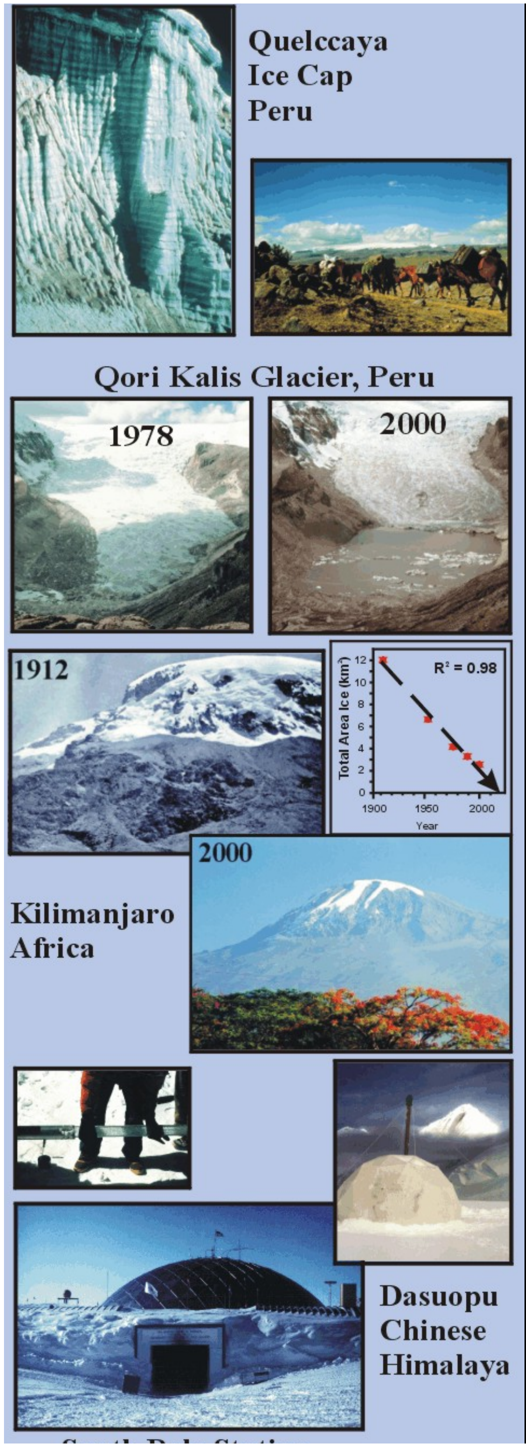



# Understanding Global Climate Change

**November 1, 2007**


**Water Institute Distinguished Scholar Seminar**

**University of Florida**



**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**
**Paolo Gabrielli**
**Ping-Nan Lin**
**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, Carrie Larsen, David Urmann, Lijia Wei**

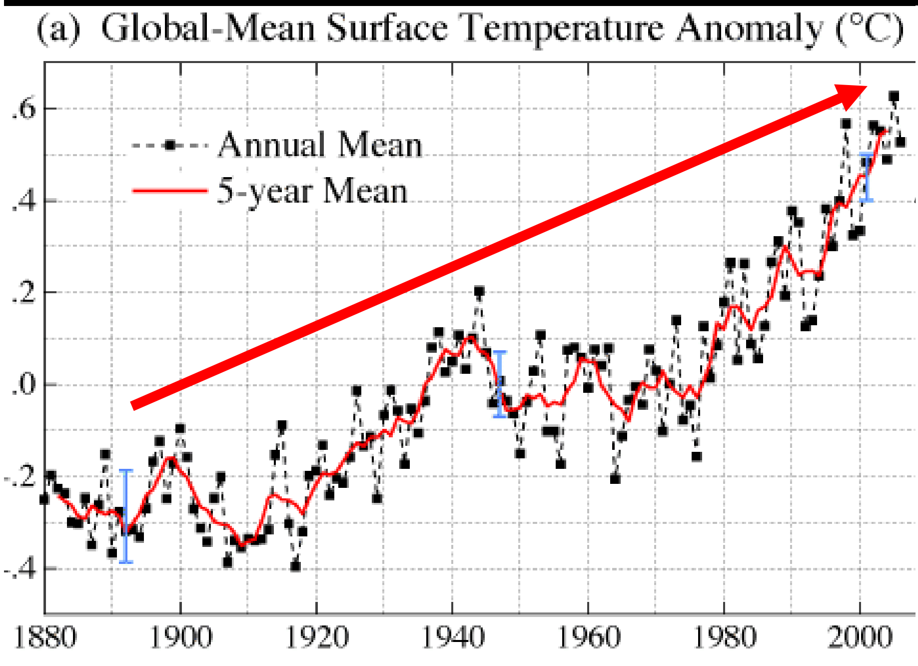
## Objectives:

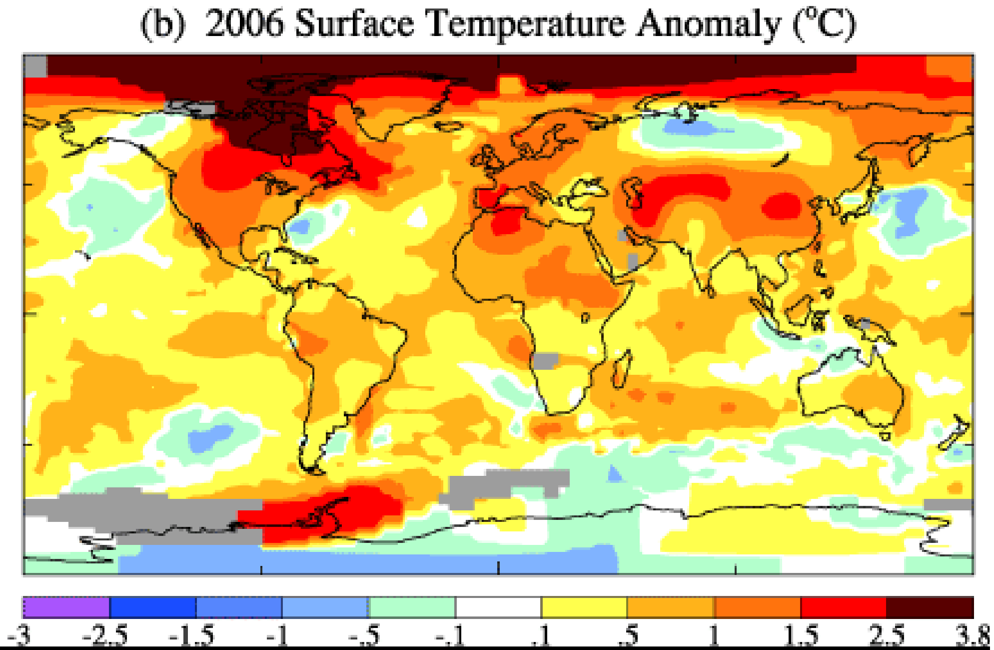
- Introduction to climate change
- Glaciers, among the first responders to global warming, serve both as indicators and drivers of climate change
- Evidence for abrupt climate change, past and present
- Evidence for recent acceleration of the rate of ice loss in the tropics – A Clear and Present Danger!
- A time perspective for current climate changes
- Conclusions

**Our Earth is warming!**

**Environmental conditions are changing!**

- **some changes are unprecedented for thousands of years**
- **some changes are occurring rapidly (years to decades) (shrinking sea ice, ecosystem disruptions, glacier retreat)**

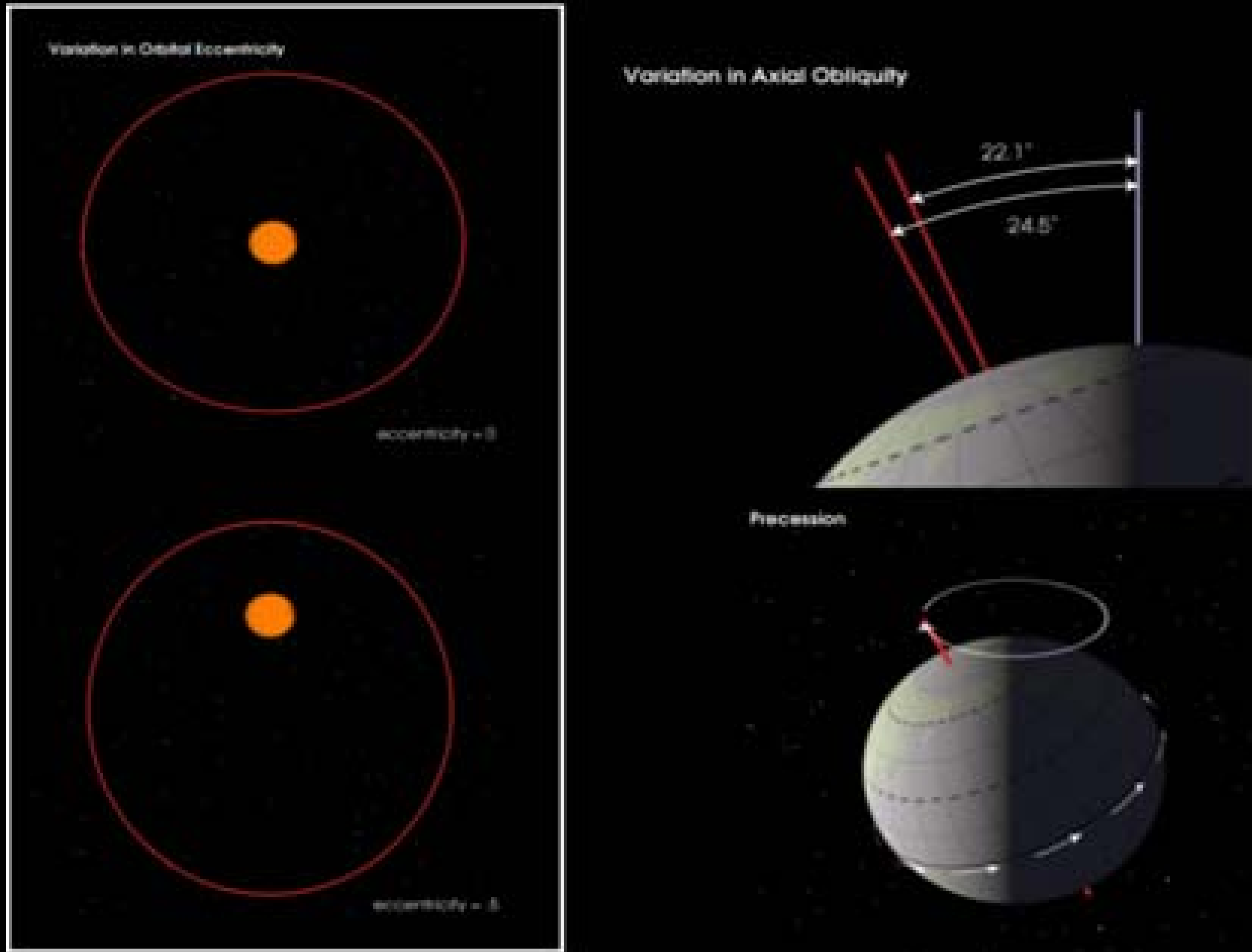



**03/16/2007 NOAA**
**2006 / 2007 warmest winter for Northern Hemisphere**

**http:www.giss.nasa.gov/research/news**

# Earth's Orbital Parameters

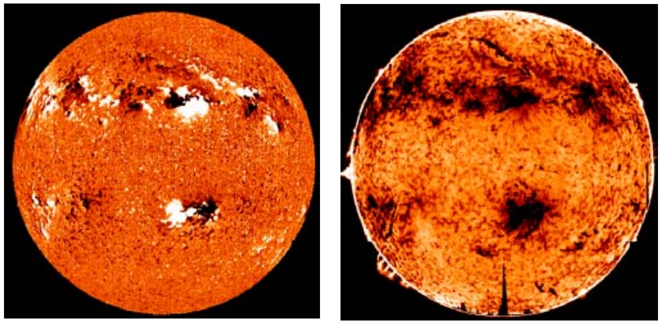



**Source** http://earthobservatory.nasa.gov/Library/Giants/Milankovitch/milankovitch_2.html

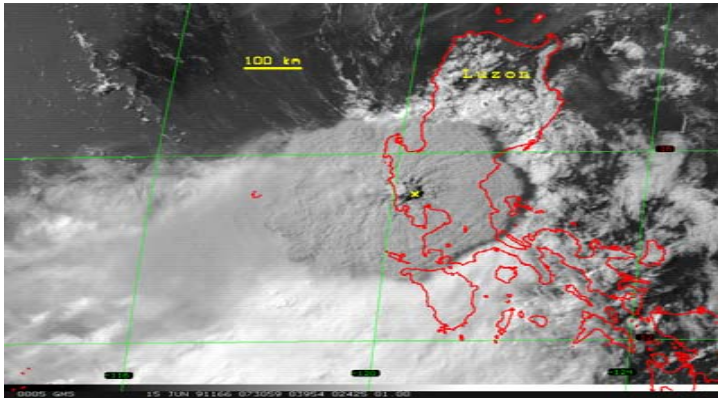
# Natural mechanisms influence climate

## Natural mechanisms

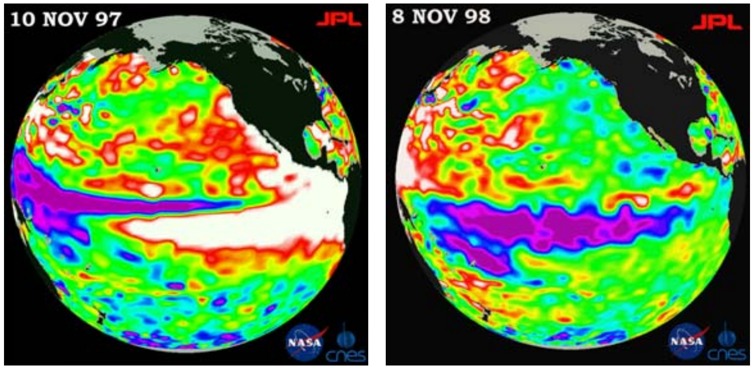
- **Changes in the Sun**



- **Changes in the amount of volcanic dust in the atmosphere**



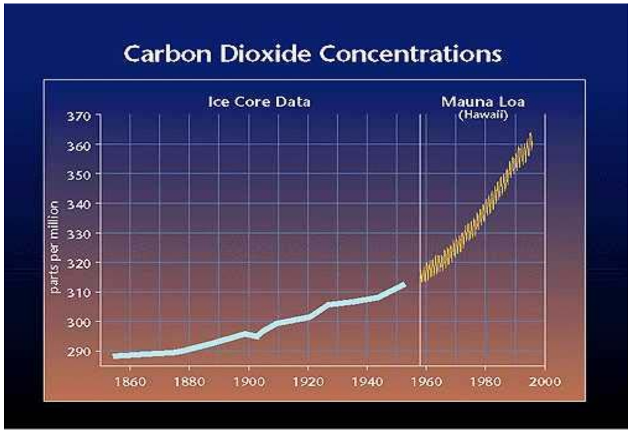

- **Internal variability of the coupled atmosphere-ocean system**



# Human factors also influence climate

## Non-natural mechanisms

- **Changes in atmospheric concentrations of greenhouse gases**

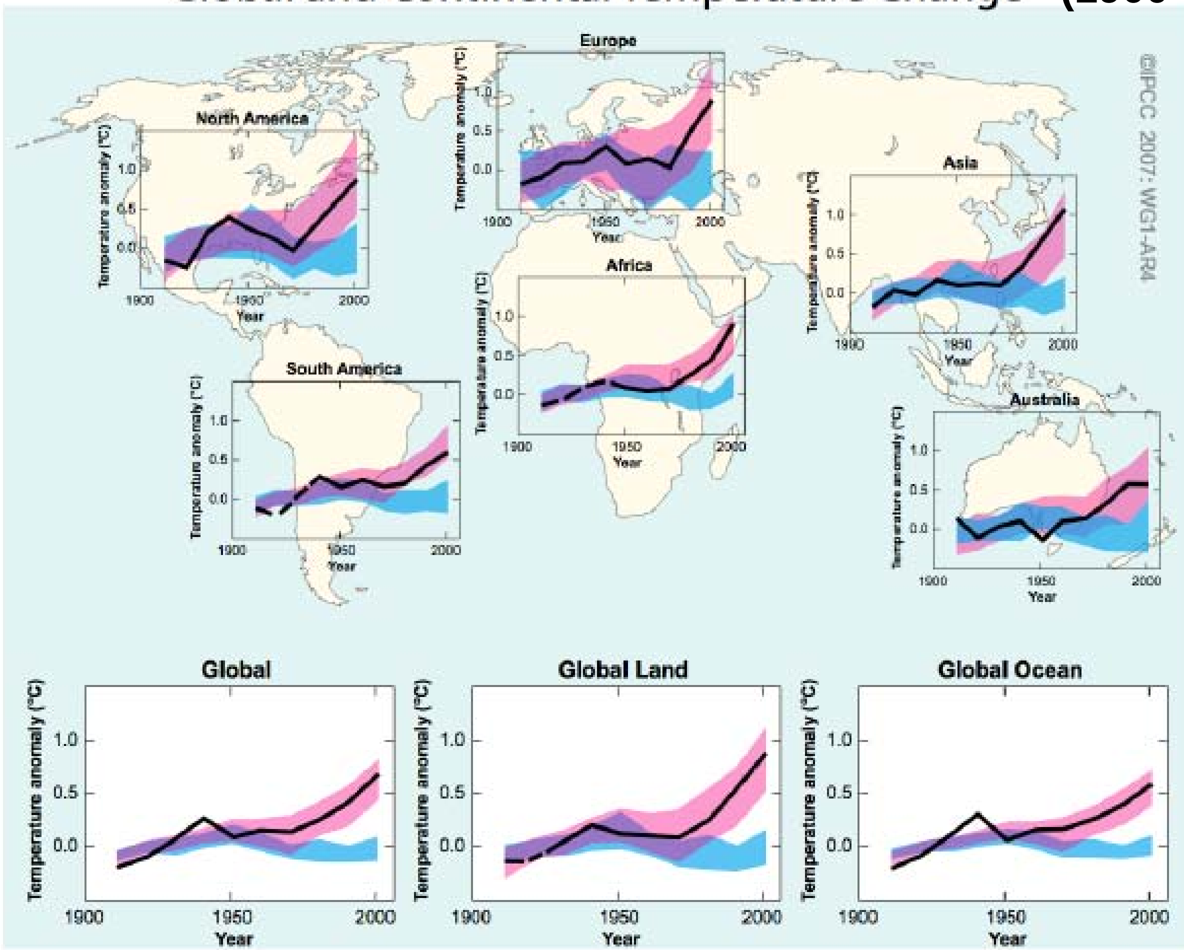



- **Changes in aerosol particles from burning fossil fuels and biomass**

Smoke from fires in Guatemala and Mexico (May 14, 1998)

- **Changes in the reflectivity (albedo) of the Earth's surface**

## Global and Continental Temperature Change **(1900 to 2000 AD)**




**Blue – natural forcings only** **Pink – natural & anthropogenic forcings**

**observations**

**February 2007**

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

1977

Quelccaya Ice Cap, Peru

High temporal resolution

East Antarctica Plateau

Long records

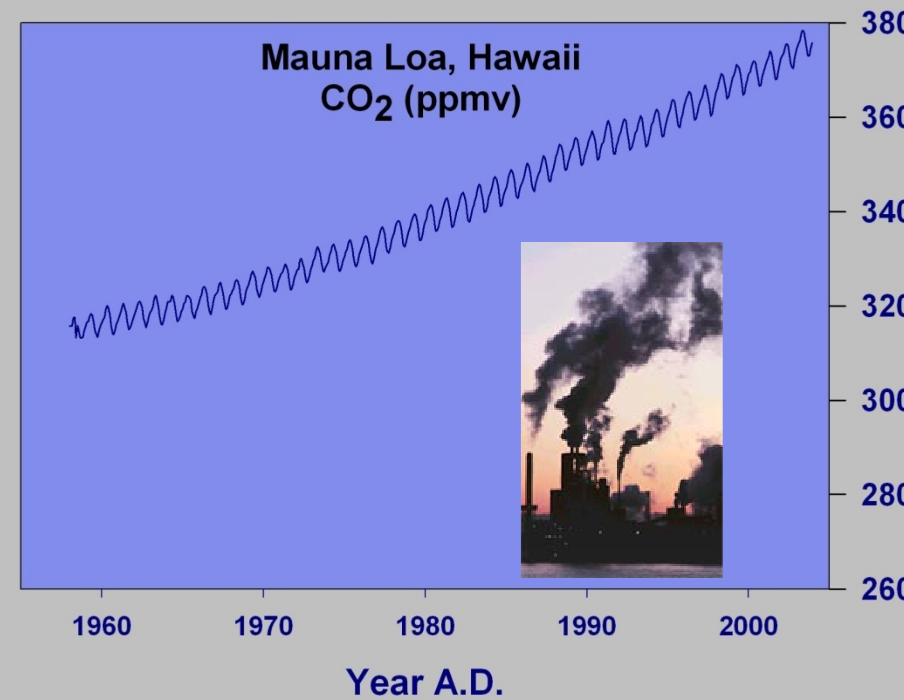
**Ice cores are powerful contributors to multi-proxy reconstructions:**

