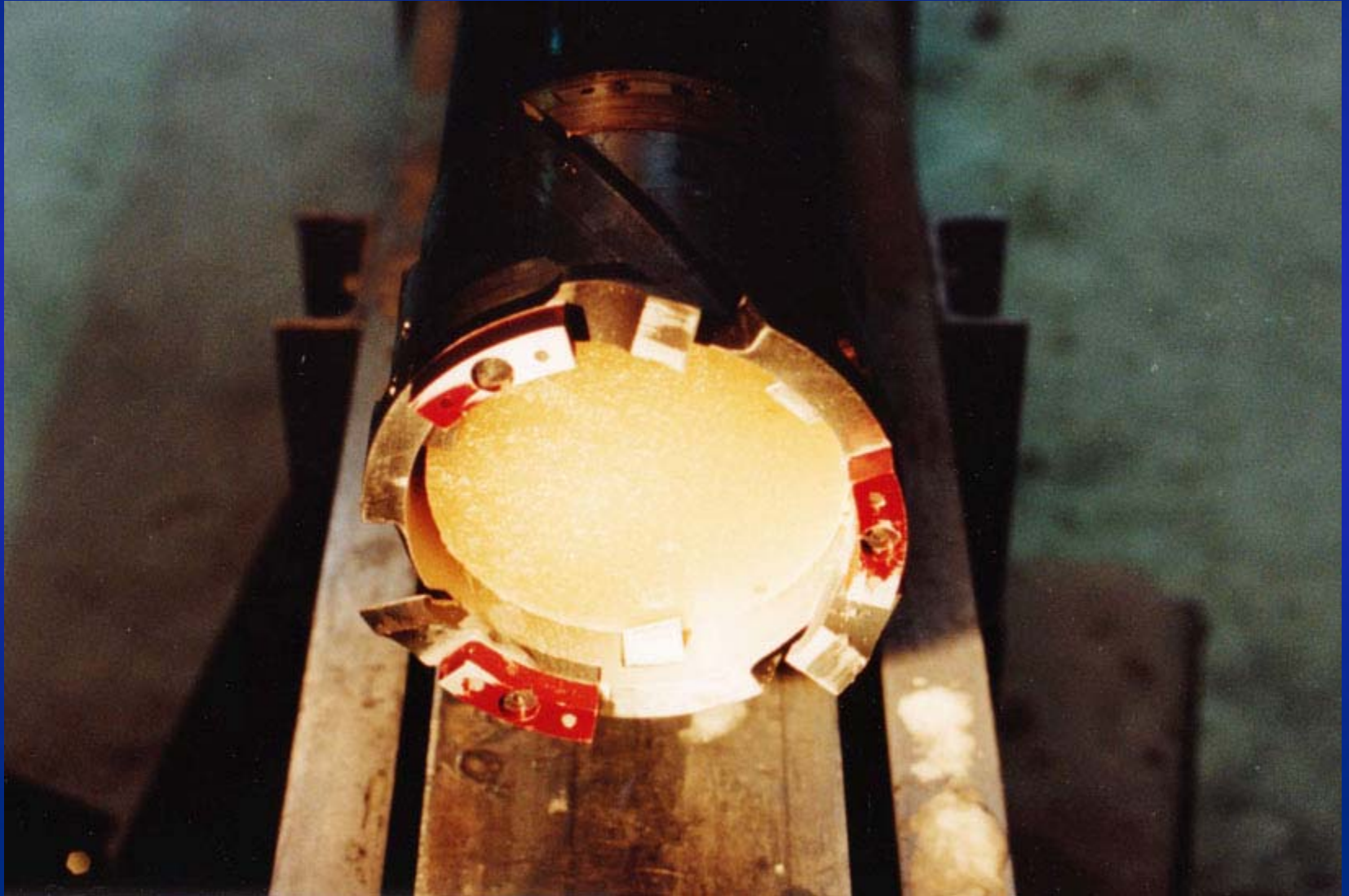
Loading cargo—Greenland



Rock drill—GISP2, Greenland



5.2" Coring Head—Greenland



Cutting silty ice into 2 m. pieces



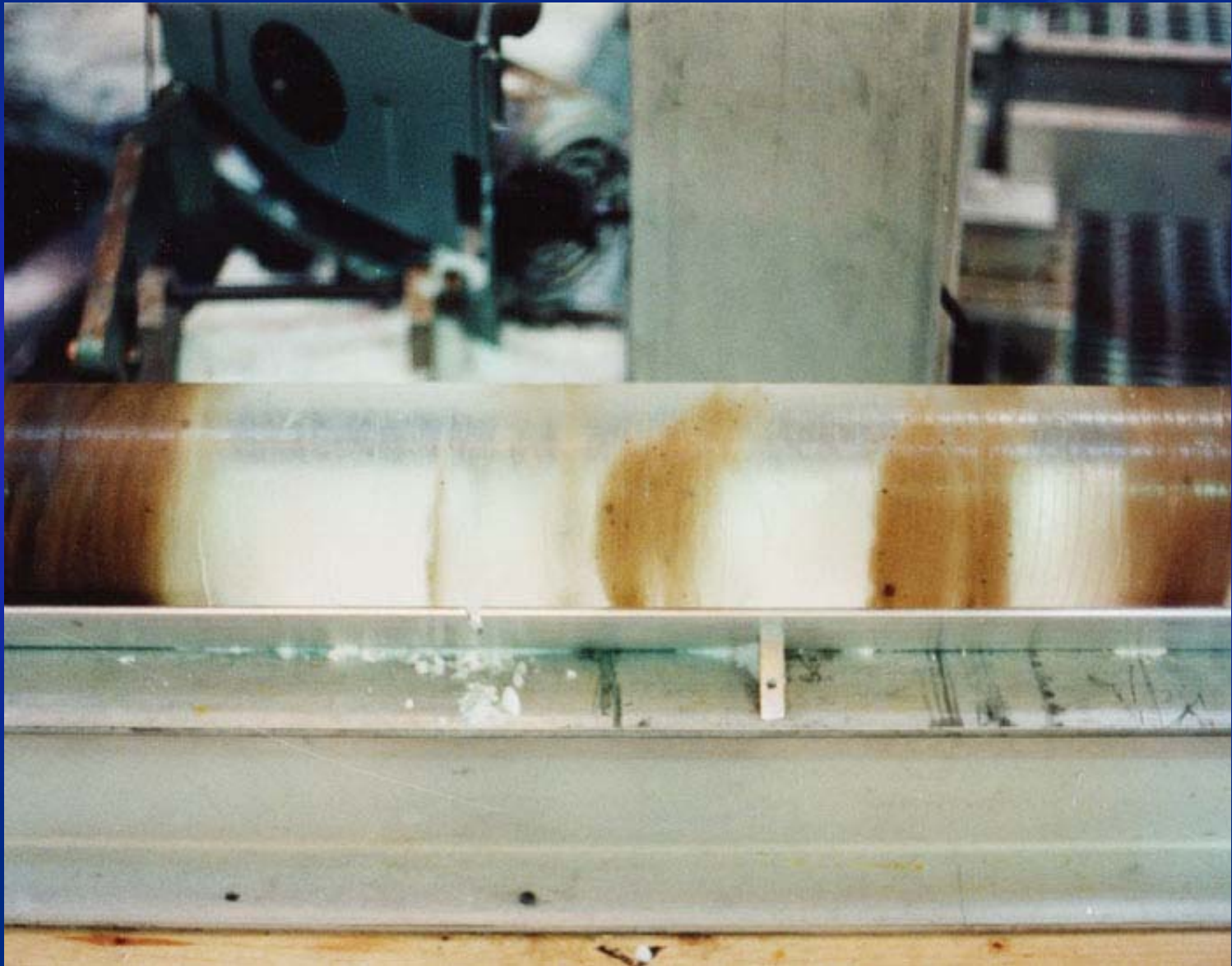
1st pebble in clear ice at 3040 m depth



1st silty ice core backlit to show detail



Silty ice at 3043 m. — visible layering



Silty ice in relaxation trench



Volcanic records in ice cores



1. Establish time lines in the ice core
 - a) Absolute ages
 - b) Correlation tool
2. Evaluate atmospheric effects of past volcanic activity
 - a) Climate
 - b) Ozone
 - c) ENSO
 - d) Determining factors
 - 1) Importance of type of eruption
 - a) Composition
 - b) Eruption height
 - 2) Importance of location of volcano

Volcanic records in ice cores

3. Modify the existing paleovolcanic record primarily for equatorial and northern hemisphere volcanoes
 - a) Incompleteness of geologic record
 - b) Minor nature of more recent eruptions
4. Determine changes in paleocirculation patterns (in general)
 - a) Prevalence of volcanic signals from certain regions

Volcanic signals in ice cores

1. ECM record

- a) High ECM spikes = high H_2SO_4

2. Chemical signal

- a) High SO_4 , Cl, NO_3 (possible)

