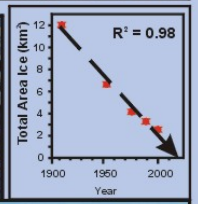
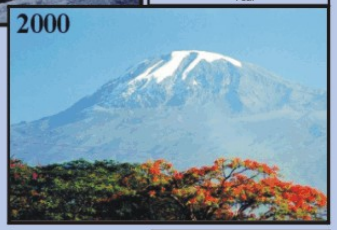
Quelccaya
Ice Cap
Peru

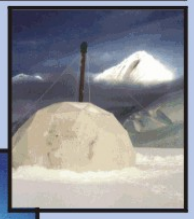
Qori Kalis Glacier, Peru




Kilimanjaro
Africa



Dasuopu
Chinese
Himalaya

South Pole Station

# Abrupt Climate Change: Past, Present and Future

**Lonnie G. Thompson**
**University Distinguished Professor**
**School of Earth Sciences & Byrd Polar Research Center**
**The Ohio State University**

***Ice Core Paleoclimate Research Group***

**Ellen Mosley-Thompson**
**Henry Brecher**
**Mary Davis**
**Sangsuk Lee**
**Ping-Nan Lin**
**Matthew Makou**
**Victor Zagorodnov**

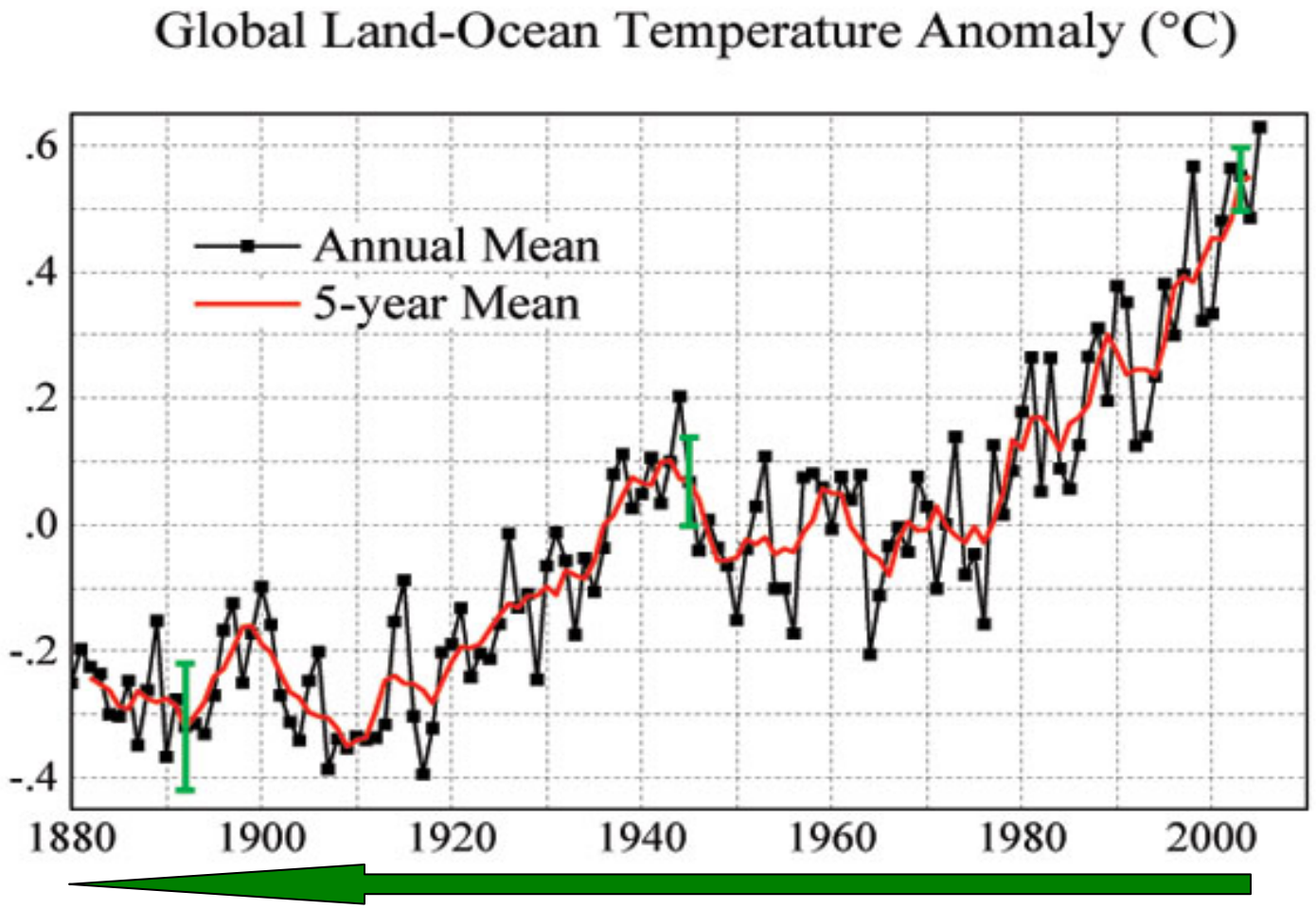
**Funding provided by:**
**NSF: Climate Dynamics and Polar Programs**
**NASA: Earth Sciences**
**NOAA: Paleoclimatology**
**Comer Foundation**

**Graduate Students:** **Liz Birkos, Aron Buffen, Natalie Kehrwald, David Urmann, Lijia Wei**

## Objectives:

- **Glaciers our most visible evidence of global warming**
- **Things we know with certainty**
- **Evidence for abrupt climate change past and present**
- **Evidence for recent acceleration in the rates of ice loss in the tropics**
- **A time perspective for the current climate change**
- **The human response**

# The Meteorological Record is Very Short



# Earth's ice sheets and glaciers preserve long, high resolution histories

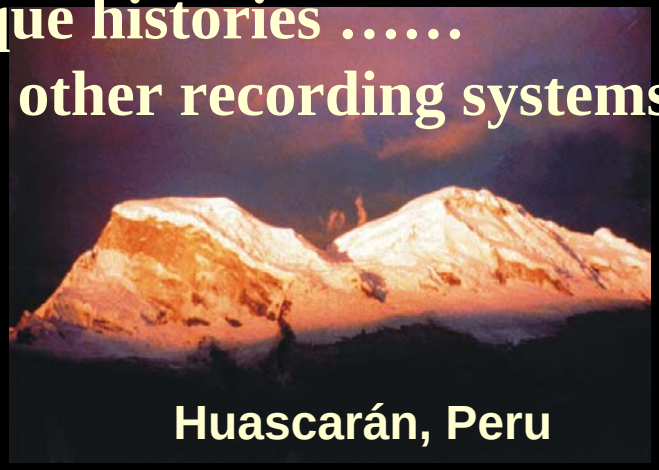
1977
Quelccaya Ice Cap, Peru

High temporal resolution

East Antarctica Plateau

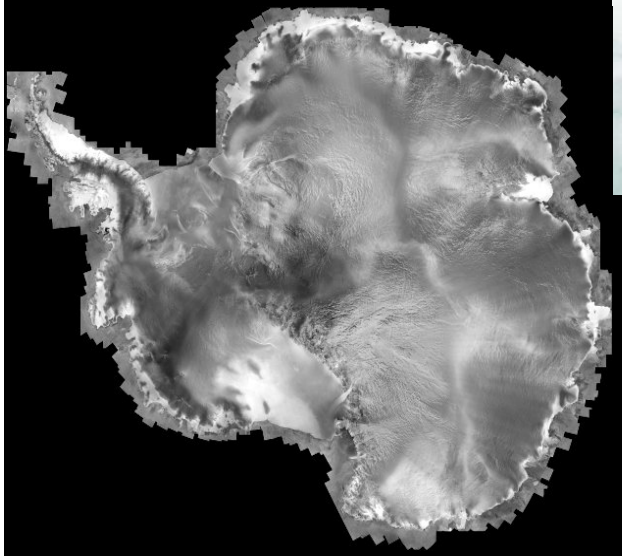
Long records

# Ice cores provide unique histories ……
## from regions where other recording systems are limited or absent

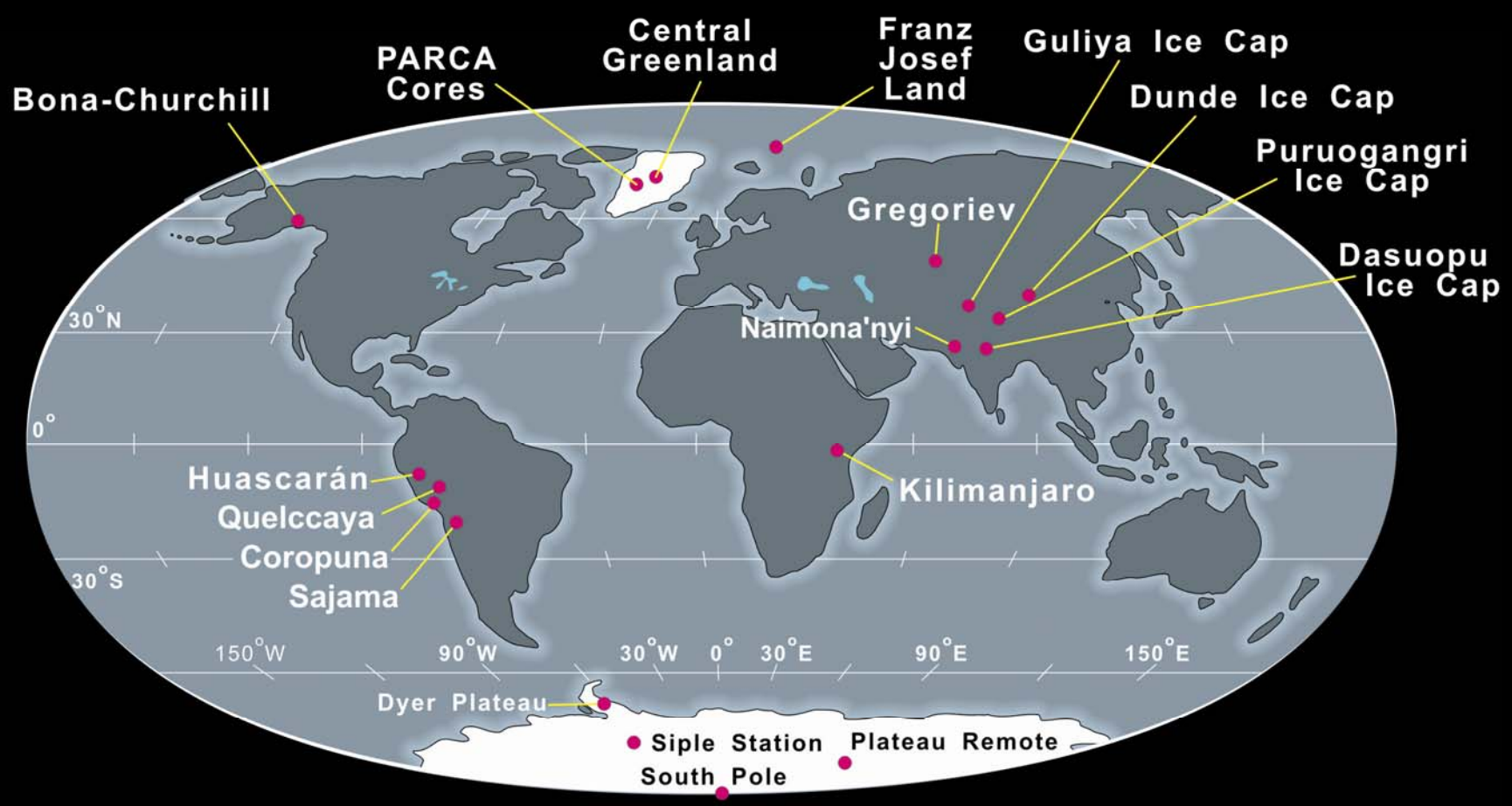


Huascarán, Peru

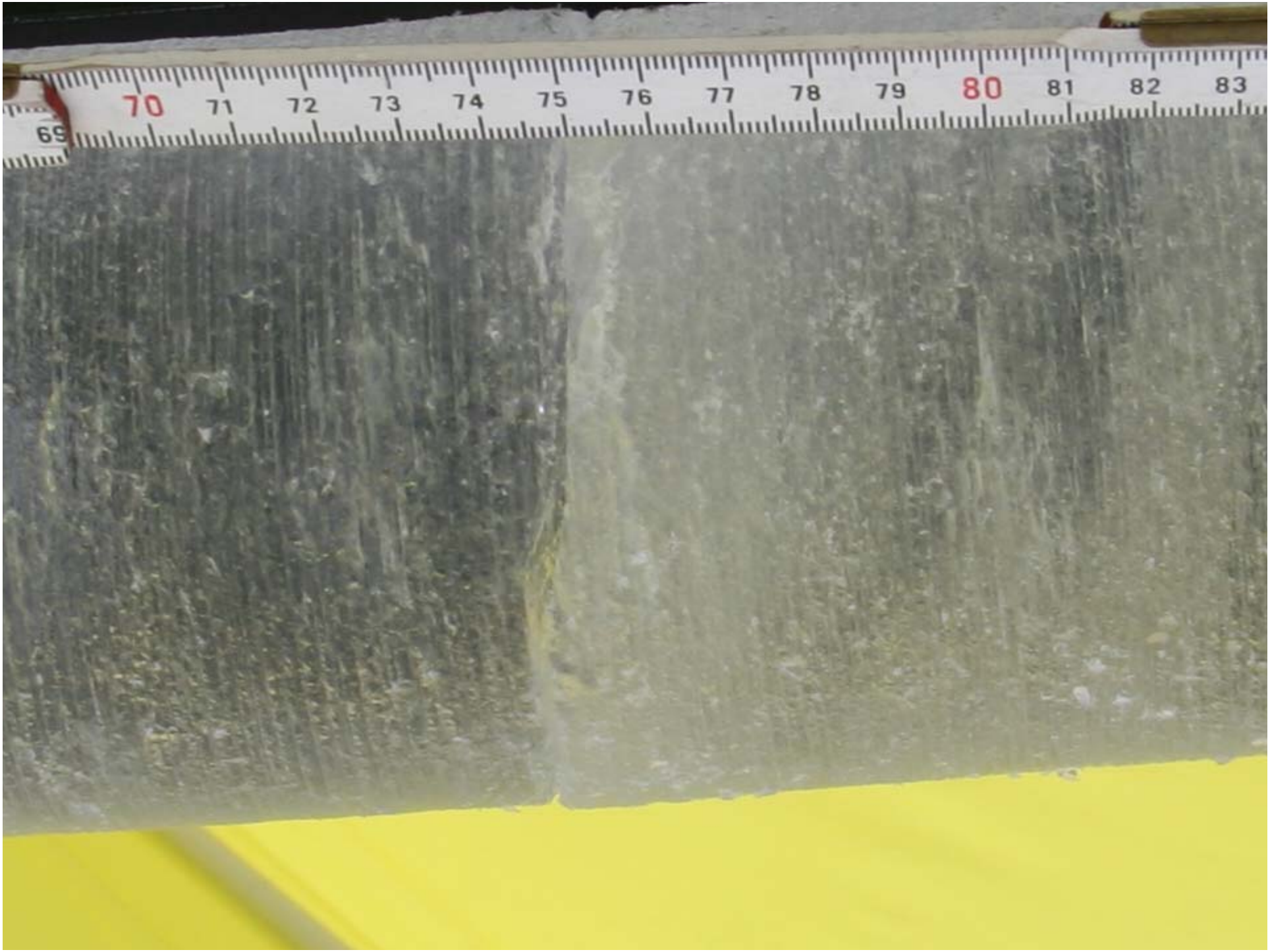
Dasuopu Glacier
Southern Tibet



# Sites where the OSU team has drilled ice cores




青藏高原第四纪冰川遗迹分布图
QUATERNARY GLACIAL DISTRIBUTION MAP OF QINGHAI-XIZANG (TIBET) PLATEAU
LEGEND
Dunde
Guliya
Puruogangri
Dasuopu
Proposed Research Area


70
71
72
73
74
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76
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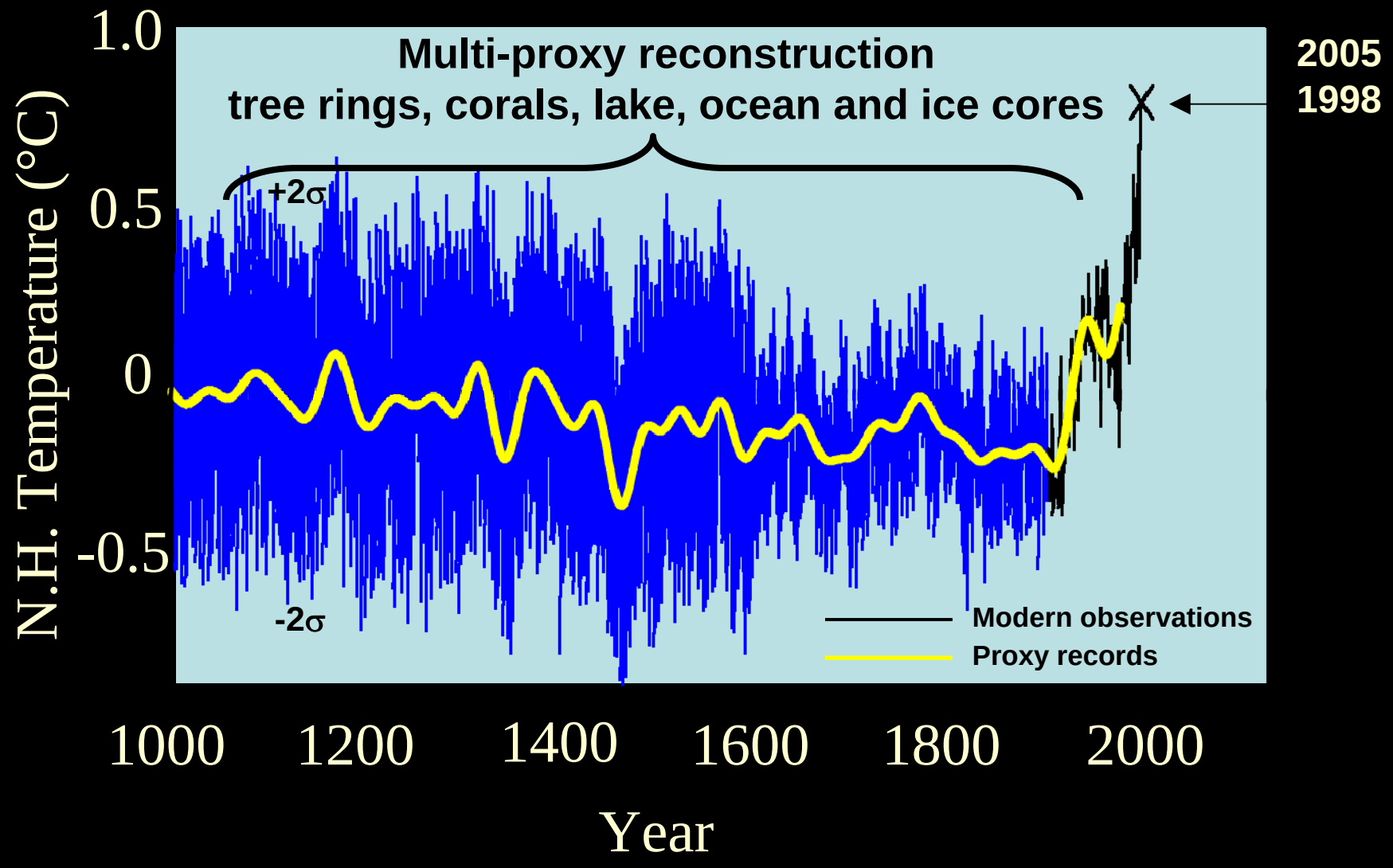
80
81
82
83

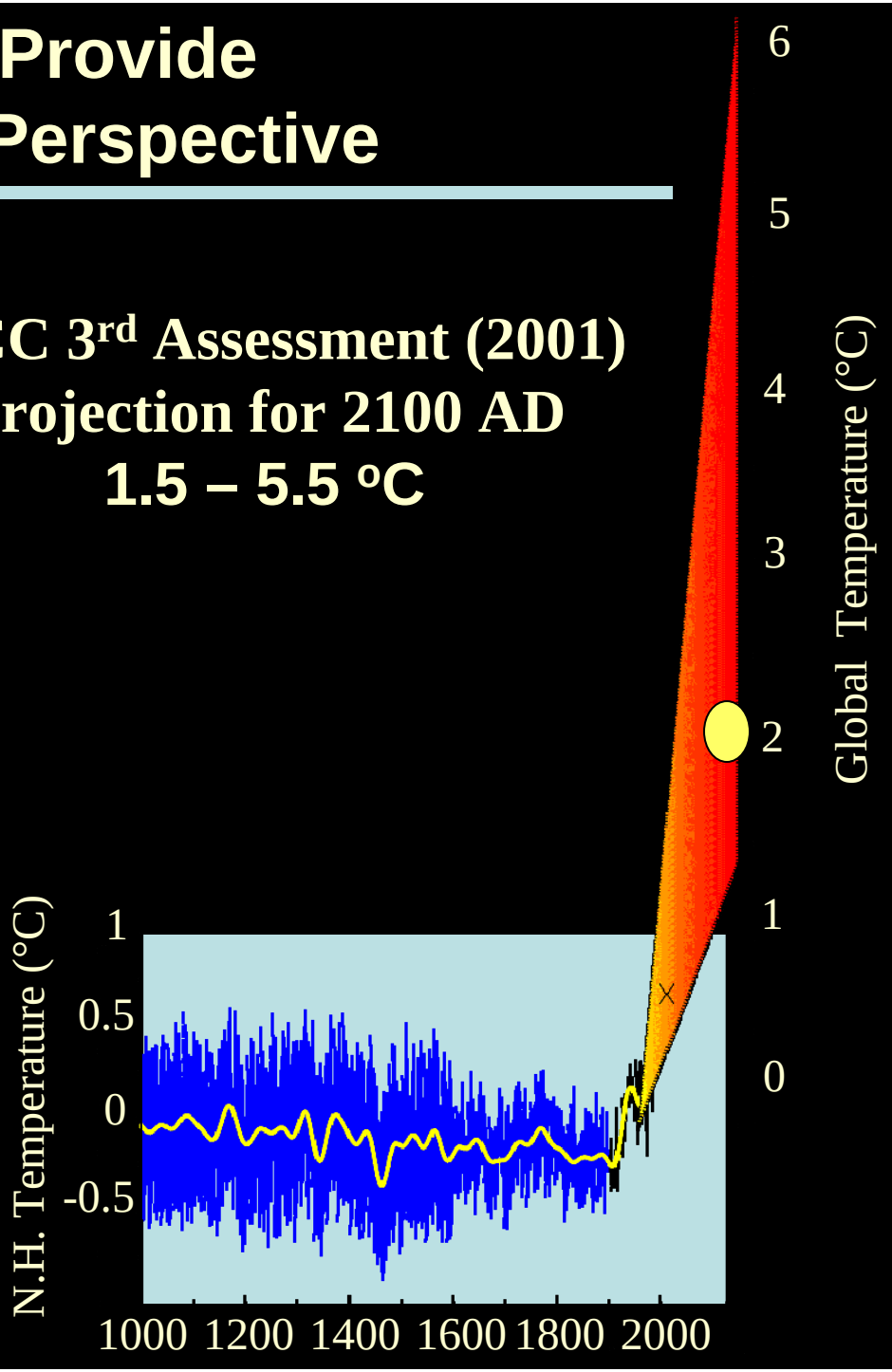
# Proxy Records Provide A Critical Time Perspective




Mann *et al. GRL* 26:759-762, 1999.

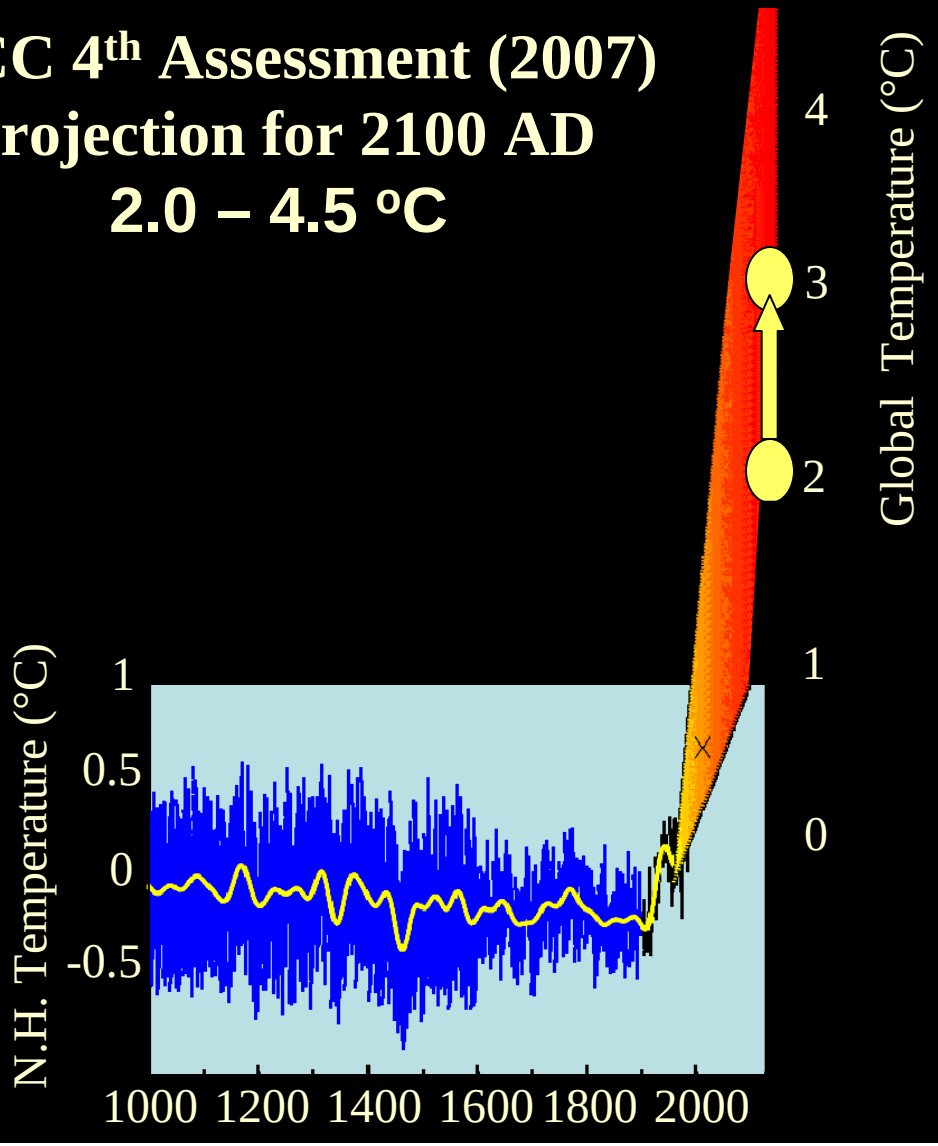
# Proxy Records Provide a Critical Time Perspective