1) they provide multiple lines of climatic & environmental evidence

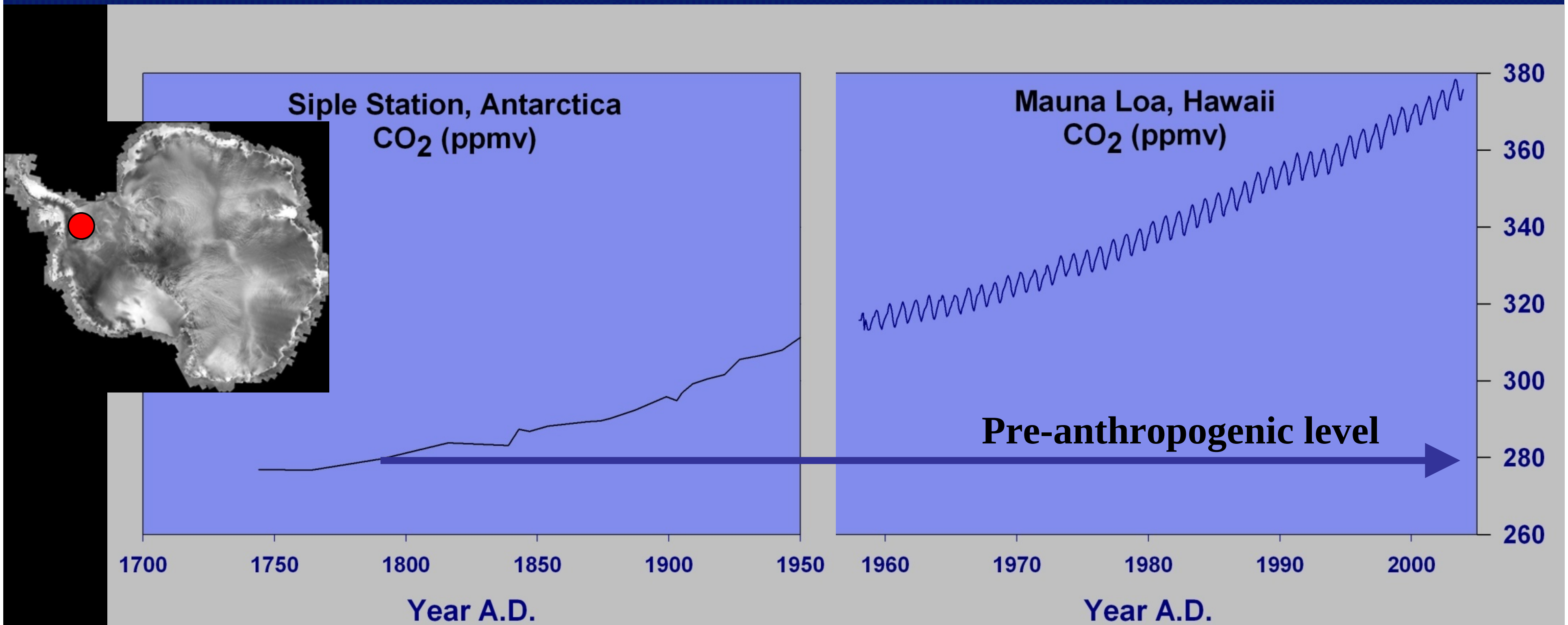
2) ideal for revealing rapid climate changes

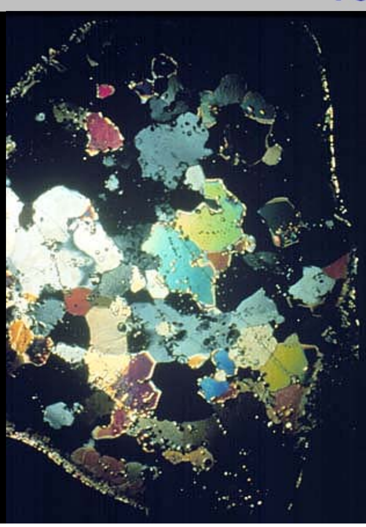

Guliya ice cap, Tibet

# Carbon Dioxide Concentrations

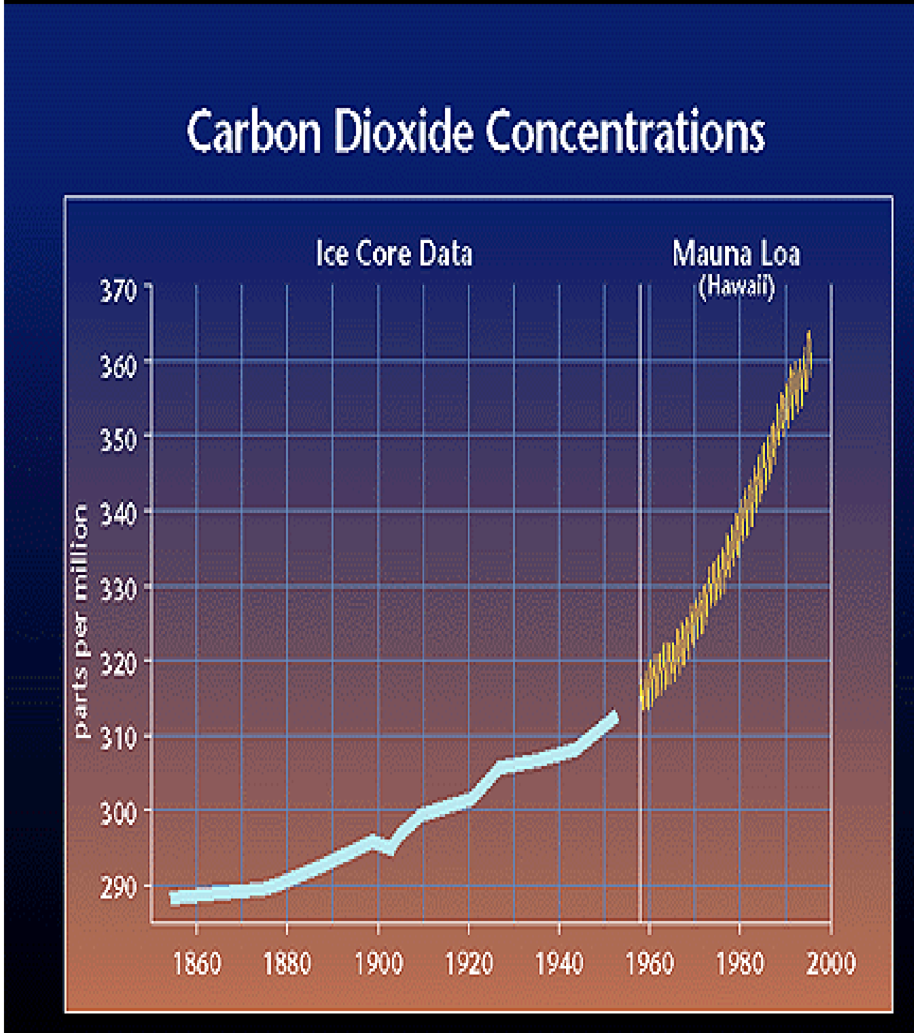


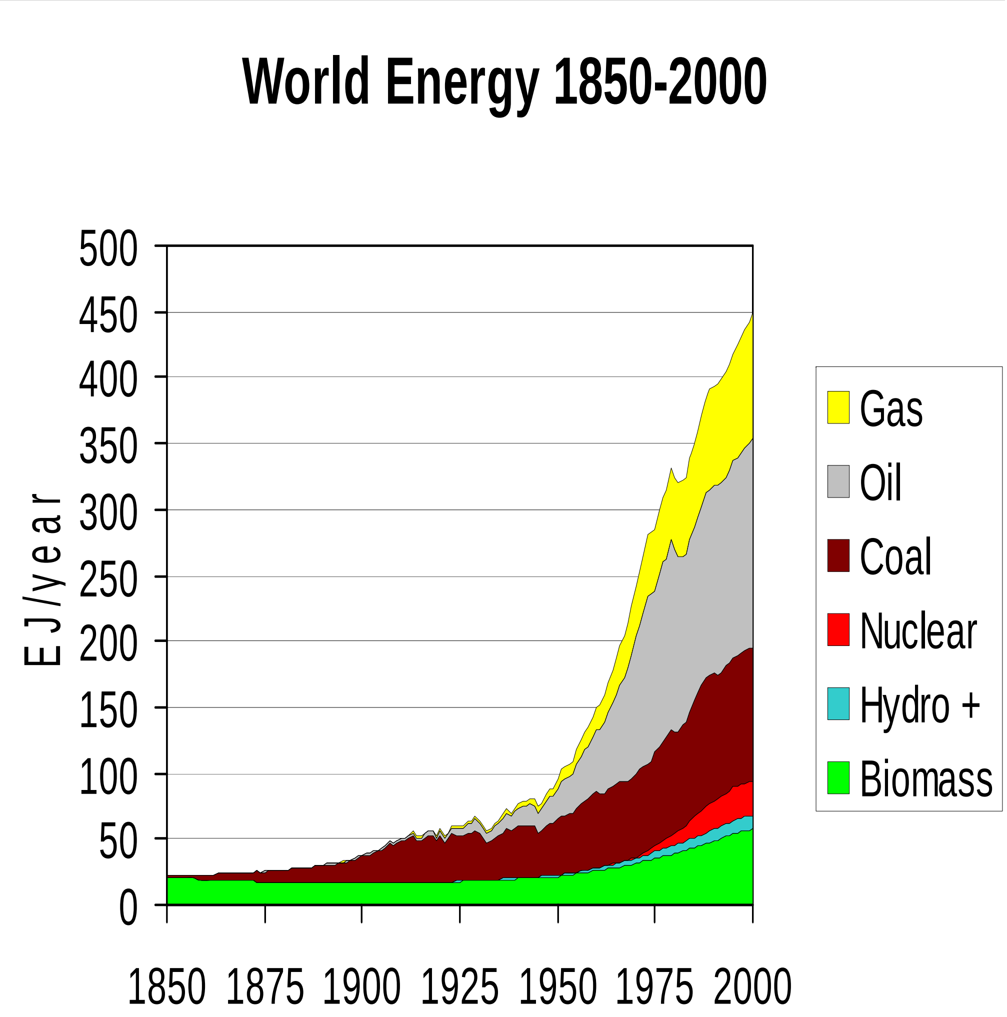

# Carbon Dioxide Concentrations

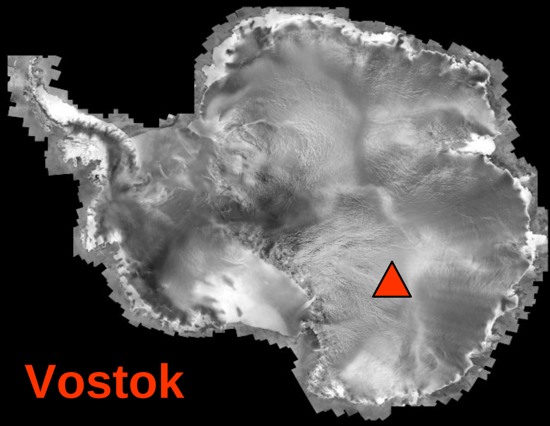


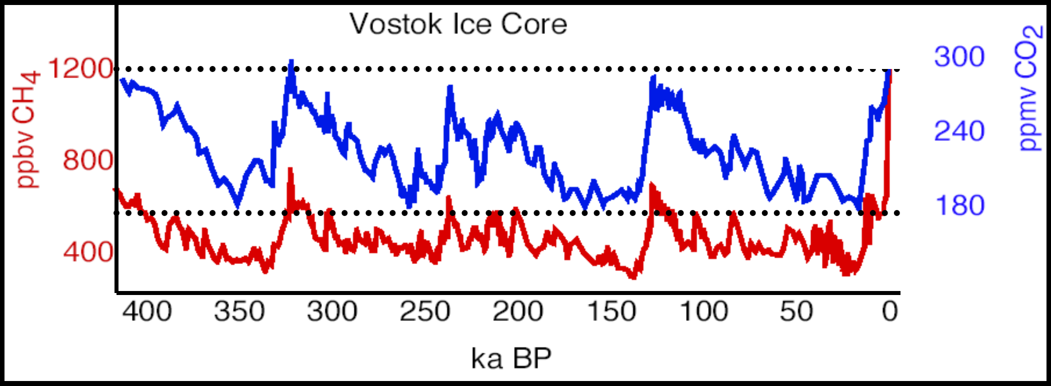
**The increase in atmospheric carbon dioxide is primarily due to world energy consumption and secondarily due to deforestation.**



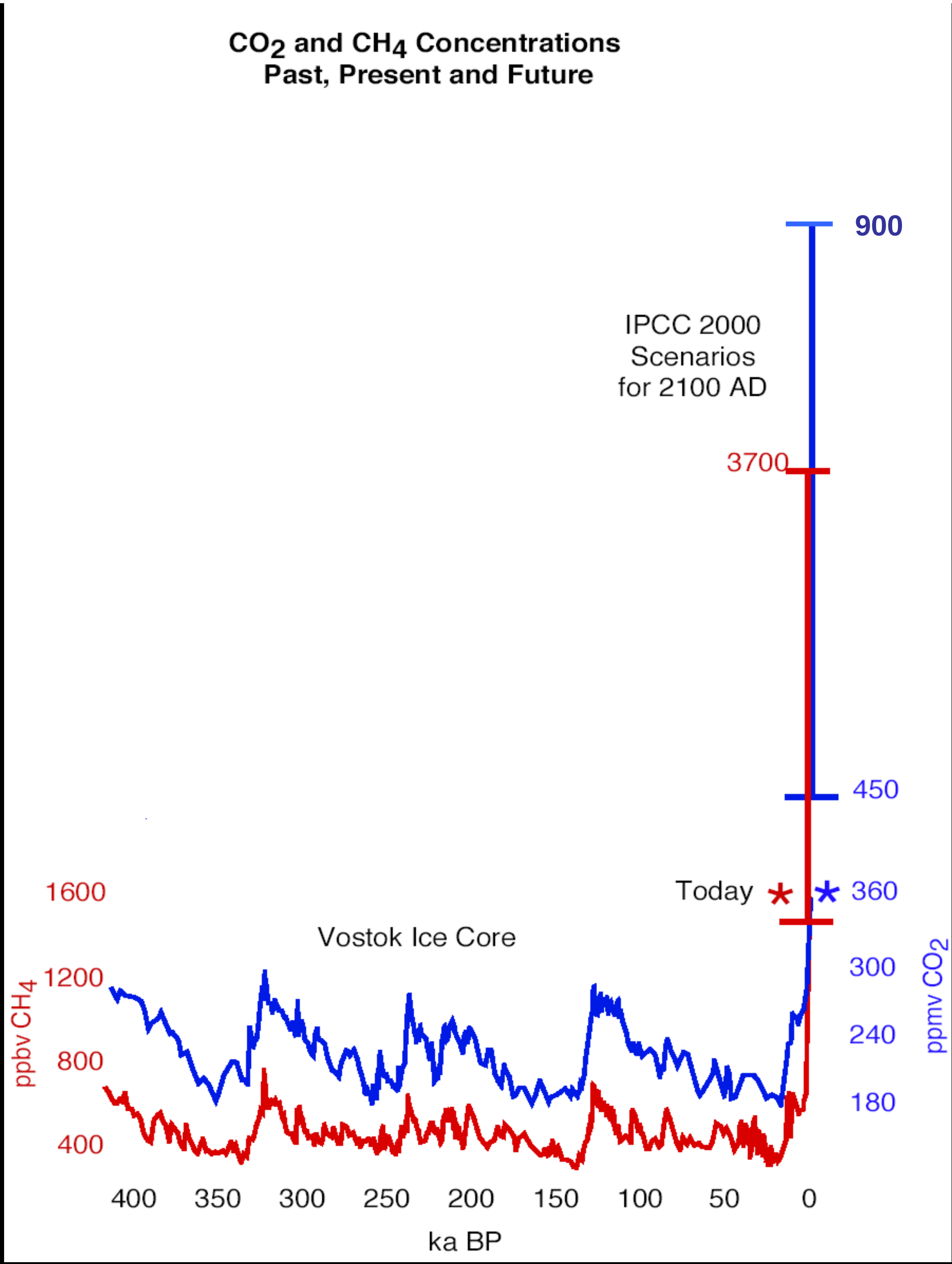






**The Vostok ice core extends back through multiple glacial and interglacial stages - recording the changes in the composition of the Earth's atmosphere**




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



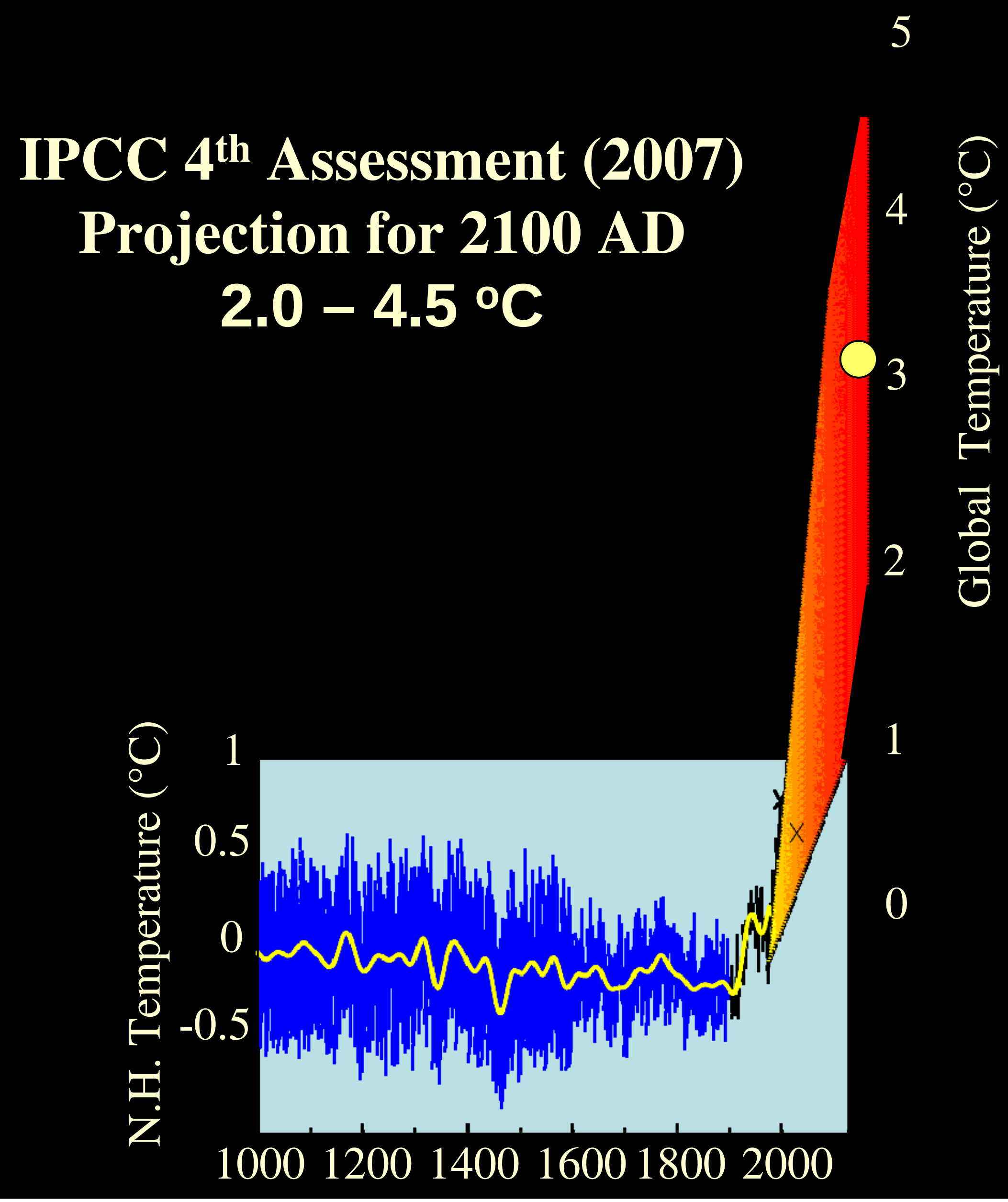

**By 2100:**
**$CO_2$ ~ 900 ppmv**

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

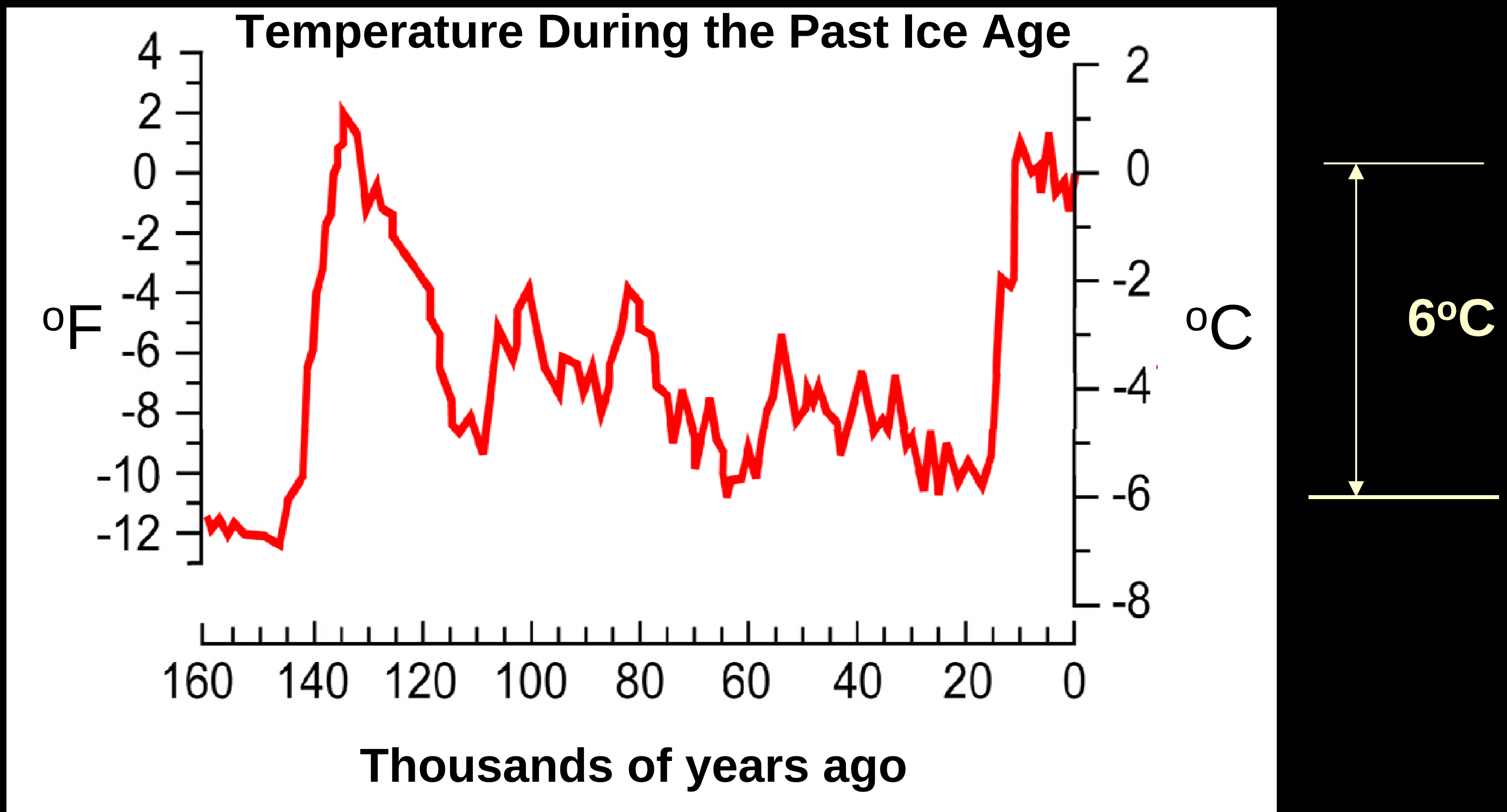
**Today:**
**$CO_2$ is 380 ppmv**
**$CH_4$ is 1750 ppbv**