3. Microparticles

- a) High concentration
- b) High mass

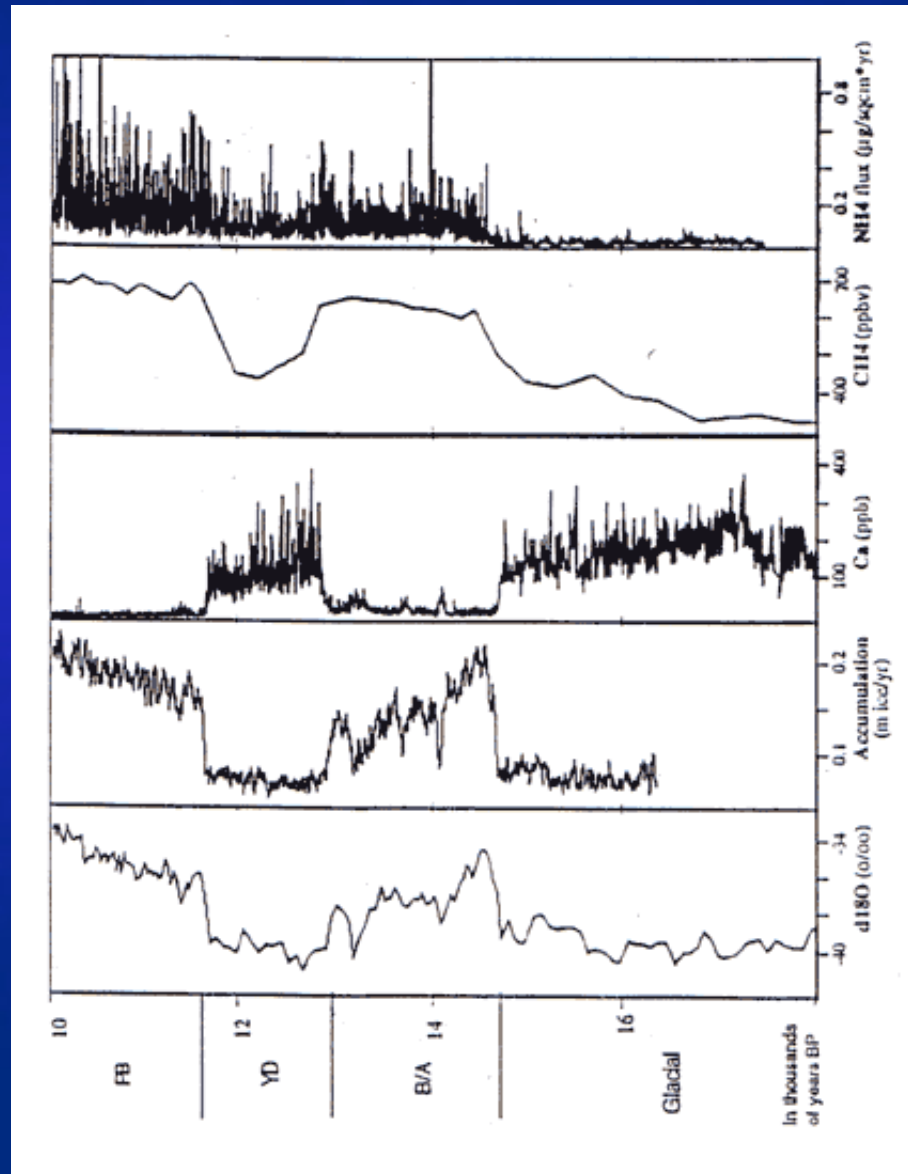
4. Tephra in ice core

- a) SEM and electron microprobe
- b) Comparison of chemical composition with that of eruption

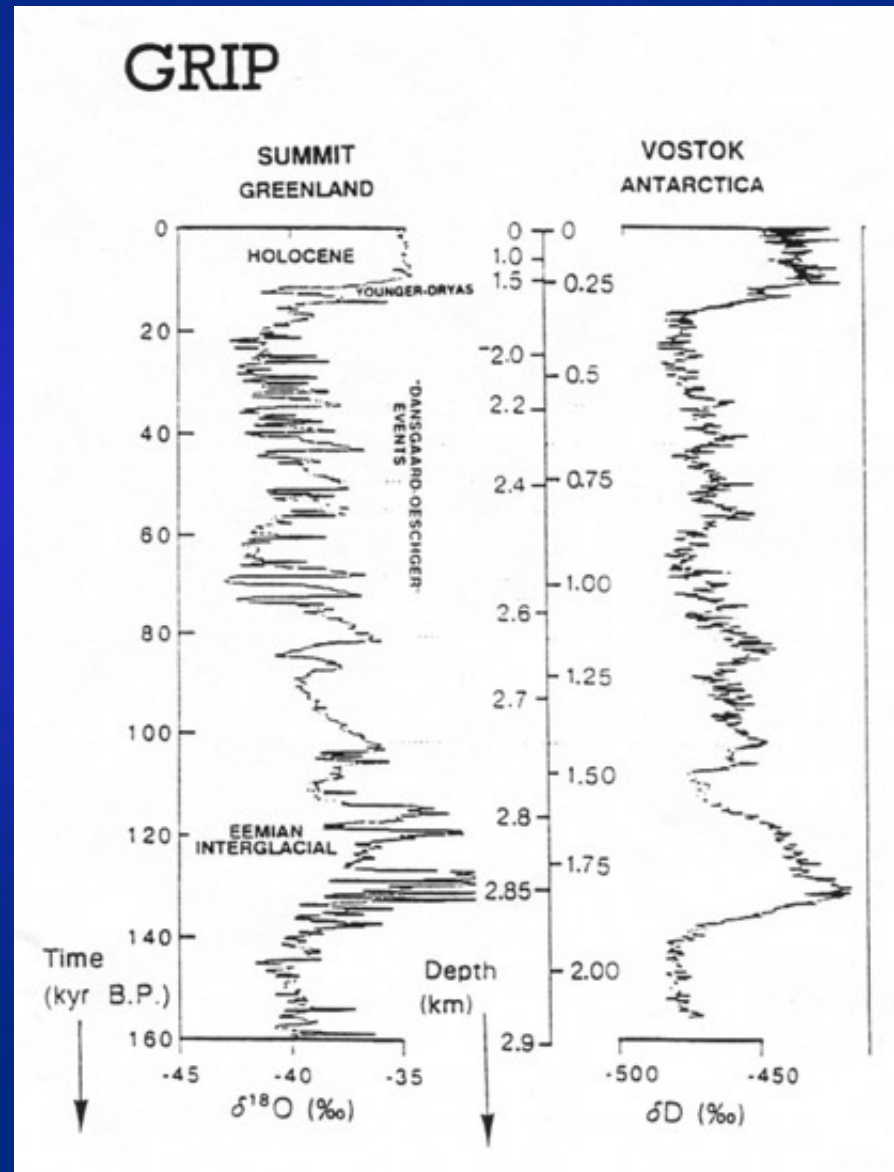
Effects of great volcanic eruptions in ice core