**IPCC 3rd Assessment (2001)**
**Projection for 2100 AD**
**1.5 – 5.5 ºC**



# Proxy Records Provide a Critical Time Perspective

**IPCC 4th Assessment (2007)**
**Projection for 2100 AD**
**2.0 – 4.5 ºC**



# Earth's ice sheets and glaciers preserve long, high resolution histories

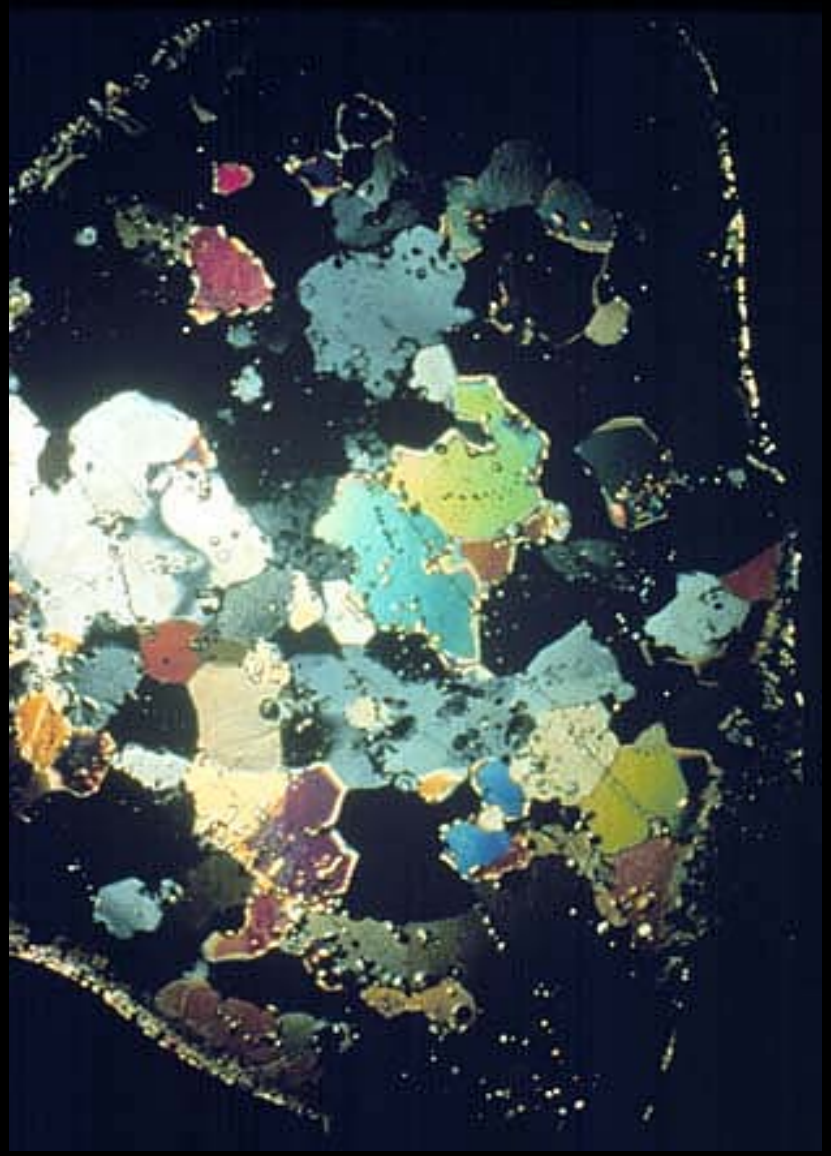
1977
Quelccaya Ice Cap, Peru

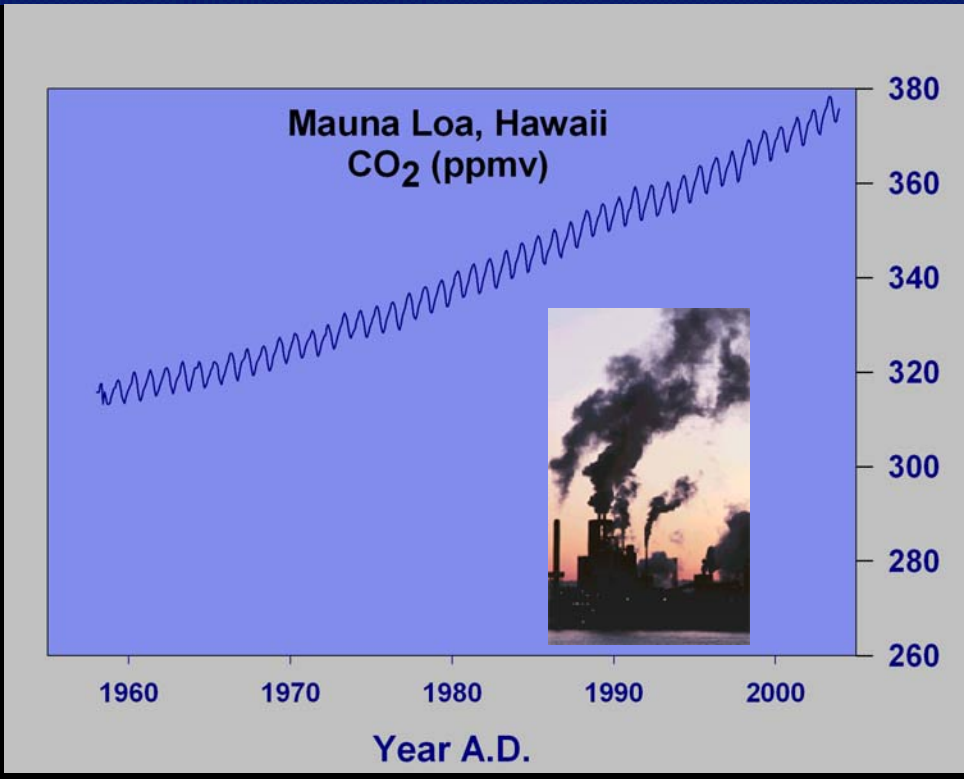
High temporal resolution

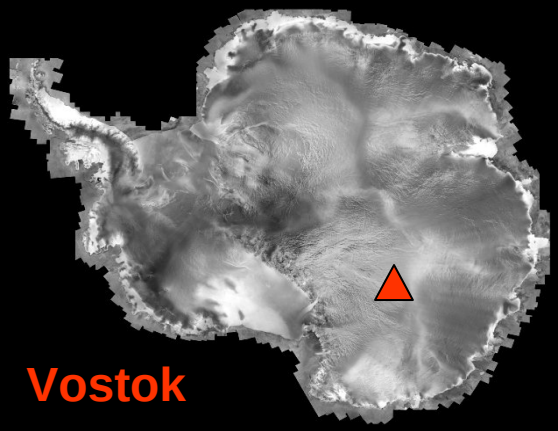
East Antarctica Plateau

Long records

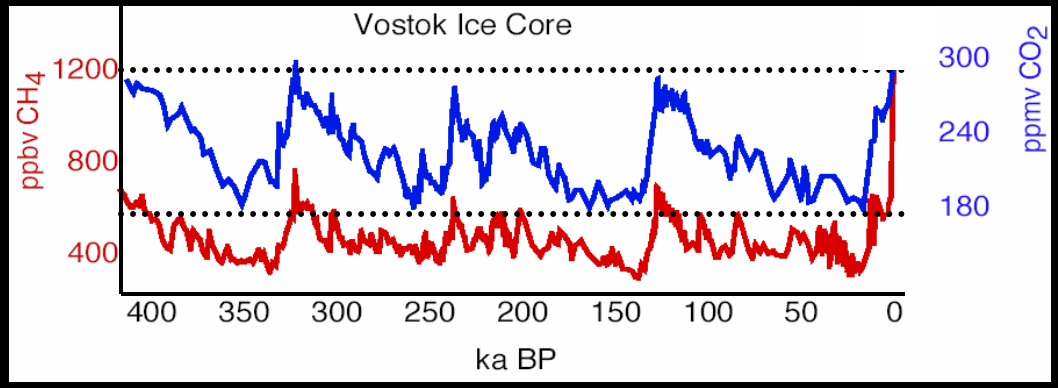
# Carbon Dioxide Concentrations



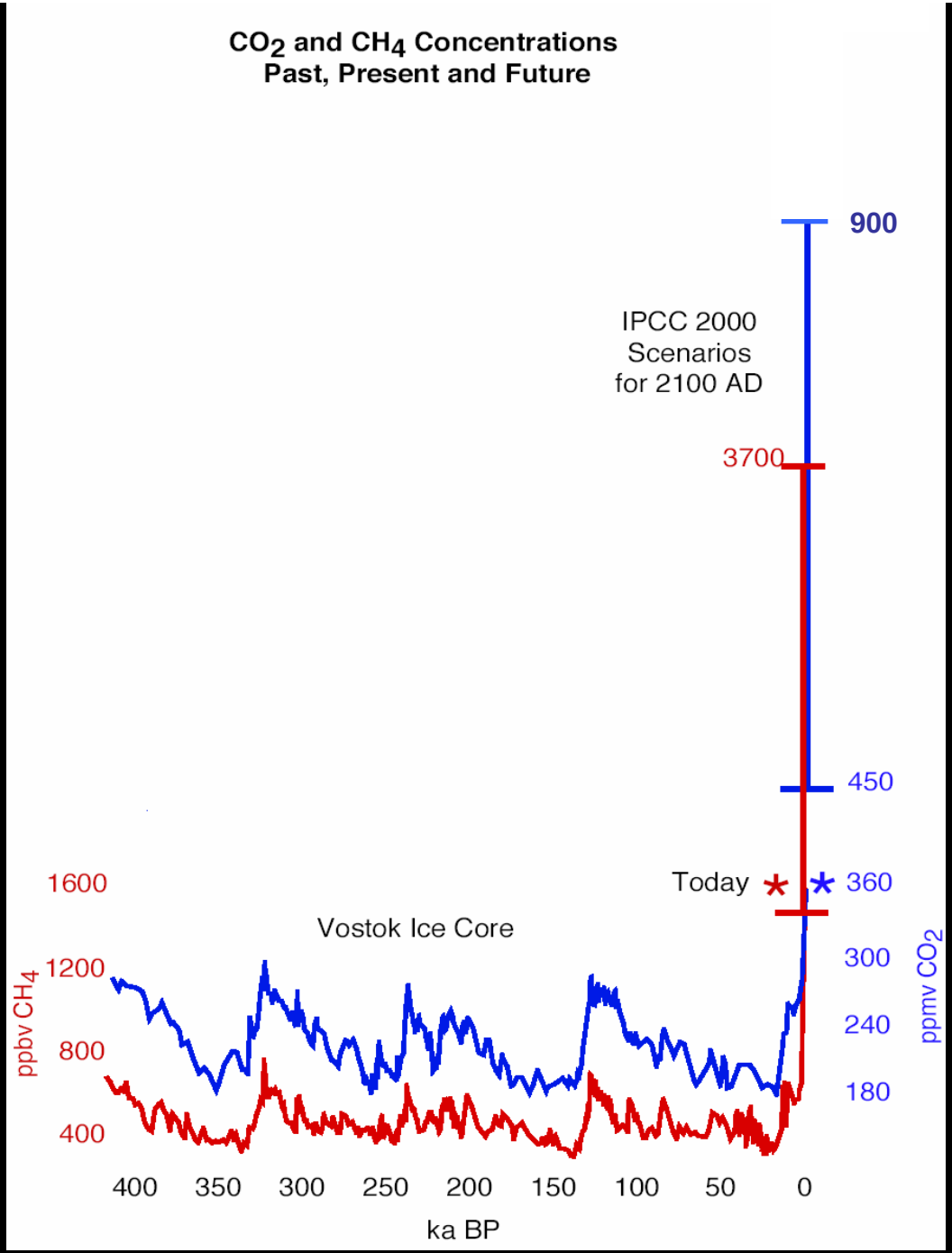



**The Vostok ice core extends back through multiple glacial and interglacial stages - recording the changes in the composition of the Earth's atmosphere**




*Houghton et al., 2001*
*Petit et al., 1999*



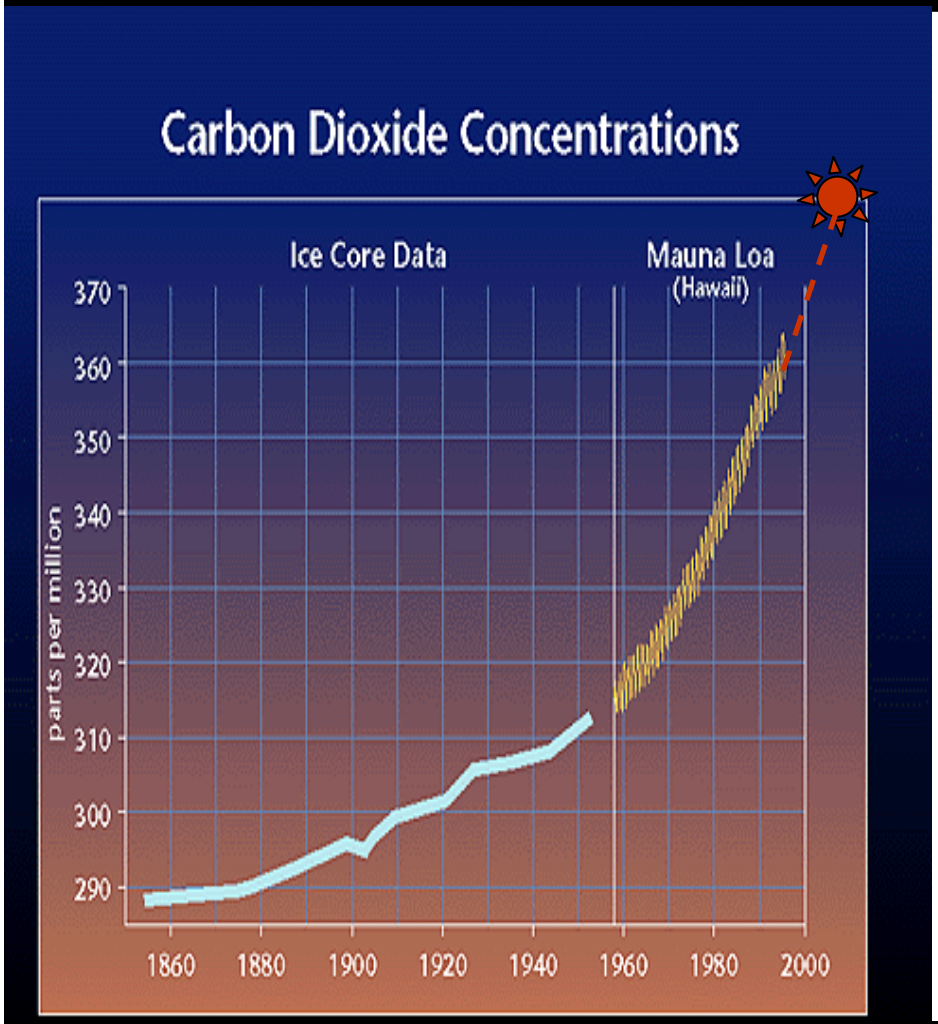

**By 2100:**
**$CO_2$ ~ 900 ppmv**

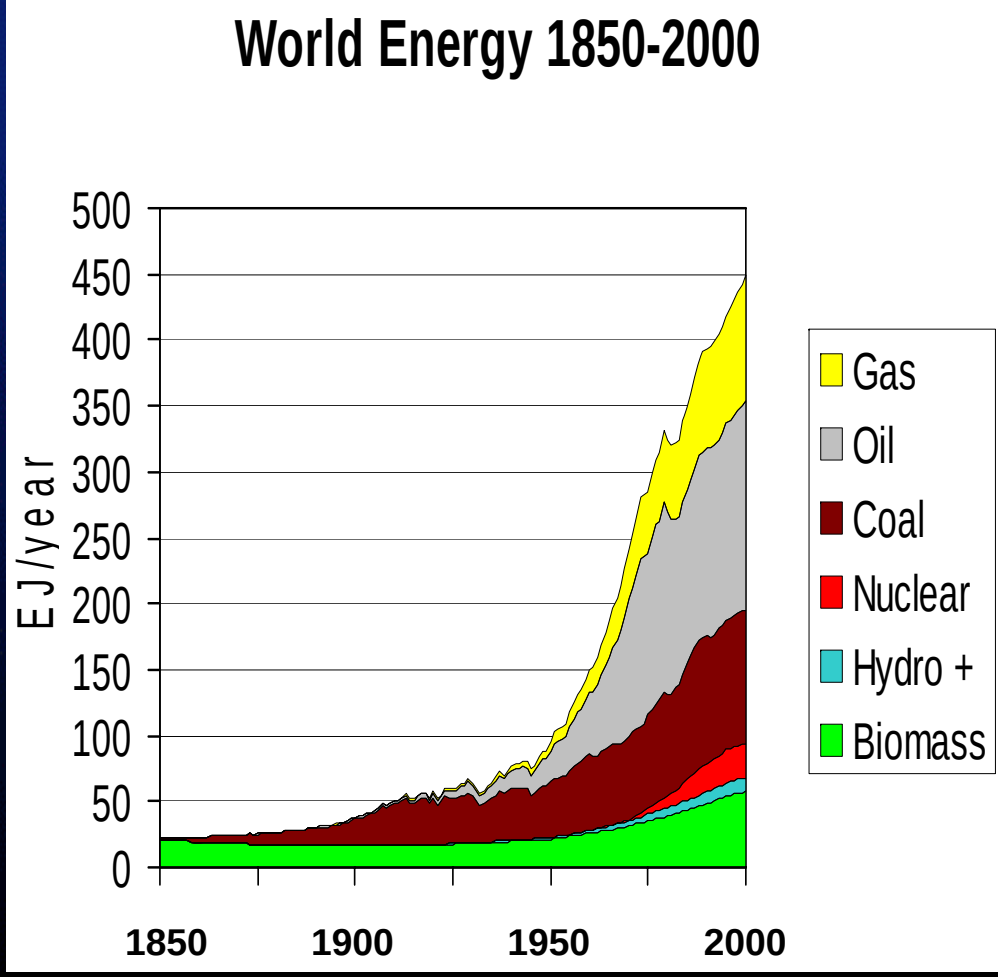
**By 2100:**
**$CH_4$ ~ 3750 ppbv**

**Today:**
**$CO_2$ is 380 ppmv**
**$CH_4$ is 1750 ppbv**

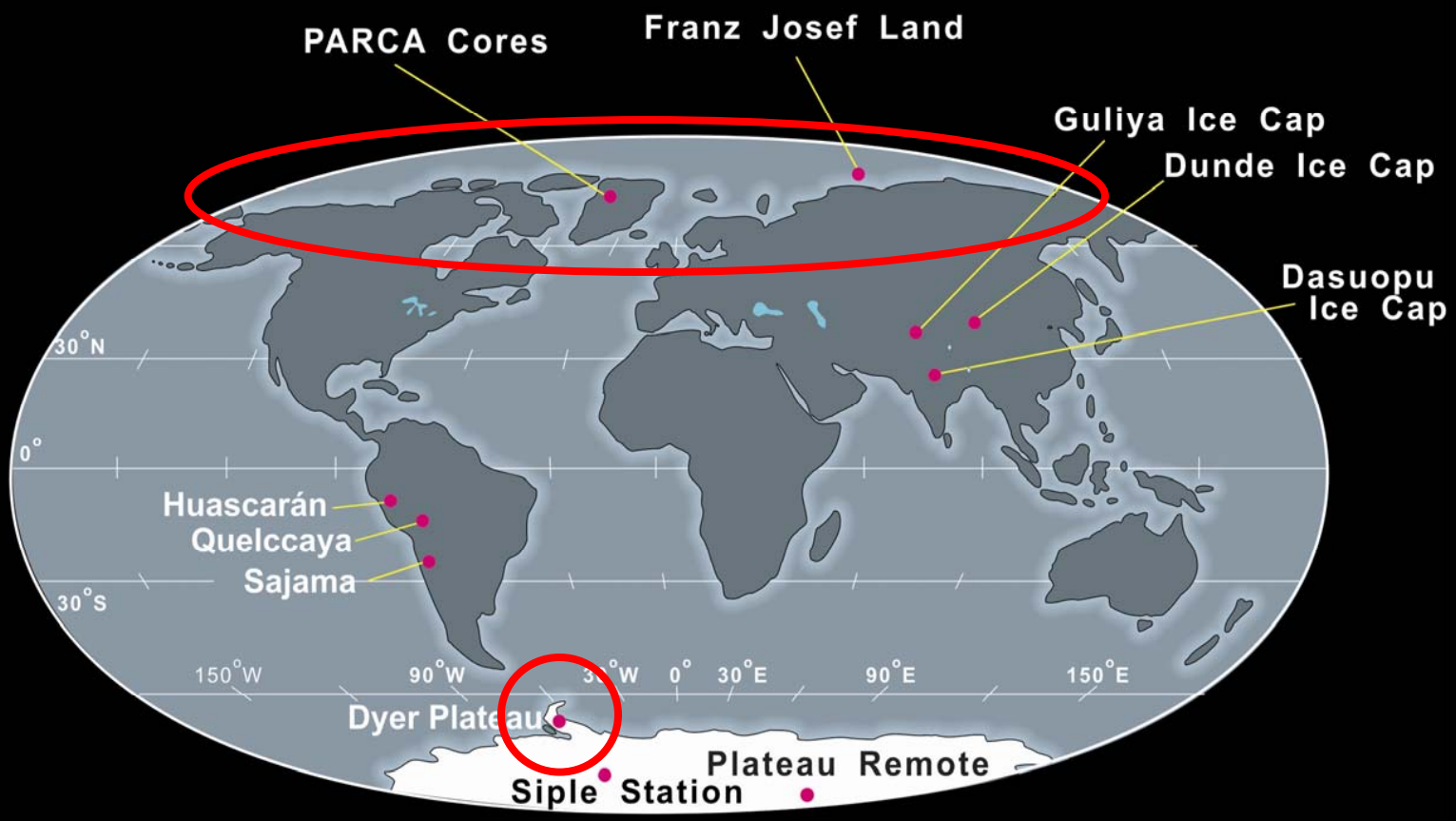
*Houghton et al., 2001*
*Petit et al., 1999*

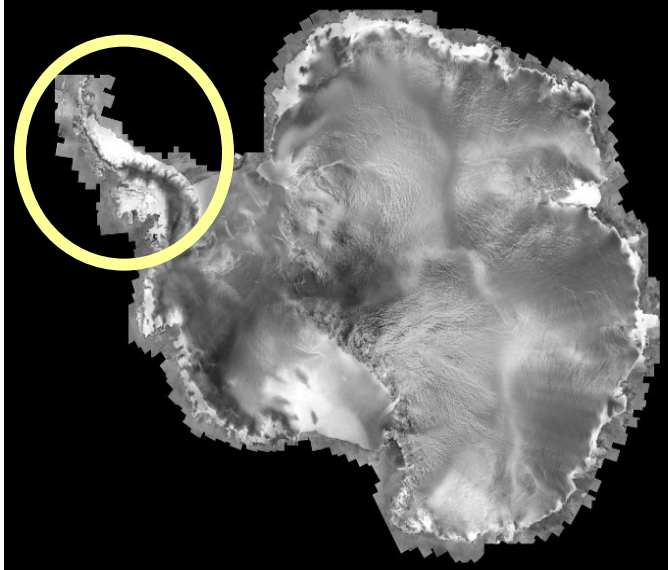
**The increase in atmospheric carbon dioxide is primarily due to world energy consumption and secondarily due to deforestation.**



# Areas where the Earth is warming most rapidly at this time

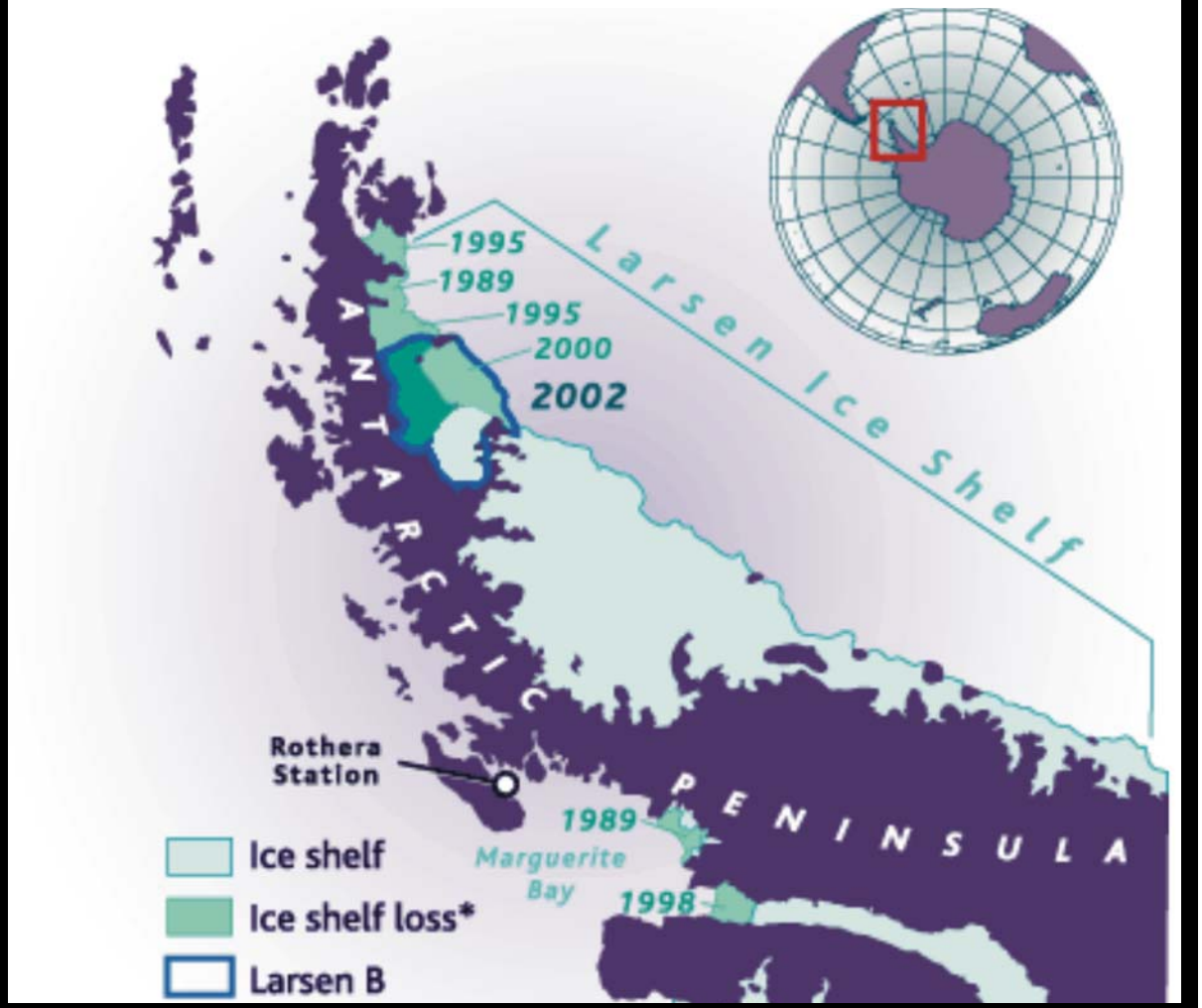




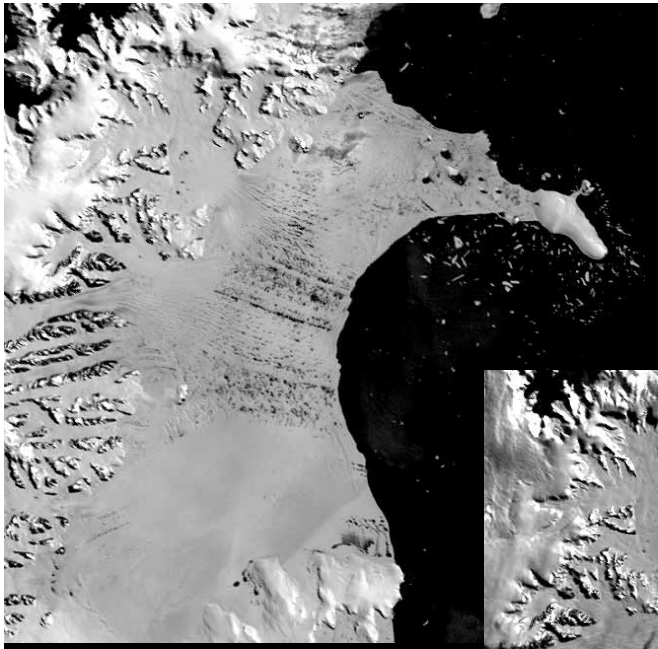
- Earth's cold regions and their icy cover are well documented <u>indicators</u> of climate change

- High latitude/elevation processes are important <u>drivers</u> in climate change

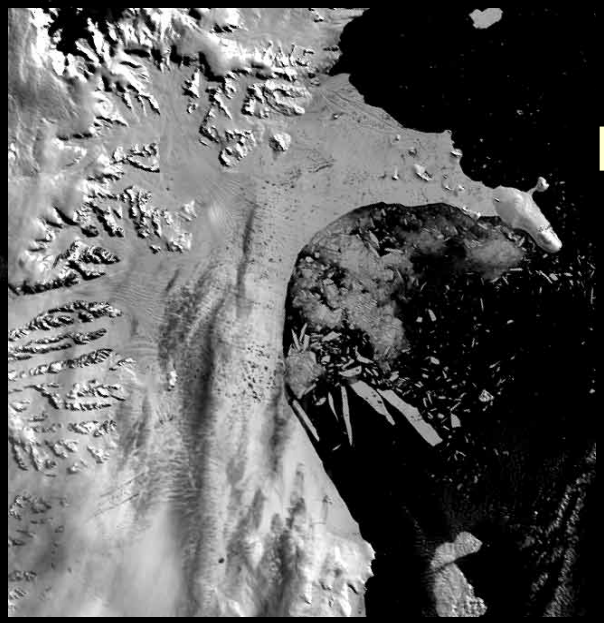
**Temperatures in the Peninsula region have warmed ~2.0°C in the last 50 years.**



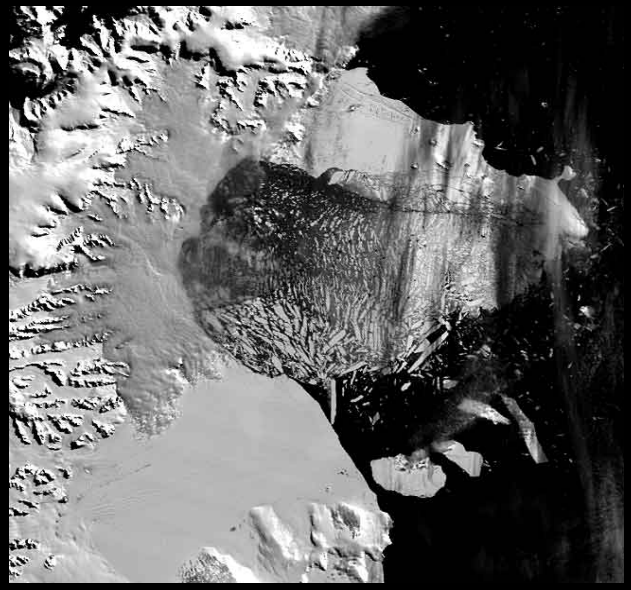
**Part of the Larsen B Ice Shelf collapsed in 31 days (2002)**