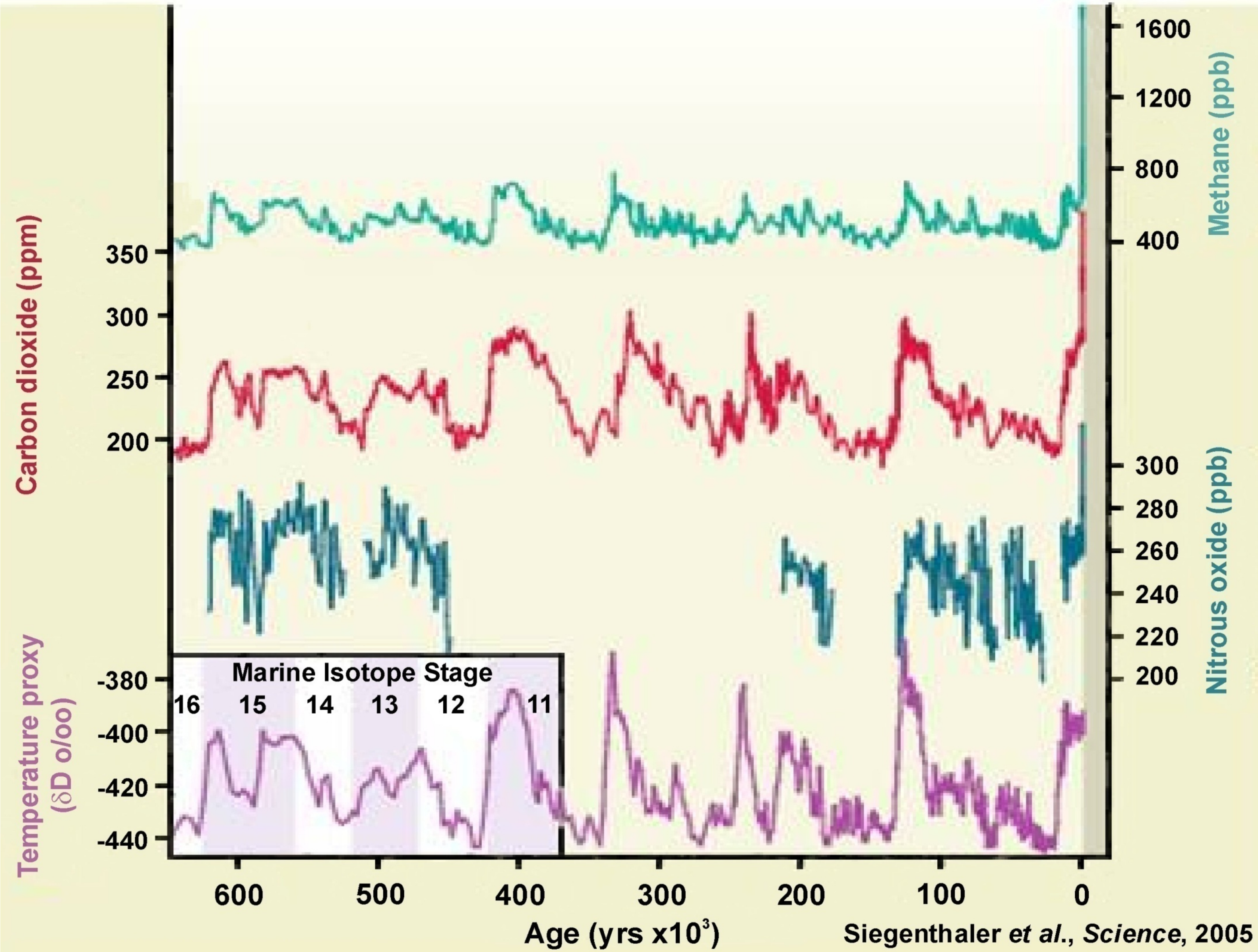
***Houghton et al., 2001***
***Petit et al., 1999***

# Proxy Records Provide A Critical Time Perspective

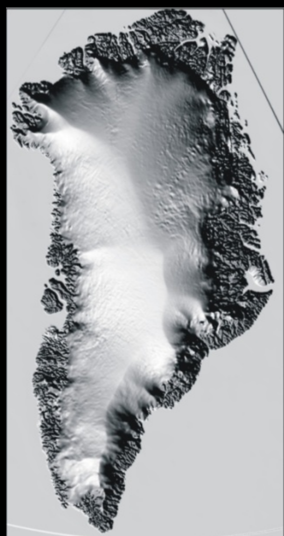


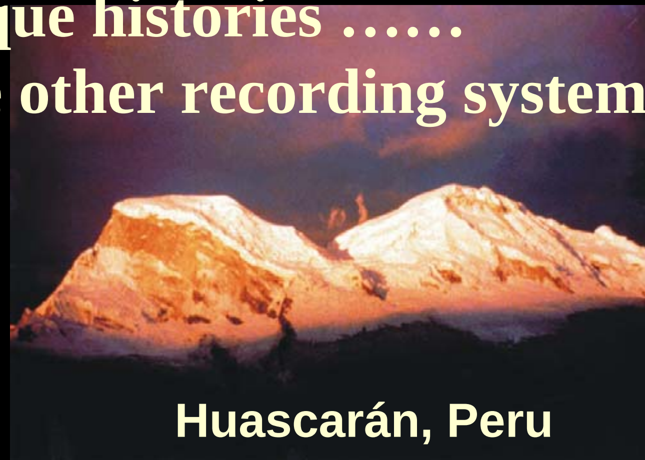
# Should we worry about a +3ºC change?




Carbon dioxide (ppm)
350
300
250
200
Temperature proxy
(δD o/oo)
-380
-400
-420
-440
Methane (ppb)
1600
1200
800
400
Nitrous oxide (ppb)
300
280
260
240
220
200
Marine Isotope Stage
16
15
14
13
12
11
600
500
400
300
200
100
0
Age (yrs x10³)
Siegenthaler et al., Science, 2005

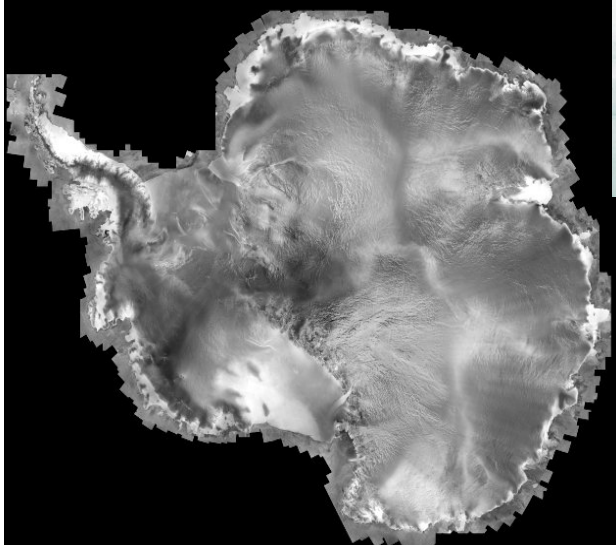
# Ice cores provide unique histories ……
# from regions where other recording systems are limited or absent



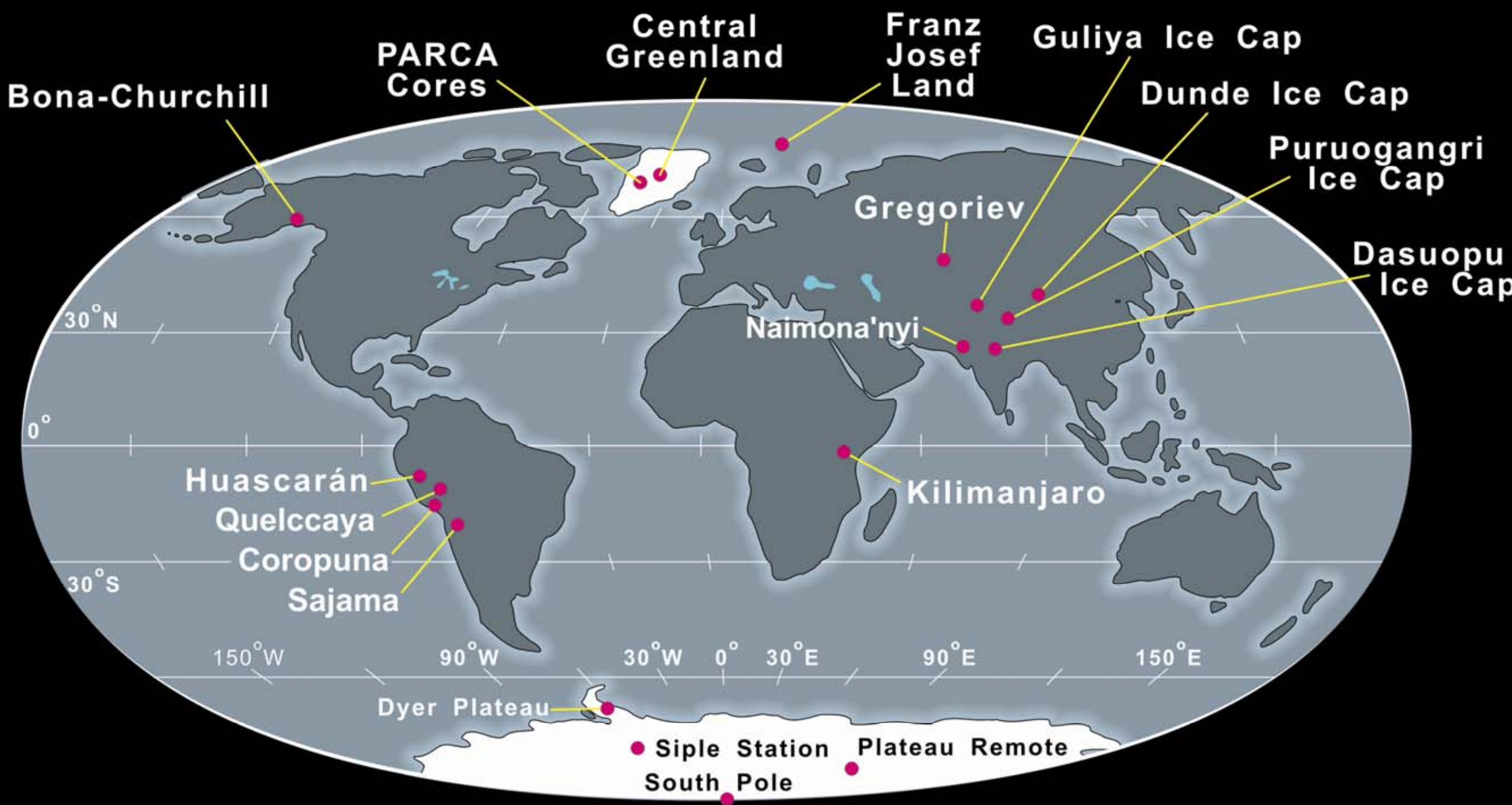


Huascarán, Peru

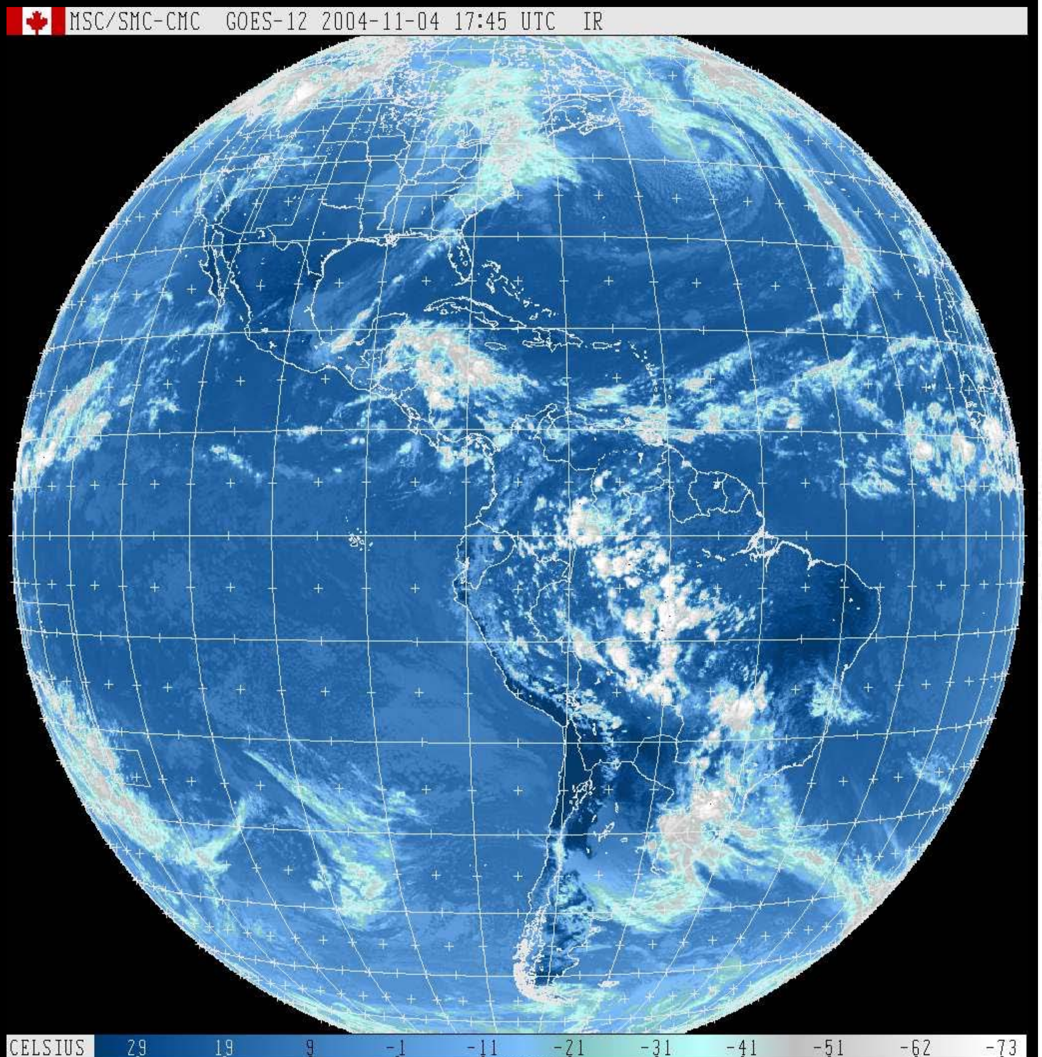
Dasuopu Glacier
Southern Tibet



# Sites where the OSU team has drilled ice cores



# Zonal Distribution of Annual Precipitation



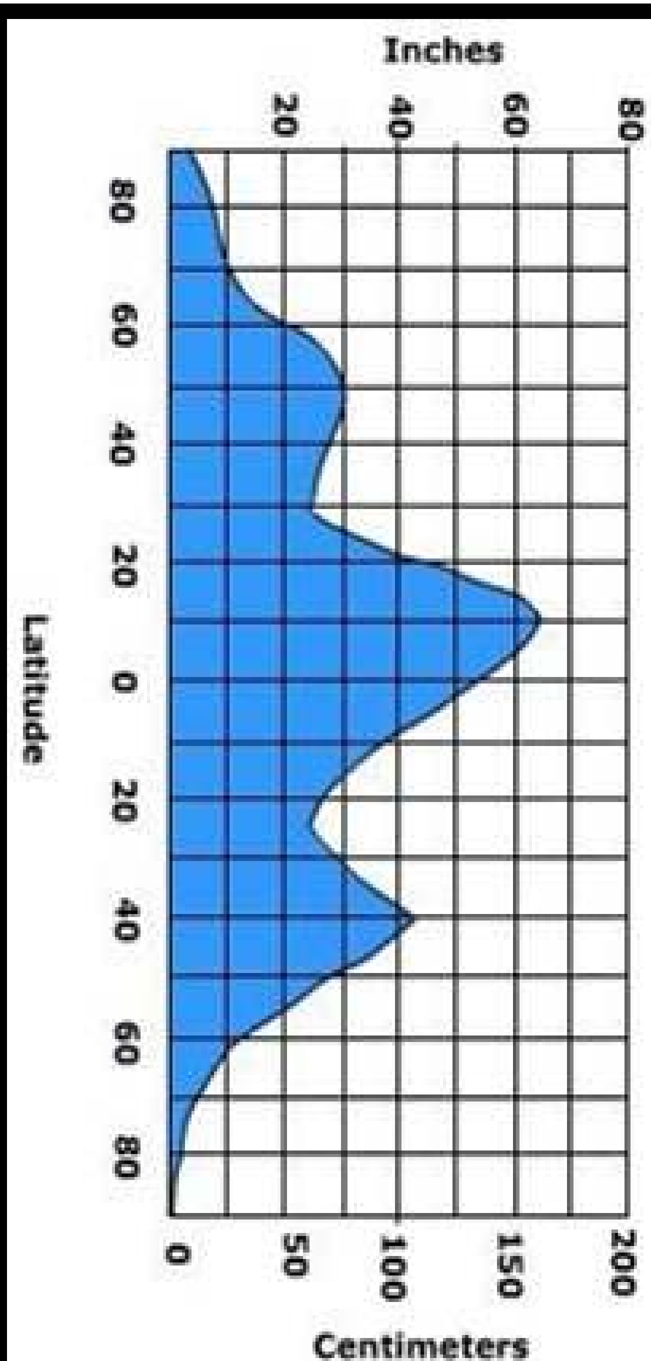
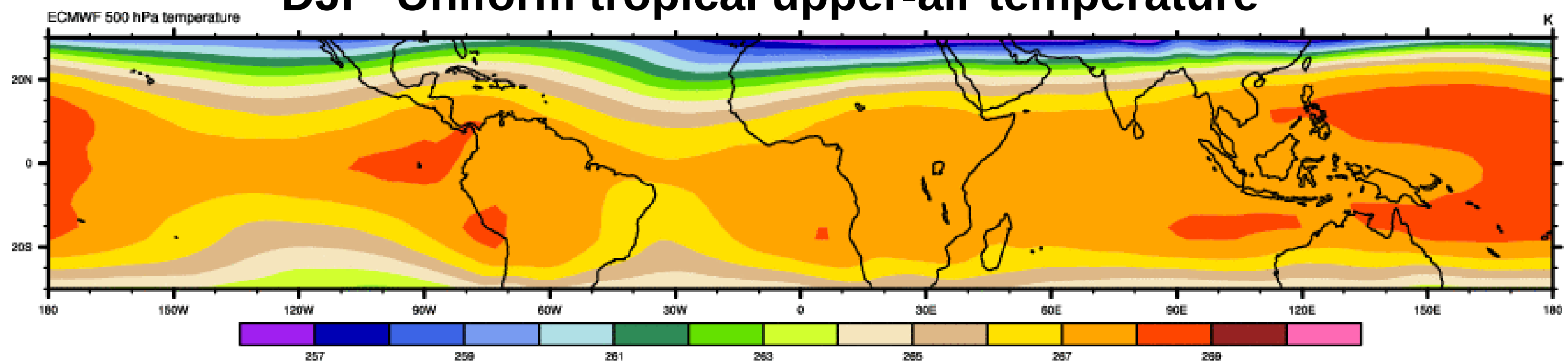
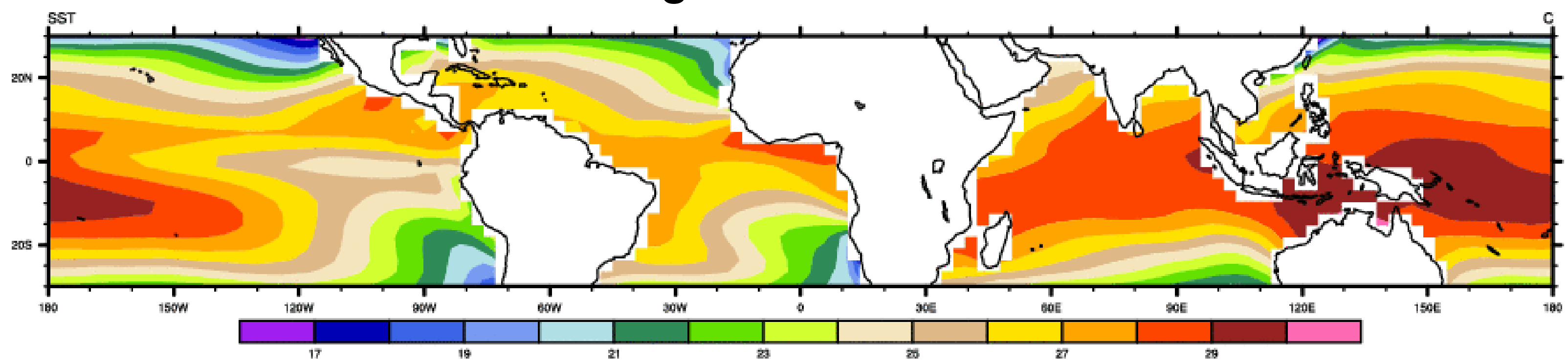




**Image from GOES-12 Satellite Nov 4, 2004**

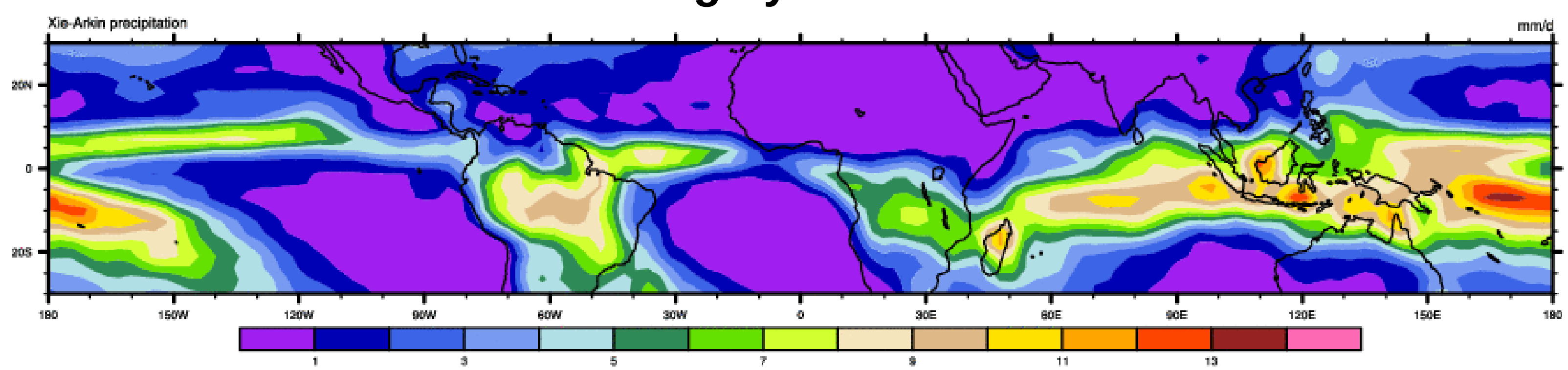
## DJF  Uniform tropical upper-air temperature