Depth	Volcanic eruption and age
32.11	Katmai, Alaska, 1912 AD; <i>Excellent match, volcanic glass</i>
41.57–41.66	Krakatau, Sumatra/Java, 1883 AD; <i>Two different ash compositions. A second eruption?</i>
70.95–71.45	Laki, Iceland and Asame, Japan, 1783 AD; <i>Ash and glass</i>
86.75–86.97	Several possible eruptions, 1720's; <i>Two distinct groups of ash possibly from Japan or Iceland</i>
101.2–101.3	Tarumai, Japan, 1667 AD; <i>Phytolitic composition ash</i>
116.22–117.31	Nevada del Ruiz, Columbia, 1595 AD; <i>Dalcitic glass</i>
147.3	Mt. St. Helens, USA, 1479 AD; <i>Excellent match, ash</i>
174.6	Oraefajakull, Iceland, 1362 AD; <i>Very good match, rhyolitic ash</i>
199.66–200.06	Unknown, 1259 AD; <i>Possibly El Chichon</i>

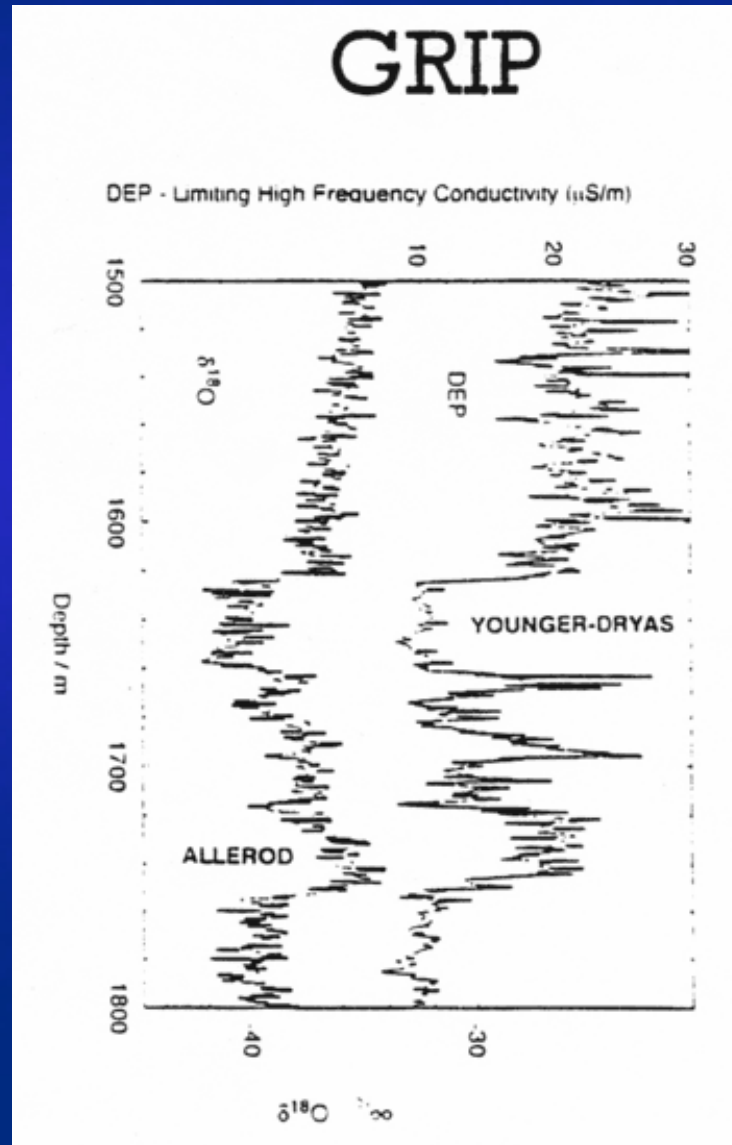
Multi-parameter view of the period 10–18 kyr B.P.