**Jan 31**



**Feb 23**



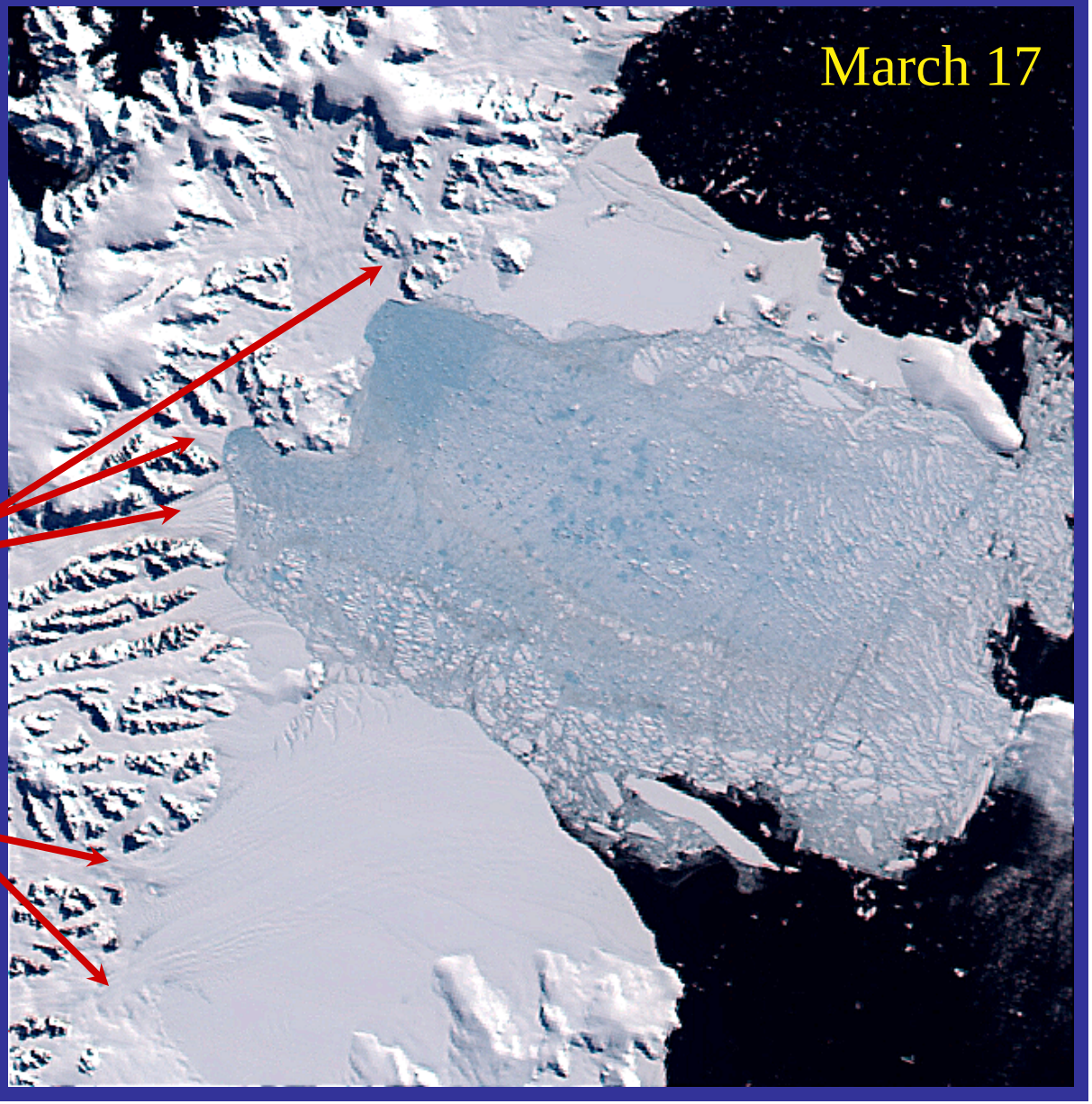
**Mar 3**

# Ice Shelves and the Buttressing Effect

Collapsing ice shelves don't directly raise sea level, but…

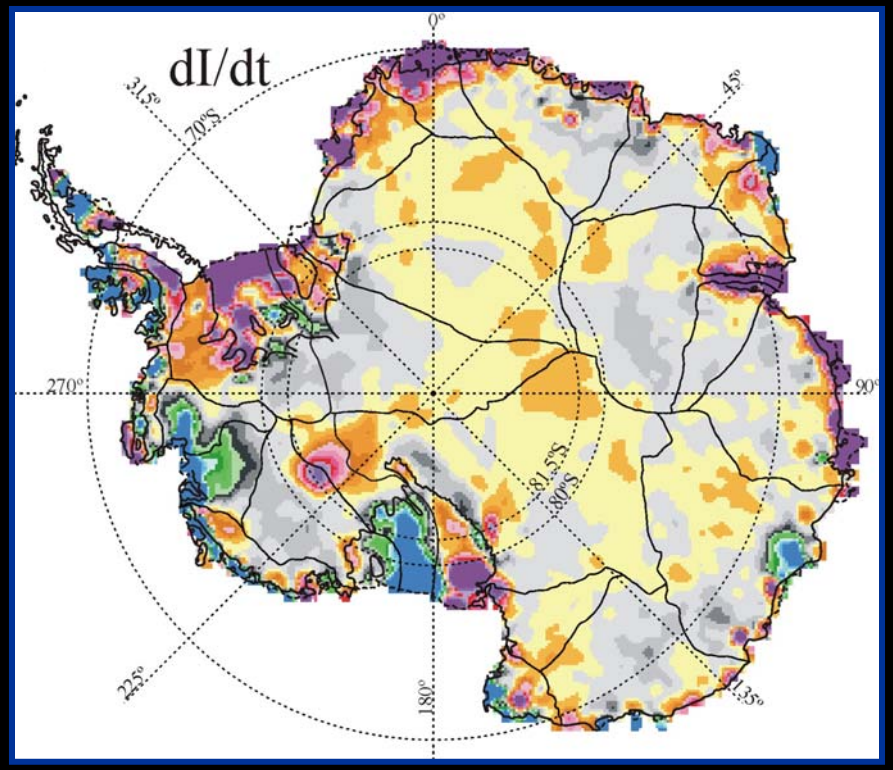
- Increase in flow speed up to 8-fold
- Thinning by as much as 40 m in six months

- Glaciers that fed the remaining parts of the ice shelf did not accelerate

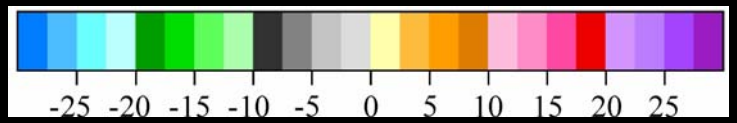



Ted Scambos, NSIDC

# Antarctic Ice Sheet Elevation




Ice Thickness Change From Altimetry

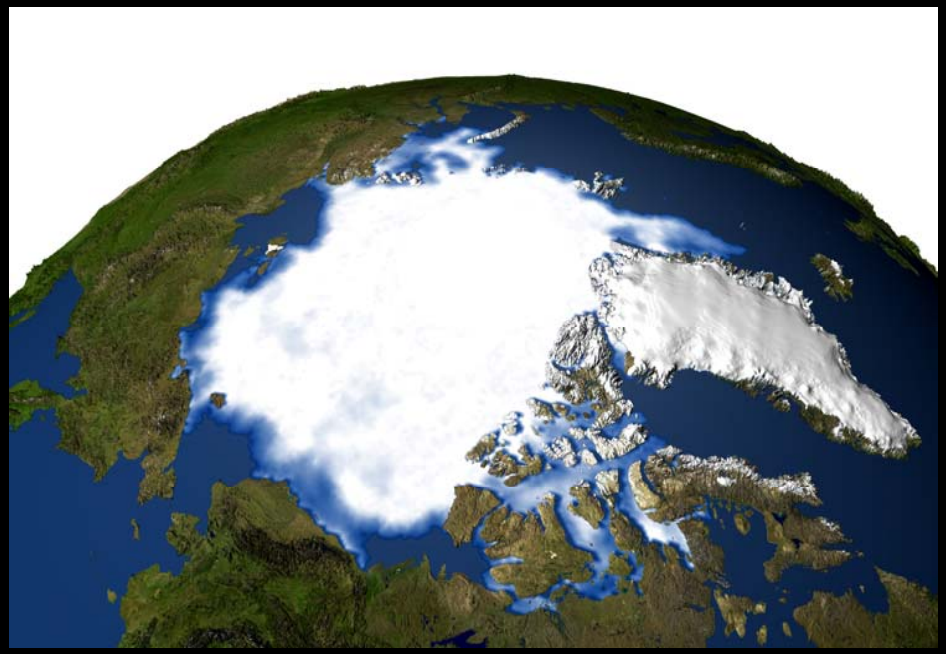


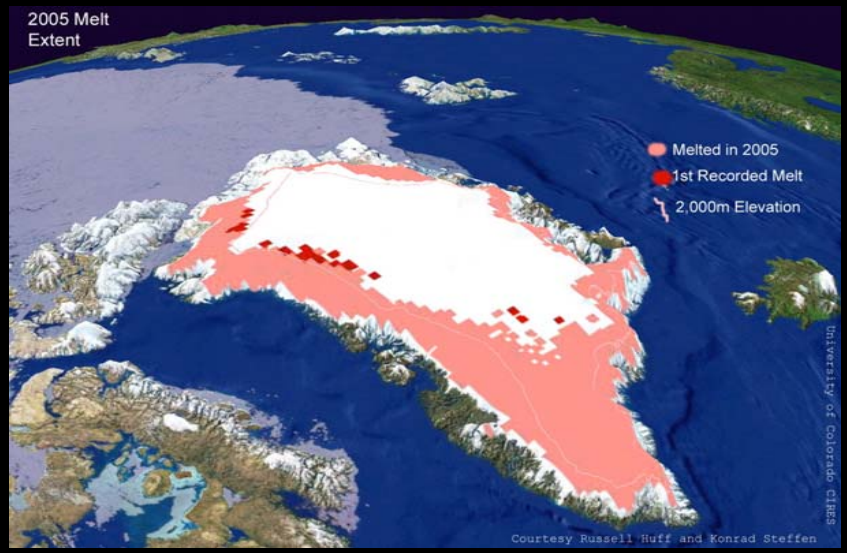

(cm/yr)

Zwally et al. 2005

- **Altimeter data indicate East Antarctic thickening with increased snowfall and surface cooling**
- **Locally, Pine Island and Thwaites Glaciers *Thinning* (0.75-2.5 ma-1; Wingham) and *Accelerating***
- **GRACE 2002-2005: Ice sheet mass decrease at a rate of 152 ± 80 km3/year of ice, equivalent to 0.4 ± 0.2 mm/year of global sea level rise. Much larger than balance calculation (Velicogna and Wahr, 2006)**

# The Greenland Ice Sheet



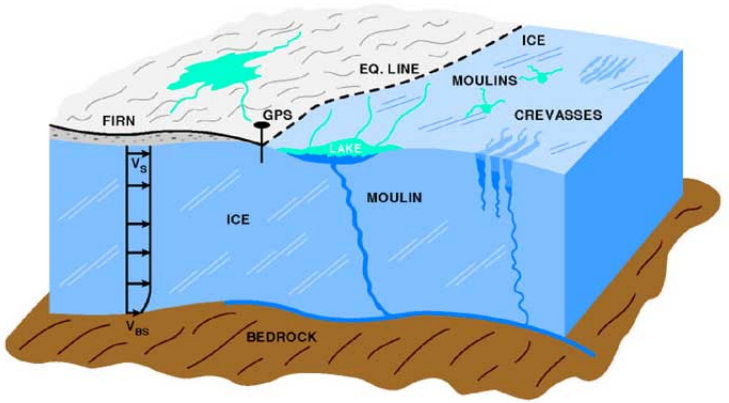



- 7 m sea level equivalent
- Unlike Antarctica, experiences substantial surface melt in the summer time over much of its area
- Rimmed by outlet glaciers with some floating ice tongues; ice shelves are absent

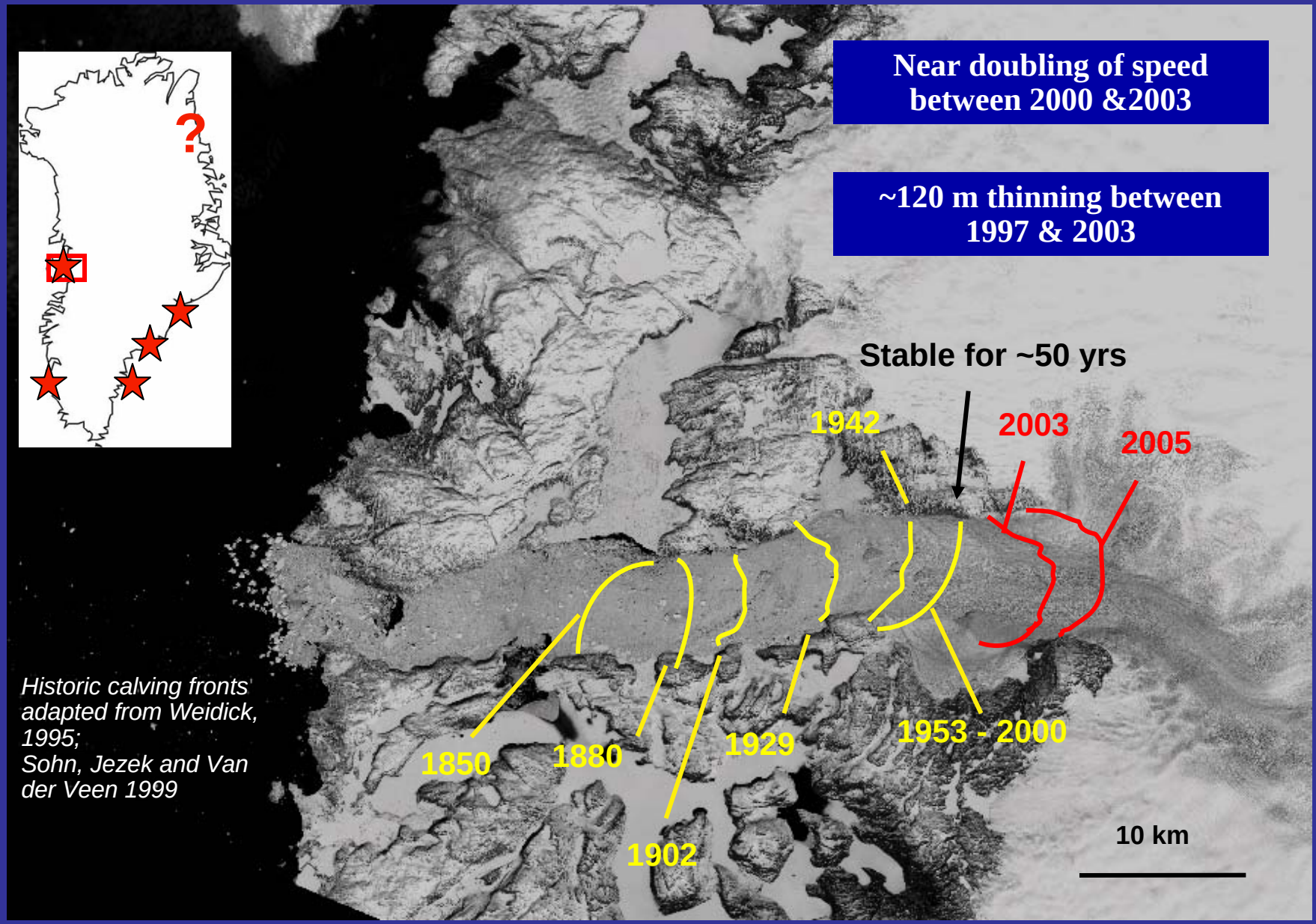
**The warming in the Arctic is now well-documented …..**
**Arctic Climate Impact Assessment**
**available at http://www.acia.uaf.edu/**

**East Greenland: summer melt water running into a moulin**

**Photo by Roger J. Braithwaite**




# Retreat of the Jakobshavn Ice Stream



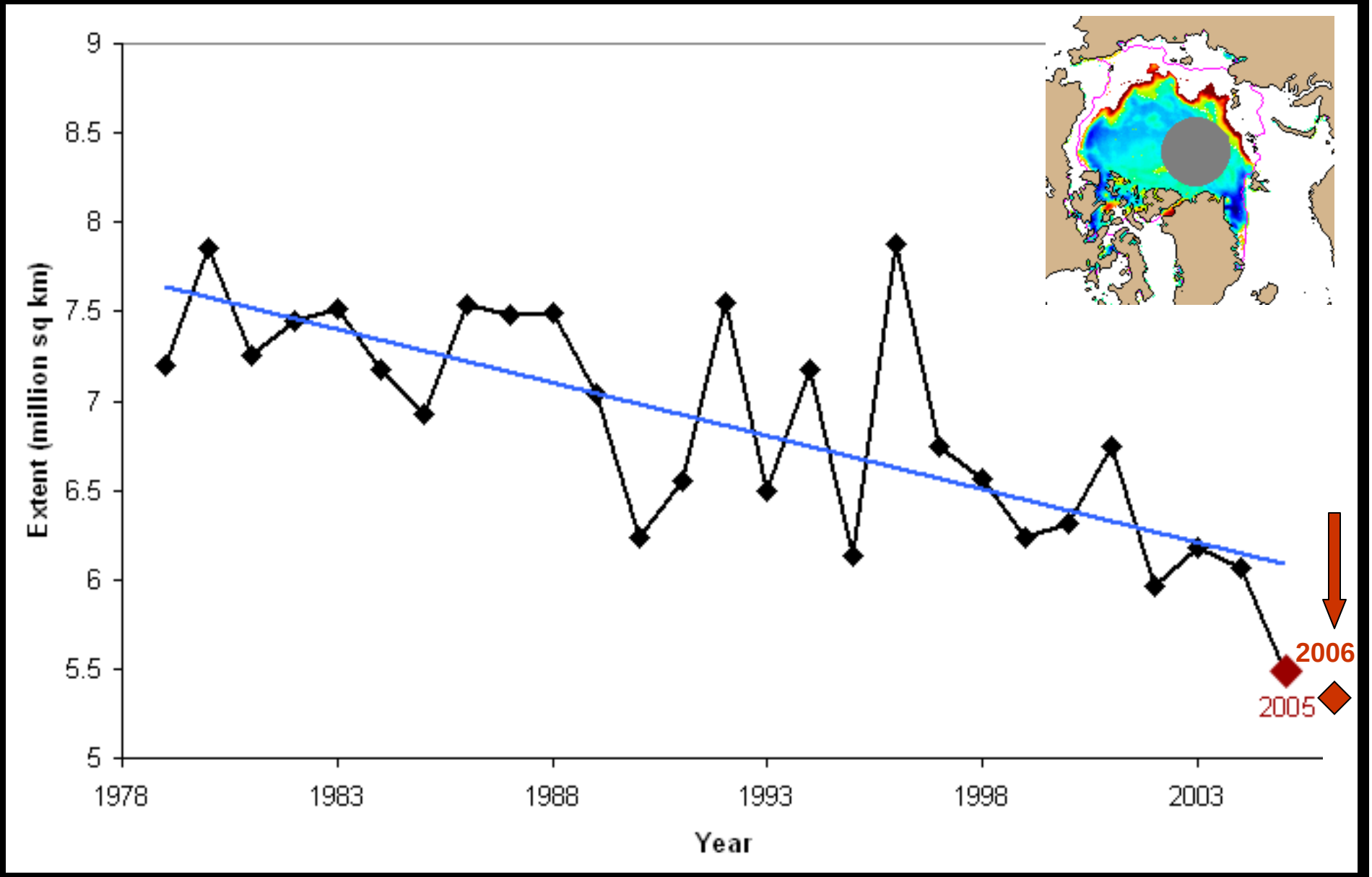
# Perennial Sea Ice Cover

- Significant reduction in perennial sea ice cover over the last 25 years (10% per decade)
- When replaced, it is with younger thinner ice
- Submarine data indicate 40% thinner ice than in the several decades before the mid-1990s


Yellow Line is the 1979-2004 average

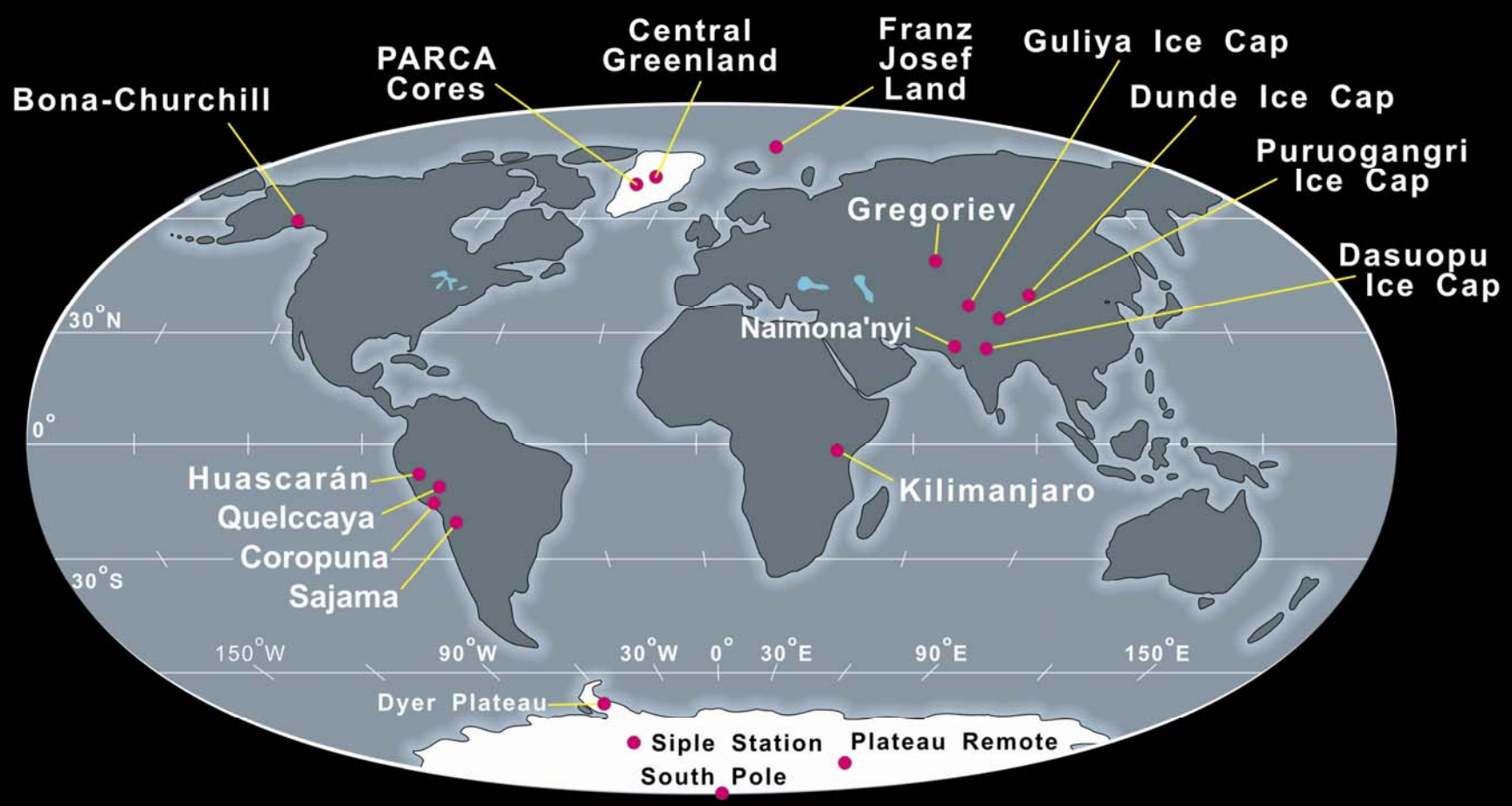
Source: GSFC Scientific Visualization Studio and J. Comiso