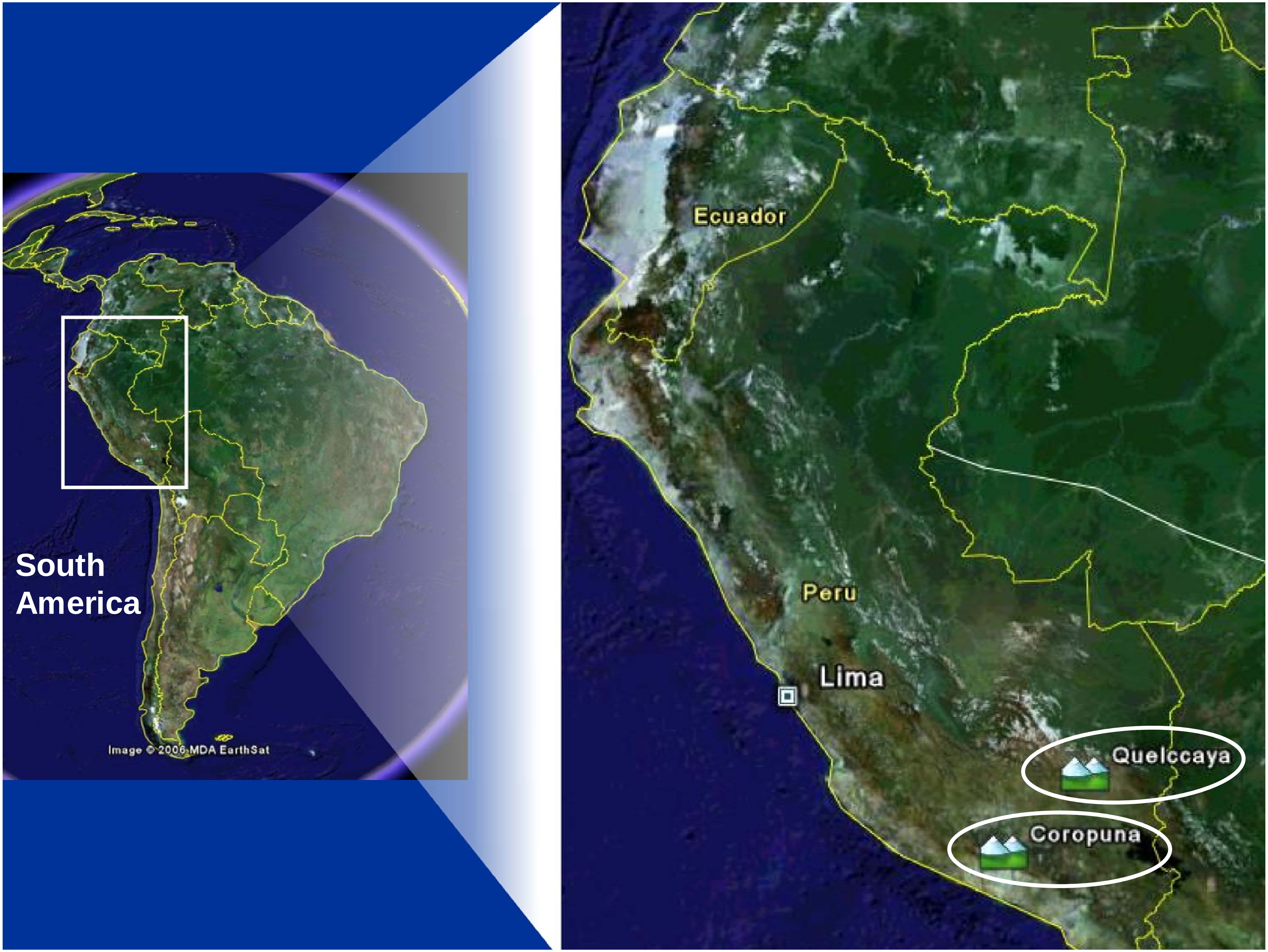

## DJF  Larger SST variations




## DJF     Rainfall roughly follows warm SST

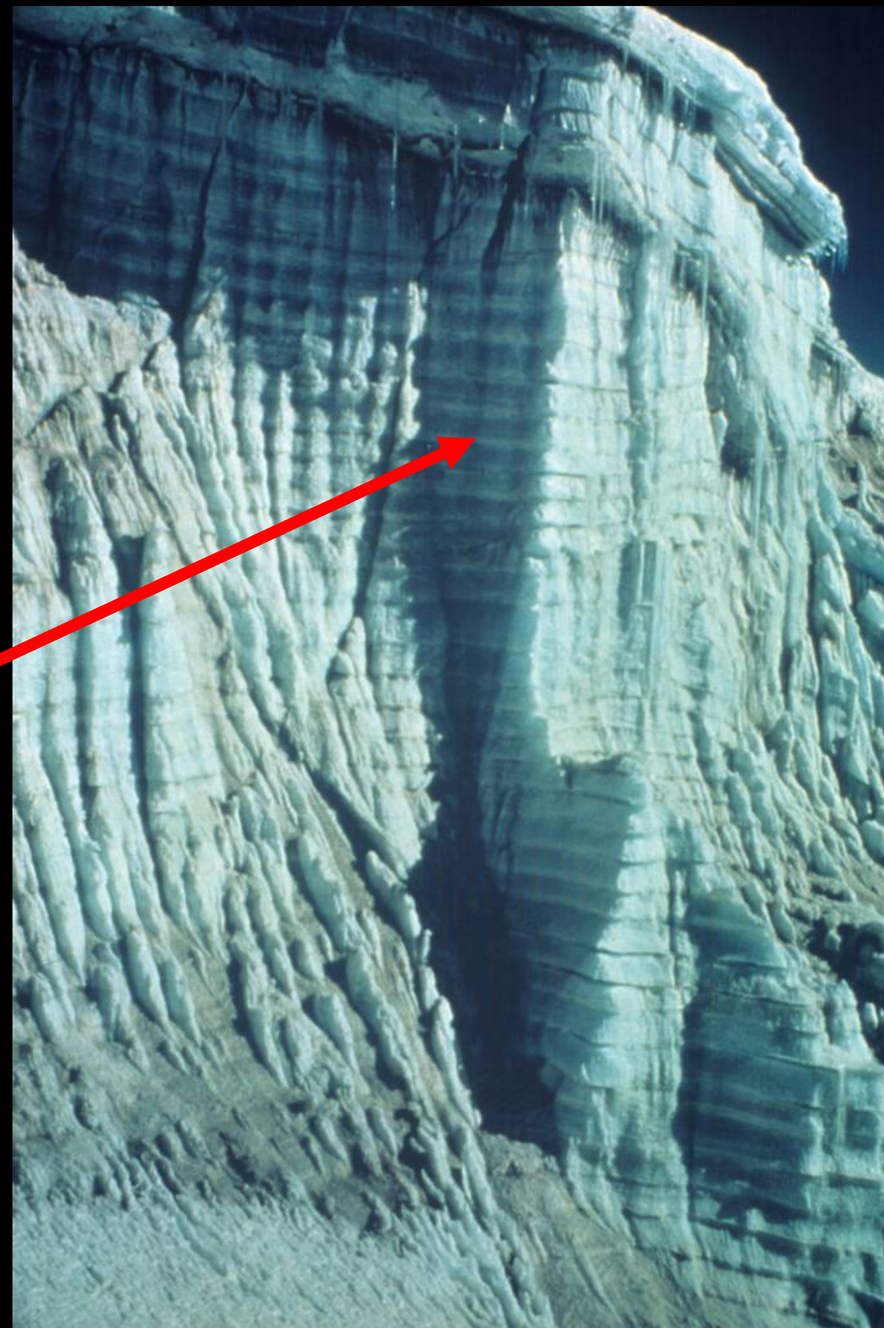



**(Sobel and Bretherton, *J. Climate* , *2000***

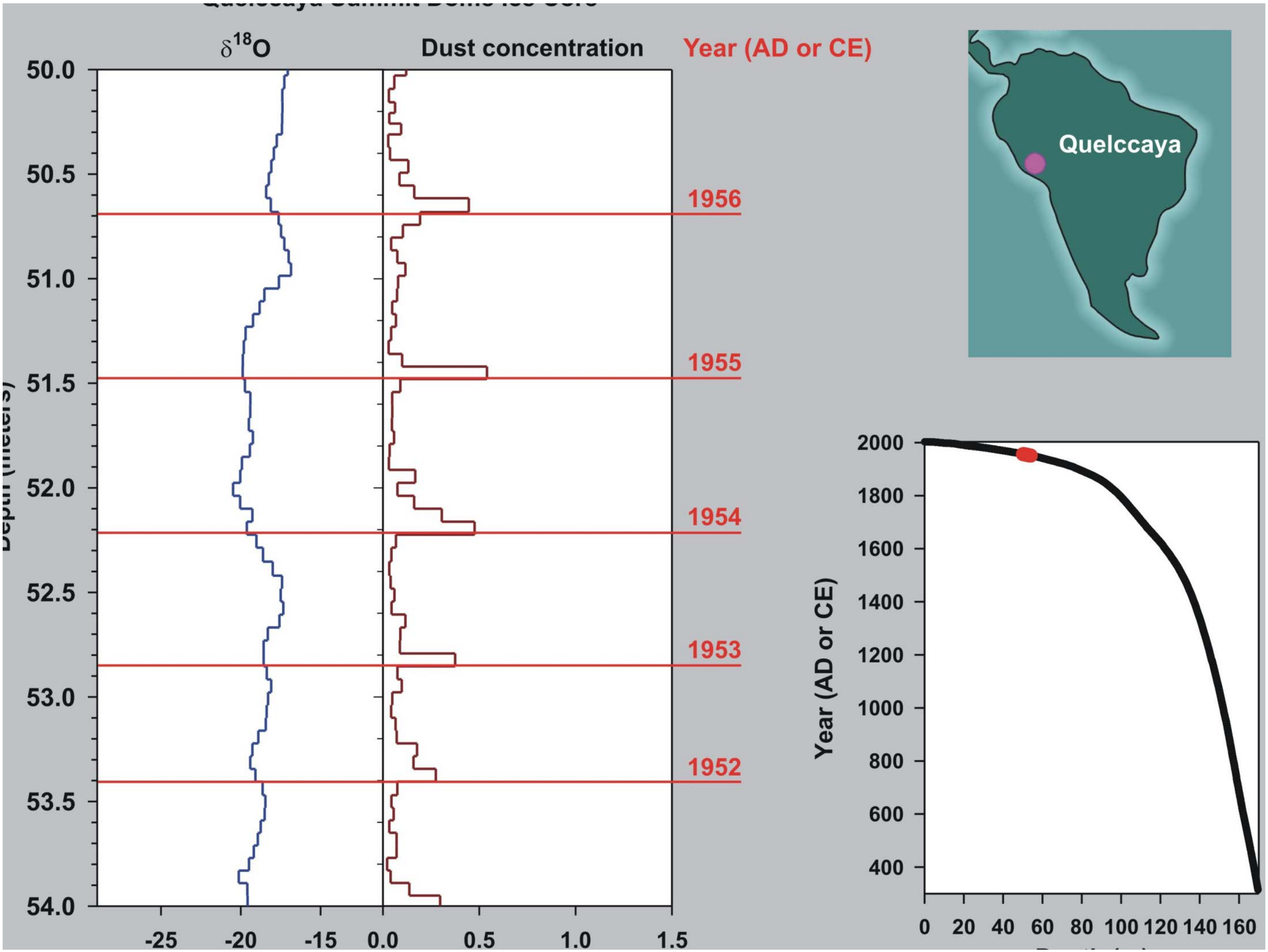

South America
Image © 2006 MDA EarthSat
Ecuador
Peru
Lima
Quelccaya
Coropuna

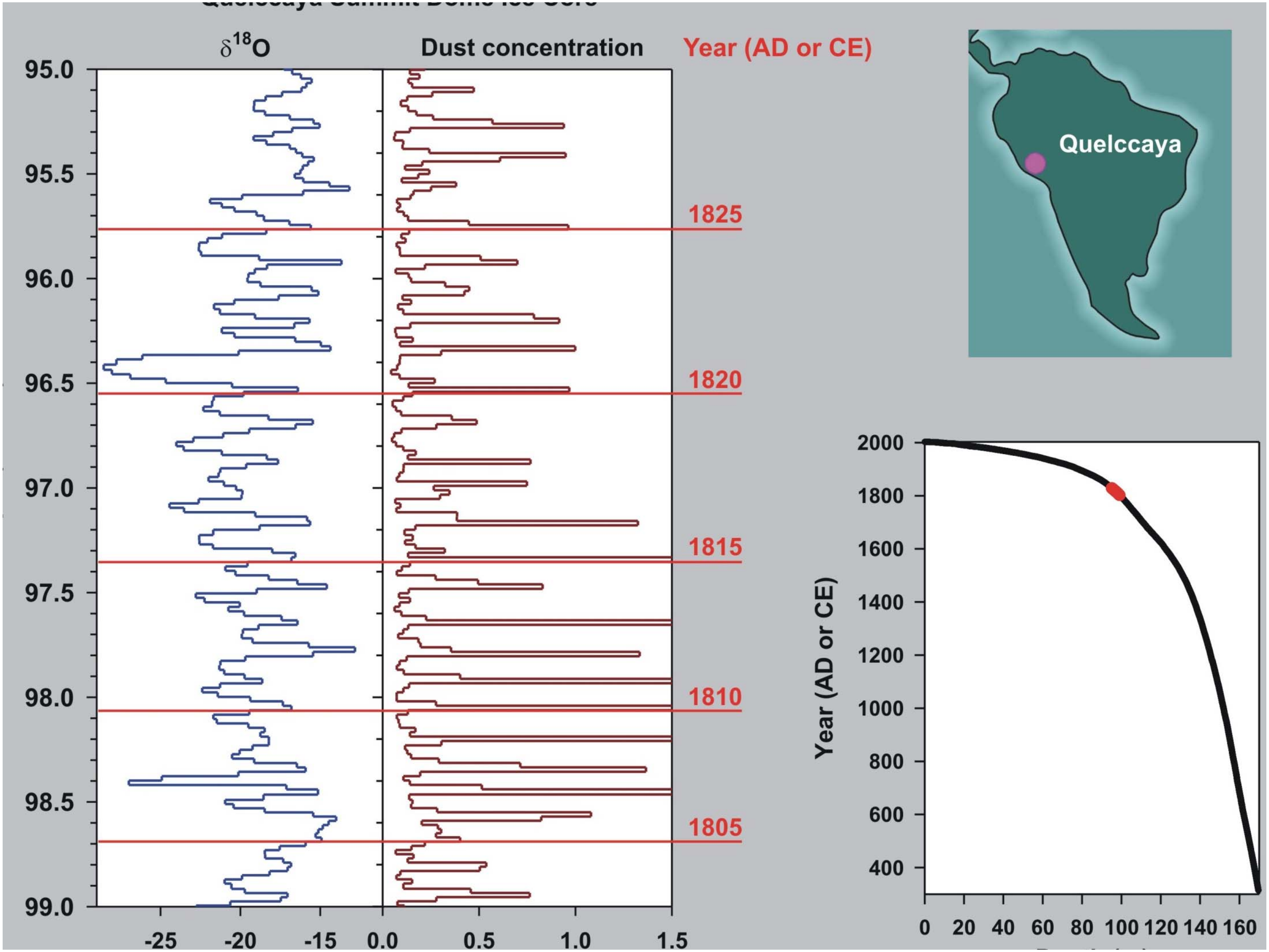
## Side of Quelccaya ice cap, Peru

Annual layers

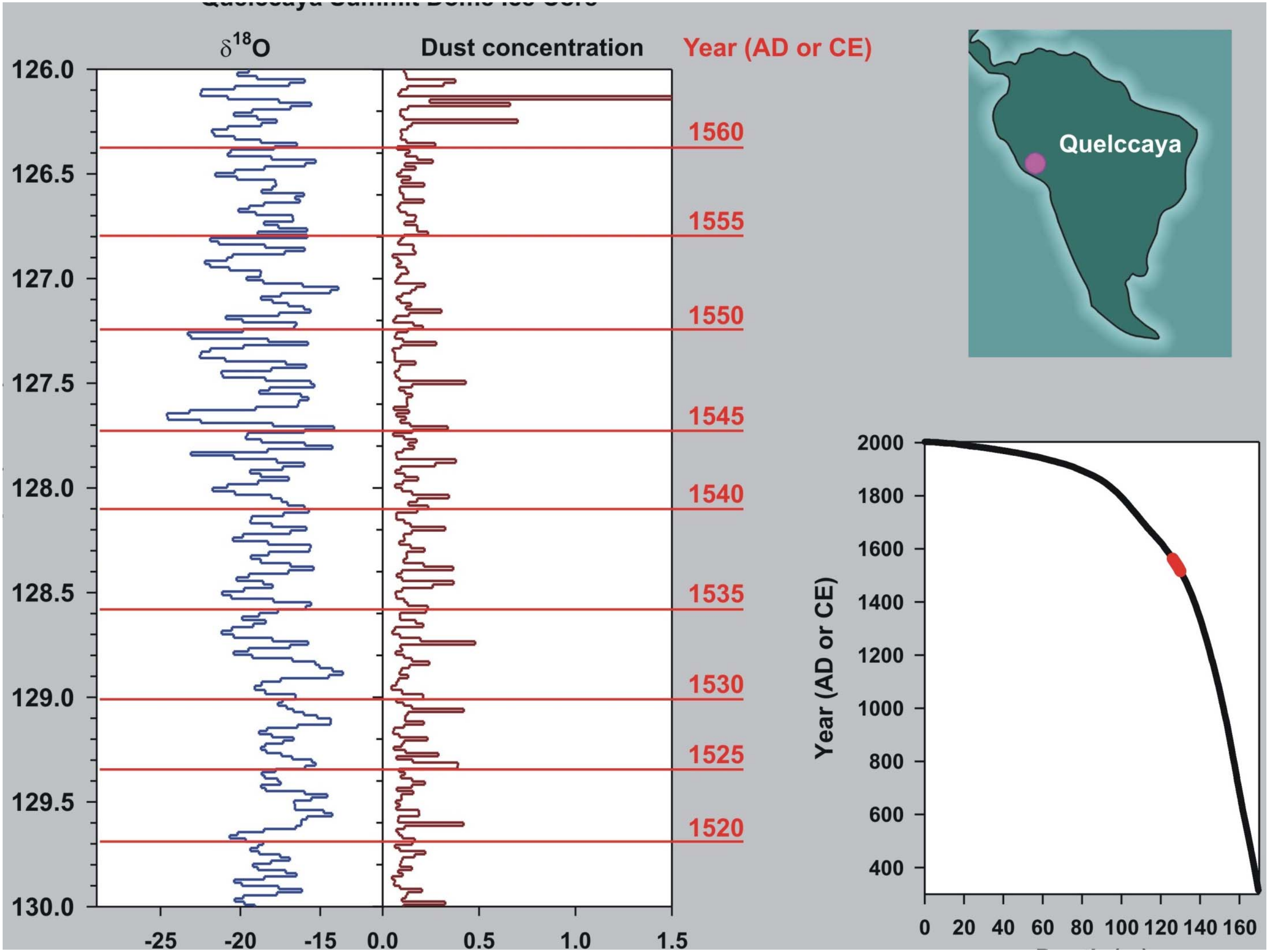


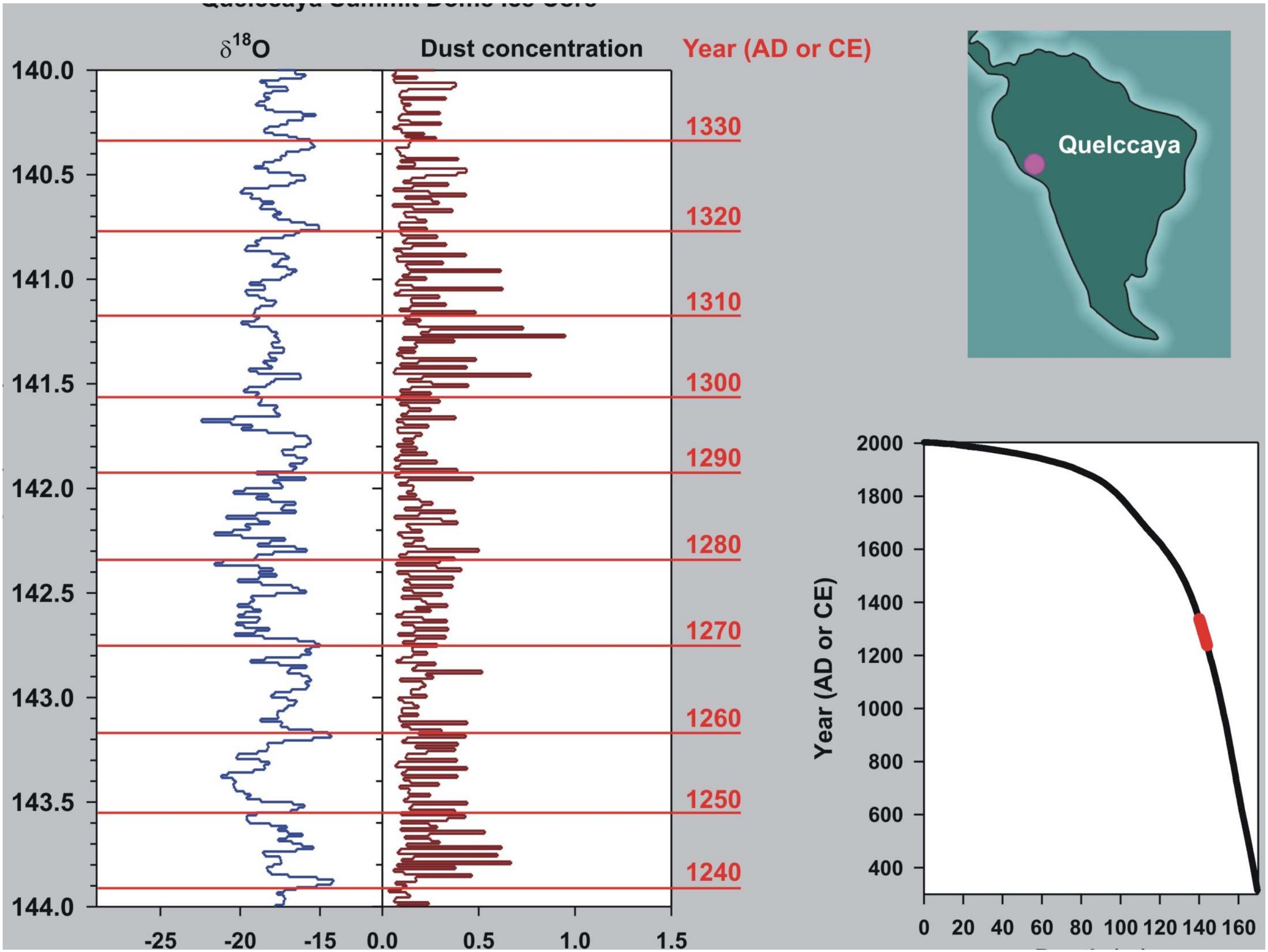

MOUNTAIN


δ18O
Dust concentration
Year (AD or CE)
50.0
50.5
51.0
51.5
52.0
52.5
53.0
53.5
54.0
1956
1955
1954
1953
1952
-25
-20
-15
0.0
0.5
1.0
1.5
Quelccaya
Year (AD or CE)
2000
1800
1600
1400
1200
1000
800
600
400
0
20
40
60
80
100
120
140
160