Isotope profile of GRIP core

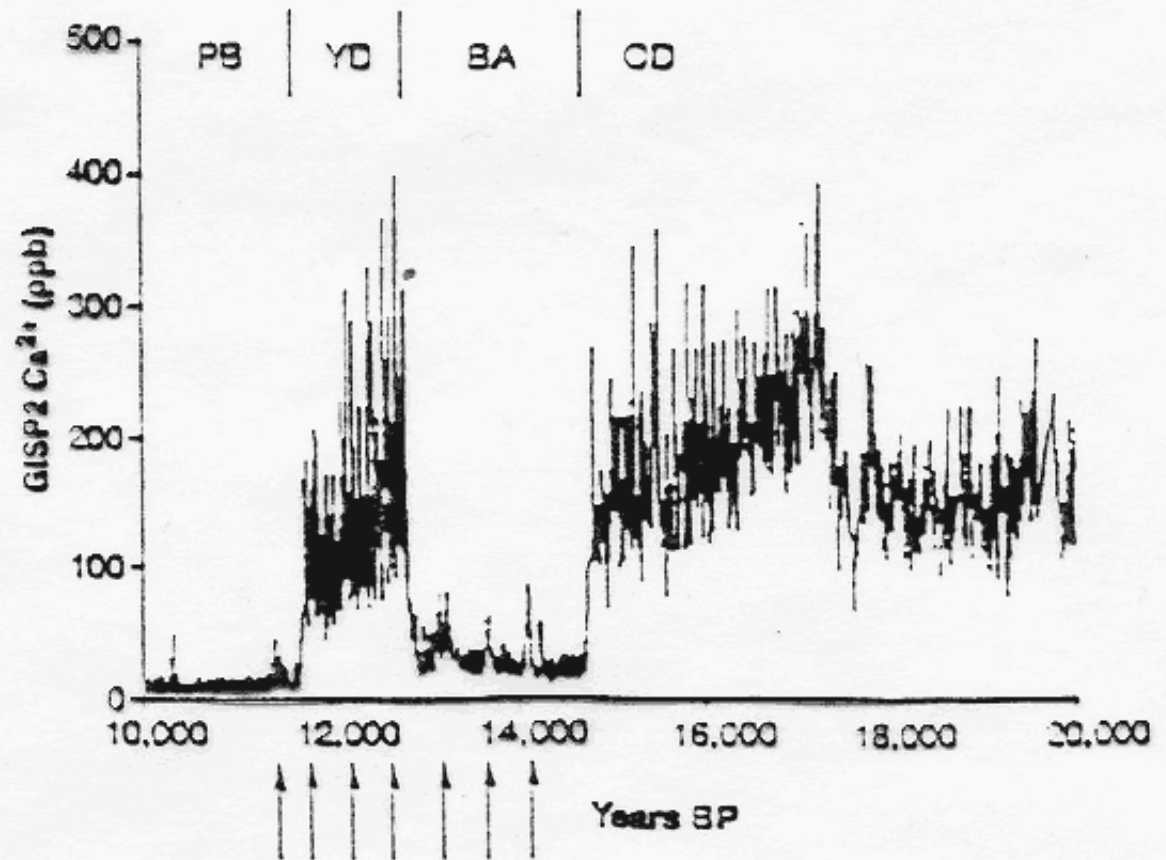


Oxygen isotope profile

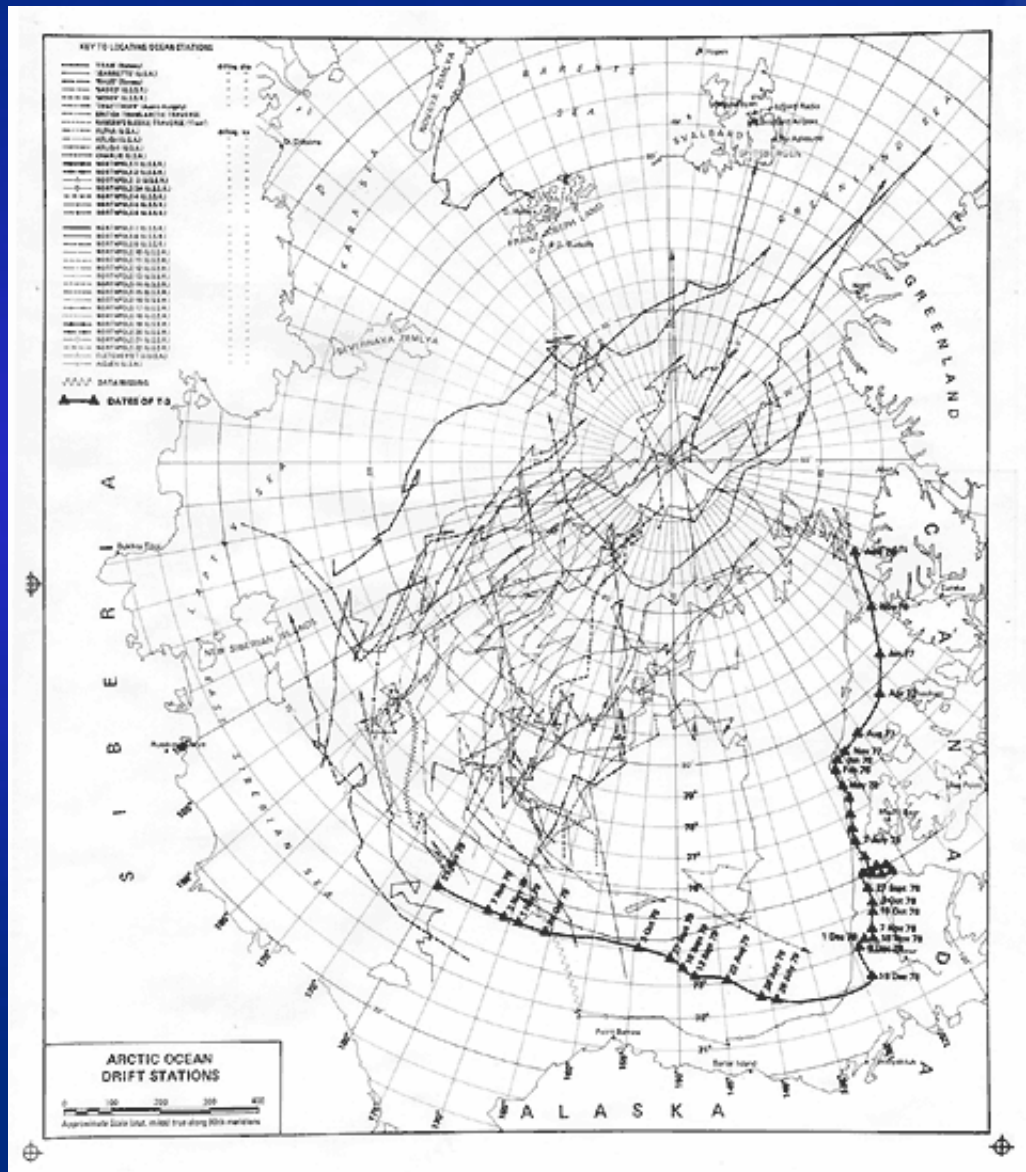


Atmosphere during the Younger Dryas

Calcium concentration (ppb) covering the period ~10,000 to 20,000 years ago. Sample resolution is ~2 years through the Holocene, a mean of 3.48 years within the YD and