# Arctic Sea Ice Decline Intensifies

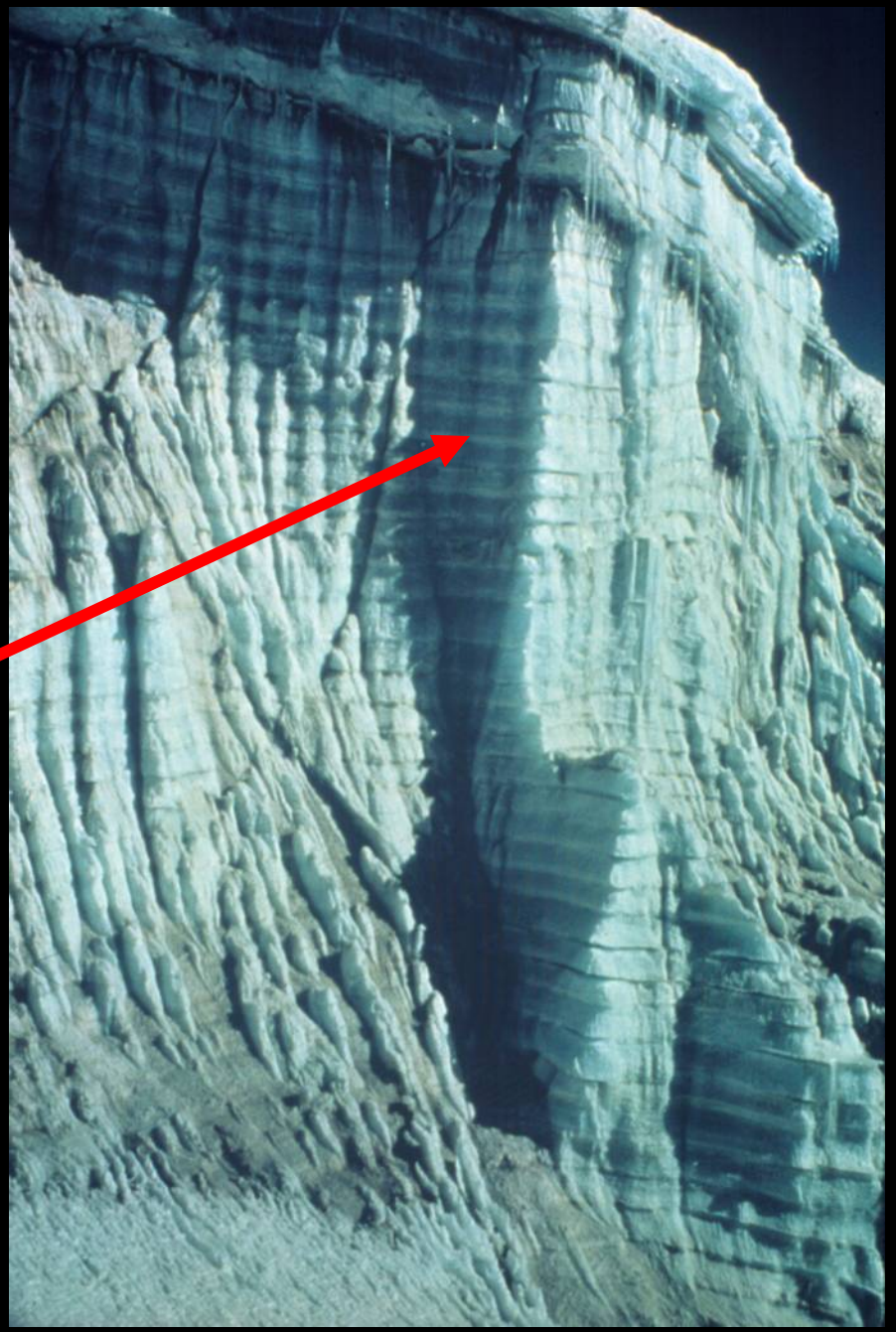


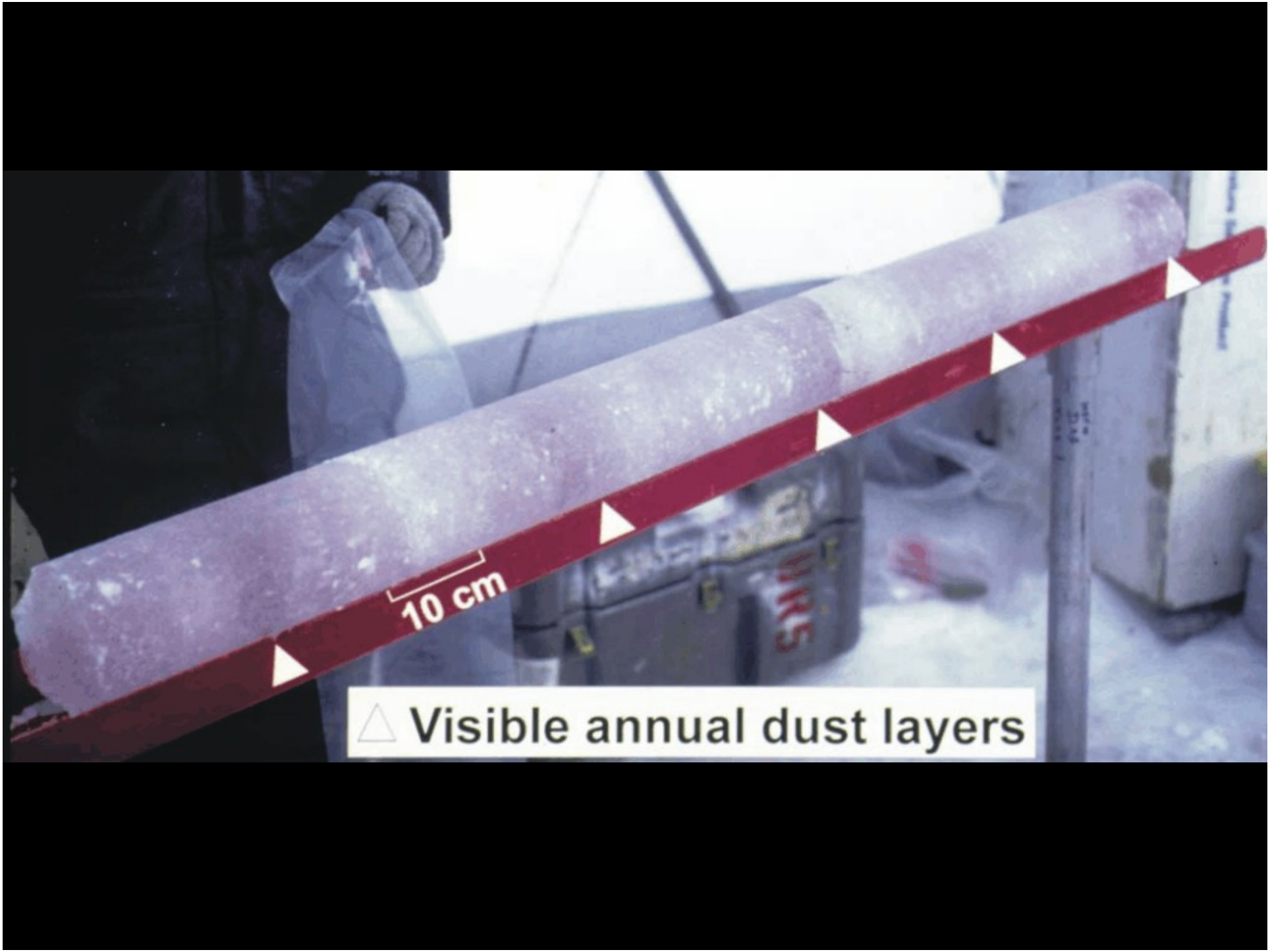

September 28, 2005

# Sites where the OSU team has drilled ice cores

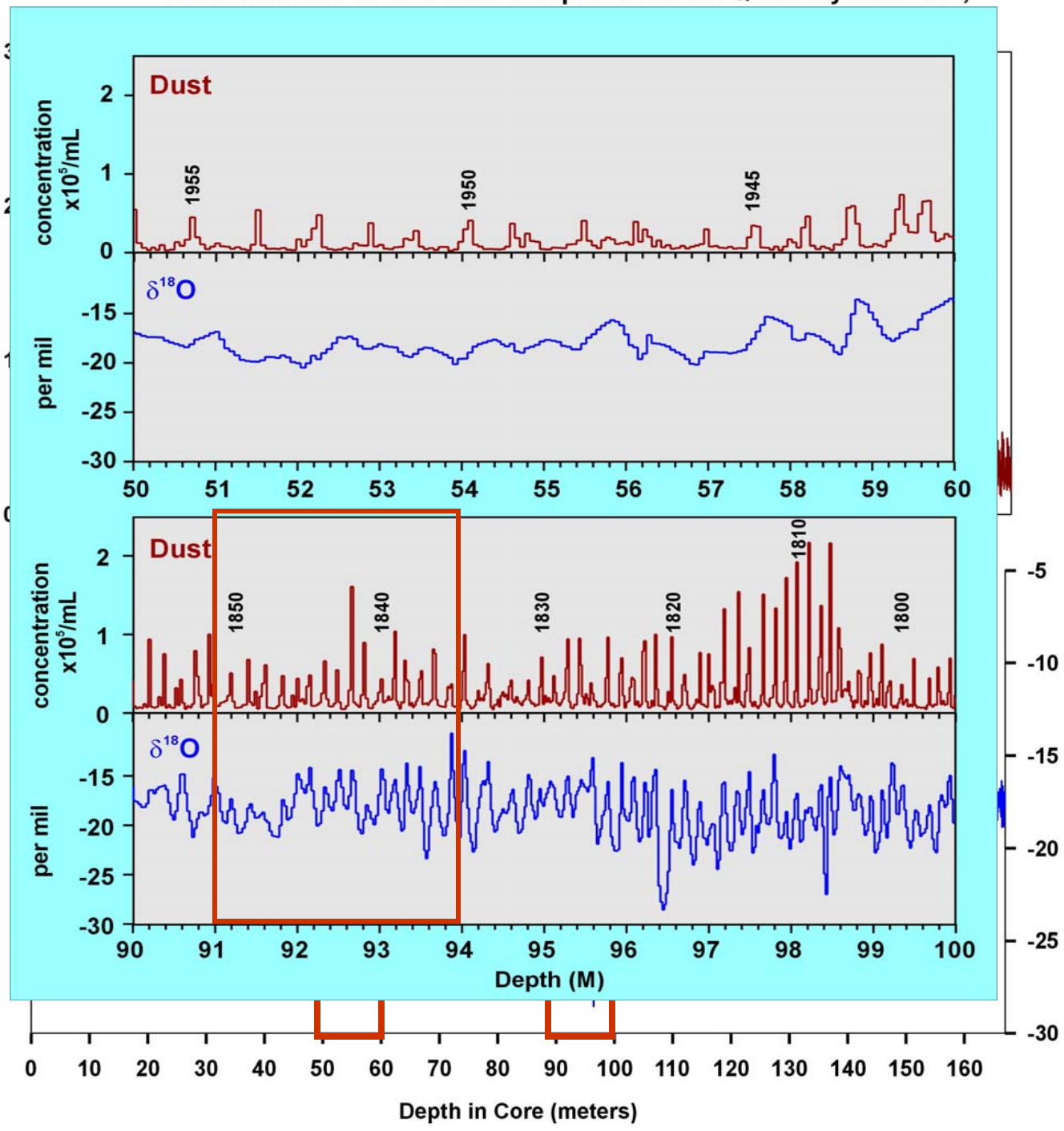


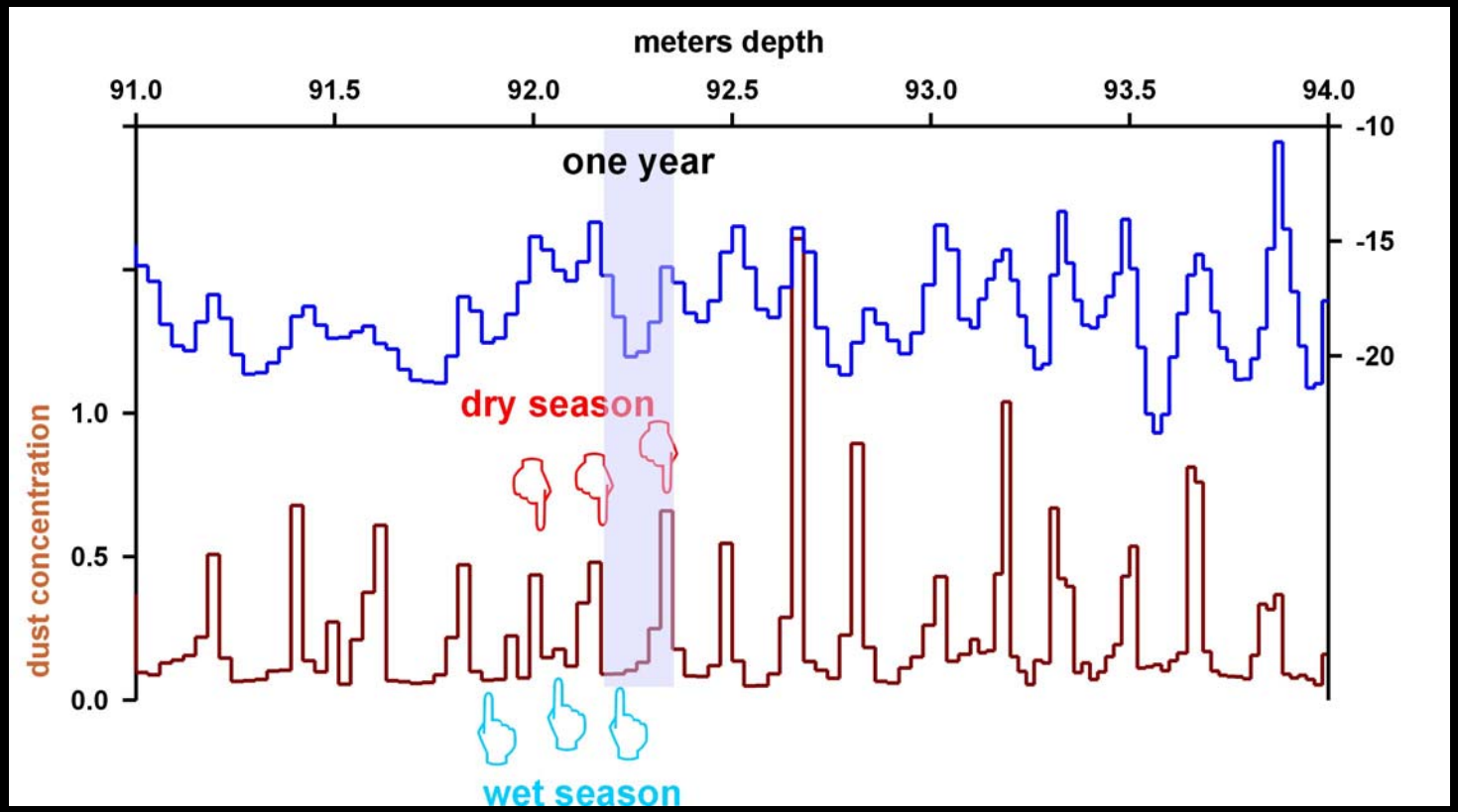
Side of Quelccaya ice cap, Peru

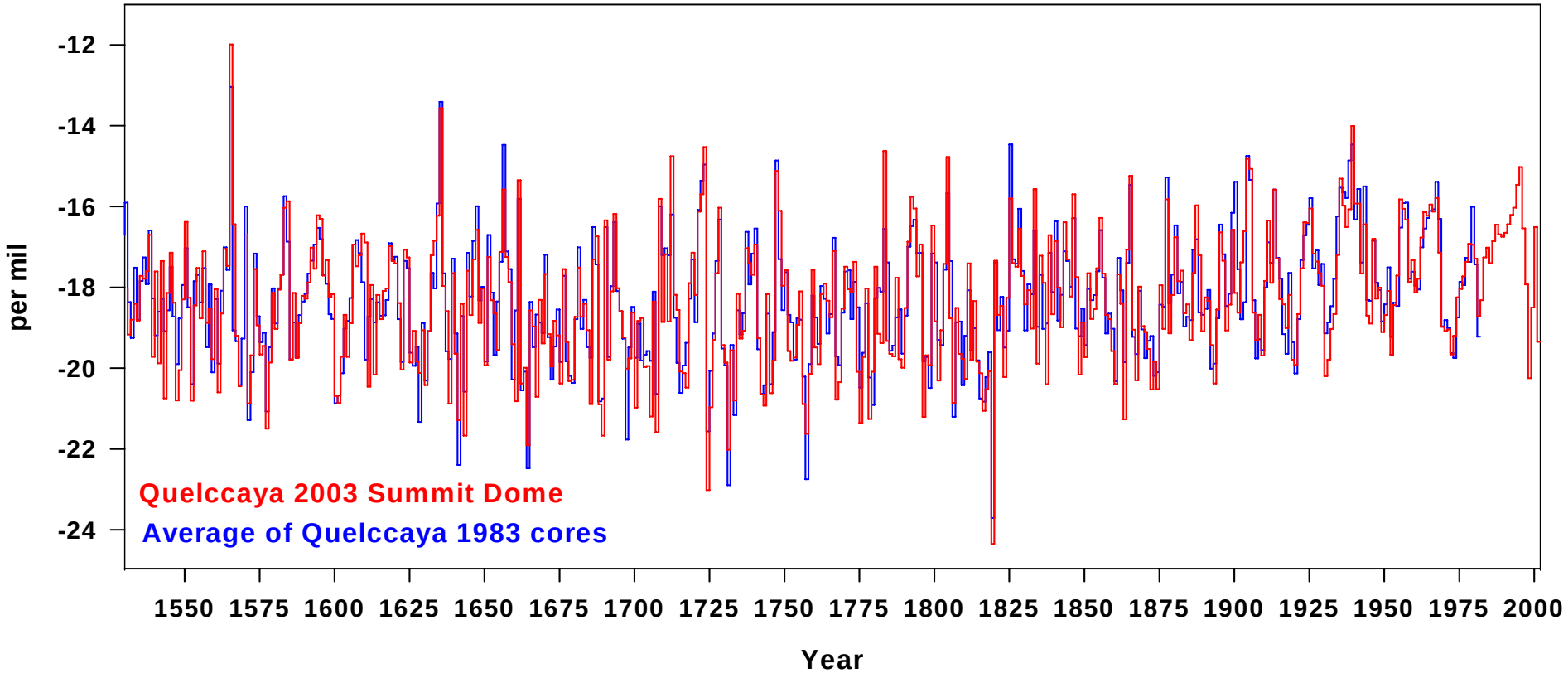


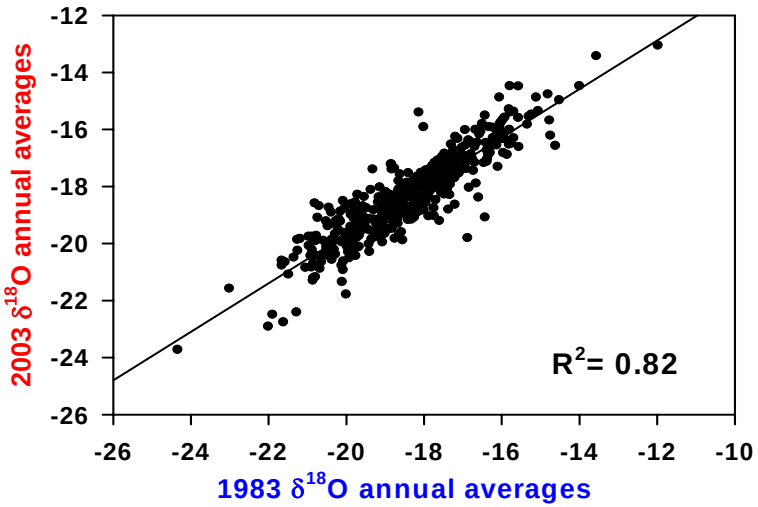

10 cm
△ Visible annual dust layers

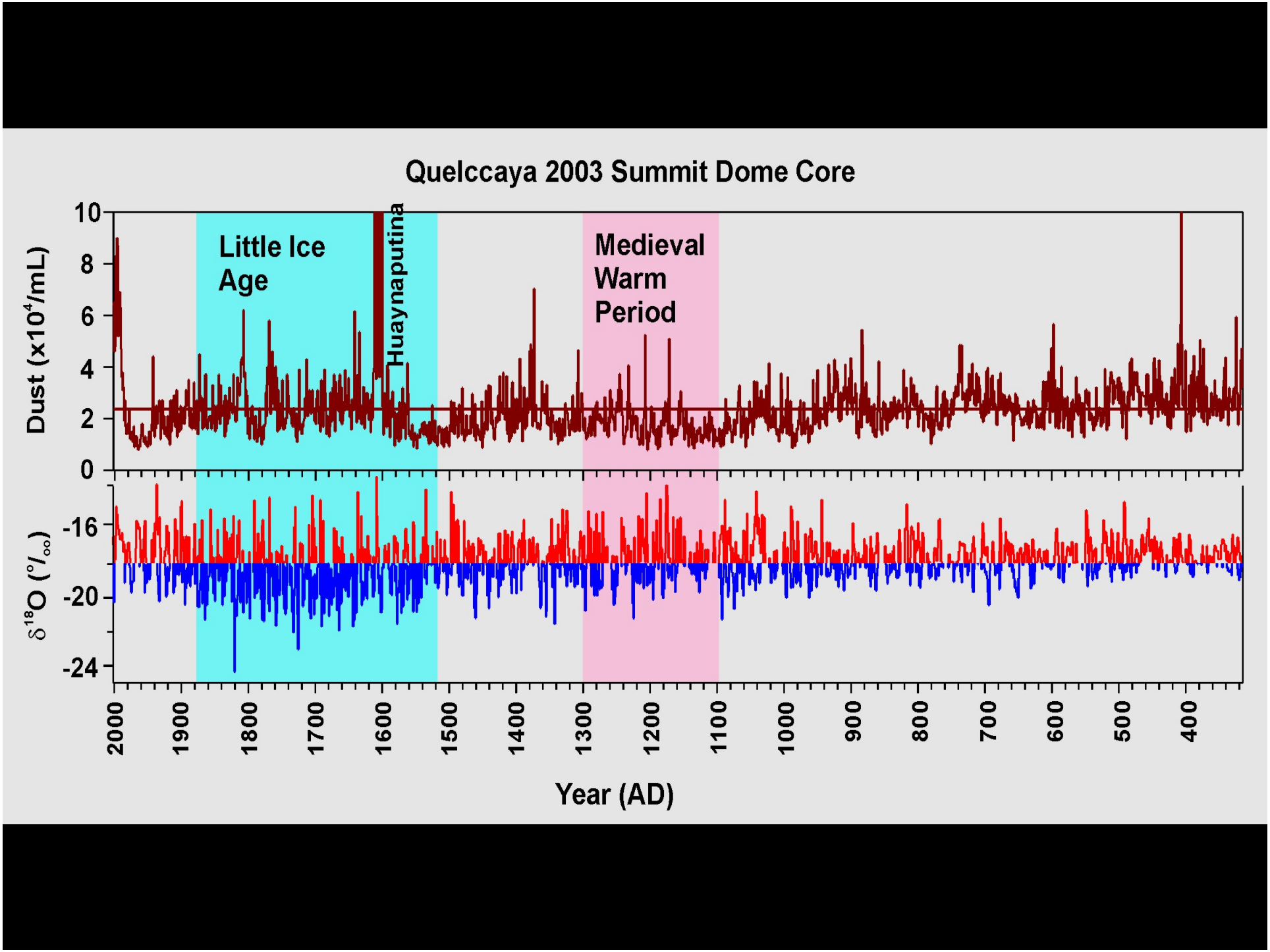
Measurements of over 7000 samples from the Quelccaya ice core,



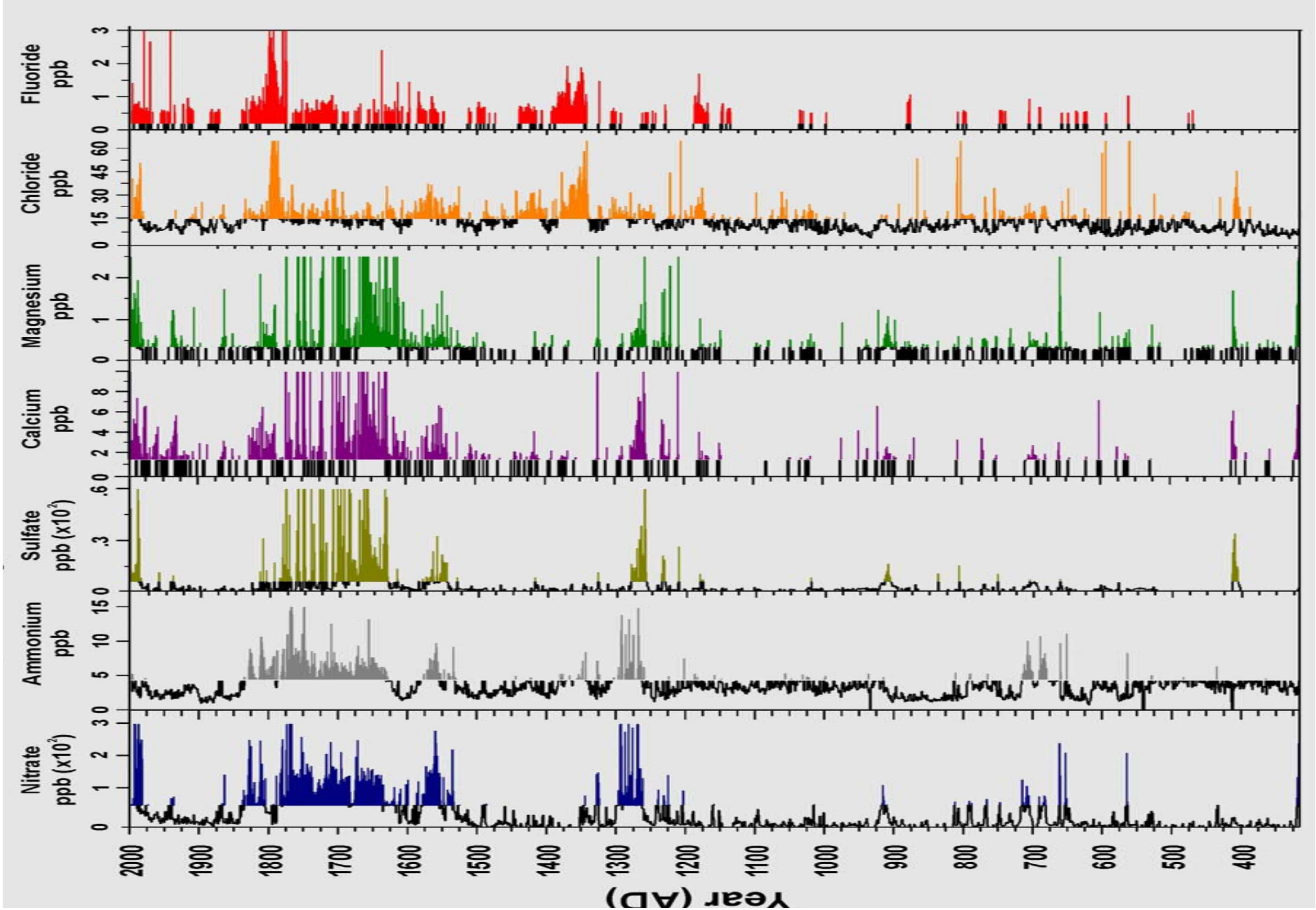

meters depth
91.0
91.5
92.0
92.5
93.0
93.5
94.0
one year
-10
-15
-20
dry season
dust concentration
1.0
0.5
0.0
wet season

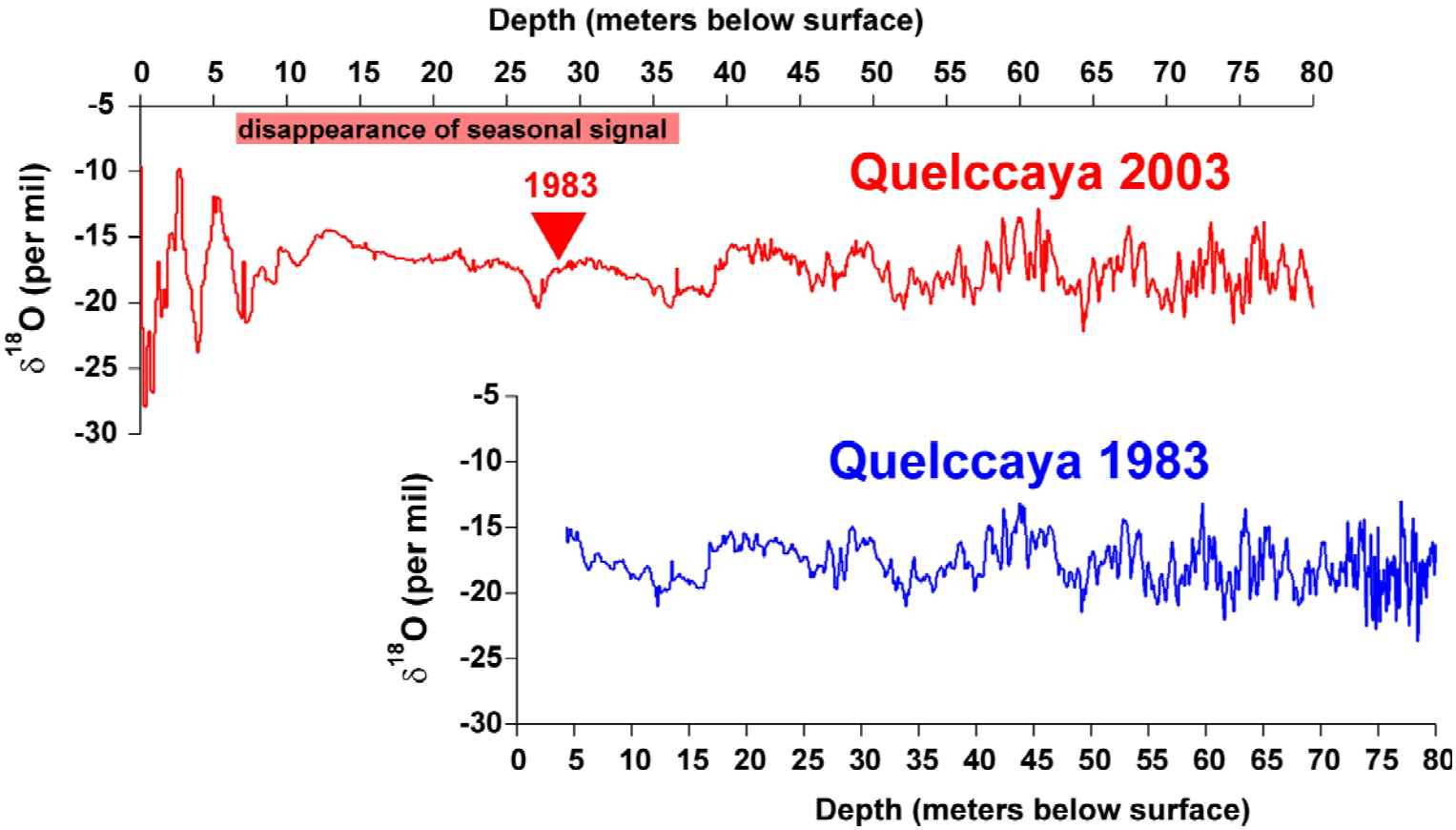

per mil
-12
-14
-16
-18
-20
-22
-24
Quelccaya 2003 Summit Dome
Average of Quelccaya 1983 cores
1550 1575 1600 1625 1650 1675 1700 1725 1750 1775 1800 1825 1850 1875 1900 1925 1950 1975 2000
Year


2003 δ18O annual averages
-12
-14
-16
-18
-20
-22
-24
-26
R2= 0.82
-26 -24 -22 -20 -18 -16 -14 -12 -10
1983 δ18O annual averages

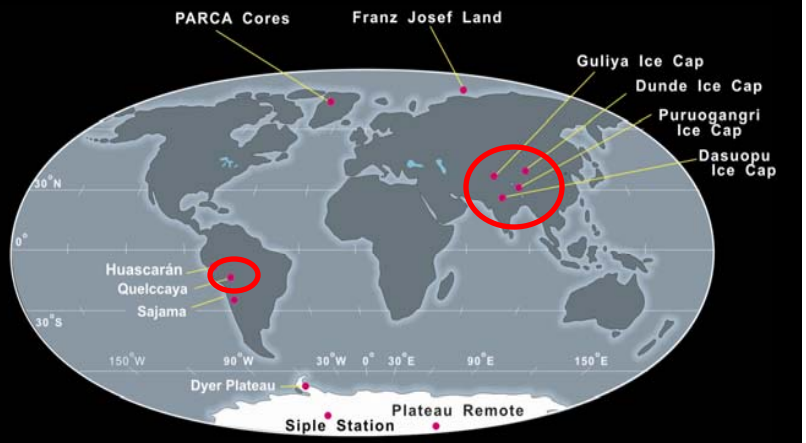

Quelccaya 2003 Summit Dome Core
Little Ice Age
Huaynaputina
Medieval Warm Period
Dust (x10⁴/mL)
10
8
6
4
2
0
δ¹⁸O (°/₀₀)
-16
-20
-24
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
Year (AD)