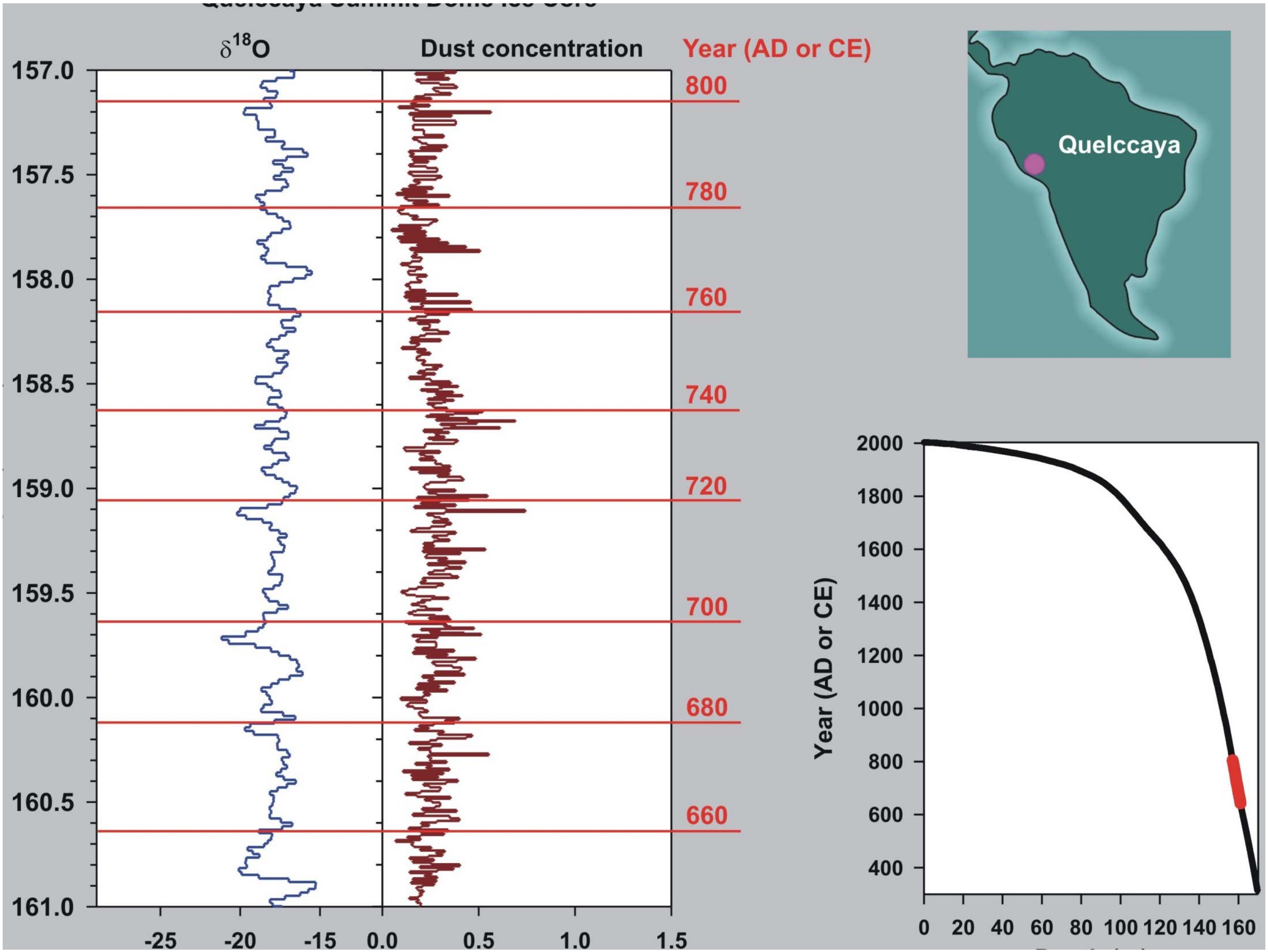


δ18O
Dust concentration
Year (AD or CE)
95.0
95.5
96.0
96.5
97.0
97.5
98.0
98.5
99.0
1825
1820
1815
1810
1805
-25
-20
-15
0.0
0.5
1.0
1.5
Quelccaya
Year (AD or CE)
2000
1800
1600
1400
1200
1000
800
600
400
0
20
40
60
80
100
120
140
160


δ18O
Dust concentration
Year (AD or CE)
126.0
126.5
127.0
127.5
128.0
128.5
129.0
129.5
130.0
1560
1555
1550
1545
1540
1535
1530
1525
1520
-25
-20
-15
0.0
0.5
1.0
1.5
Quelccaya
Year (AD or CE)
2000
1800
1600
1400
1200
1000
800
600
400
0
20
40
60
80
100
120
140
160

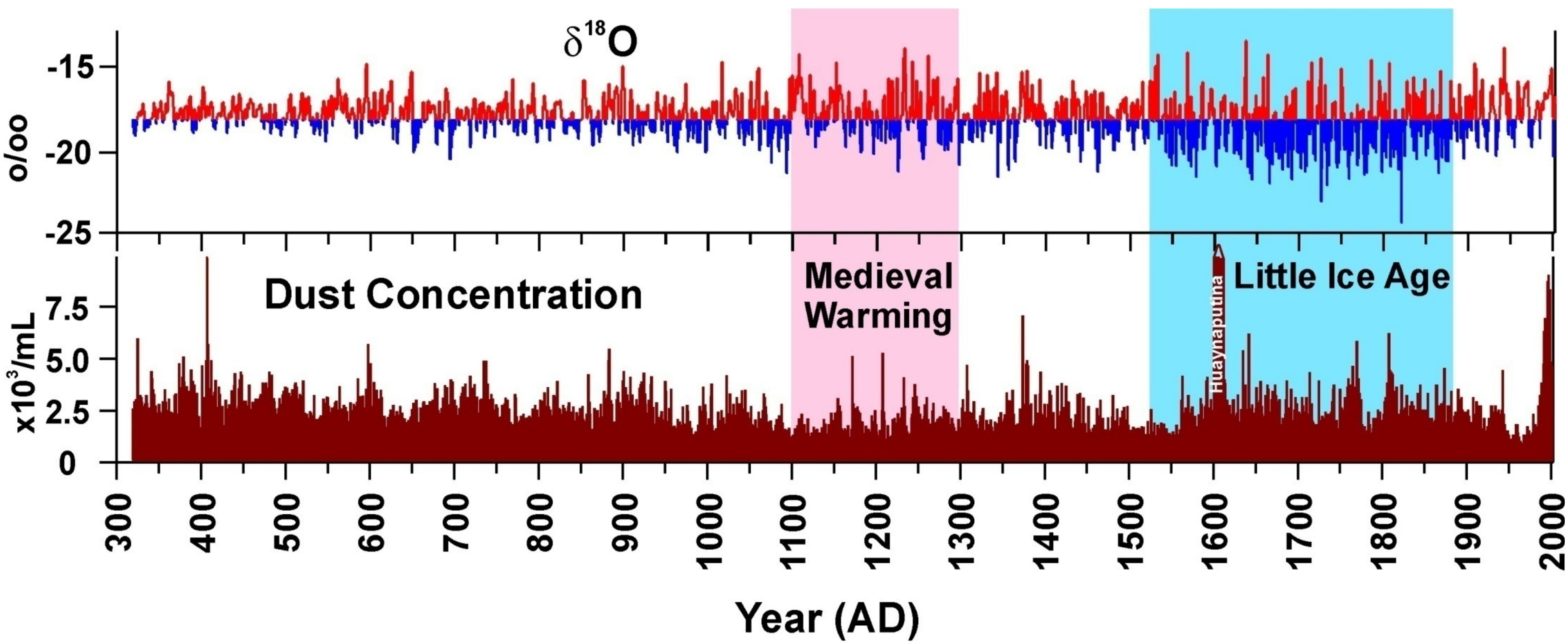


δ18O
Dust concentration
Year (AD or CE)
140.0
140.5
141.0
141.5
142.0
142.5
143.0
143.5
144.0
-25
-20
-15
0.0
0.5
1.0
1.5
1330
1320
1310
1300
1290
1280
1270
1260
1250
1240
Quelccaya
2000
1800
1600
1400
1200
1000
800
600
400
Year (AD or CE)
0
20
40
60
80
100
120
140
160

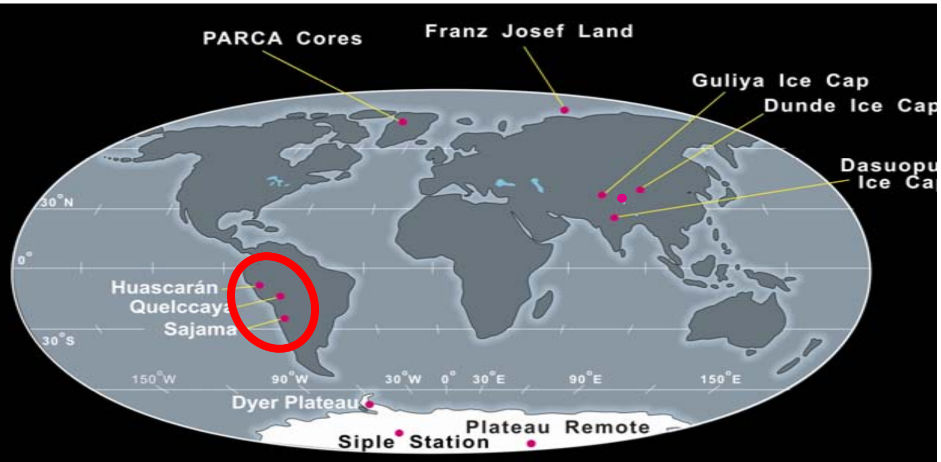


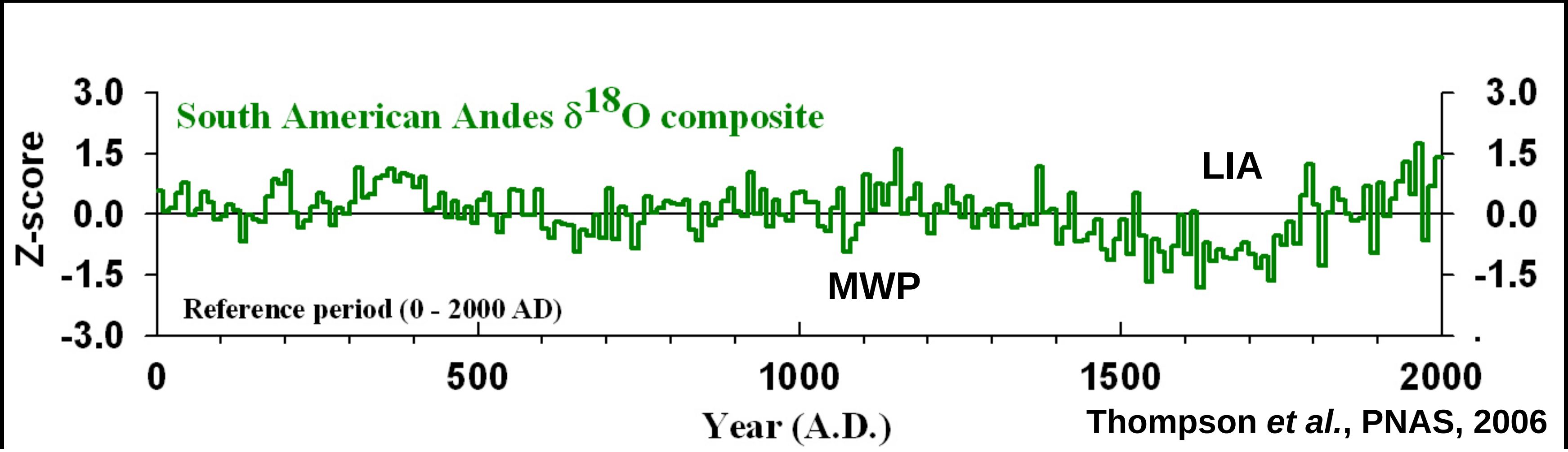
δ18O
Dust concentration
Year (AD or CE)
157.0
157.5
158.0
158.5
159.0
159.5
160.0
160.5
161.0
800
780
760
740
720
700
680
660
-25
-20
-15
0.0
0.5
1.0
1.5
Quelccaya
2000
1800
1600
1400
1200
1000
800
600
400
Year (AD or CE)
0
20
40
60
80
100
120
140
160

# Quelccaya 2003, Summit Core



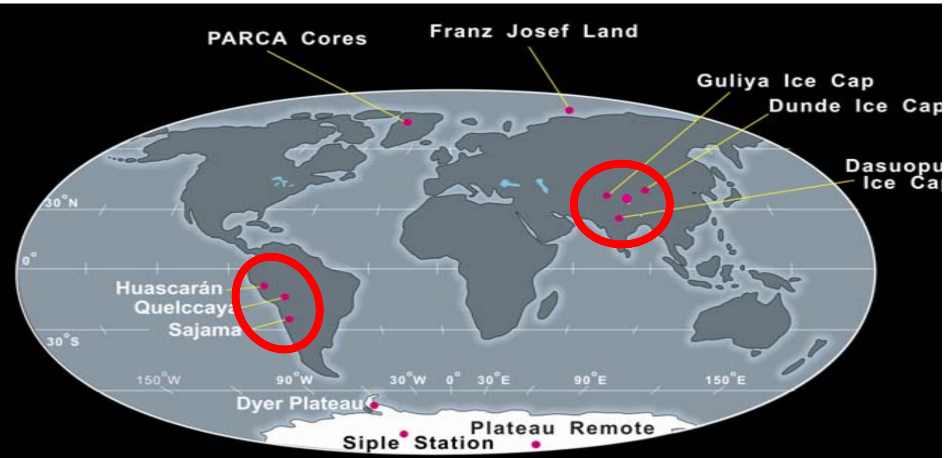
**High elevation, low latitude ice cores record**
**- large-scale climate changes**
**- regional differences**

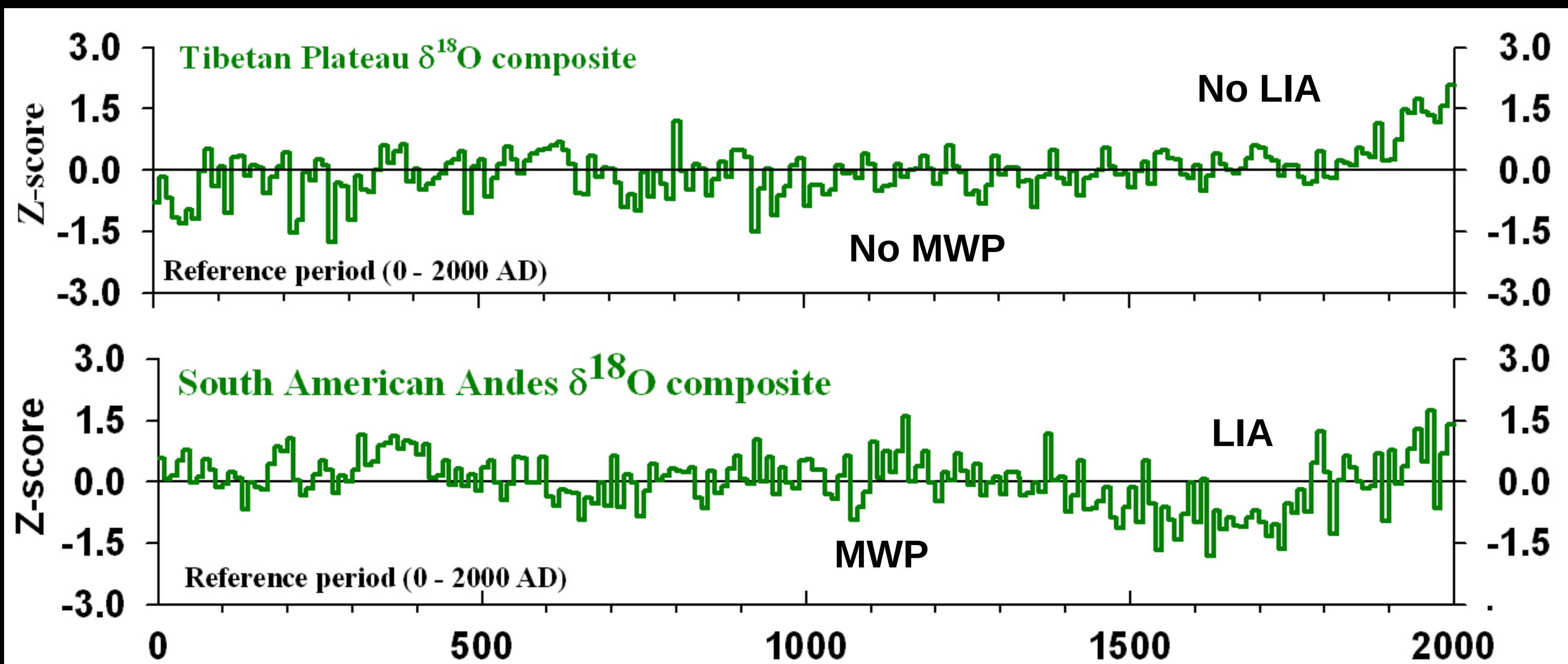



**Thompson *et al.*, PNAS, 2006**

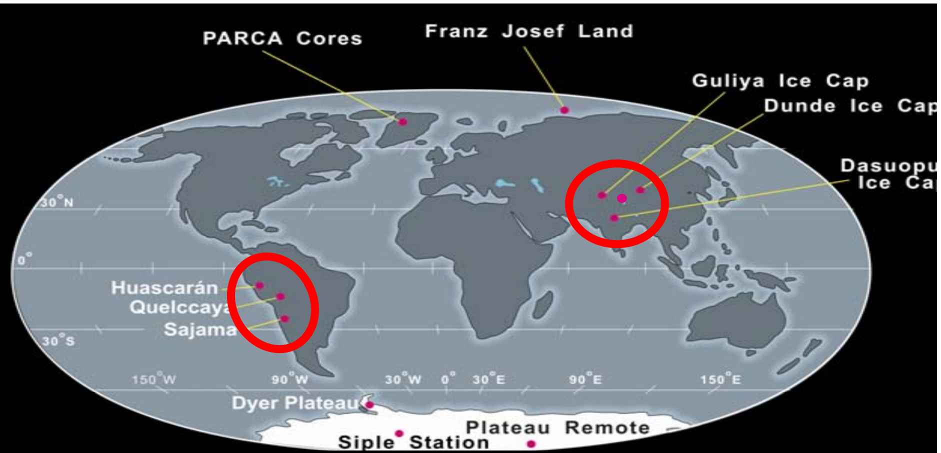
**High elevation, low latitude ice cores record**
**- large-scale climate changes**
**- regional differences**

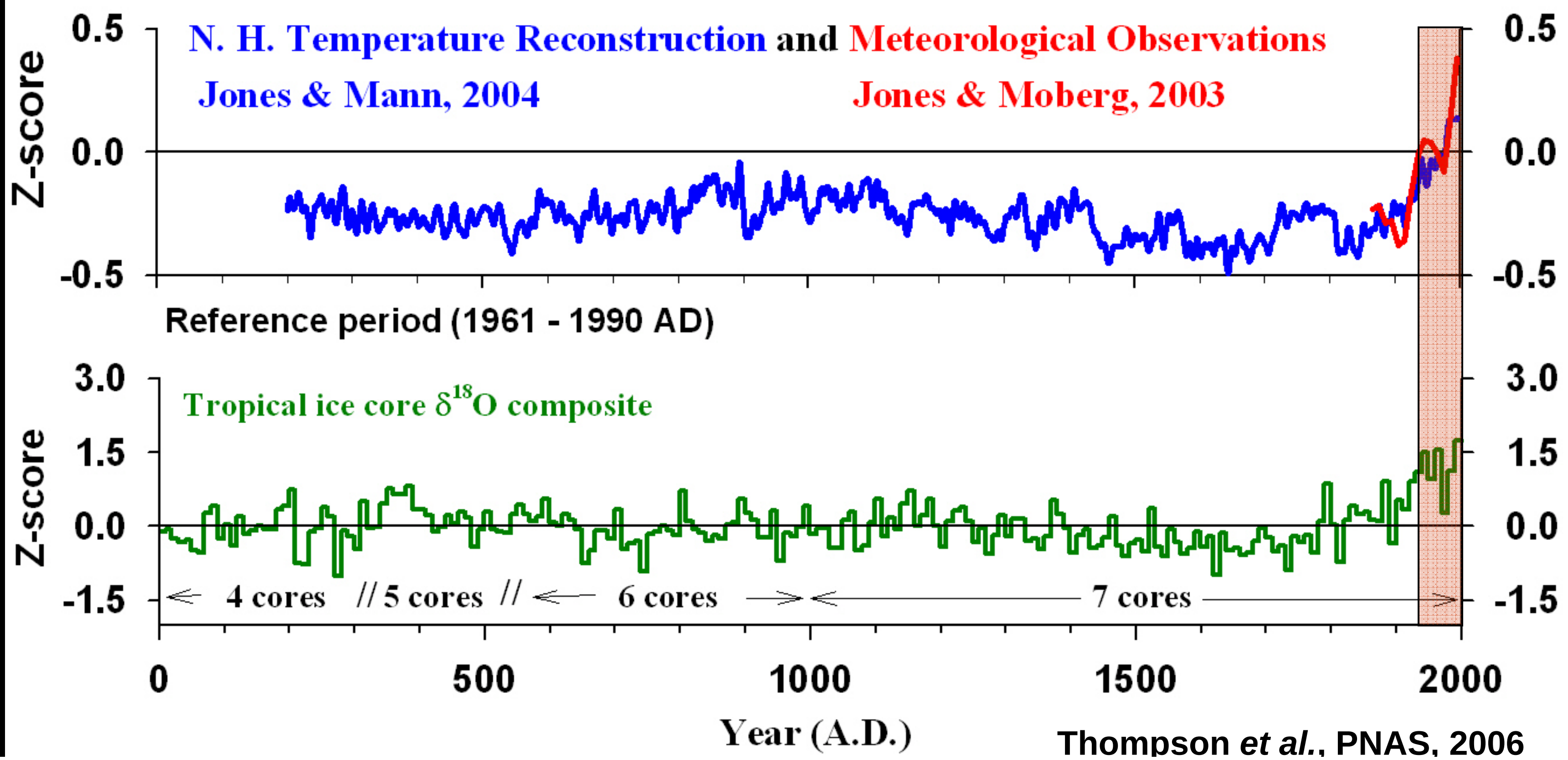



Thompson *et al.*, PNAS, 2006

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




Thompson *et al.*, 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)