BA, and ~3 to 15 years during the OD. Arrows mark periods of increased calcium concentration referred to in the text. Years BP, years before present.



Arctic Ocean drift stations

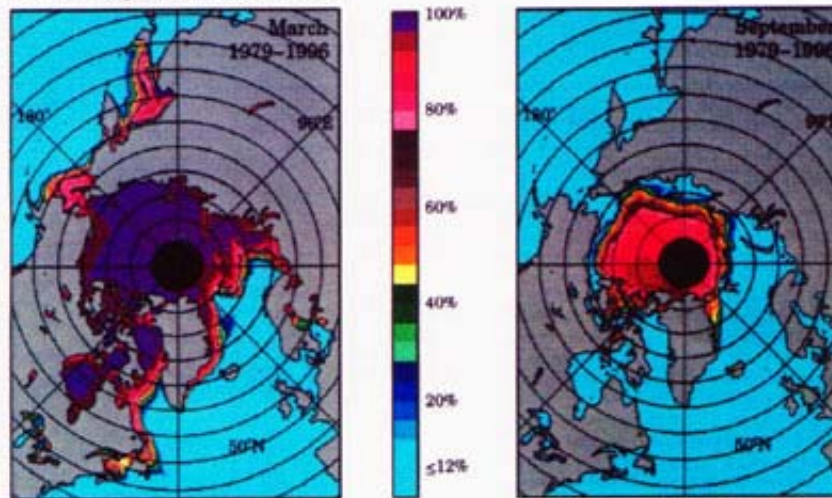


Sea ice concentrations

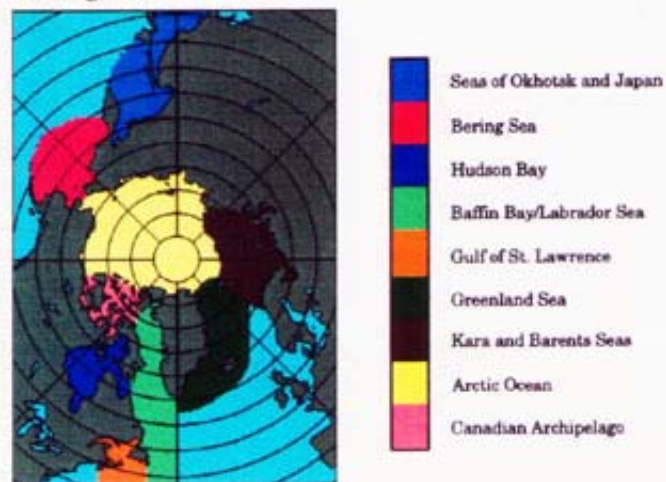
PARKINSON ET AL.: ARCTIC SEA ICE EXTENTS, AREAS, AND TRENDS