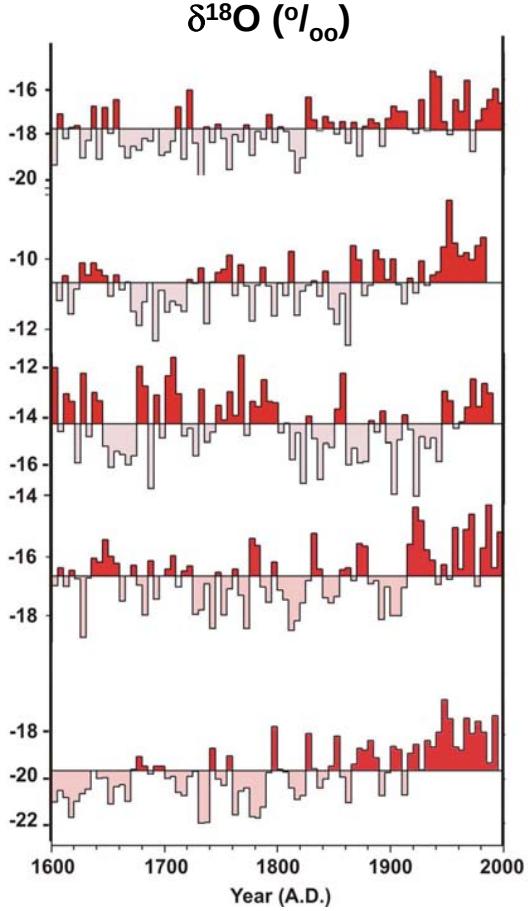
# Quelccaya 2003 Summit Dome Core



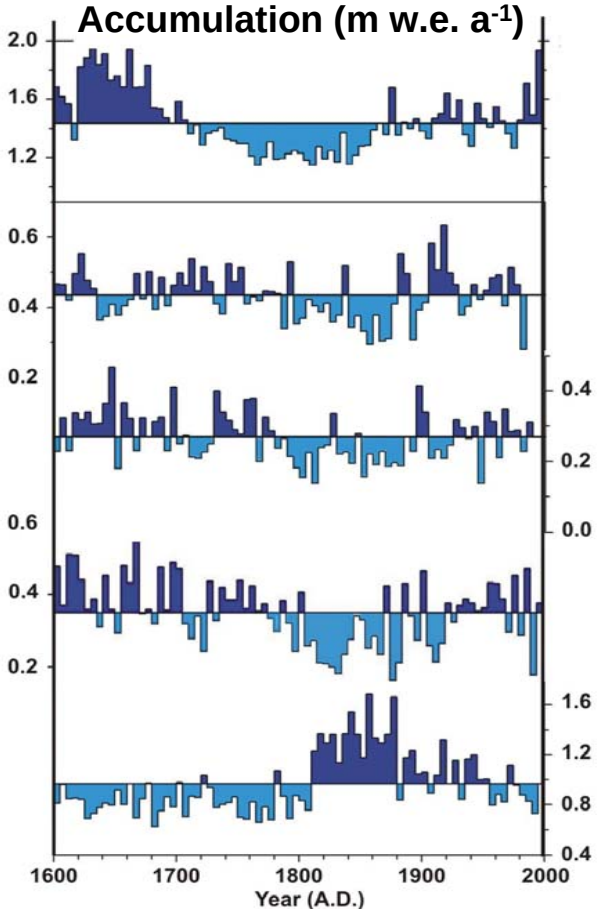

Depth (meters below surface)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
-5 -10 -15 -20 -25 -30
δ18O (per mil)
disappearance of seasonal signal
1983
Quelccaya 2003
Quelccaya 1983
Depth (meters below surface)

## In low latitudes does $\delta^{18}O$ reflect primarily temperature or precipitation?

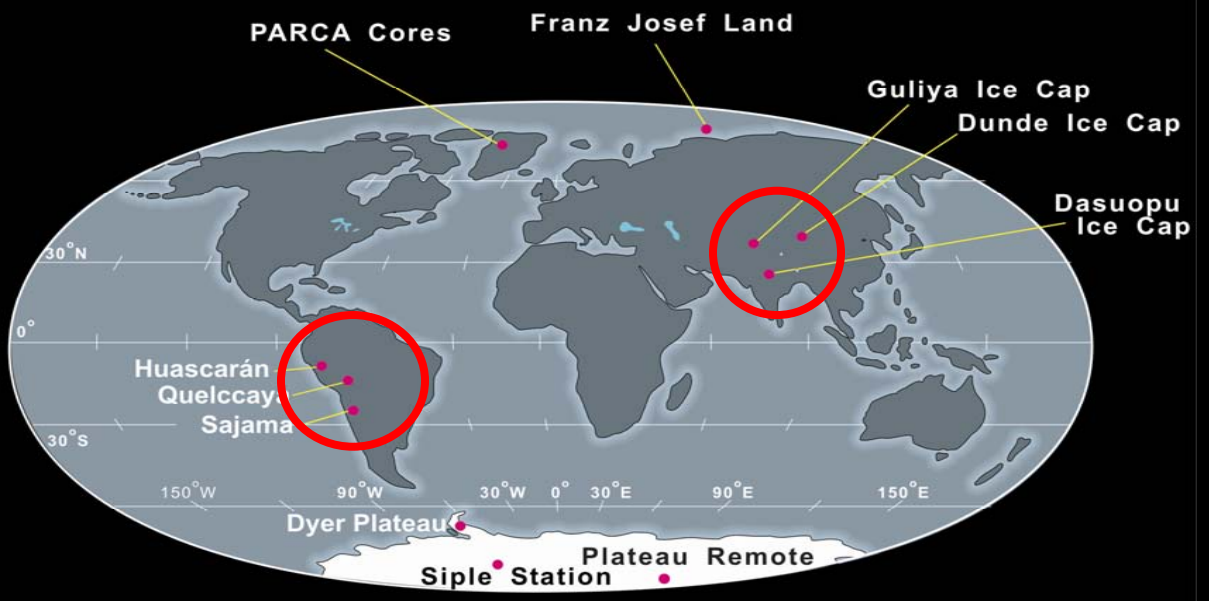


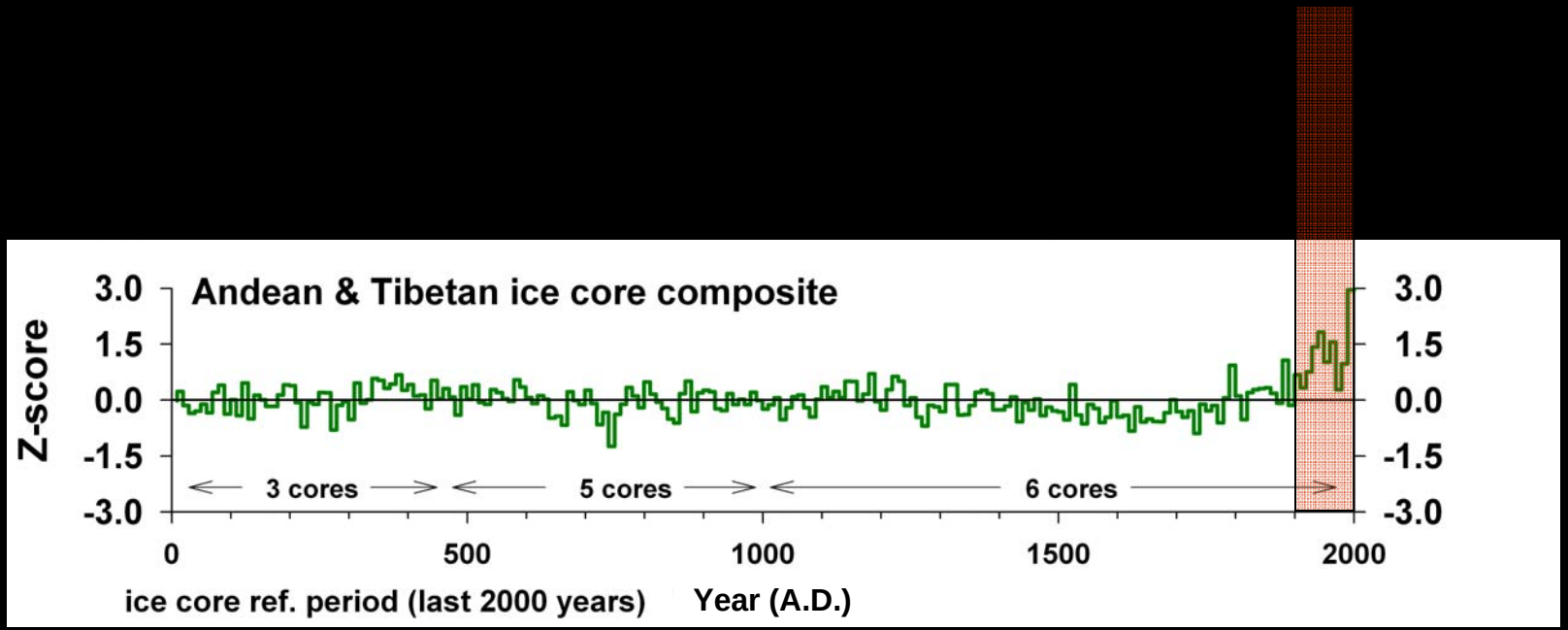




| $R^2$ | |
|---|---|
| Quelccaya | 0.002 |
| Dunde | 0.004 |
| Guliya | 0.001 |
| Puruogangri | 0.000 |
| Dasuopu | 0.016 |



**High elevation, low latitude ice cores record large-scale climate changes**




Thompson *et al.*, *Climatic Change*, 2003, *PNAS*, 2006

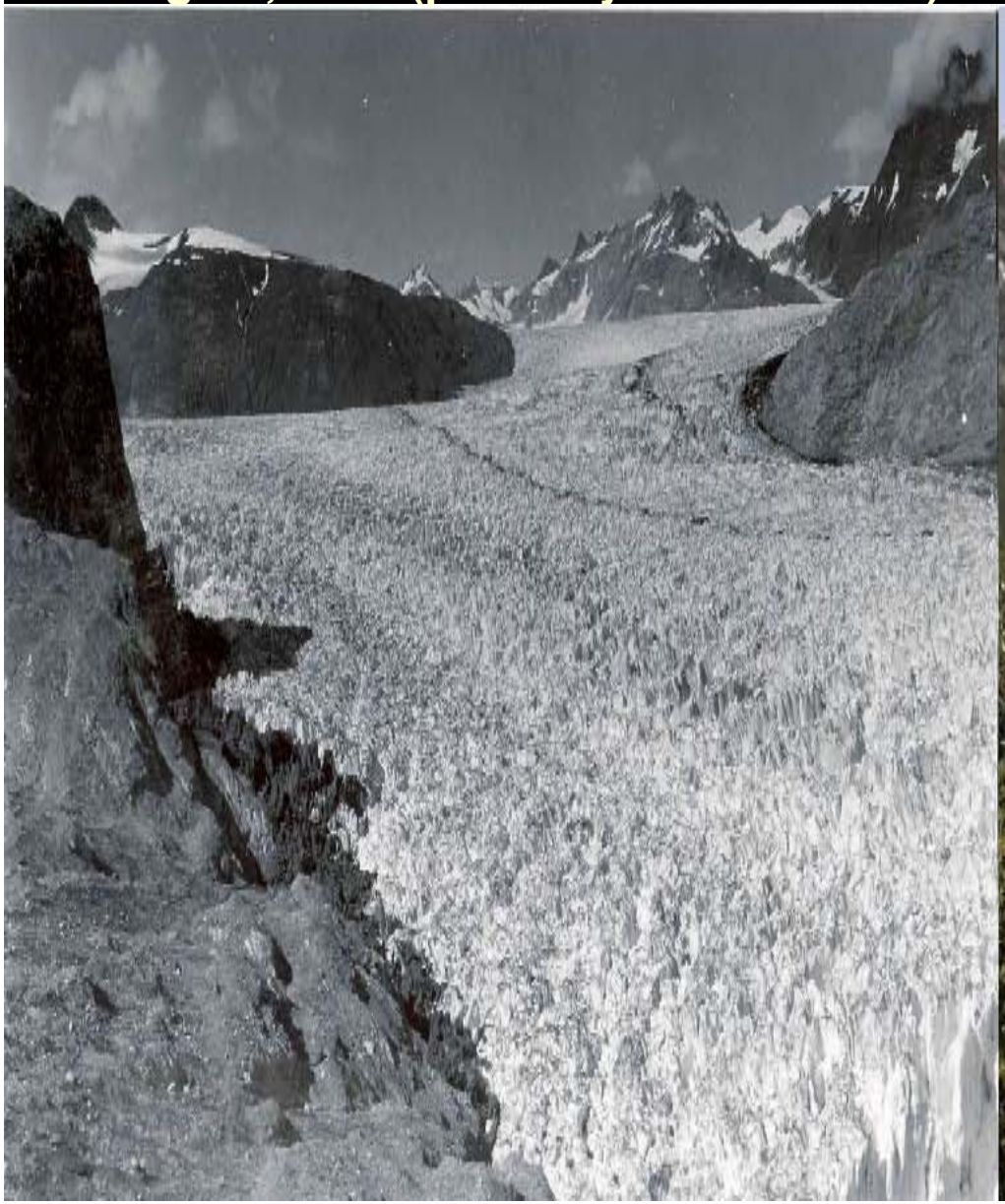
# McCall Glacier  Brooks Range, Alaska

Austin Post,1958

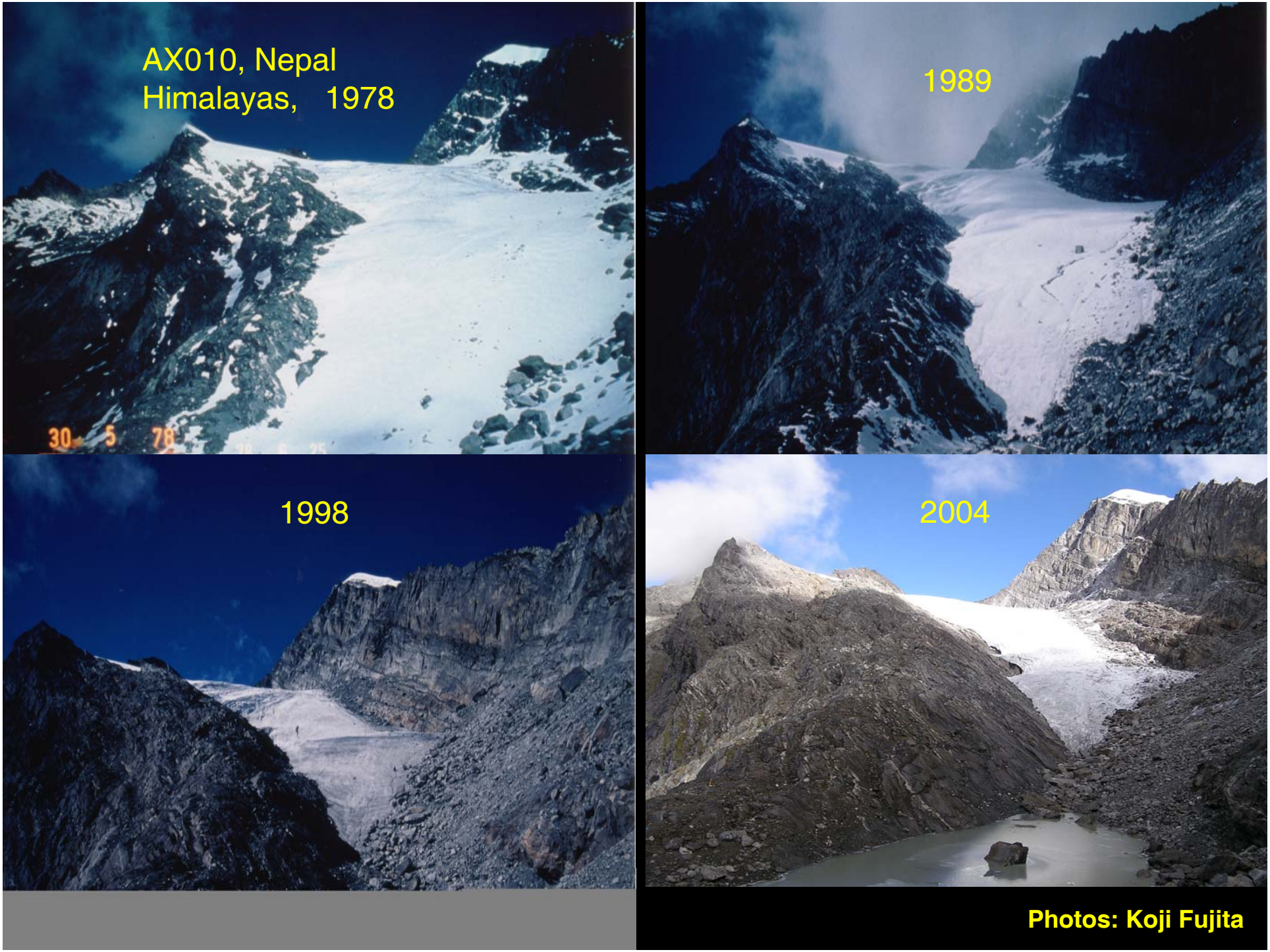
Matt Nolan, 2003

# Muir Glacier, SE Alaska

August, 1941 (photo by William Field)



August, 2004 (photo by Bruce Molnia)


AX010, Nepal
Himalayas, 1978
30 5 78
1989
1998
2004
Photos: Koji Fujita

# Glacier National Park, Grinnel Glacier


Photo: Fred Kiser, Glacier National Park archives

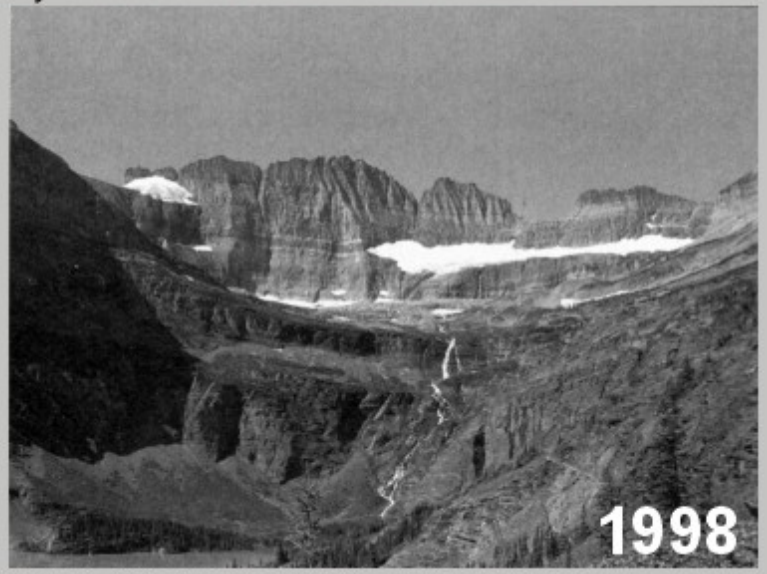



Photo: Karen Holzer, US Geological Survey

# Glacier National Park, Boulder Glacier

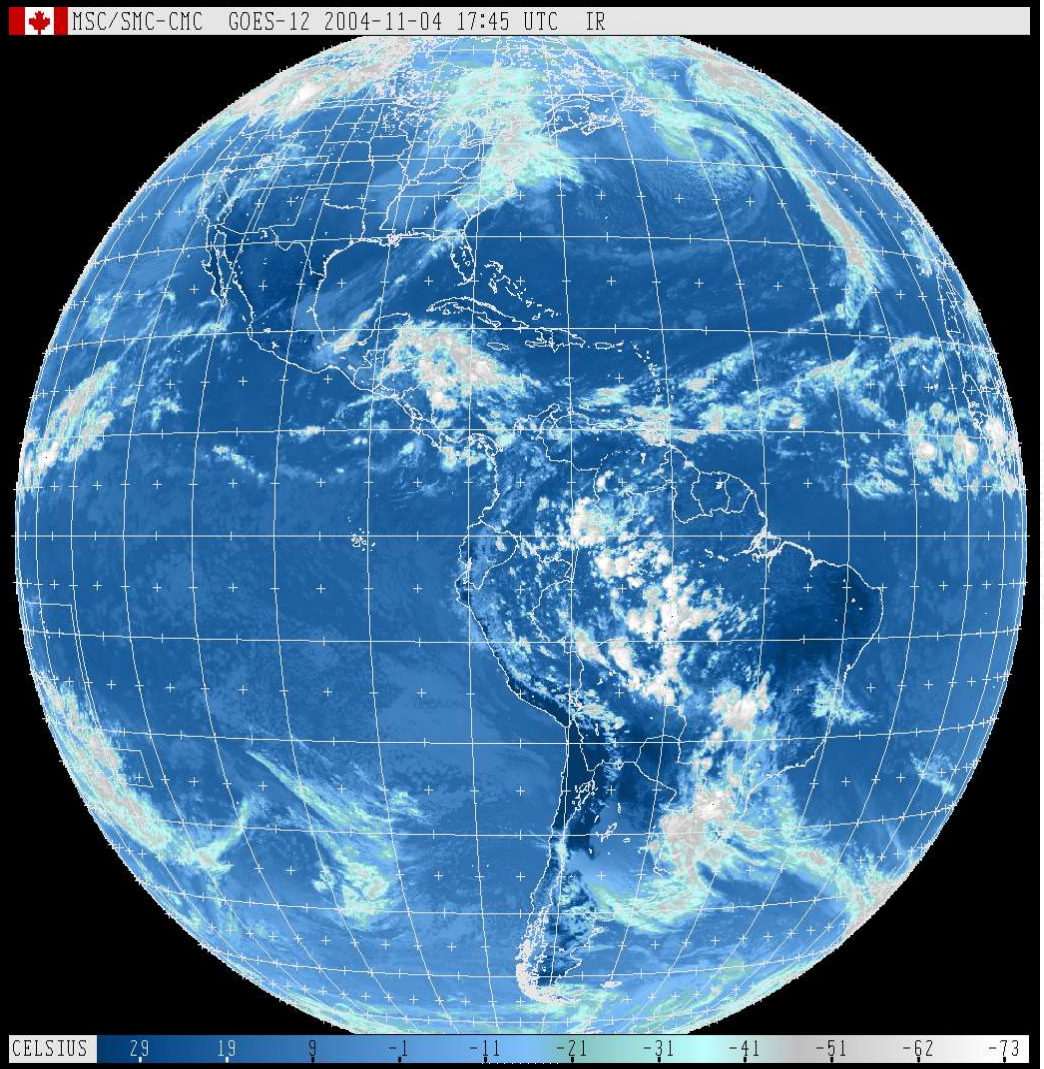

Photo: George Grant, Glacier National Park archives


Photo: Jerry DeSanto, National Park Service

Source: *BioScience*, Vol. 53 No. 2, Feb 2003

# Glaciar Lanín Norte


# Zonal Distribution of Annual Precipitation



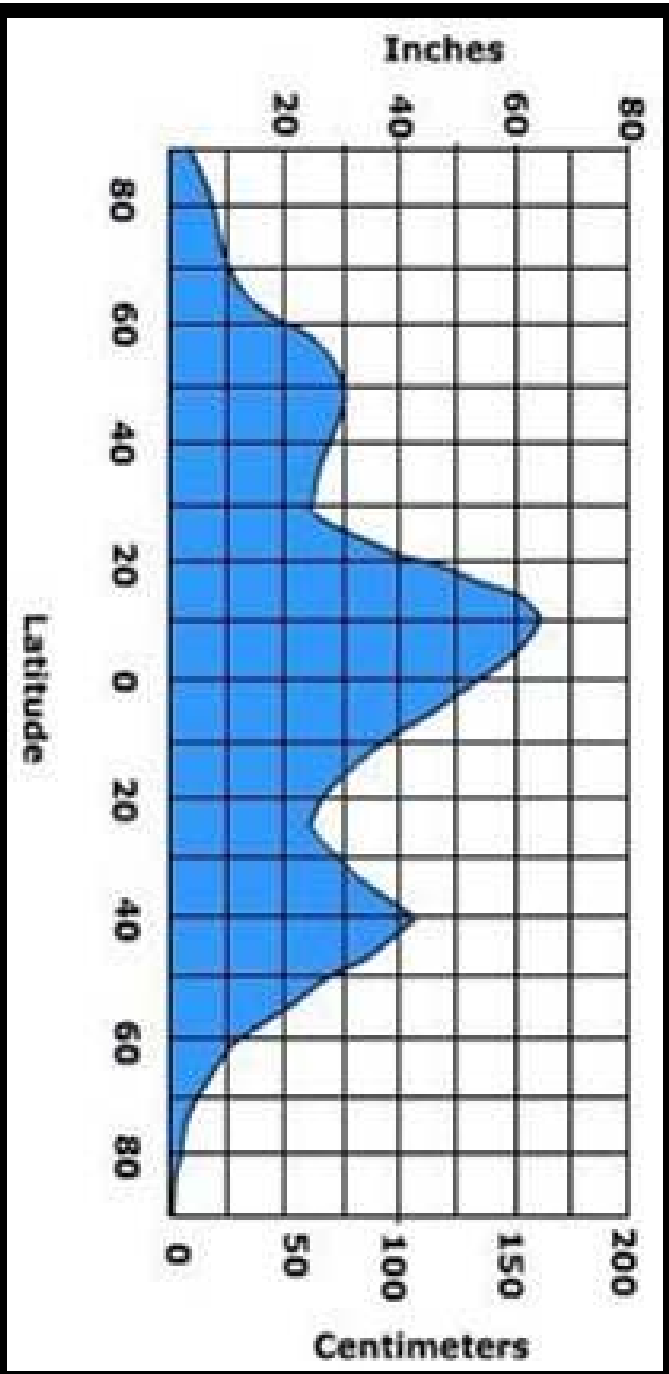
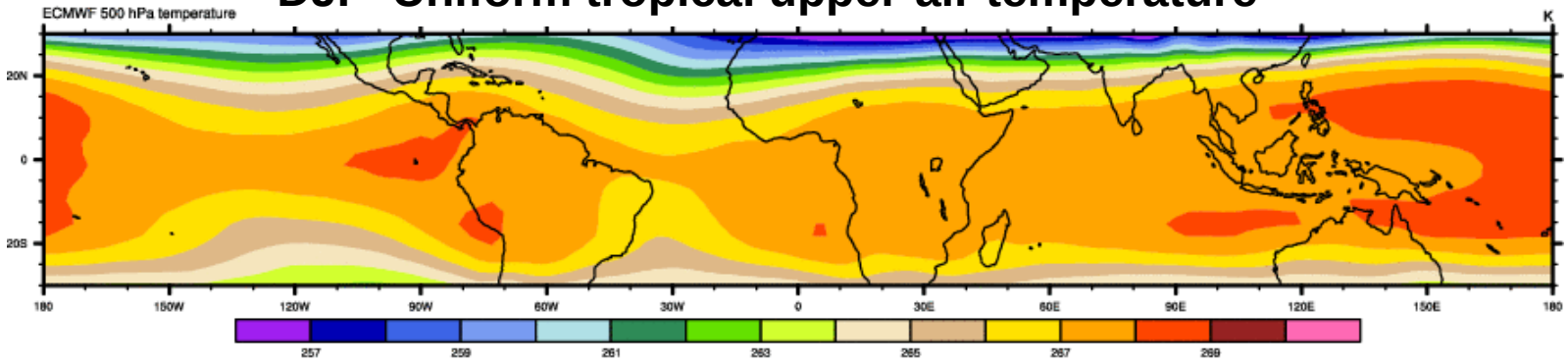
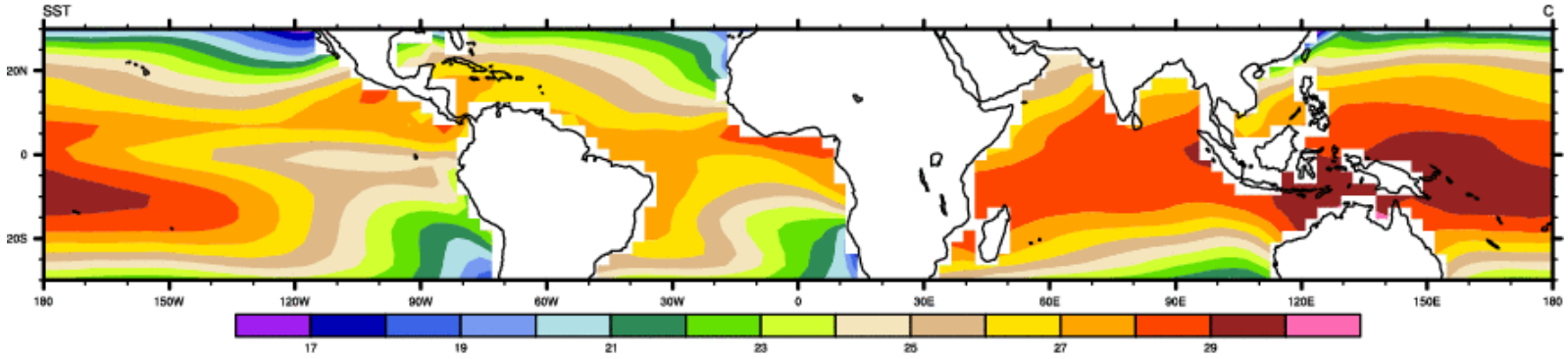