**Photos: Koji Fujita**

# Glacier National Park, Grinnel Glacier


Photo: Fred Kiser, Glacier National Park archives

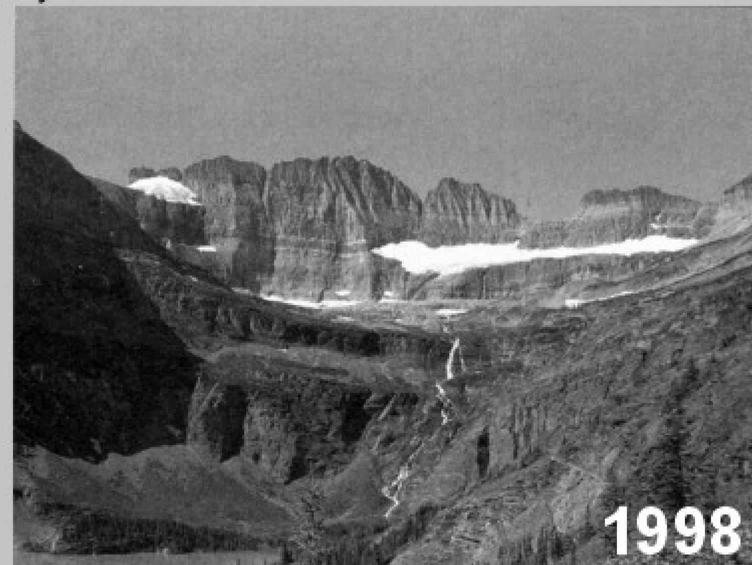



Photo: Karen Holzer, US Geological Survey

# Glacier National Park, Boulder Glacier

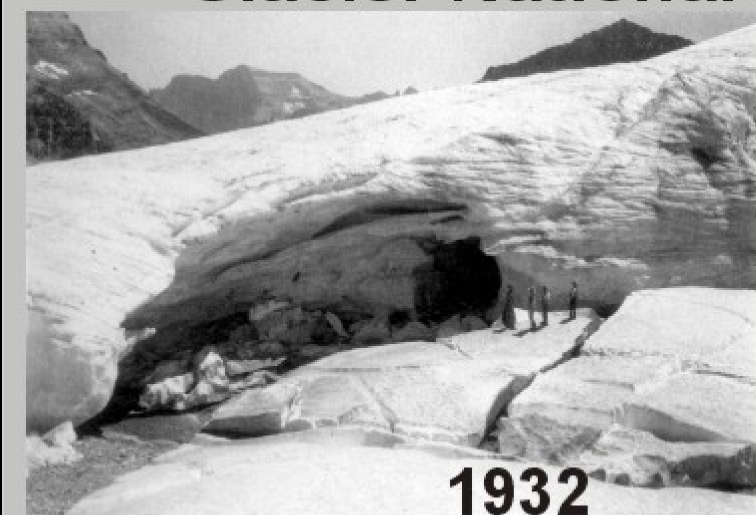



Photo: George Grant, Glacier National Park archives


Photo: Jerry DeSanto, National Park Service

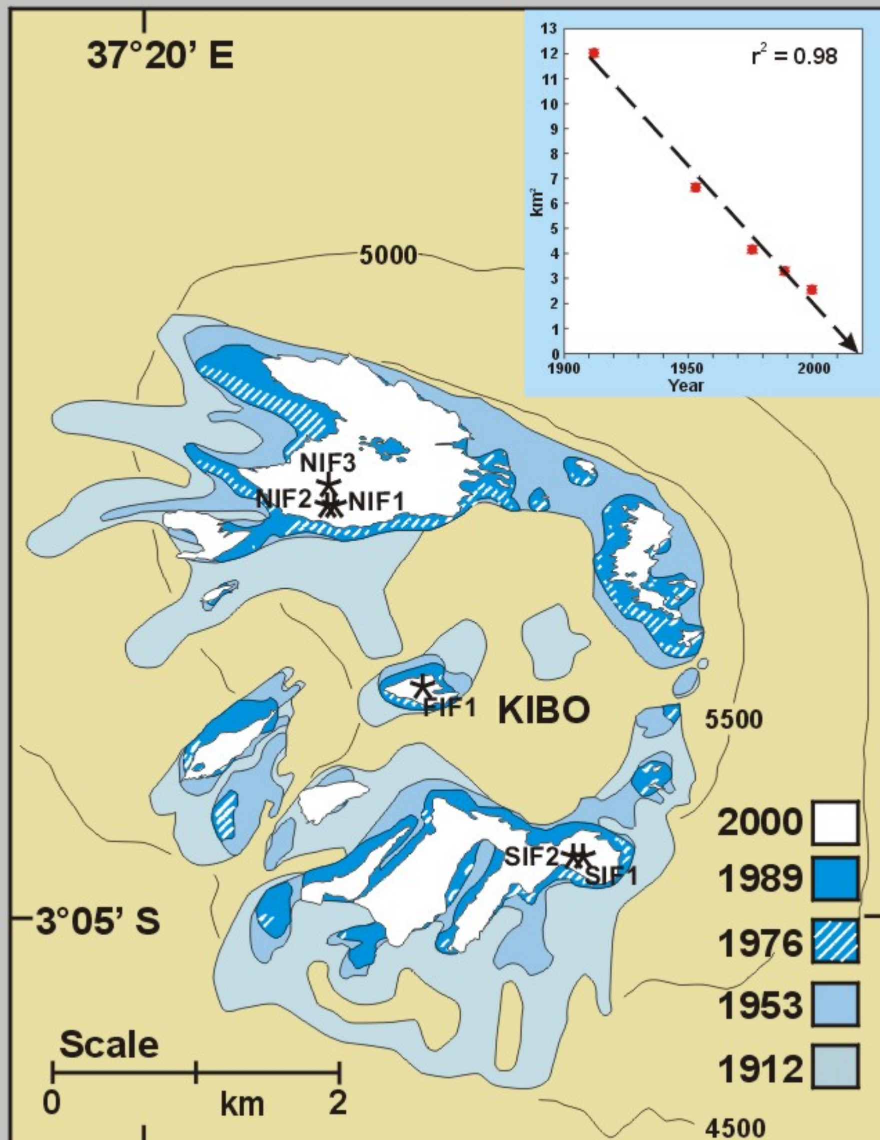
Source: *BioScience*, Vol. 53 No. 2, Feb 2003

# Glaciar Lanín Norte



# 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


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

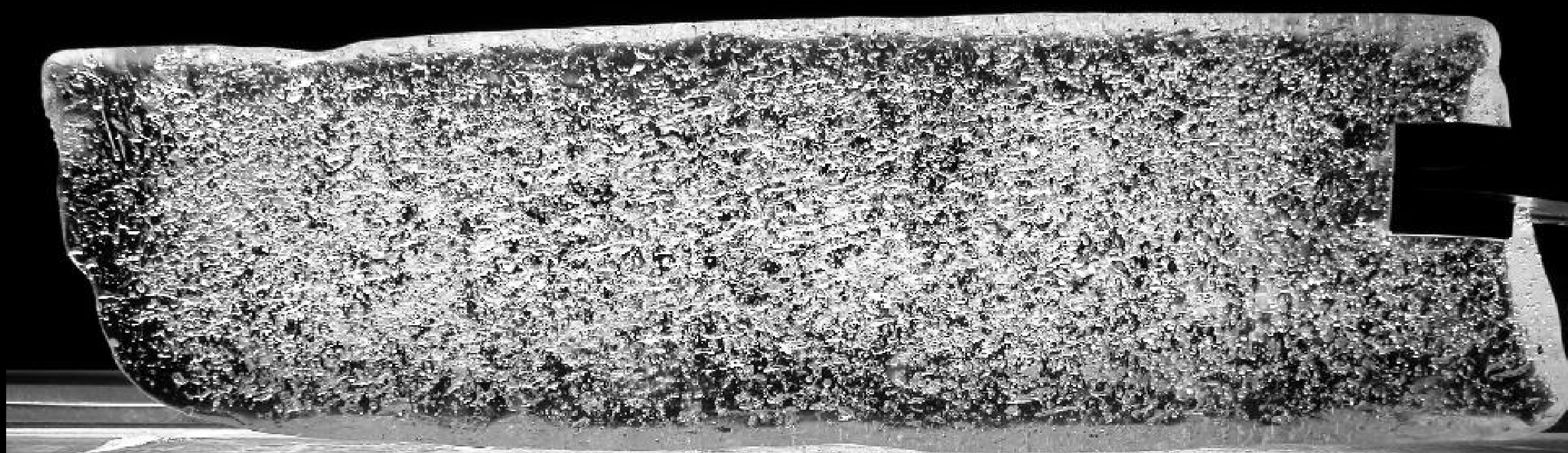
# Drill shelter on Northern Ice Field, Kilimanjaro in 2000

# Kilimanjaro (2000) Northern Ice Field Core 3

Tube 1: top: 0.00 m

← Elongated bubbles

Tube 43: top: 42.84 m

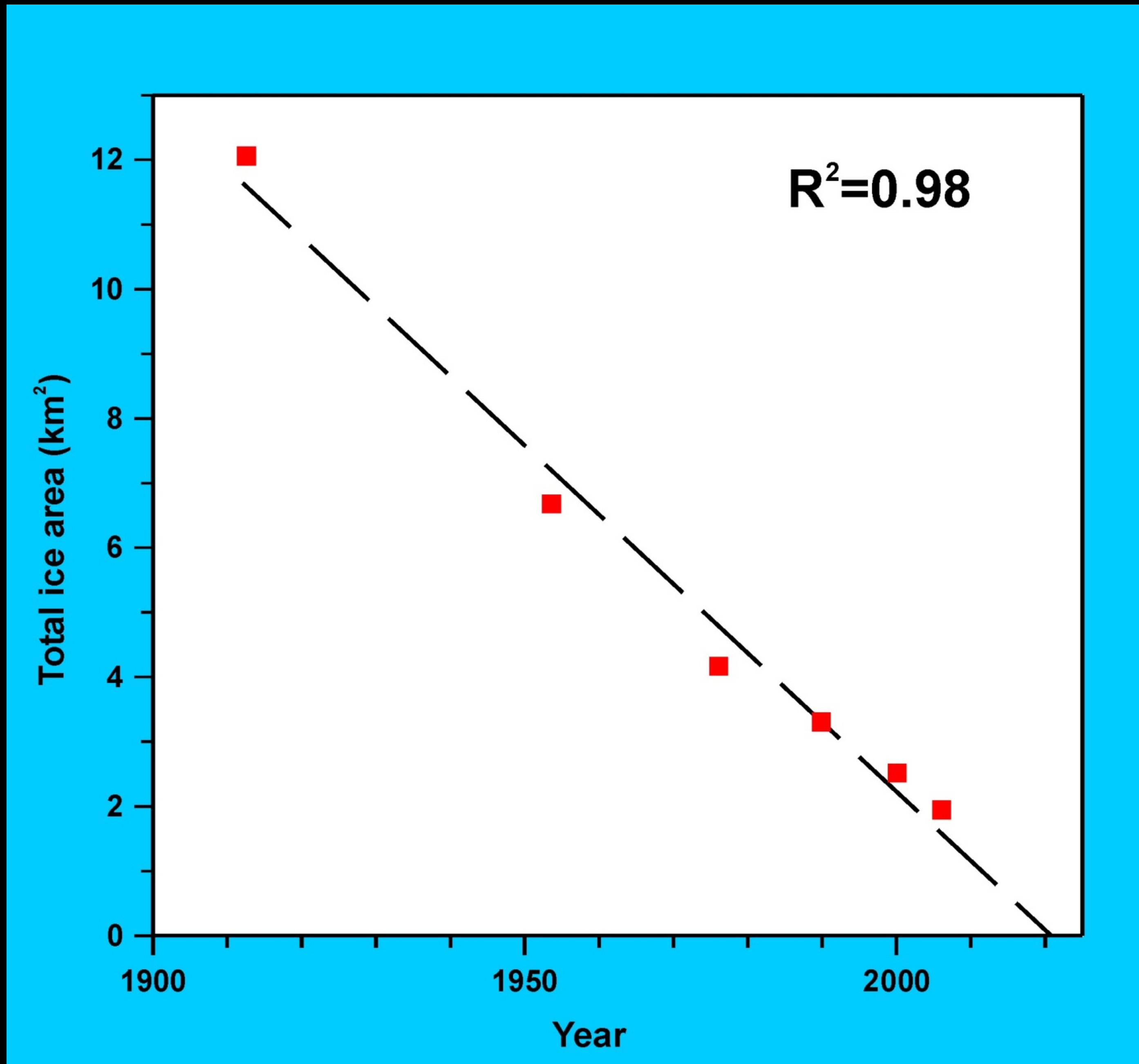


# •Kilimanjaro

Feb 2000

Jan 2006

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



$R^2$=0.98
Total ice area (km$^2$)
0
2
4
6
8
10
12
1900
1950
2000
Year

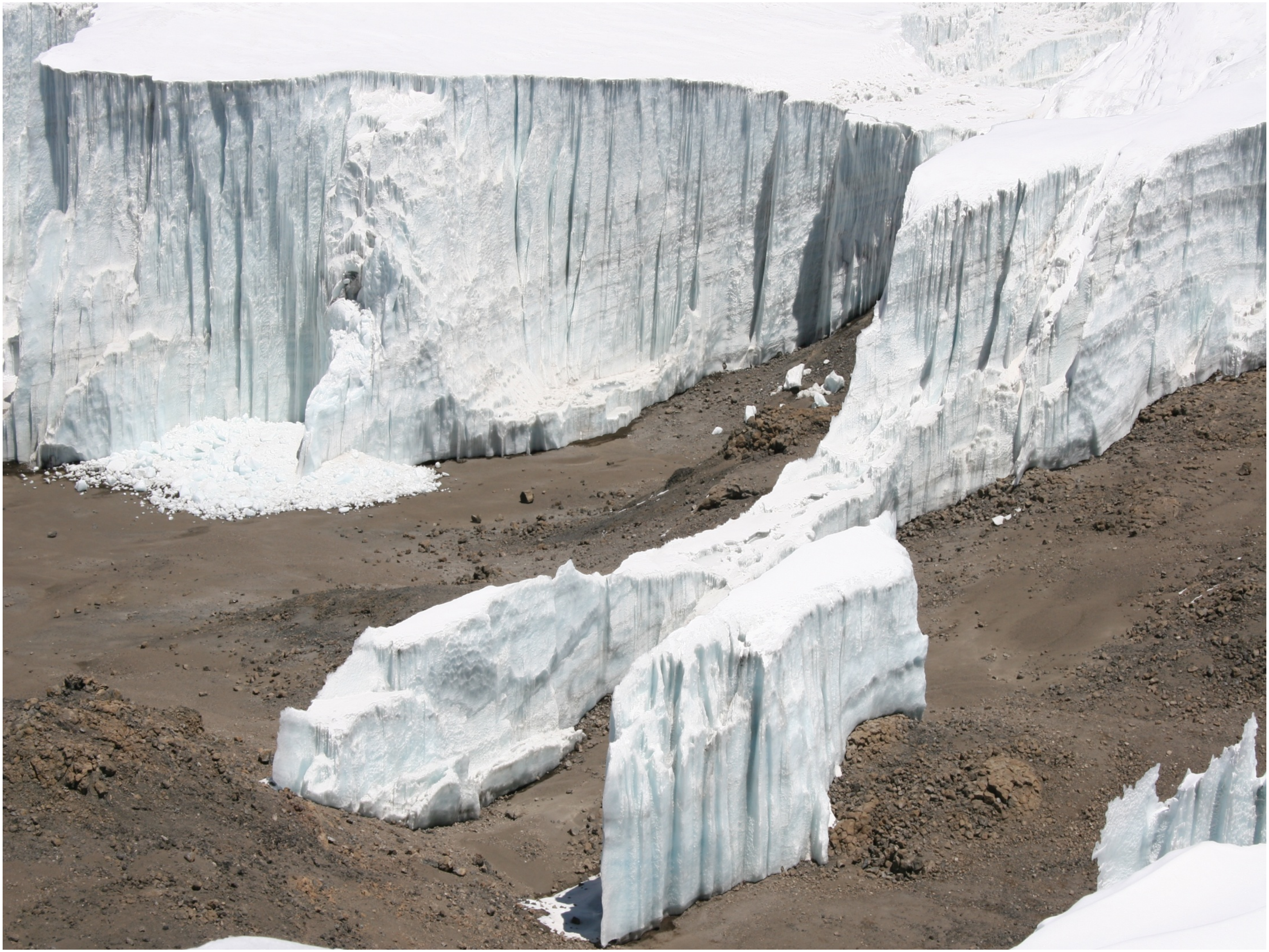
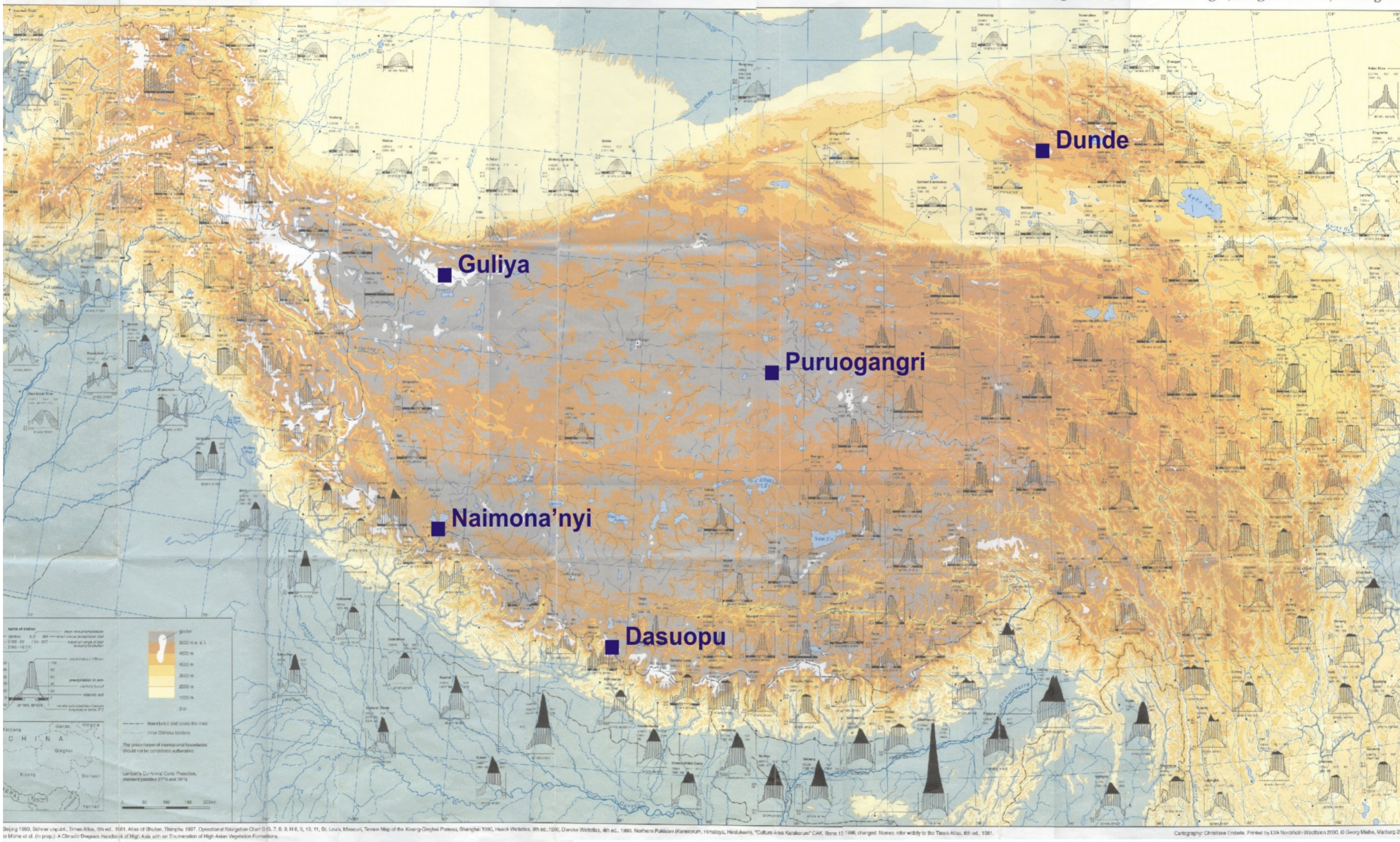
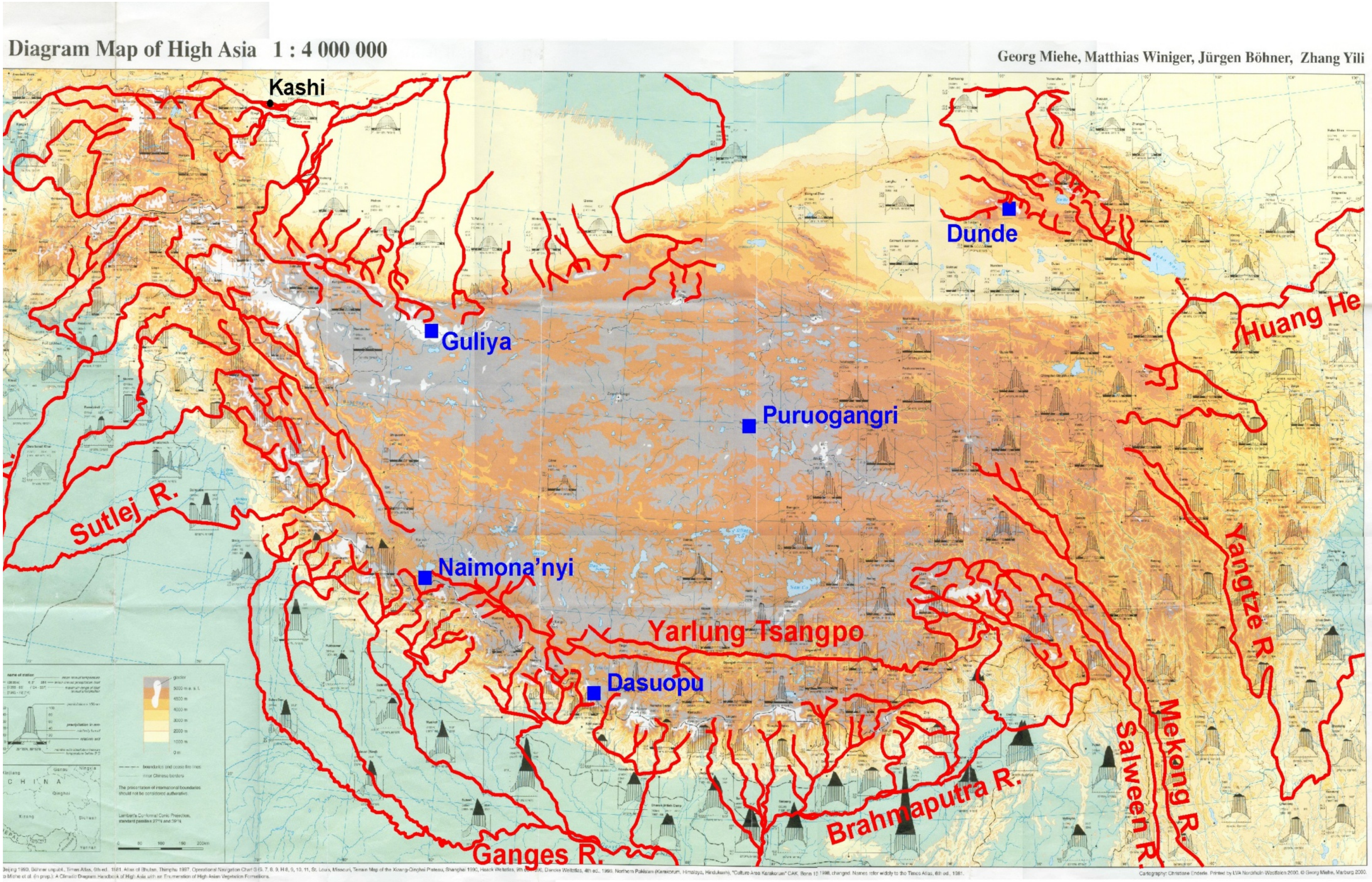