20,839

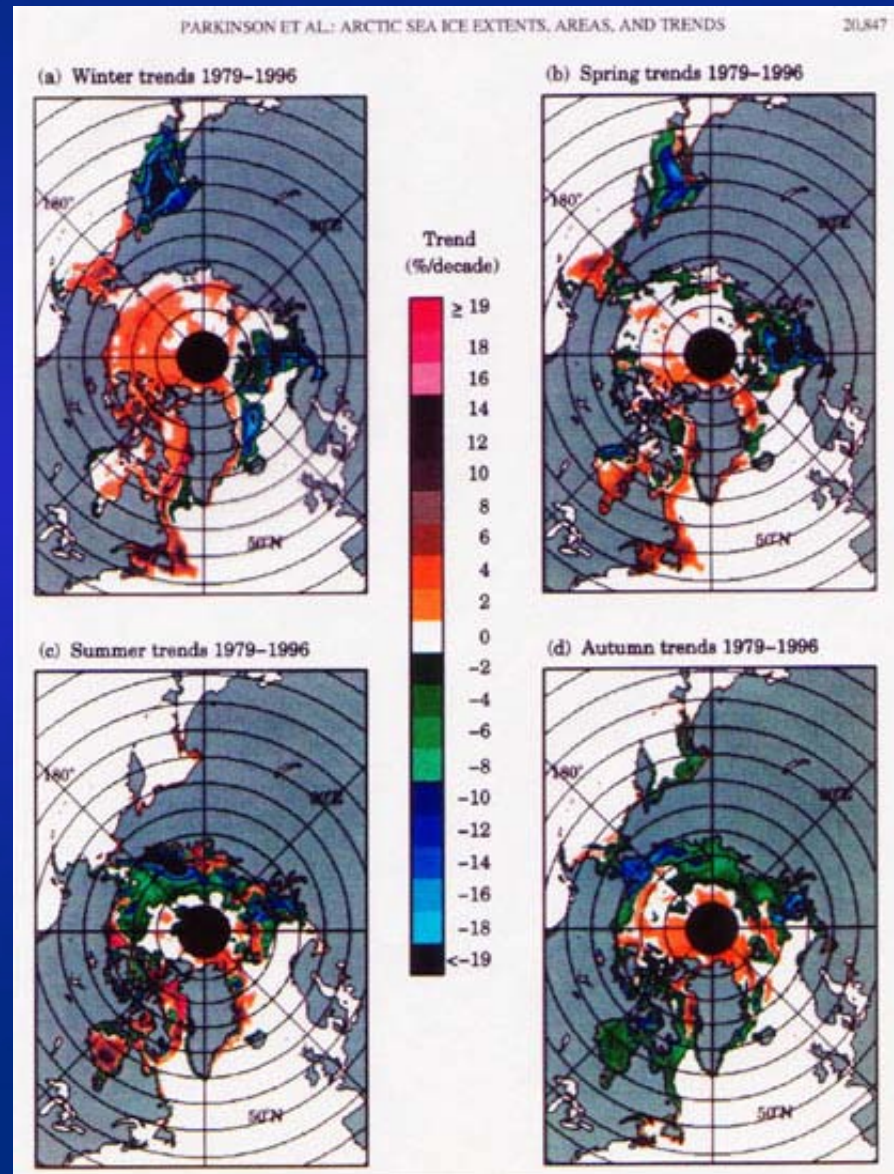
(a) Average ice concentrations



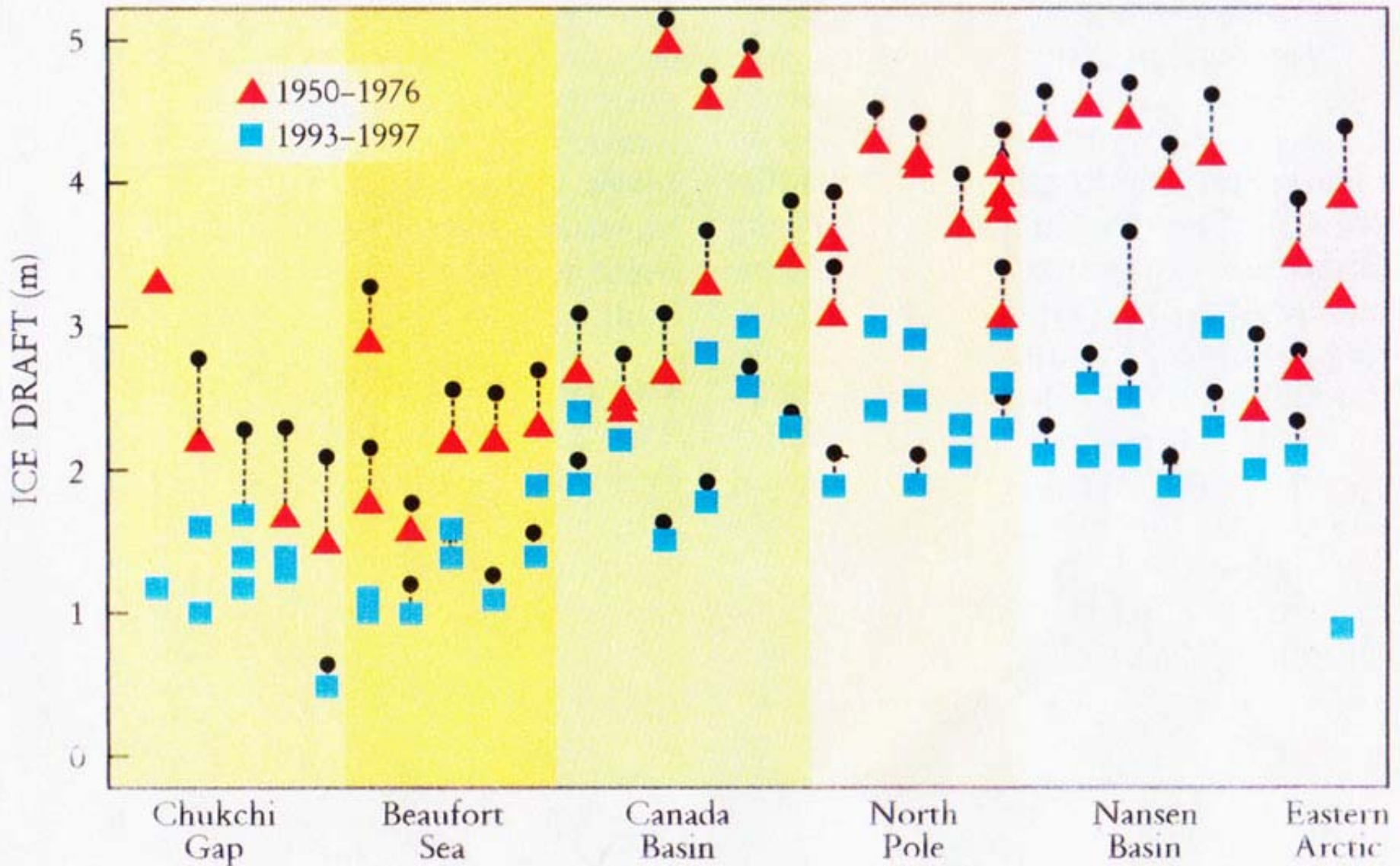
(b) Regions



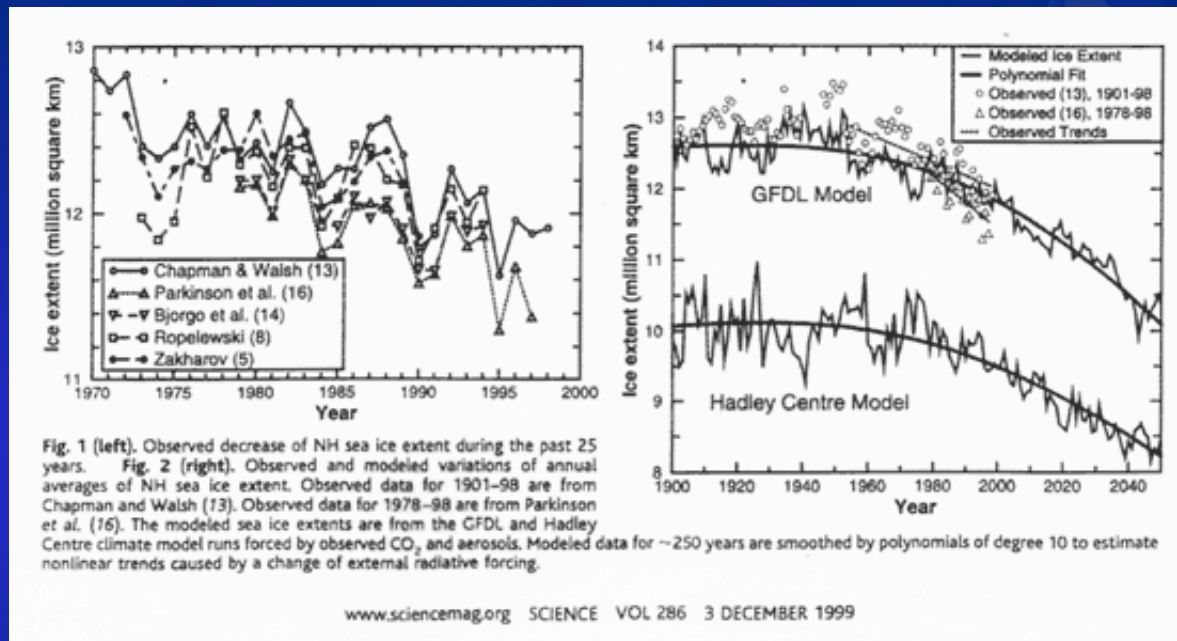
Decadal trends



Ice draft, 1950-76 & 1993-97



Sea ice extent



The variability in both the Hadley Centre and GFDL models is in very good agreement and almost equal to the observed magnitude of decrease in northern hemisphere sea ice. Both models predict continued substantial sea ice extent and thickness decreases in the next century.

Some results relating to climate

Calcium and microparticle concentrations are a measure of atmospheric dust concentration. They were more than ten times larger during the last glaciation.

$^{18}\text{O}/^{16}\text{O}$ or $^2\text{H}/^1\text{H}$ is the main proxy for temperature at the time of the corresponding snow fall. This air becomes entrained in the ice.

The transition from the last glaciation to the post-glacial epoch appears to be a fast increase about 14,000 years ago.

Some results relating to climate

After about 1,000 years, the temperature started to decrease again and reached cold glacial values again about 12,500 years ago (5 to 12°C colder than present). The return to the cold phase is known as the "Younger Dryas" and lasted on the order of 1,000 years.

About 11,700 years ago the temperature abruptly increased again by about 6° C.

Some results relating to climate

The last interglacial period lasted from about 135,000 to about 115,000 years before present. It is located in the core from Greenland between 2,780 and 2,870 m below the surface. The stable isotope record indicates drastic climate variations.

Temperatures were on the order of 2°C warmer than today. Is this an analog of our climate after “greenhouse” warming?

Some results relating to climate

There have been dramatic climate changes over the period of 100,000 to 10,000 years ago. There have been significant temperature changes in 6,000 to 10,000 year cycles when both air and water temperatures tended to cool. Following the cooling cycle, temperatures rose several degrees within a 30 year period.

Why has our climate system remained stable for the past 8,000 to 10,000 years? Could our own activities alter this stability? Or is radical climate change inevitable no matter what we do?

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