Image from GOES-12 Satellite Nov 4, 2004

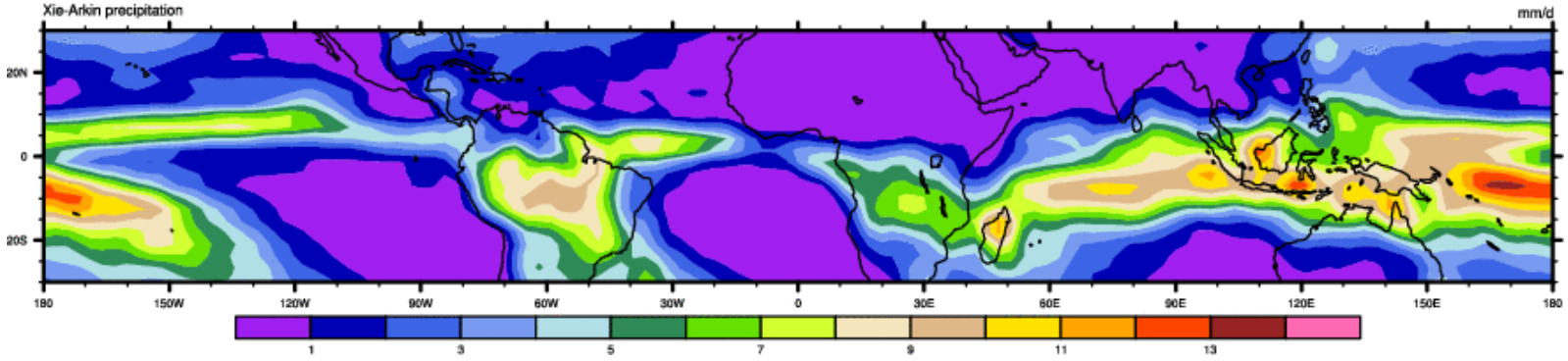
## DJF Uniform tropical upper-air temperature



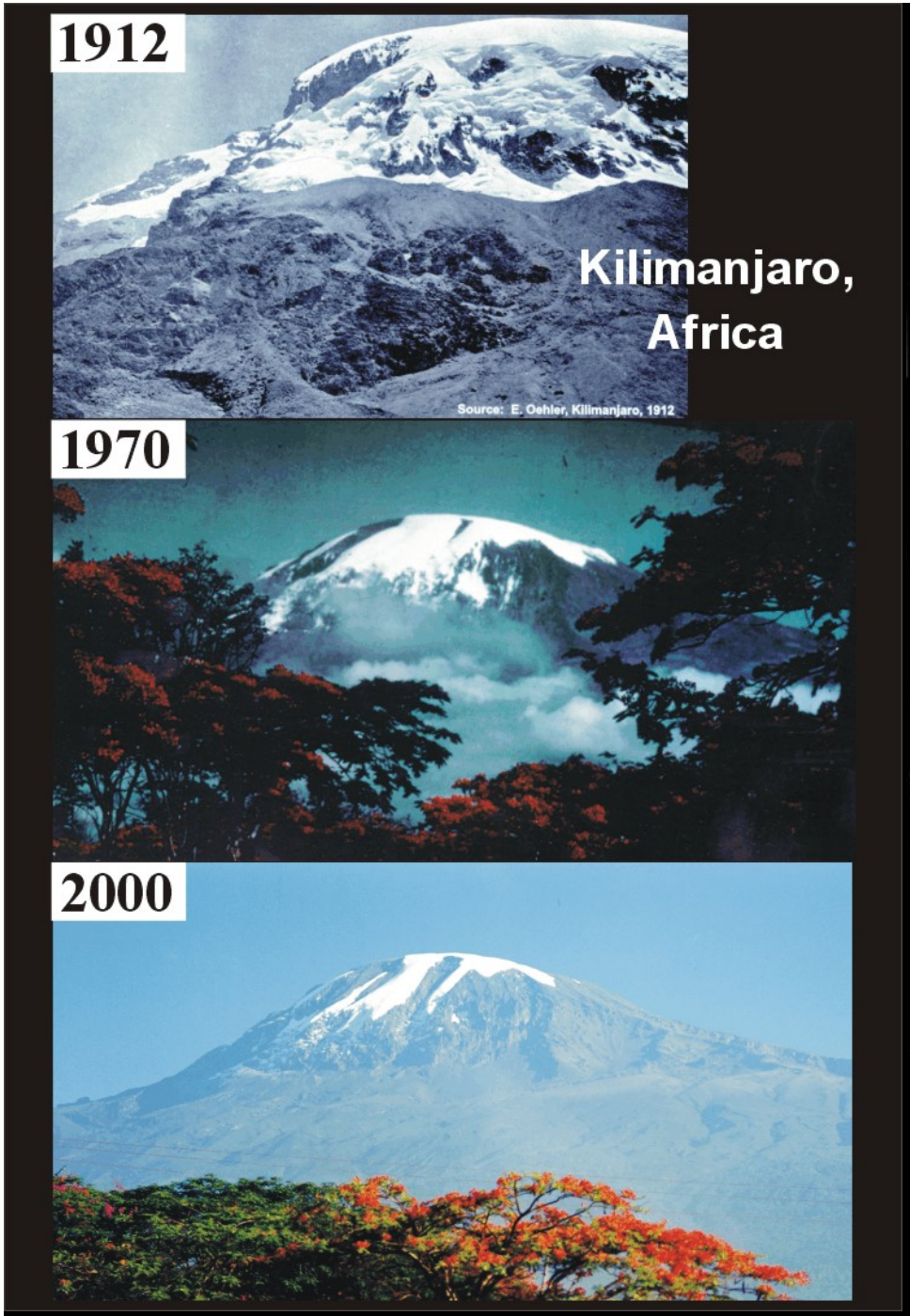

## DJF Larger SST variations




## DJF Rainfall roughly follows warm SST

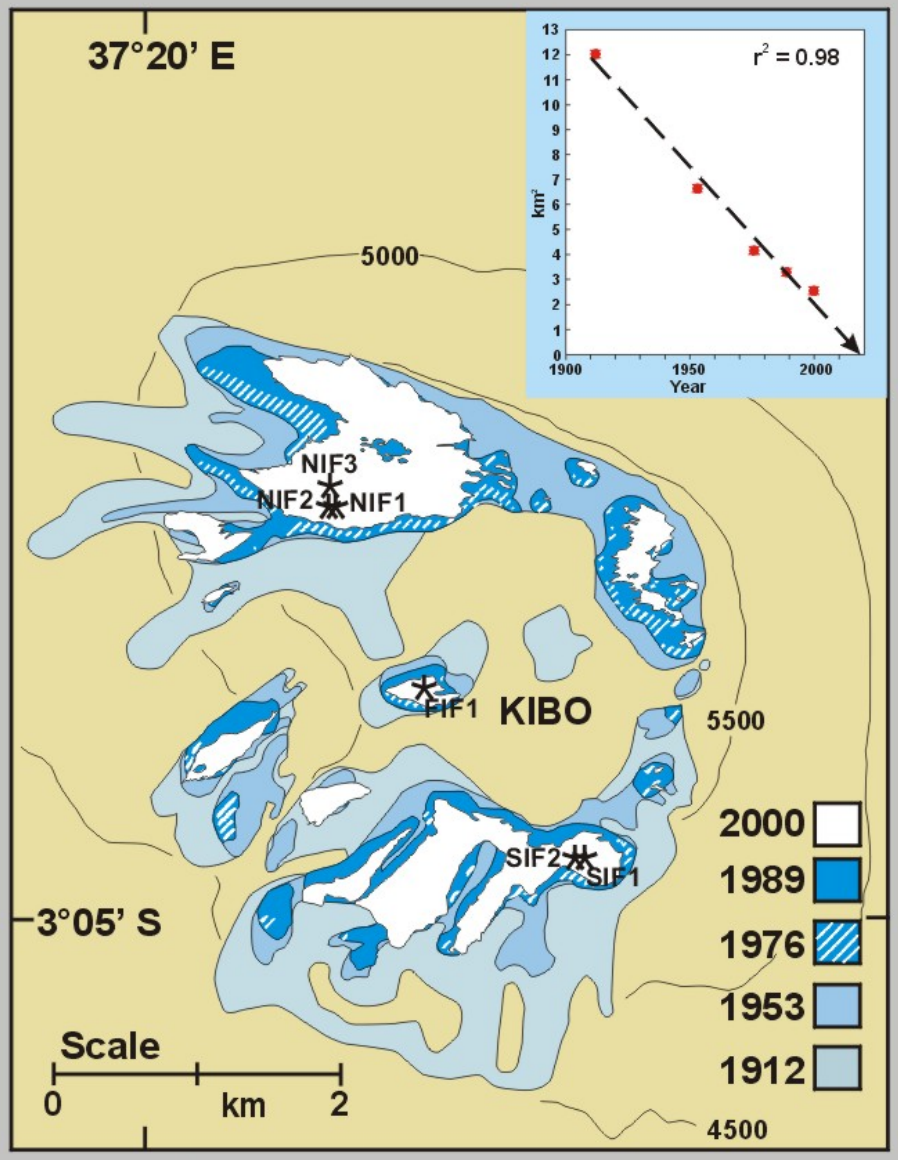



(Sobel and Bretherton, *J. Climate , 2000*

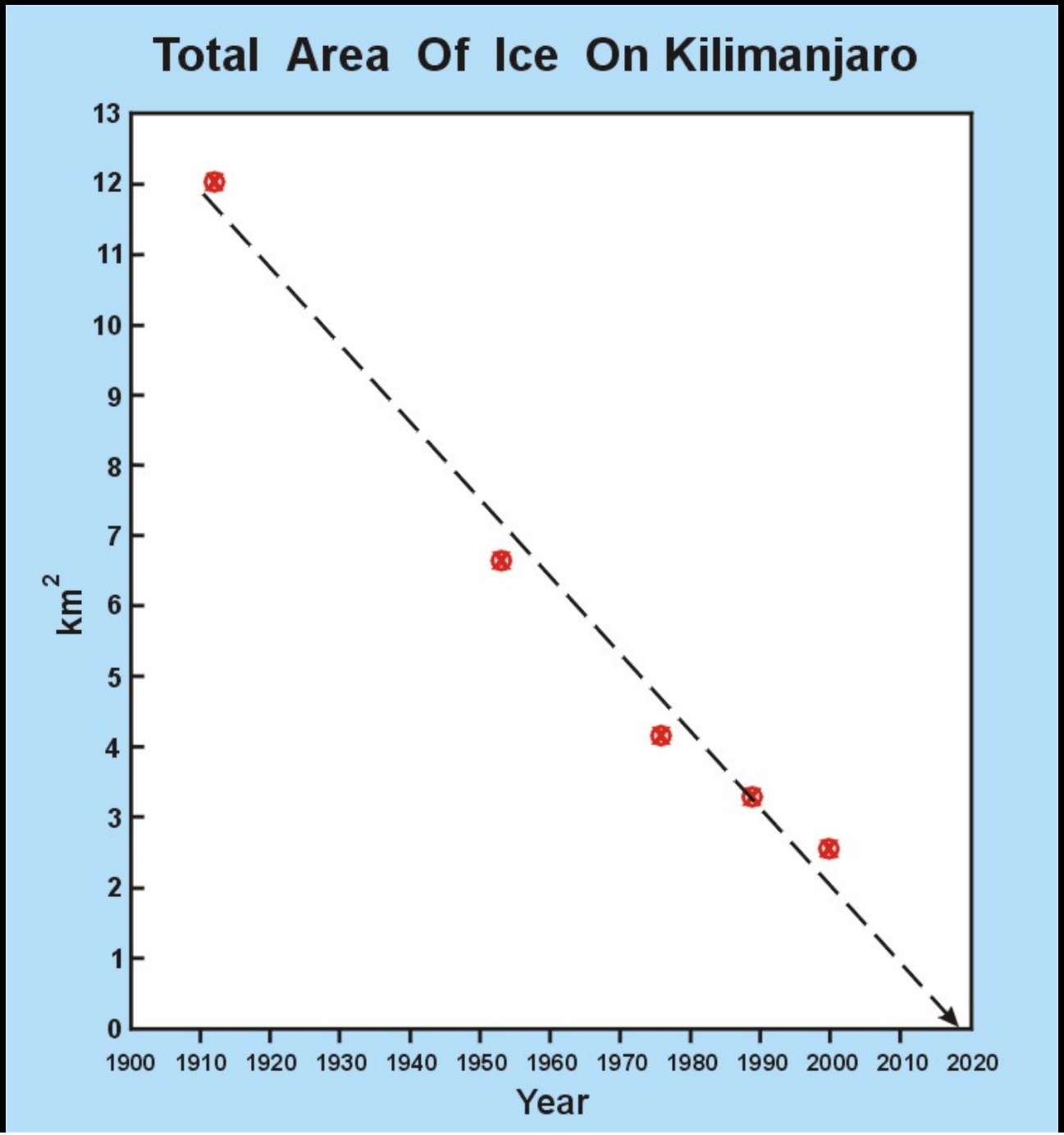



## Aerial photo in 2000

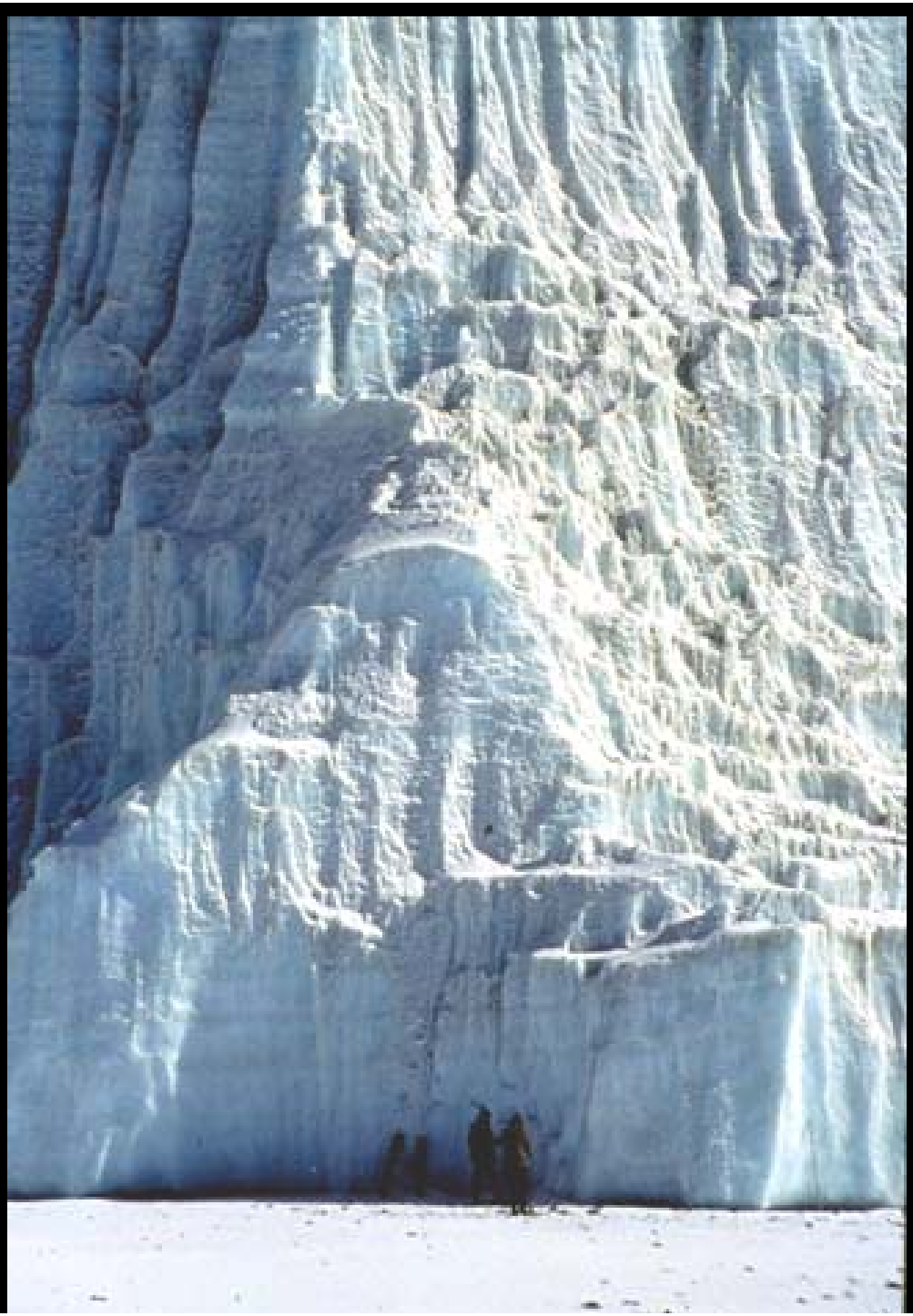
# *Total Area Of Ice On Kilimanjaro*
## *(1912, 1953, 1976, 1989, 2000)*




1912 - 1989 after Hastenrath and Greischar, *J. Glaciol.*, 1997
2000 after Thompson *et al.*, *Science*, 2002


Total Area Of Ice On Kilimanjaro
km2
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Year

**The wall of the Northern Ice Field has retreated 0.9 m per year since 2000.**

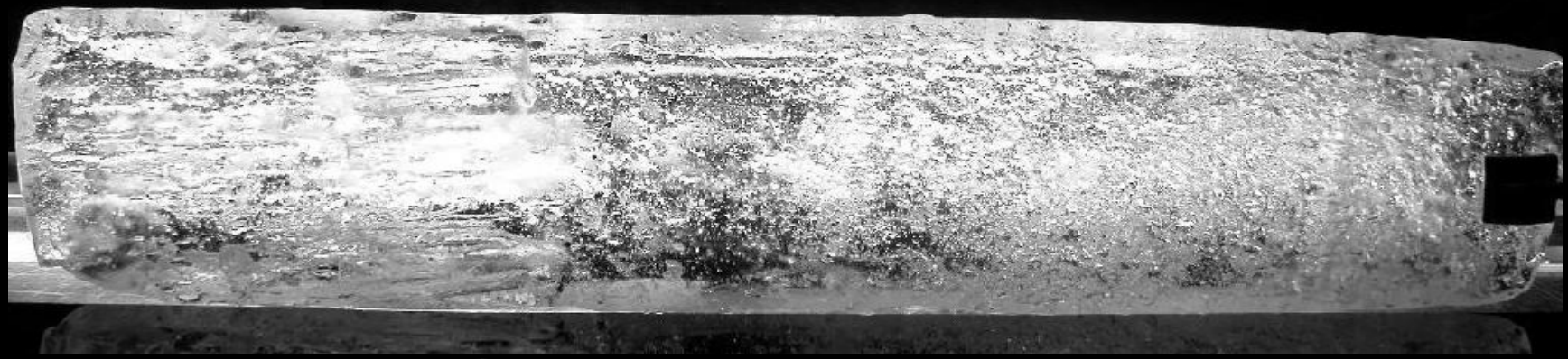


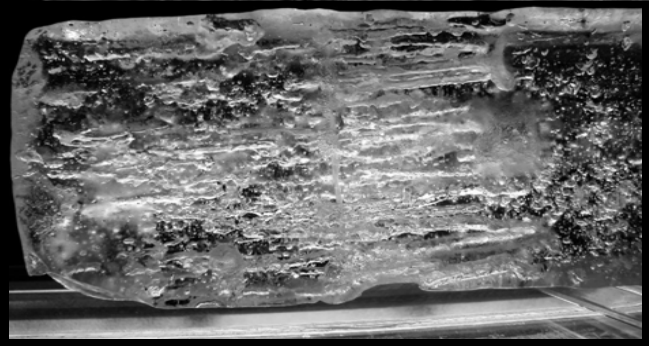

- -2.5 meters in 6 years between Feb. 2000 and Jan. 2006, FWG: -2.5 m
- SIF: over -4.5 m

**Outburst of water and ice collapse on Furtwängler Glacier (Kilimanjaro) in spring of 2003**

# Drill shelter on Northern Ice Field, Kilimanjaro in 2000

# Kilimanjaro (2000) Northern Ice Field Core 3

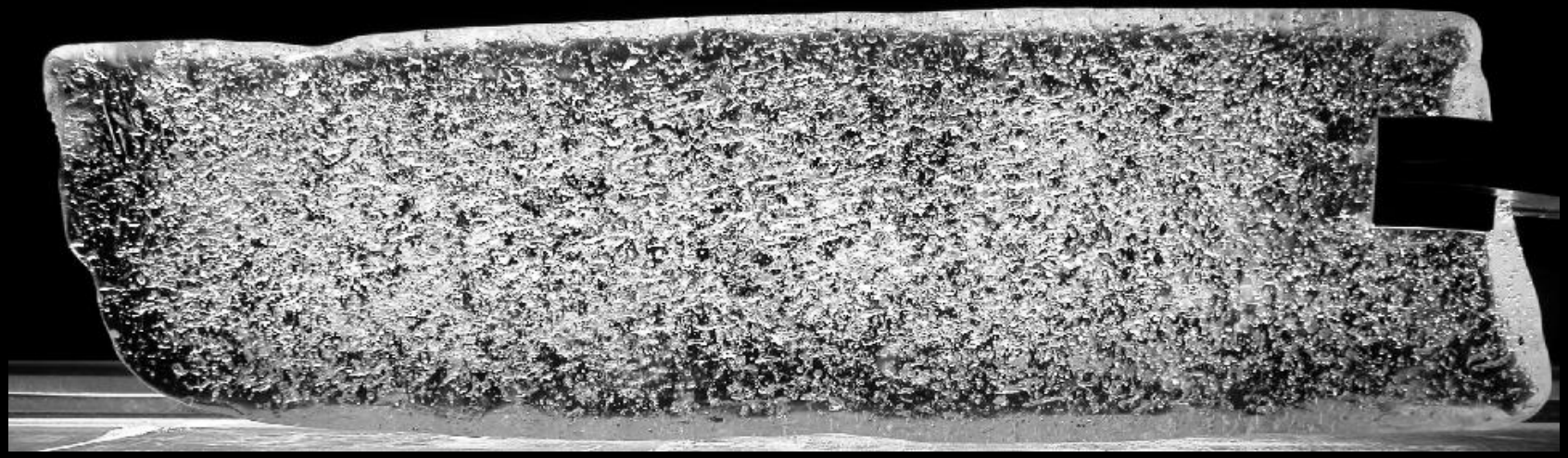




Tube 1: top: 0.00 m

Elongated bubbles

Tube 43: top: 42.84 m

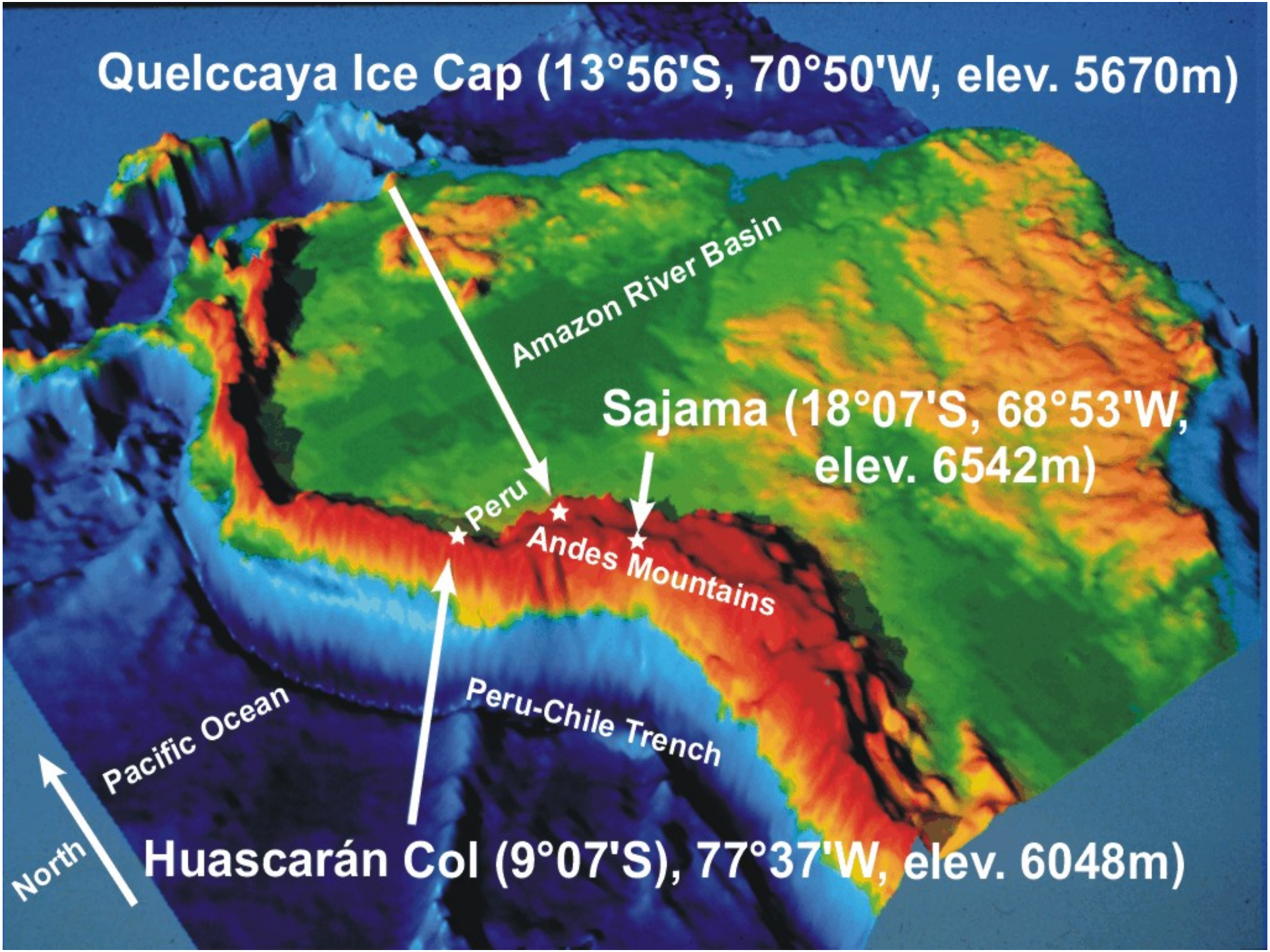


•Kilimanjaro

Feb 2000

Jan 2006

•22% of the ice cover has been lost since 2000.