**Diagram Map of High Asia 1 : 4 000 000**

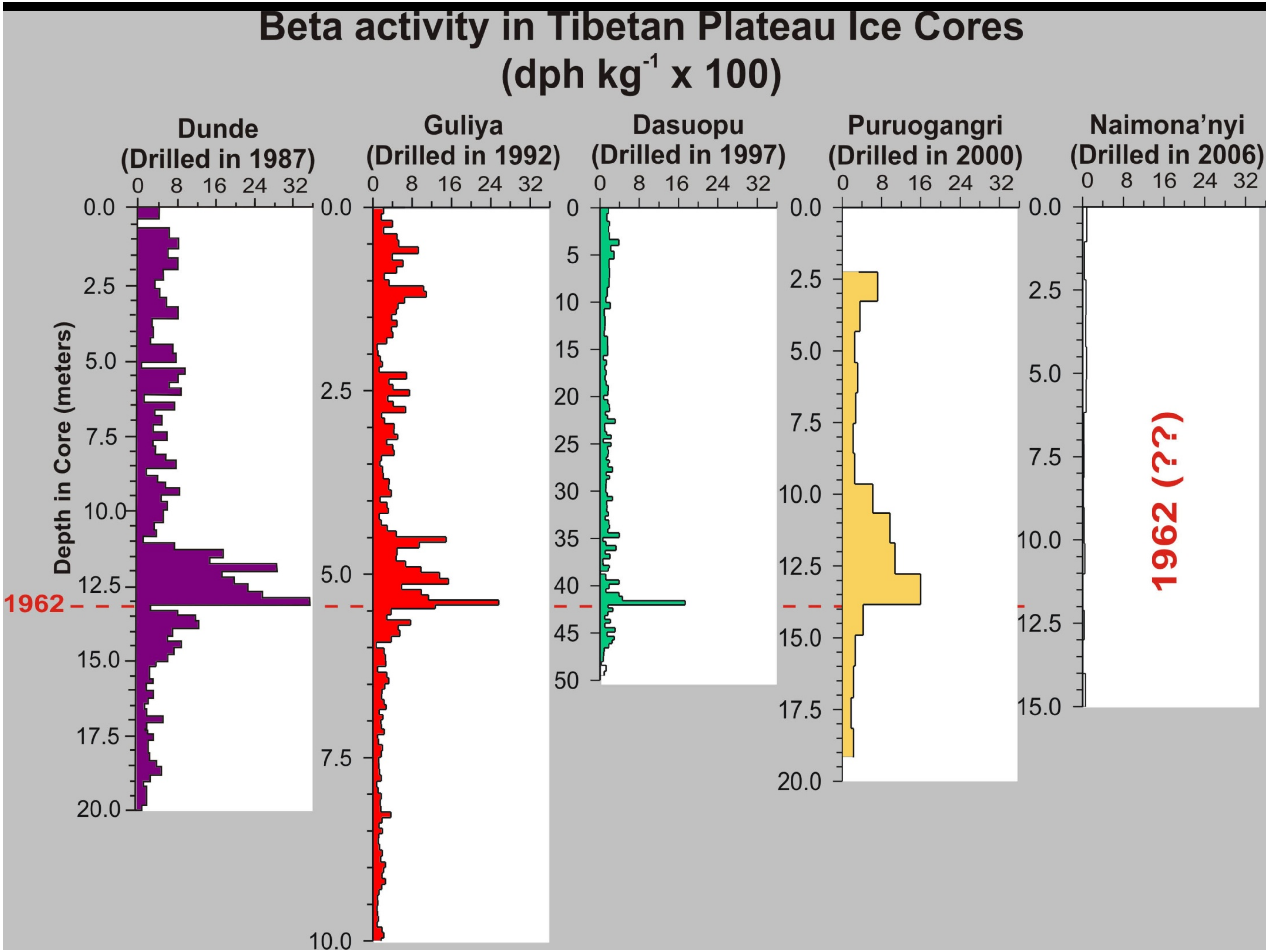
Georg Miehe, Matthias Winiger, Jürgen Böhner, Zhang Yili



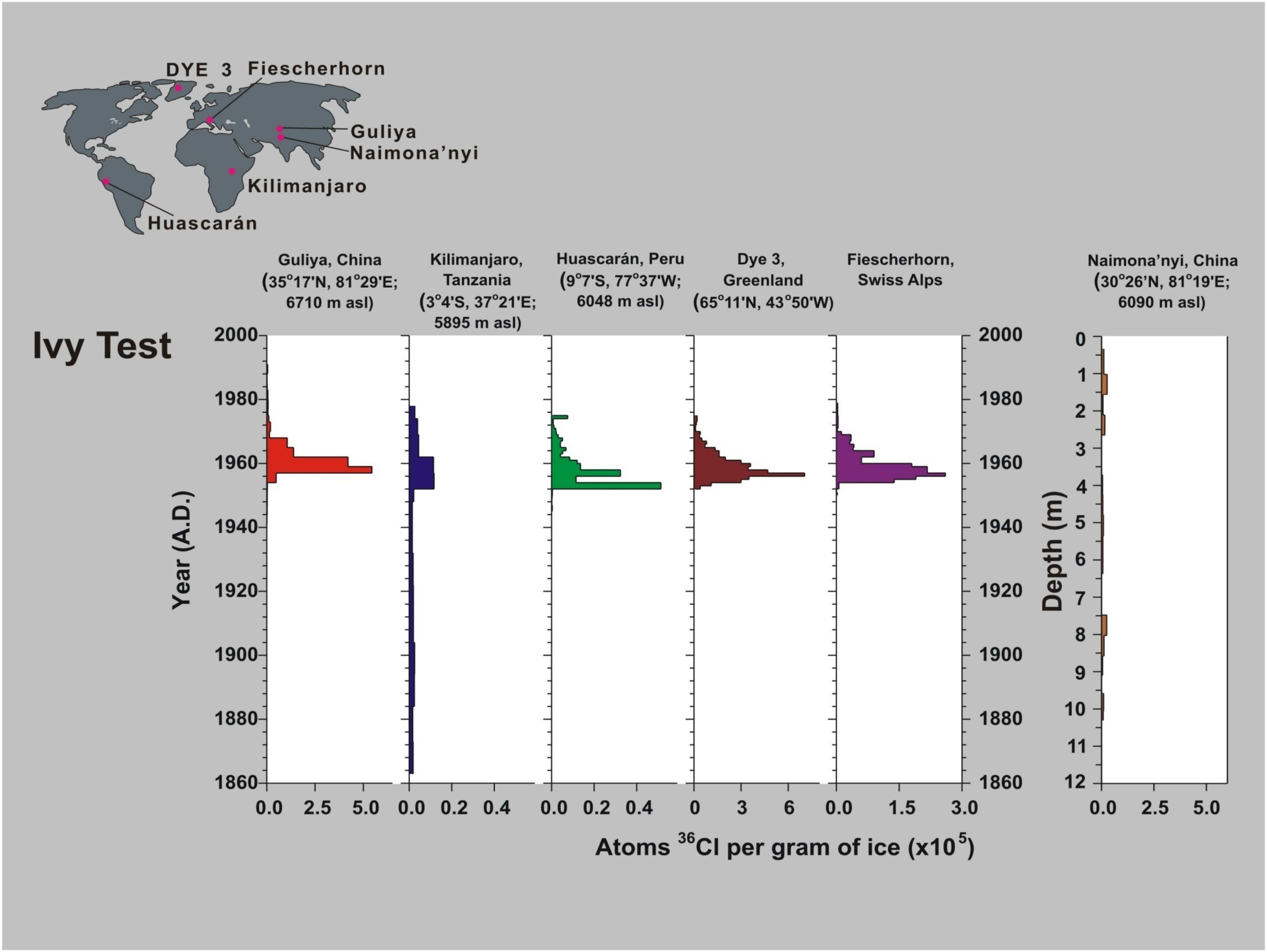



**Himalayan glaciers store about 12,000 cubic kilometers of freshwater in ~15,000 glaciers and are the lifeline for millions of people (IPCC, 2007)**

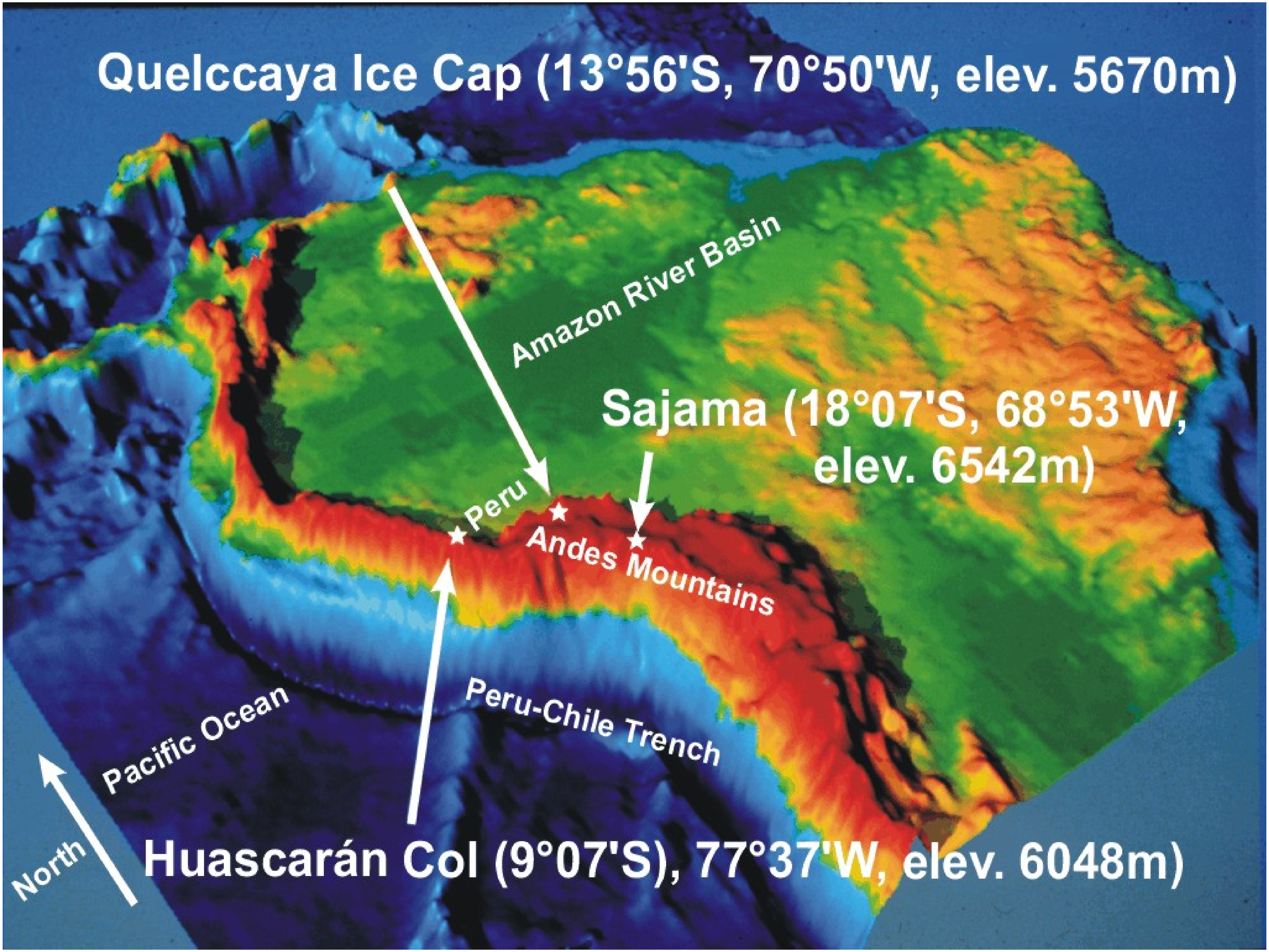

WAIKER 80



Beta activity in Tibetan Plateau Ice Cores
(dph kg-1 x 100)
Dunde
(Drilled in 1987)
Guliya
(Drilled in 1992)
Dasuopu
(Drilled in 1997)
Puruogangri
(Drilled in 2000)
Naimona'nyi
(Drilled in 2006)
0 8 16 24 32
Depth in Core (meters)
1962
1962 (??)



Ivy Test
DYE 3
Fiescherhorn
Guliya
Naimona'nyi
Kilimanjaro
Huascarán
Guliya, China (35°17'N, 81°29'E; 6710 m asl)
Kilimanjaro, Tanzania (3°4'S, 37°21'E; 5895 m asl)
Huascarán, Peru (9°7'S, 77°37'W; 6048 m asl)
Dye 3, Greenland (65°11'N, 43°50'W)
Fiescherhorn, Swiss Alps
Naimona'nyi, China (30°26'N, 81°19'E; 6090 m asl)
Year (A.D.)
Depth (m)
Atoms 36Cl per gram of ice (x10^5)


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
Peru-Chile Trench
Pacific Ocean
North
Huascarán Col (9°07'S), 77°37'W, elev. 6048m)

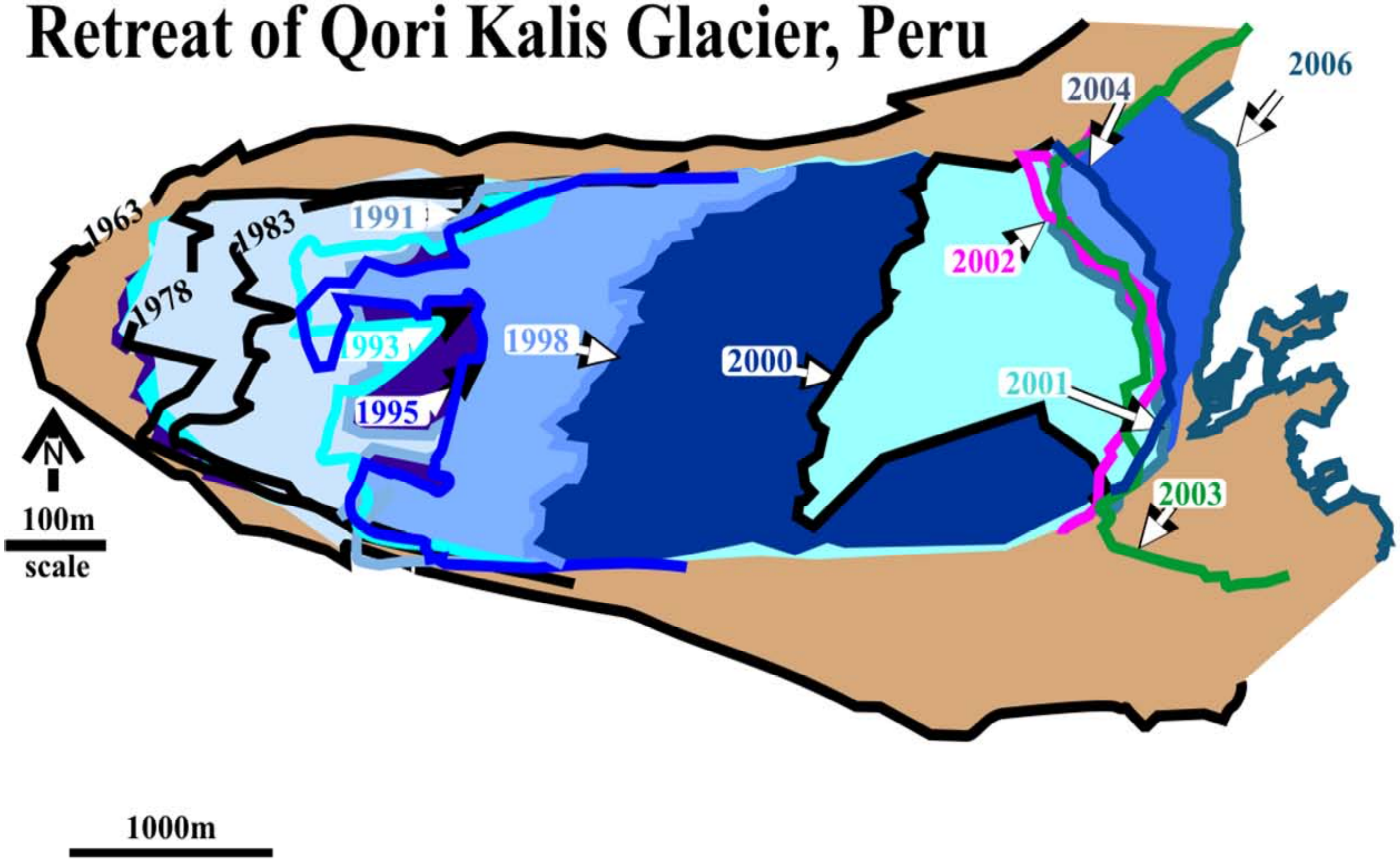
# Retreat of the Qori Kalis Glacier (Peru)