Quelccaya Ice Cap (13°56'S, 70°50'W, elev. 5670m)
Amazon River Basin
Sajama (18°07'S, 68°53'W, elev. 6542m)
Peru
Andes Mountains
Pacific Ocean
Peru-Chile Trench
North
Huascarán Col (9°07'S), 77°37'W, elev. 6048m)

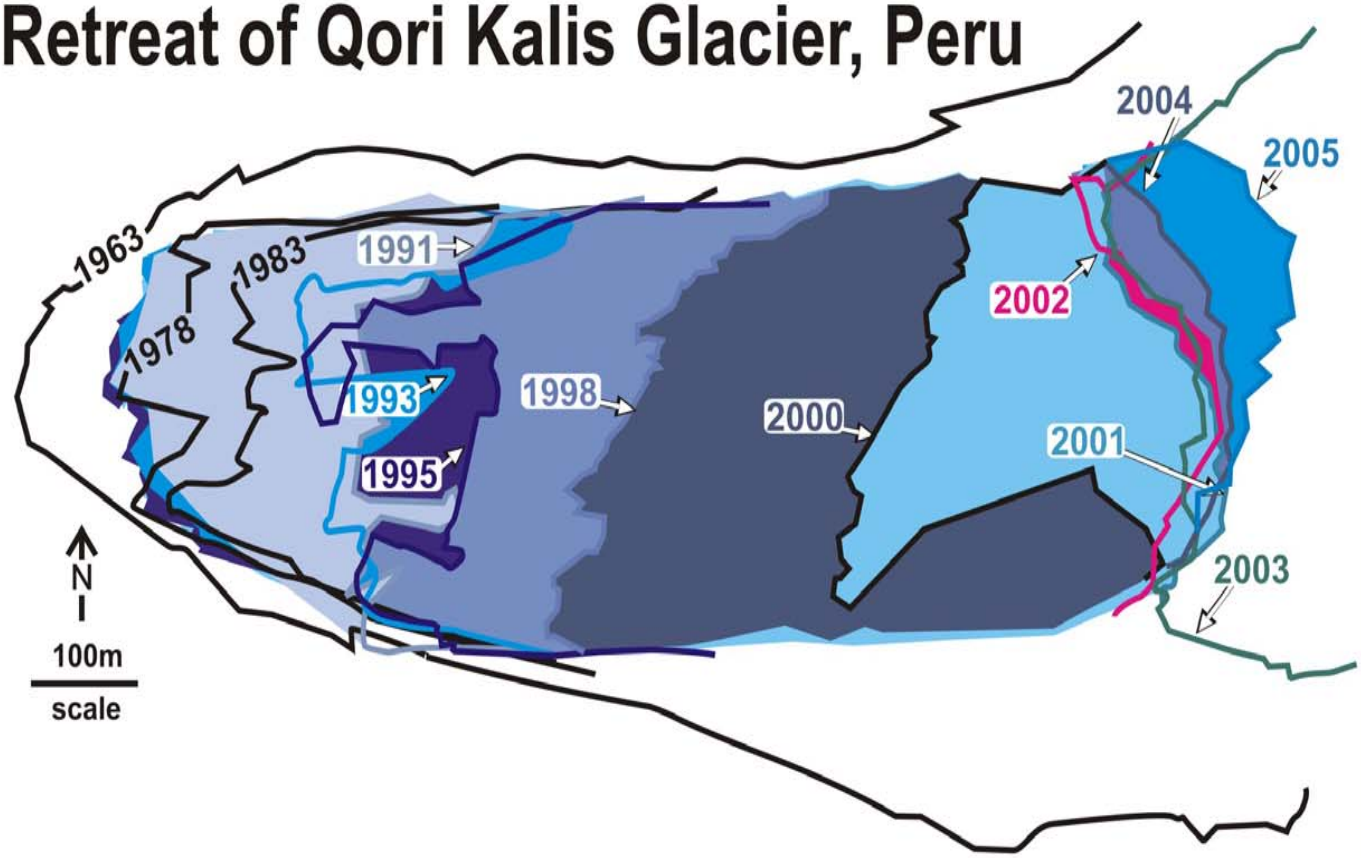
# Retreat of the Qori Kalis Glacier (Peru)

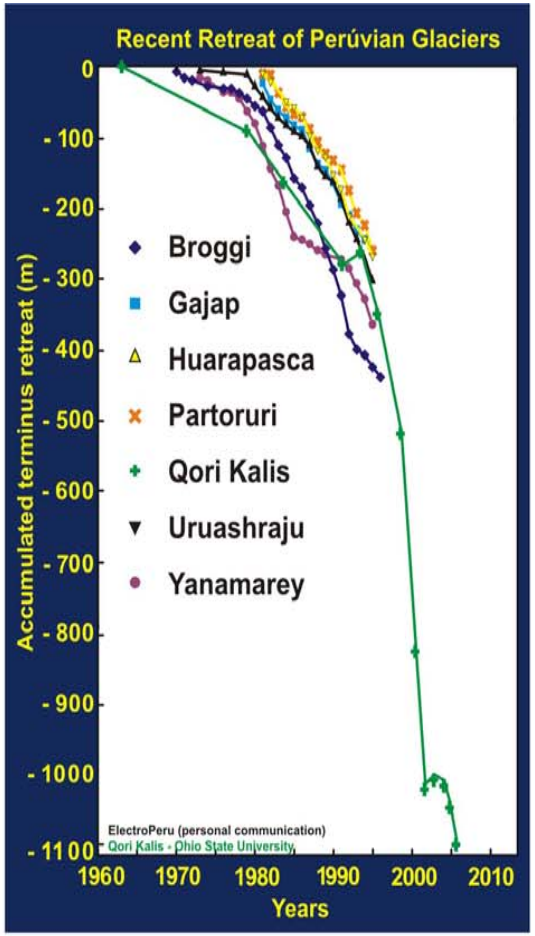
1978 – no lake

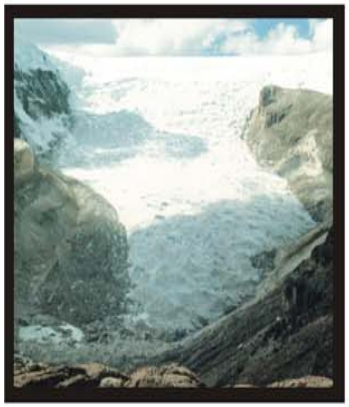
2004 –
lake covers 84 acres


Qori Kalis July 2005

# Retreat of Qori Kalis Glacier, Peru



1978

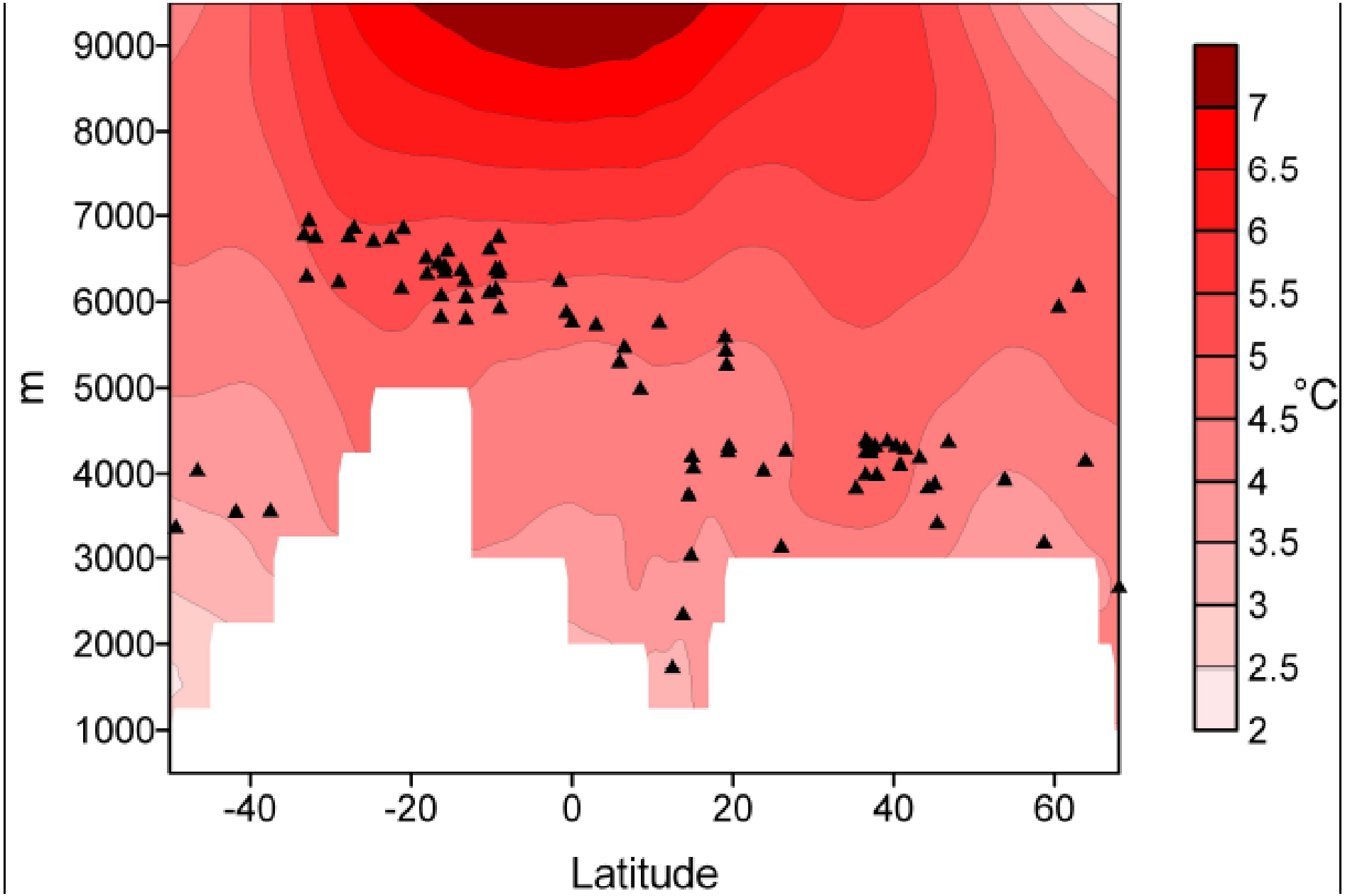
1991

1998

2000

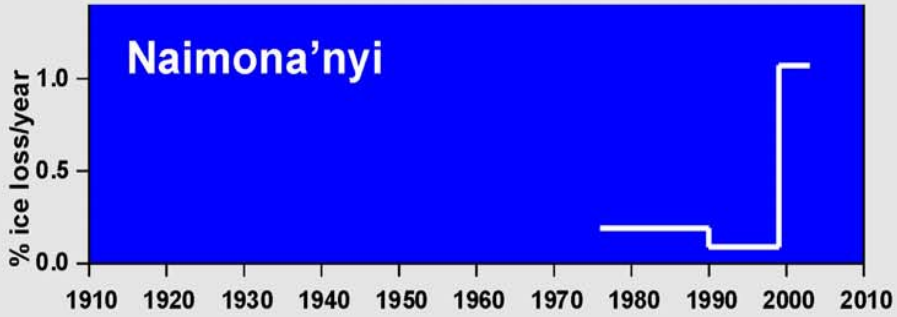
2005

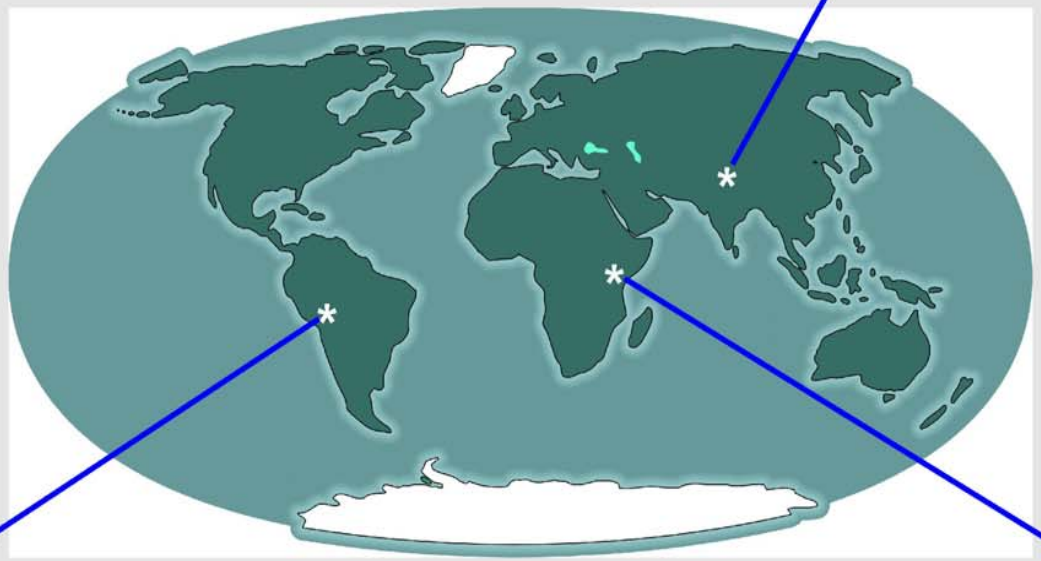

Qori Kalis, July, 2006

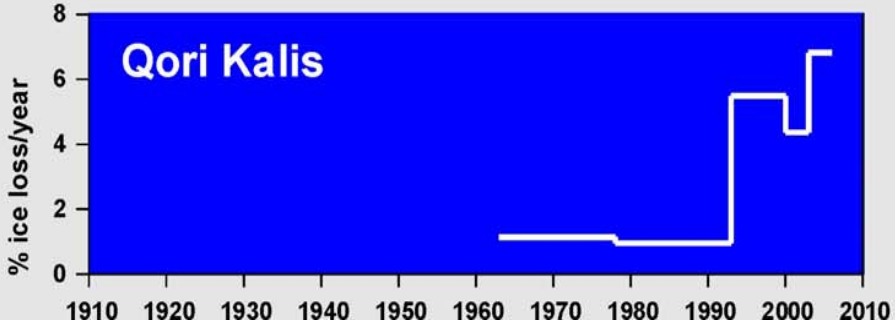


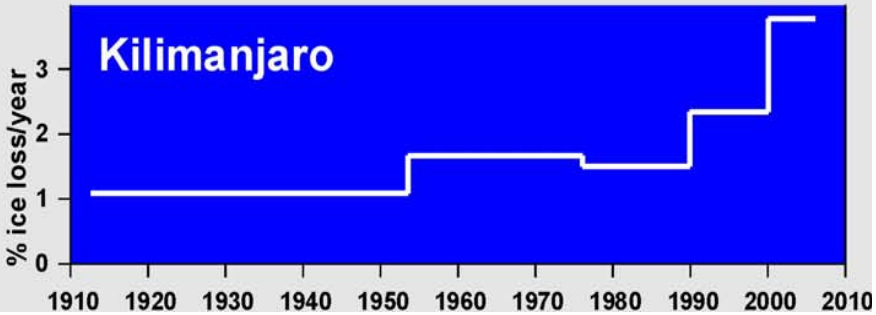

Source: *Bradley et al., 2006*

# Ice Loss from Tropical Glaciers



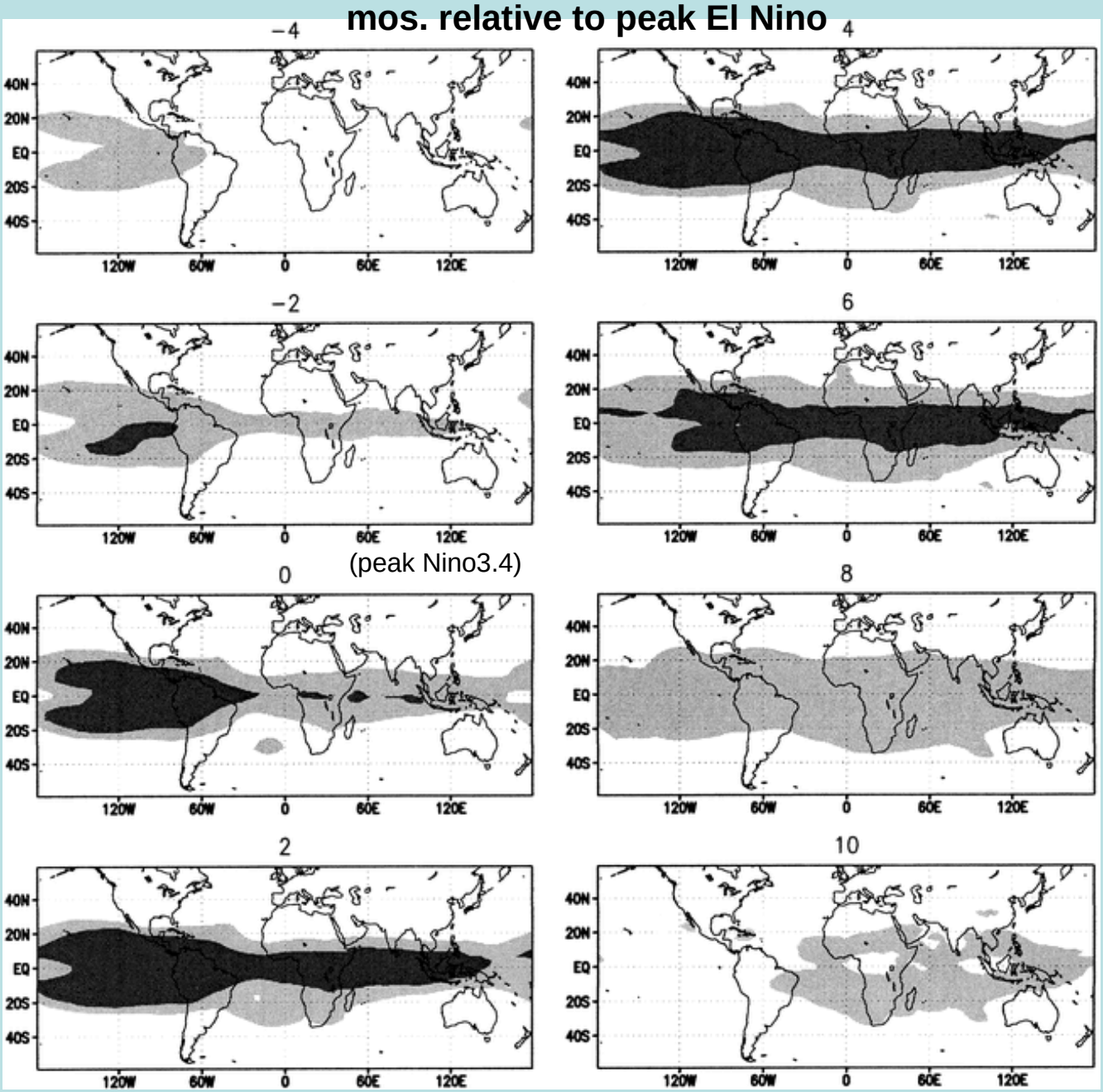


1000-300 mb average air temperature anomalies associated with ENSO (MSU2)

gray: 0.2-0.4
black: >0.4 K

Warming spreads nearly uniformly around the tropics




(Chiang and Sobel 2002, *J. Climate*)

## Things we know with certainty

- **Glaciers are disappearing and we are losing unique archives of the Earth's climate history**

- **The loss of glaciers (the world's water towers) threatens the water resources in many parts of the world – will affect 2 – 3 billion people who depend on water released from glaciers during the dry season**
  1) **hydroelectric power production**
  2) **crop irrigation**
  3) **municipal water supplies**

- **The loss of glaciers around the world will impact tourism (commerce)**

In 1915 Ernest Shackleton stated ……

“What the Ice Gets, the Ice Keeps”

But today the retreating ice
is giving up long-buried secrets …..

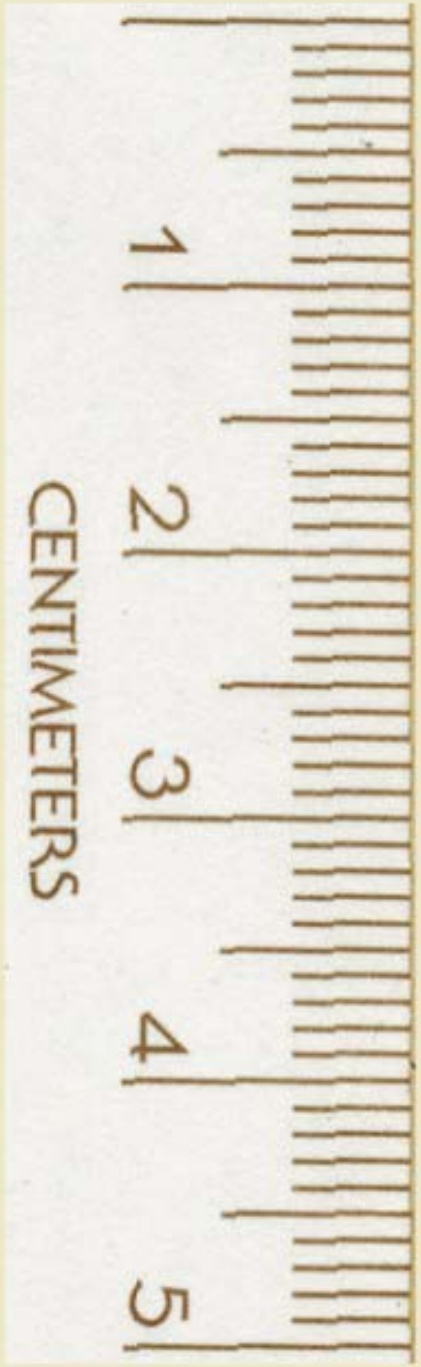
Quelccaya, Peru

1977

2002

Quelccaya Ice Cap, 2002


200 – 400 m above its modern range




## *Distichia muscoides*

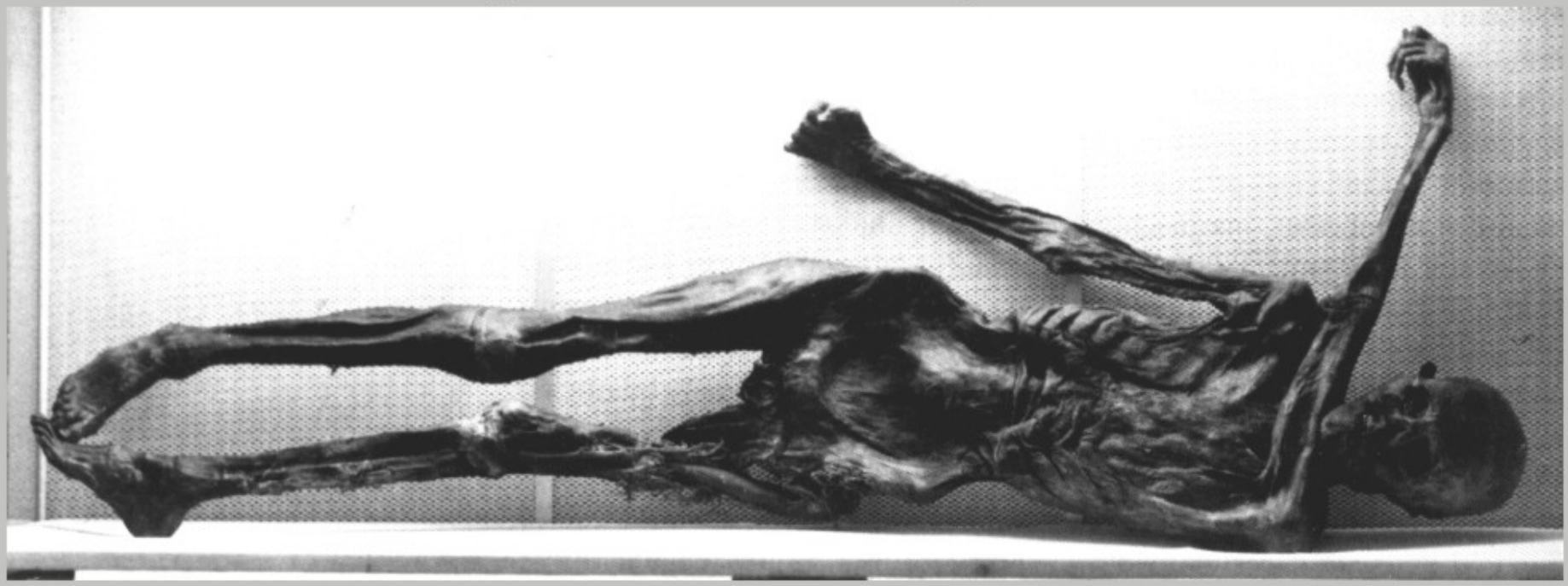
Quelccaya Plant

Modern

**5177 ± 45 yr. B.P.**

# "The Tyrolean Iceman" - "Ötzi"
# "Man from the Hauslabjoch"

## Age 5175 ± 125 years

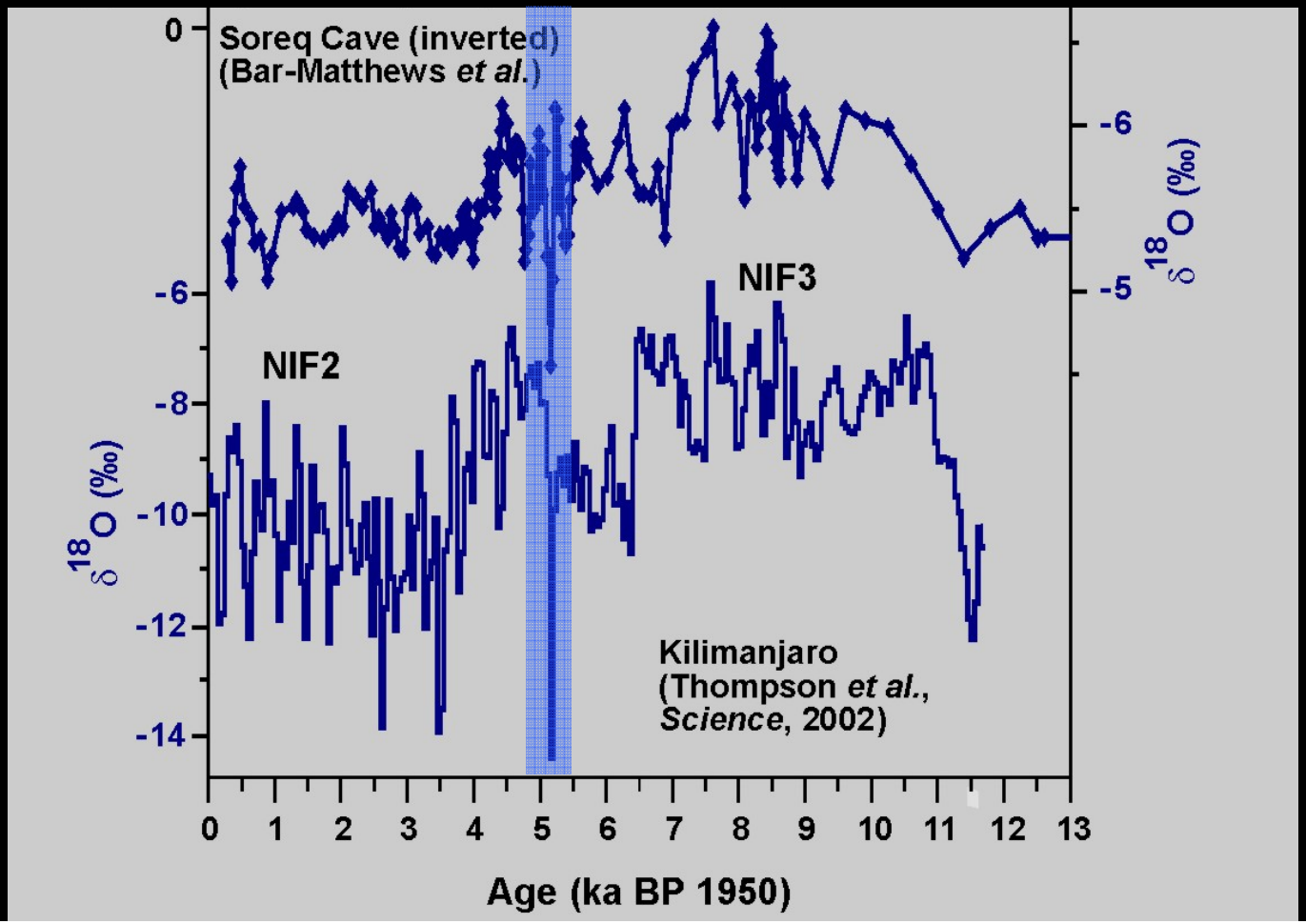


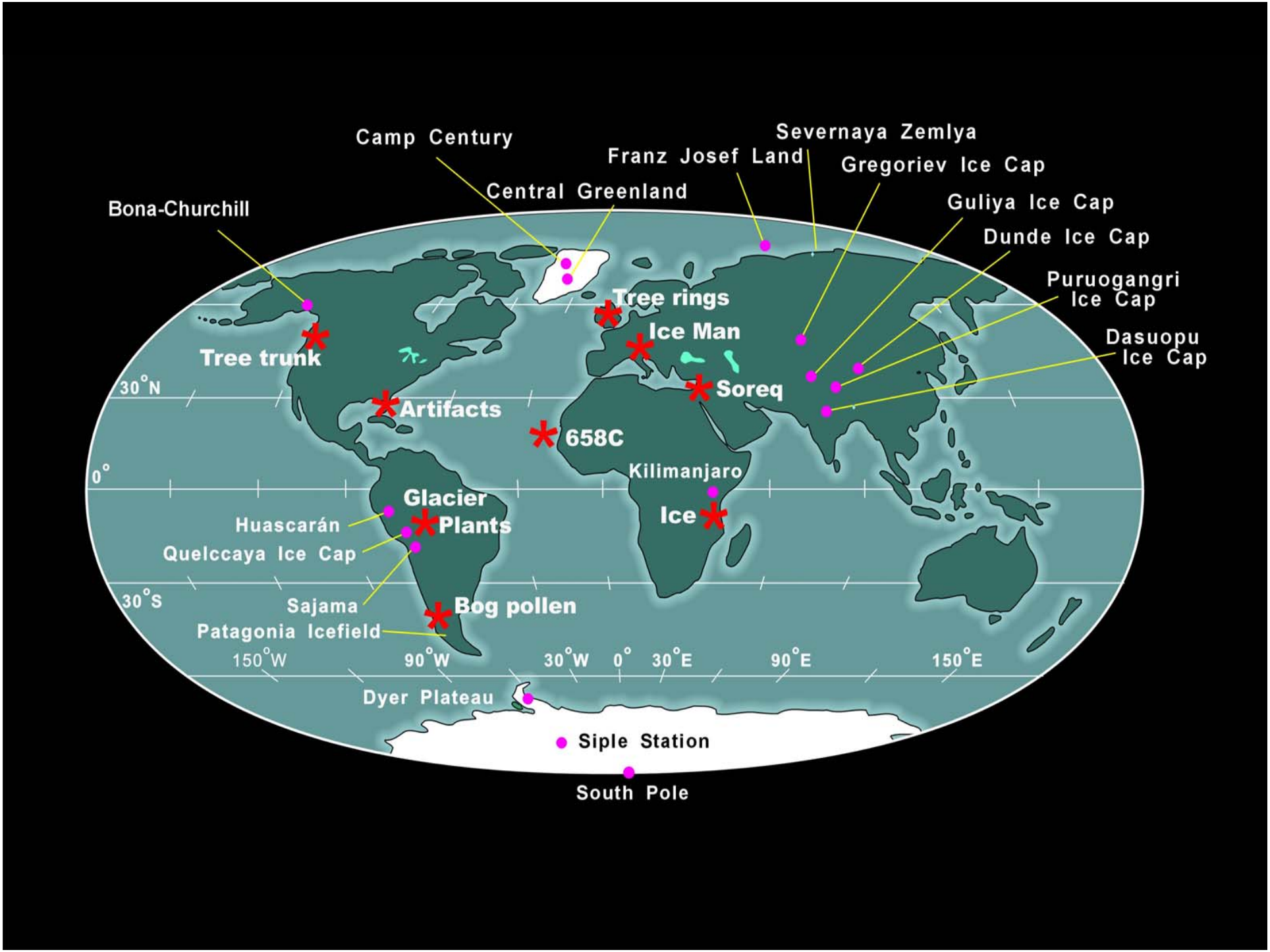
Source: http://info.uibk.ac.at/c/c5/c552/Forschung/Iceman/iceman-en.html#Finding

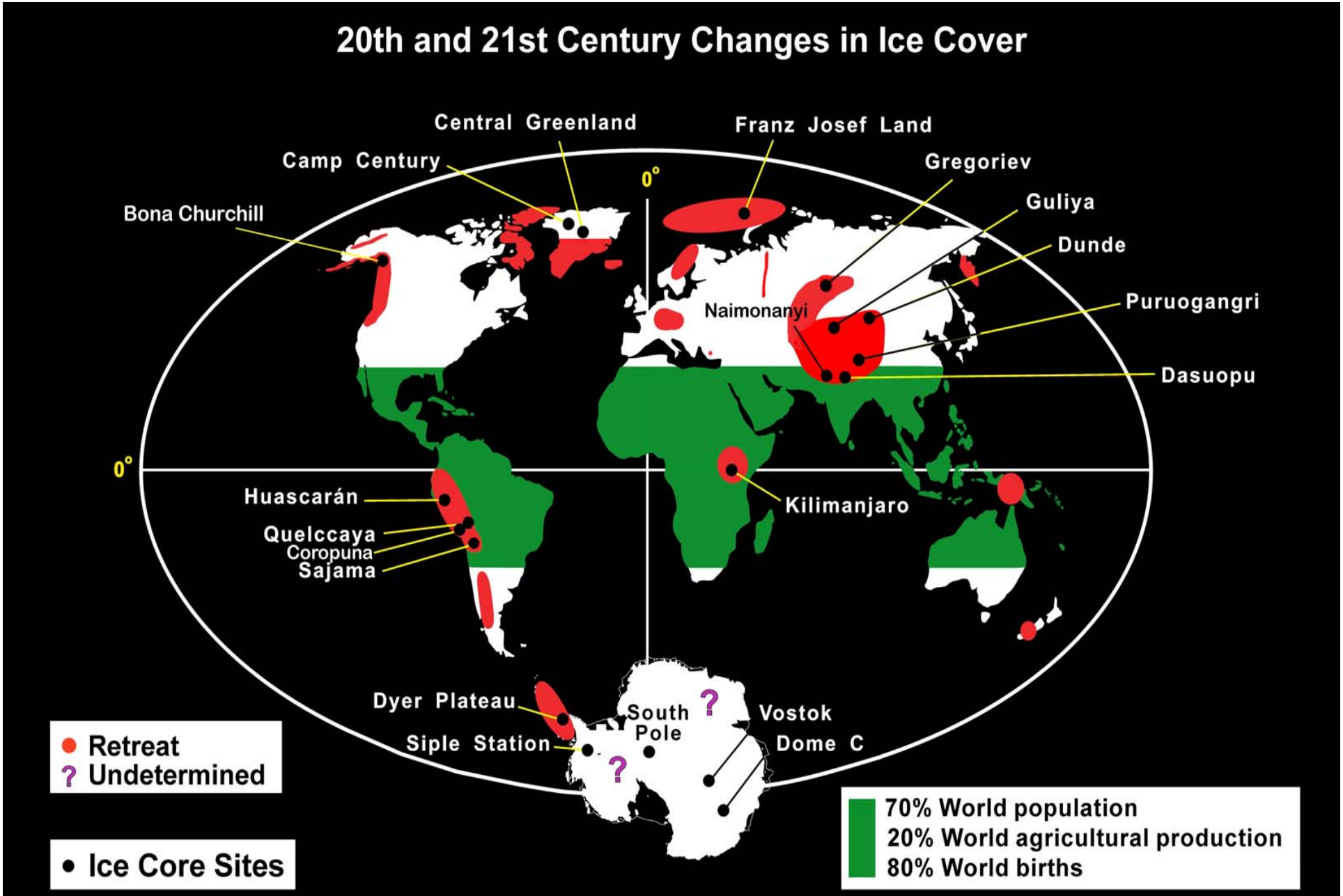
# The Kilimanjaro ice cores provide a record ~ 11,000 years long

This abrupt cooling event 5,200 years ago was contemporaneous with the reorganization of societal structures – Late Uruk abrupt climate change

- Hierarchical societies formed in the overpopulated Nile Valley and Mesopotamia;
- Neolithic settlements in the inner deserts of Arabia were abandoned




Camp Century
Severnaya Zemlya
Franz Josef Land
Gregoriev Ice Cap
Central Greenland
Guliya Ice Cap
Bona-Churchill
Dunde Ice Cap
Puruogangri Ice Cap
Tree rings
Ice Man
Dasuopu Ice Cap
Tree trunk
Soreq
30°N
Artifacts
658C
0°
Kilimanjaro
Glacier
Ice
Huascarán
Plants
Quelccaya Ice Cap
30°S
Sajama
Bog pollen
Patagonia Icefield
150°W
90°W
30°W
0°
30°E
90°E
150°E
Dyer Plateau
Siple Station
South Pole




*•Climatologically we are in unfamiliar territory, and the world's ice cover is responding dramatically*.

Glaciers, especially tropical glaciers, are

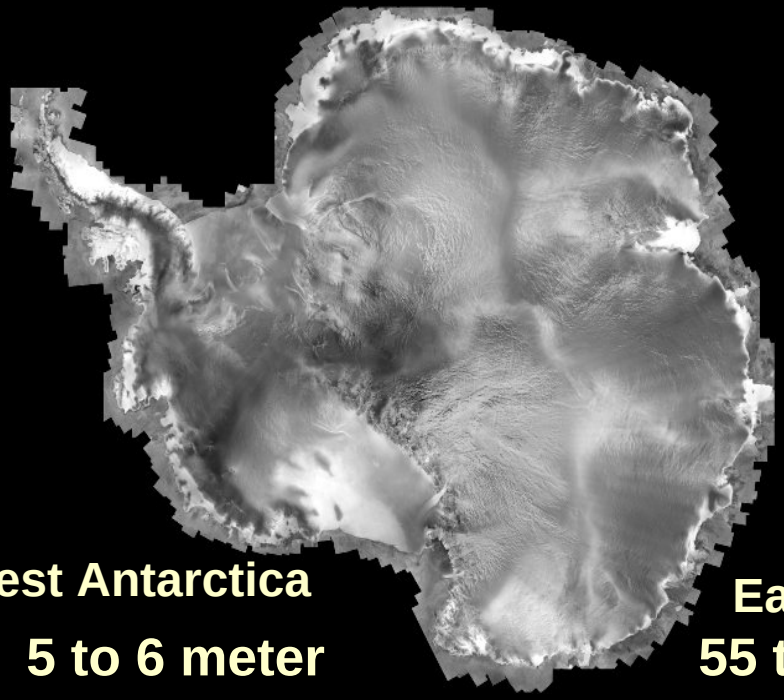
**"the canaries in the coal mine"**

for our global climate system as they integrate and respond to most key climatological variables such as temperature, precipitation, cloudiness, humidity and radiation.

- Global glacier retreat at the beginning of the 21st Century is driven mainly by increasing temperatures although regional factors (i.e., deforestation also may play a role).

Sea level is currently rising 2-3 mm a year.
This is due to
- thermal expansion of ocean
- alpine glacier mass loss (+ thermal expansion) = 0.5 meter sea level rise
- ice sheet mass loss
- pumping groundwater (irrigation)

## Antarctica



West Antarctica

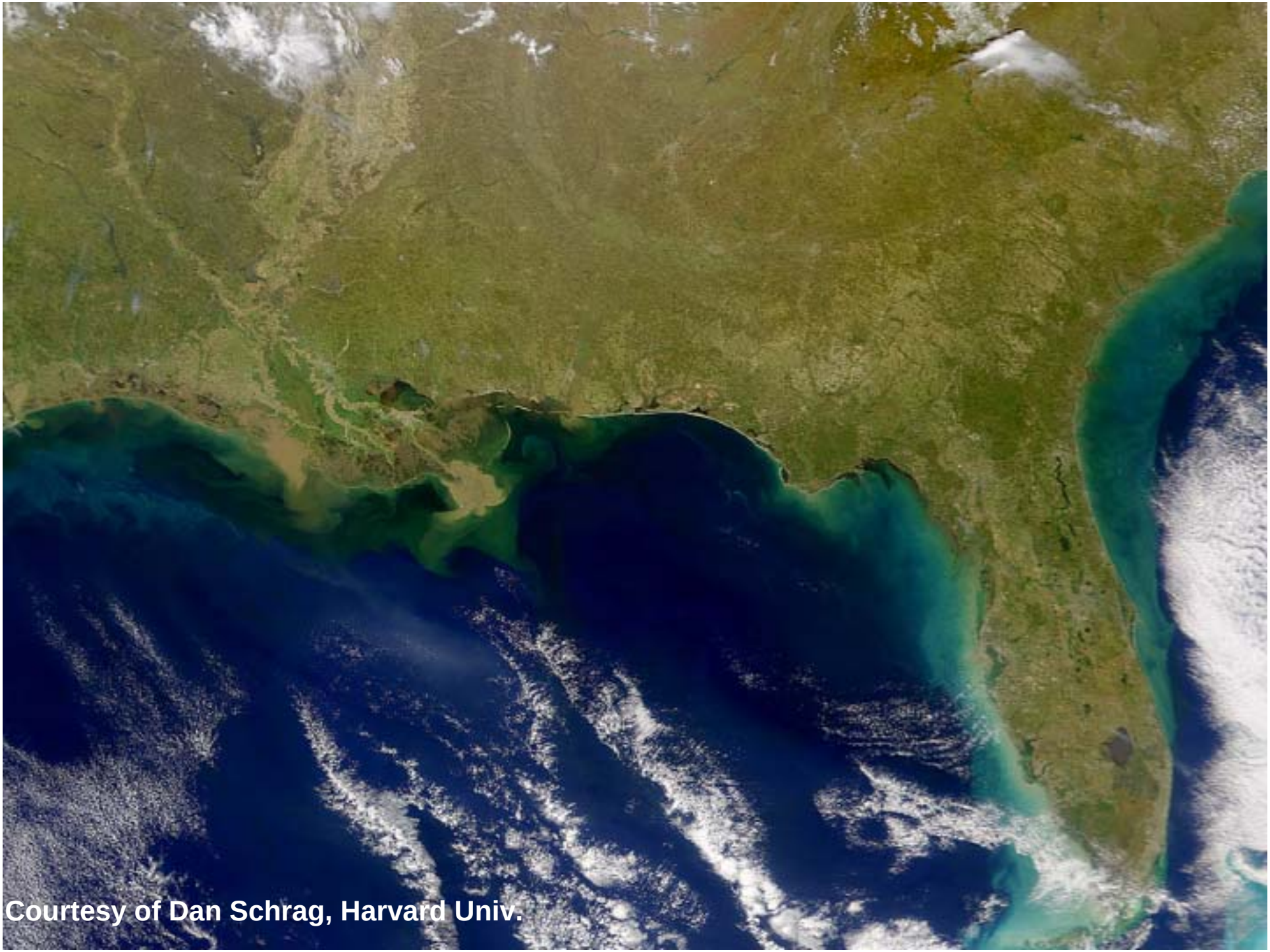
5 to 6 meter sea level rise equivalent

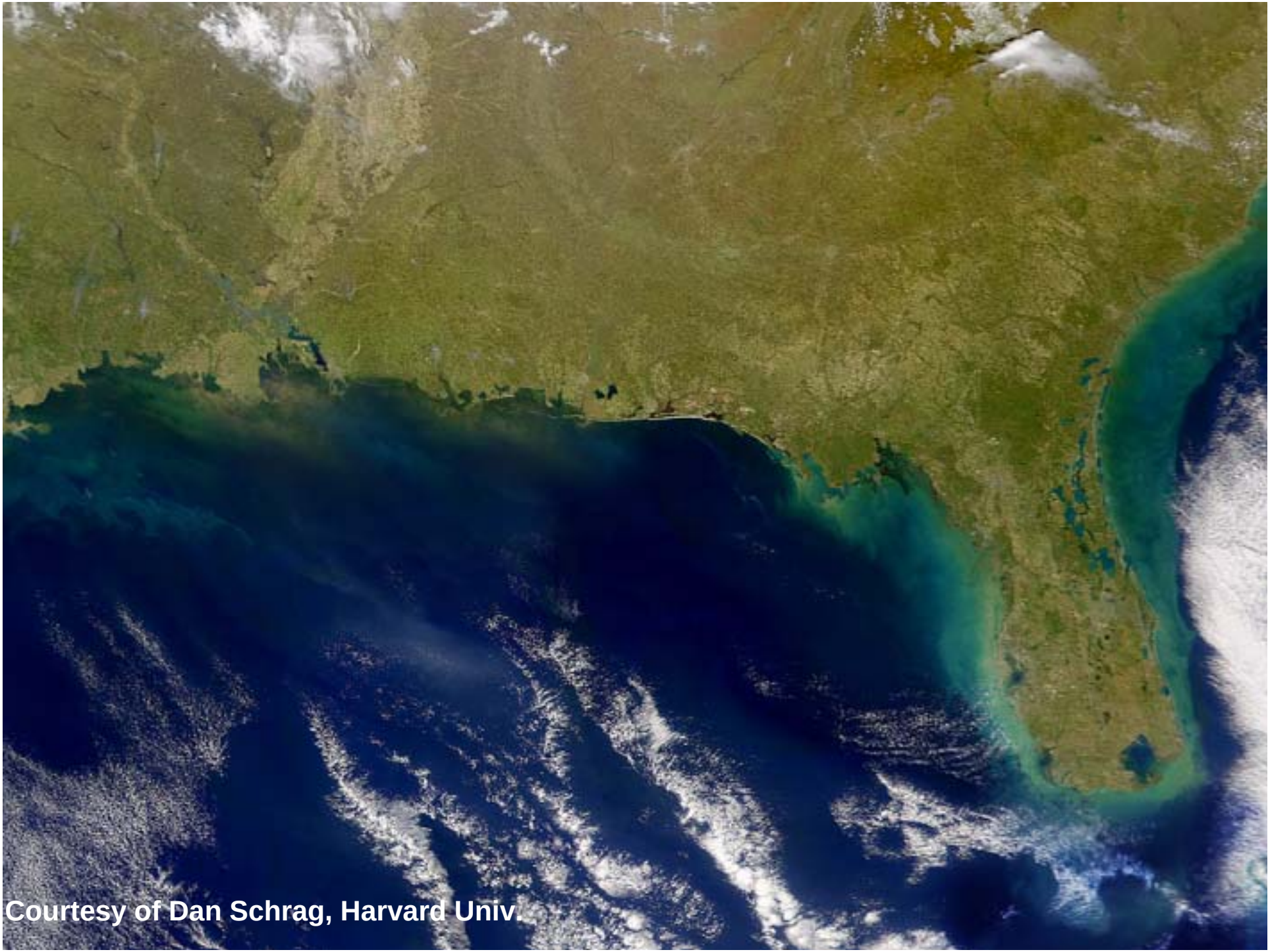
East Antarctica

55 to 60 meter sea level rise equivalent

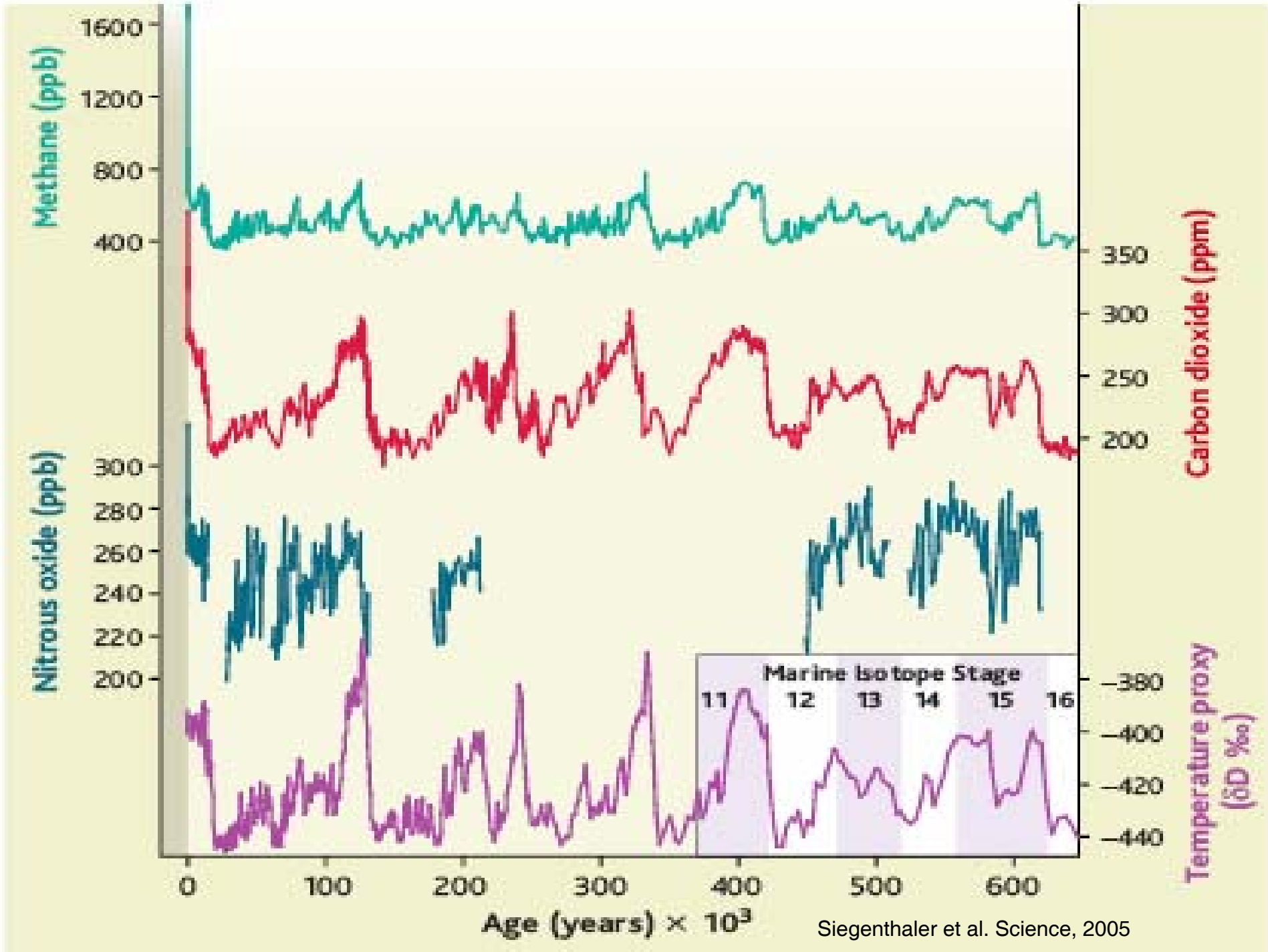
## Greenland

6 to 7 meter sea level rise equivalent


Courtesy of Dan Schrag, Harvard Univ.



Courtesy of Dan Schrag, Harvard Univ.




Siegenthaler et al. Science, 2005

## So society has three options?

- **<u>Prevention</u>, which means measures to reduce the pace & magnitude of the changes in global climate being caused by human activities.**

  Examples of prevention include reducing emissions of GHG, enhancing "sinks" for these gases, and "geoengineering" to counteract the warming effects of GHG.

- **<u>Adaptation</u>, which means measures to reduce the adverse impacts on human well-being resulting from the changes in climate that do occur.**

  Examples of adaptation include changing agricultural practices, strengthening defenses against climate-related disease, and building more dams and dikes. But it's a moving target!

- **<u>Suffering,</u> the adverse impacts that are not avoided by either mitigation or adaptation.**


Crisis
危機

# Danger

# Opportunity

# Key points made in this presentation

The 20th century is the warmest in the last 2000 years and in several places the warmest in over 5000 years.

Ice cores provide unique information that extends our knowledge of the Earth's climate history.

Climatologically we are in unfamiliar territory, and the world's ice cover is responding dramatically

Observed rapid changes in Greenland and Antarctica are not predicted by climate models (slow and linear response to climate forcing; fast glacier flow not included)

Glaciers in most parts of the world are rapidly melting and their loss will affect 2 to 3 billion people and valuable paleoclimate archives will be lost forever.

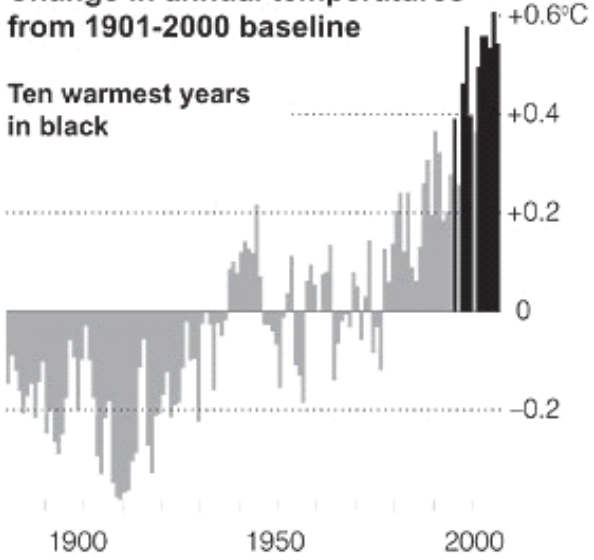
Glaciers are our most visible evidence of global warming. They integrate many climate variables in the Earth system.
Their loss is readily apparent and they have "no political agenda".


For Global  Warming --- Nature is the Time Keeper!

## Measuring Warmth . . .

Last year was the fifth warmest on record globally, according to the National Oceanic and Atmospheric Administration.

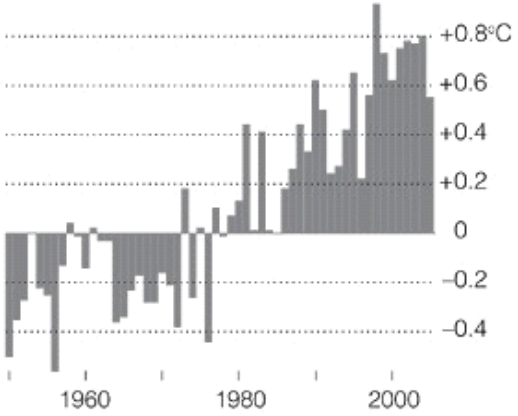
**Change in annual temperatures from 1901-2000 baseline**




## . . . And Understanding The Reasons for It

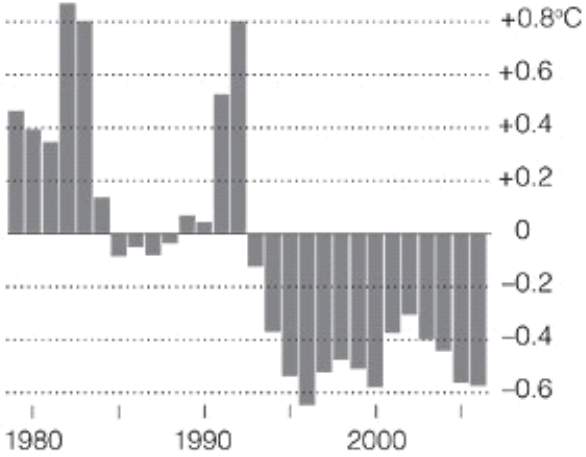
The global warming trend does not necessarily prove that human-generated greenhouse gases are heating the planet. Scientists find stronger clues in patterns of temperature changes, including a recent trend toward warmer nights.

**Change in nighttime low temperatures from 1961-1990 baseline**




A cooling of the stratosphere also suggests human-induced warming.

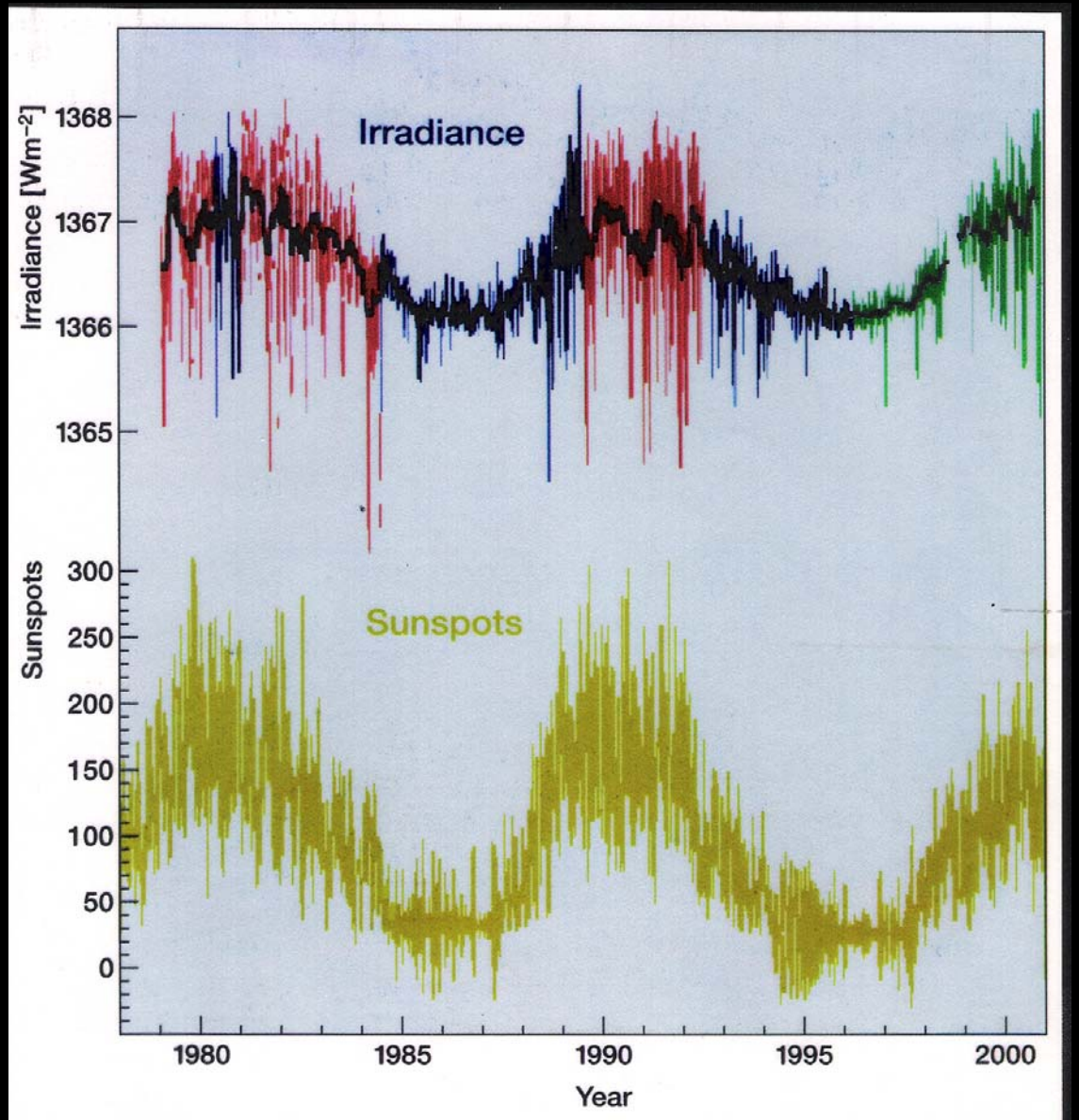
**Change in stratospheric temperatures from 1984-1990 baseline**




*Sources: National Climatic Data Center; University of Alabama, Huntsville*

The New York Times

- **Why contrarians are wrong! "Balance of evidence"**
- **Models predict and the data show that:**
  - **Stratosphere cools as surface warms (variations in the sun's output, would instead cause similar trends in the two atmospheric layers instead of opposite ones)**
  - **Temperatures have warmed more at night than during the day (This is unlikely to be caused by some variability in the sun for example, and appears linked to the greenhouse gases that hold in heat radiating from the earth's surface, even after sunset)**
  - **Temperatures have risen more in winter than in summer (opposite that would be expected if the sun was driving temperature increase)**
  - **High latitudes have warmed more that low latitudes (since more radiation is received at low latitudes would expect opposite if sun was driving change)**
  - **There has been a parallel warming trend over land and oceans. (the increase in the amount of heat-trapping asphalt cannot be the only culprit)**
  - **Several dozen top models have become progressively better at replicating climate patterns, and the present (the only way to replicate the remarkable warming, and extraordinary Arctic warming, of the recent decades is to add greenhouse gases.**




***Comparison*** of the solar irradiance with the sunspot numbers for the last two Schwabe cycles. The irradiance record is a compilation of data from different satellites. During periods of high solar activity there are more sunspots, darkening a small part of the solar disk (visible in the negative excursions of the irradiance). However, the brightness of the Sun is increased at the same time, overcompensating the darkening effect of the sunspots. (Irradiance data: credit: C. Fröhlich, PMOD).