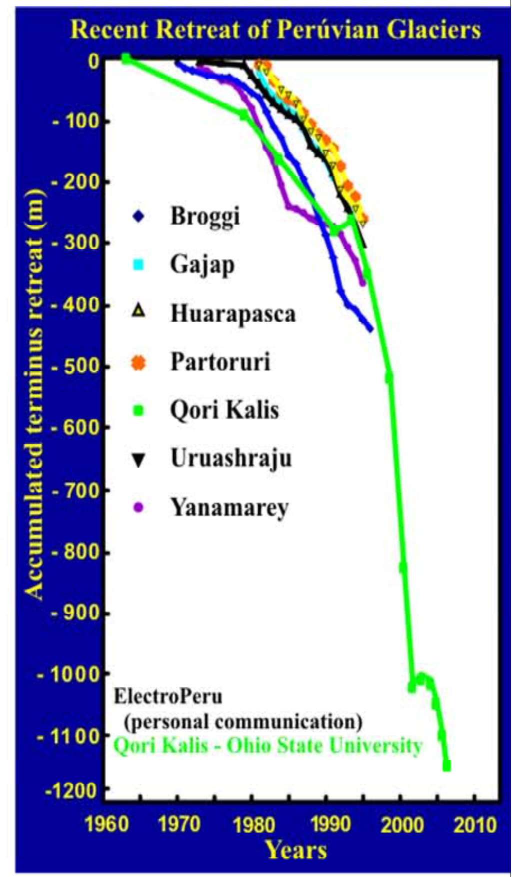


Qori Kalis July 2005


Qori Kalis, July, 2006
2006 –
lake covers 84 acres

# Retreat of Qori Kalis Glacier, Peru




1978

1991

1998

2000

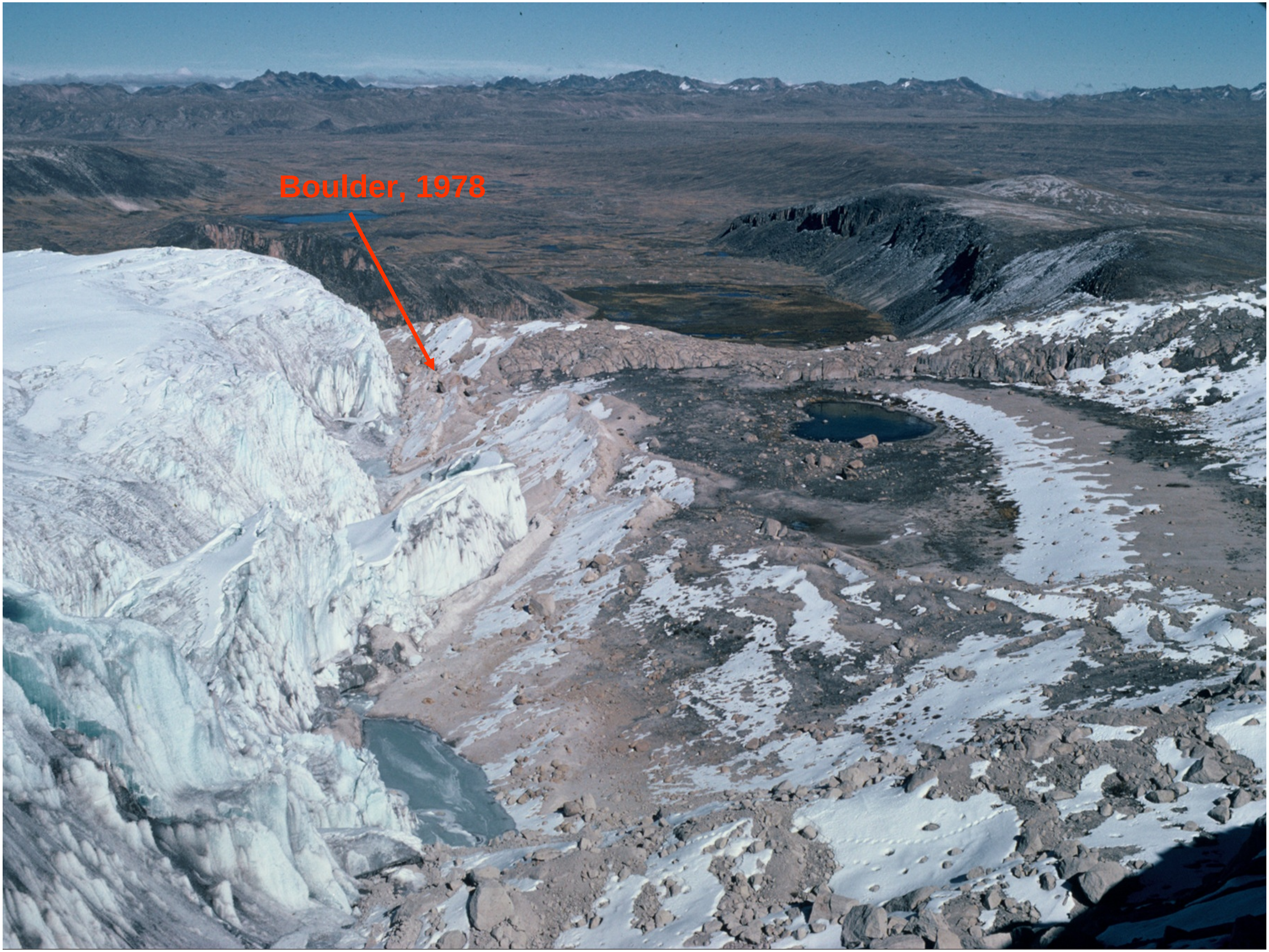
2006


2007 Thompson


1977


2006


2007 Thompson


Boulder, 1978


Boulder, 2006

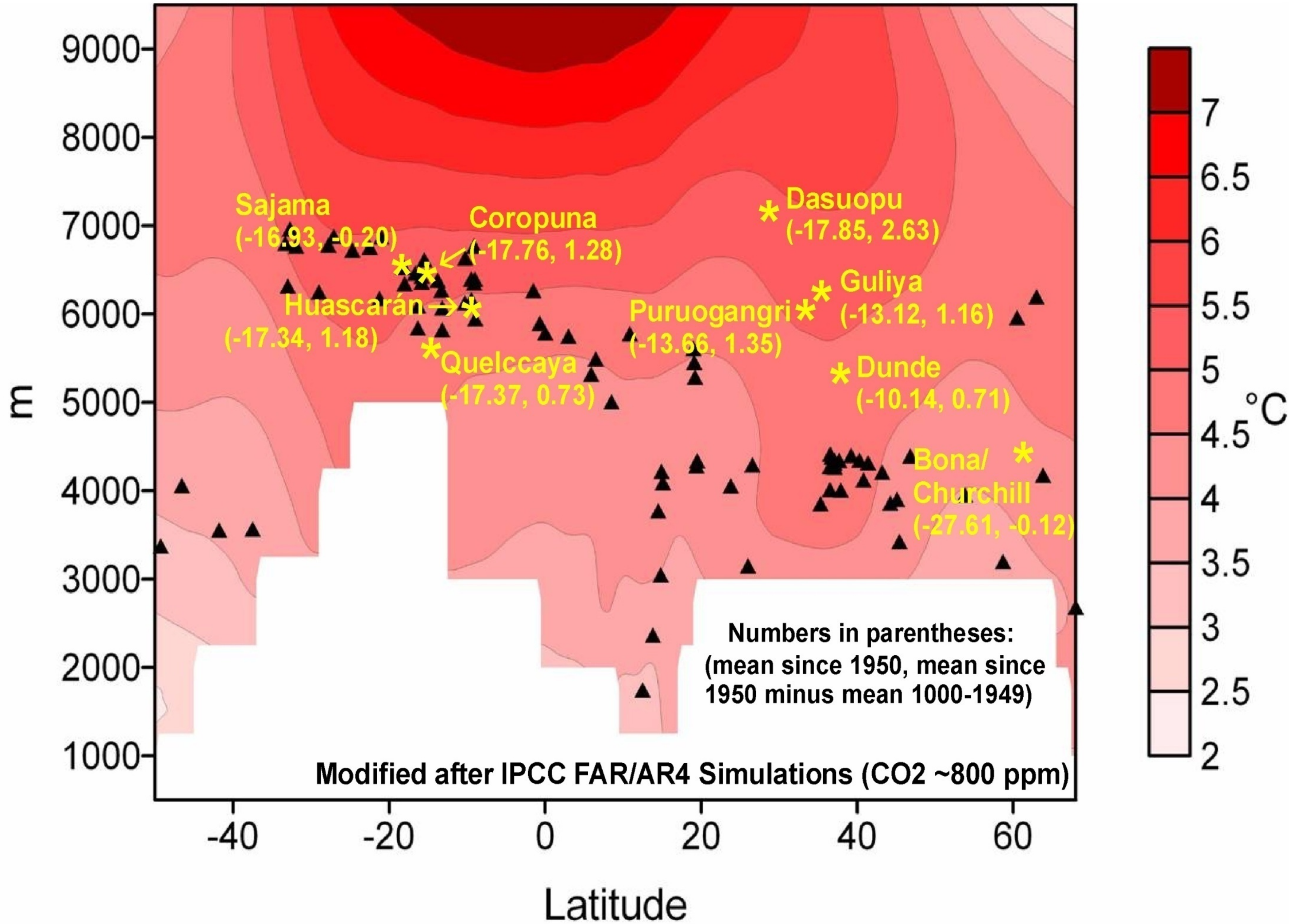

1983


2006


2007

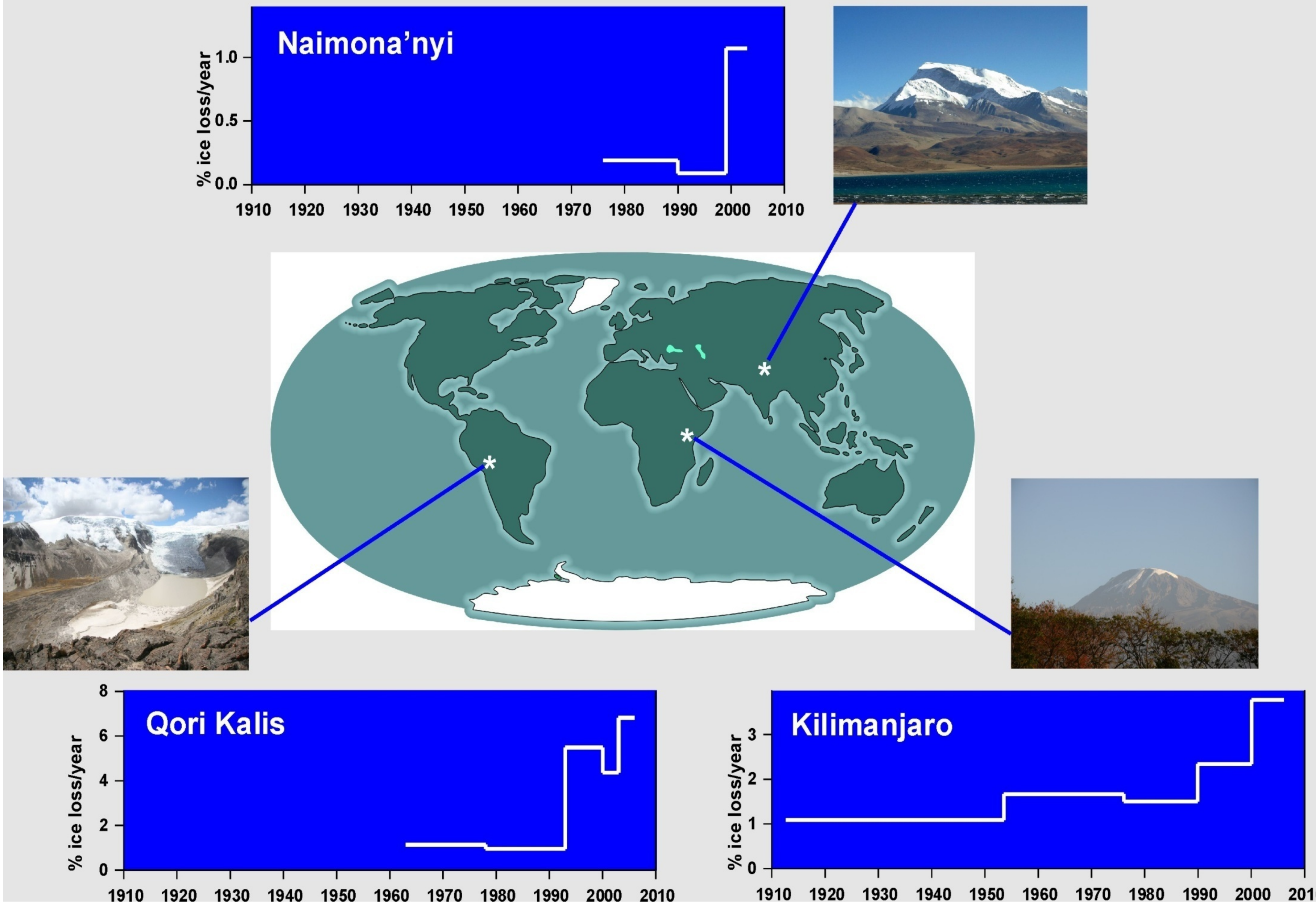

2006


2007



9000
8000
7000
6000
5000
4000
3000
2000
1000
m
-40
-20
0
20
40
60
Latitude
Sajama
(-16.93, -0.20)
Coropuna
(-17.76, 1.28)
Huascarán
(-17.34, 1.18)
Quelccaya
(-17.37, 0.73)
Dasuopu
(-17.85, 2.63)
Guliya
(-13.12, 1.16)
Puruogangri
(-13.66, 1.35)
Dunde
(-10.14, 0.71)
Bona/
Churchill
(-27.61, -0.12)
Numbers in parentheses:
(mean since 1950, mean since
1950 minus mean 1000-1949)
Modified after IPCC FAR/AR4 Simulations (CO2 ~800 ppm)
7
6.5
6
5.5
5
4.5
4
3.5
3
2.5
2
°C

# Ice Loss from Tropical Glaciers

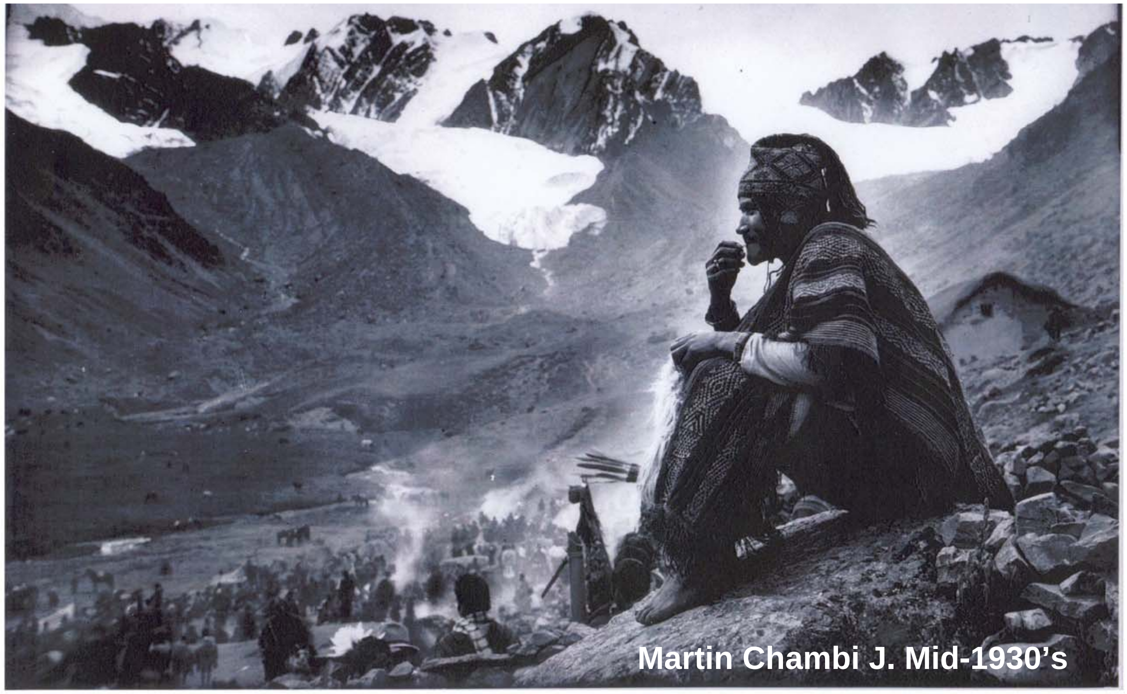


Glaciers, especially tropical glaciers, are

"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 21$^{st}$ Century is driven mainly by increasing temperatures although regional factors (i.e., deforestation also may play a role).



**Martin Chambi J. Mid-1930's**

**Qoyllur Rit'i, Peru 2006**

In 1915 Ernest Shackleton stated ……

“What the Ice Gets, the Ice Keeps”

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

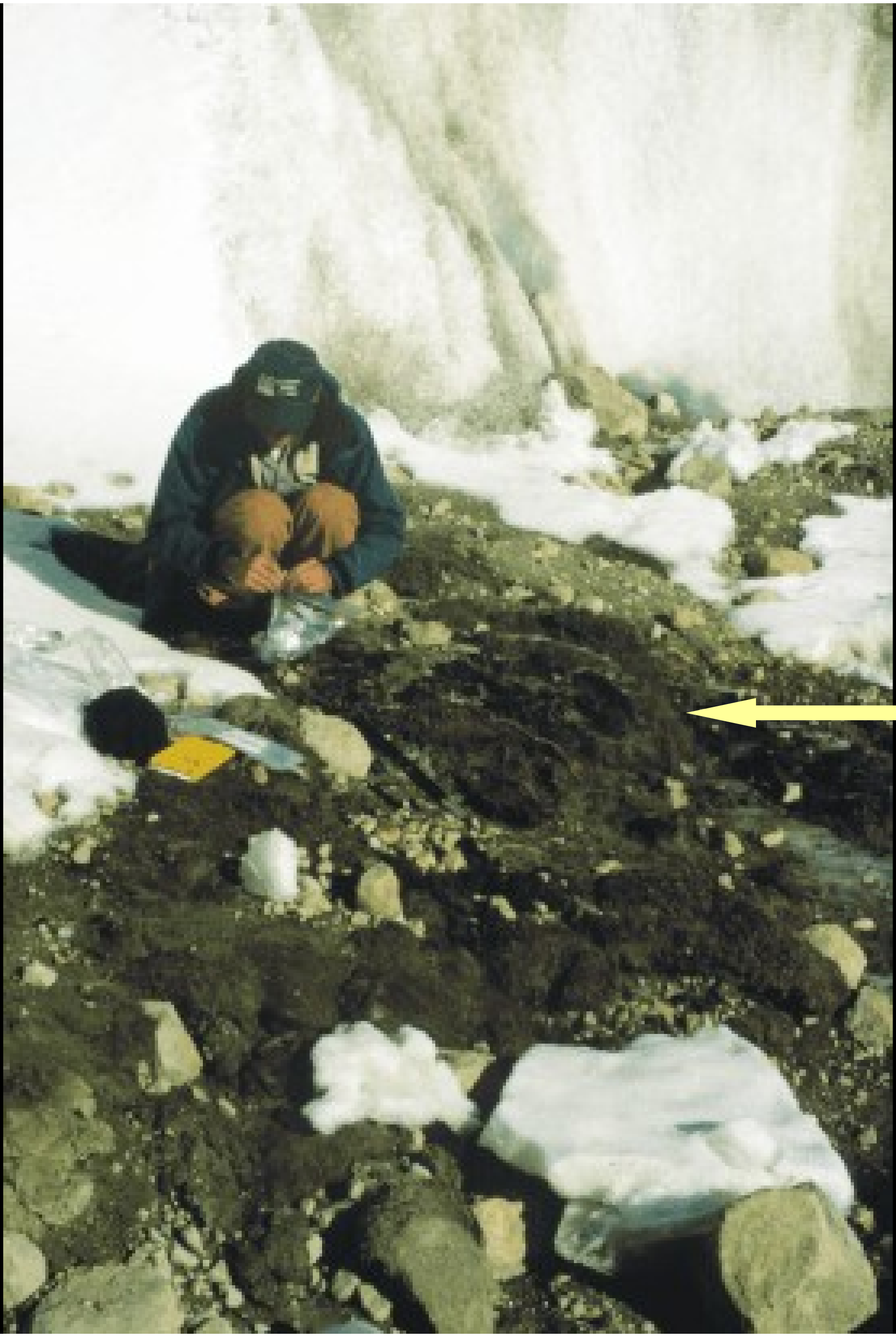
## Quelccaya, Peru

1977

2002

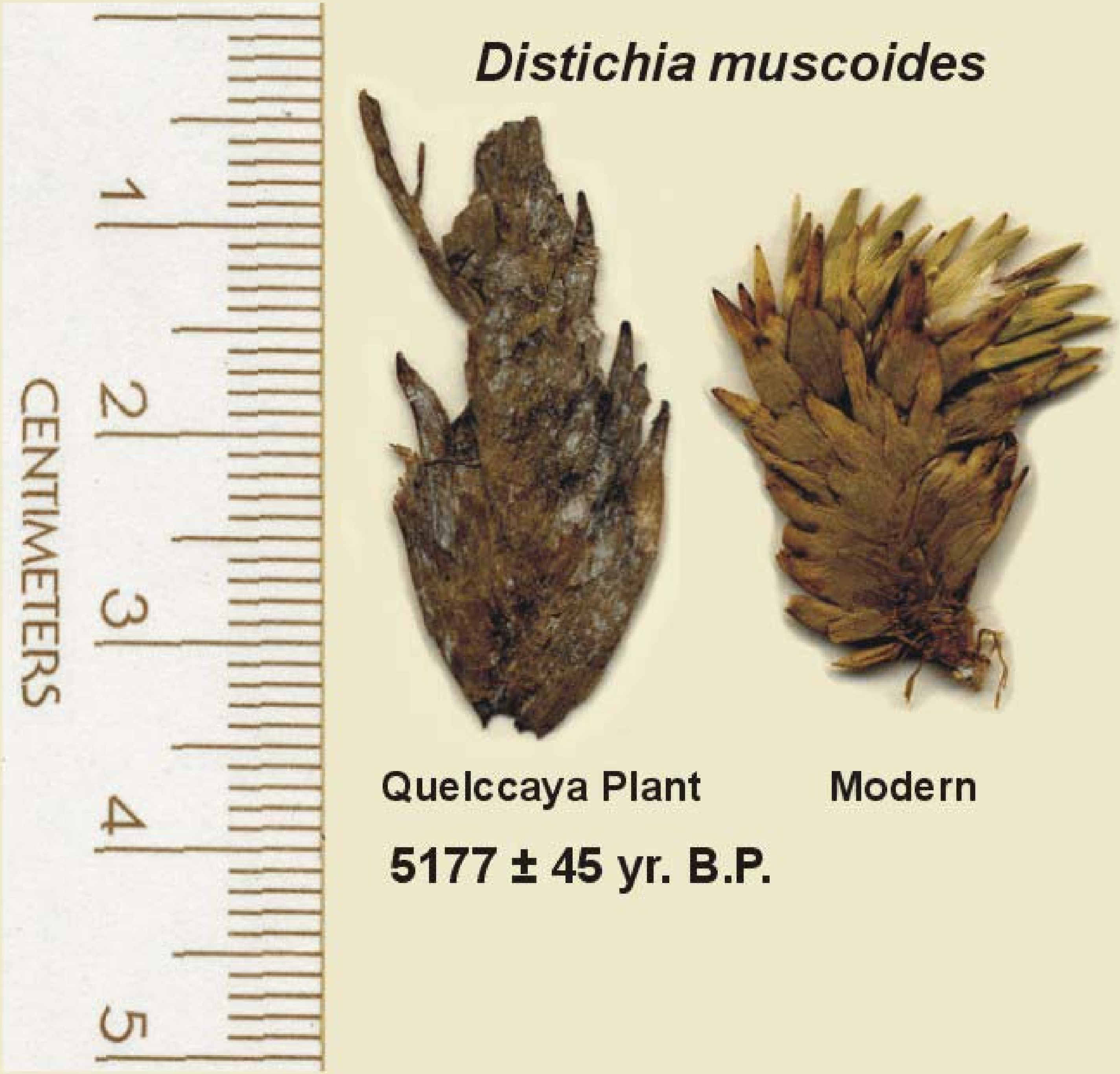
Quelccaya
Ice Cap, 2002

200 – 400 m
above its
modern range



Plant

*Distichia muscoides*

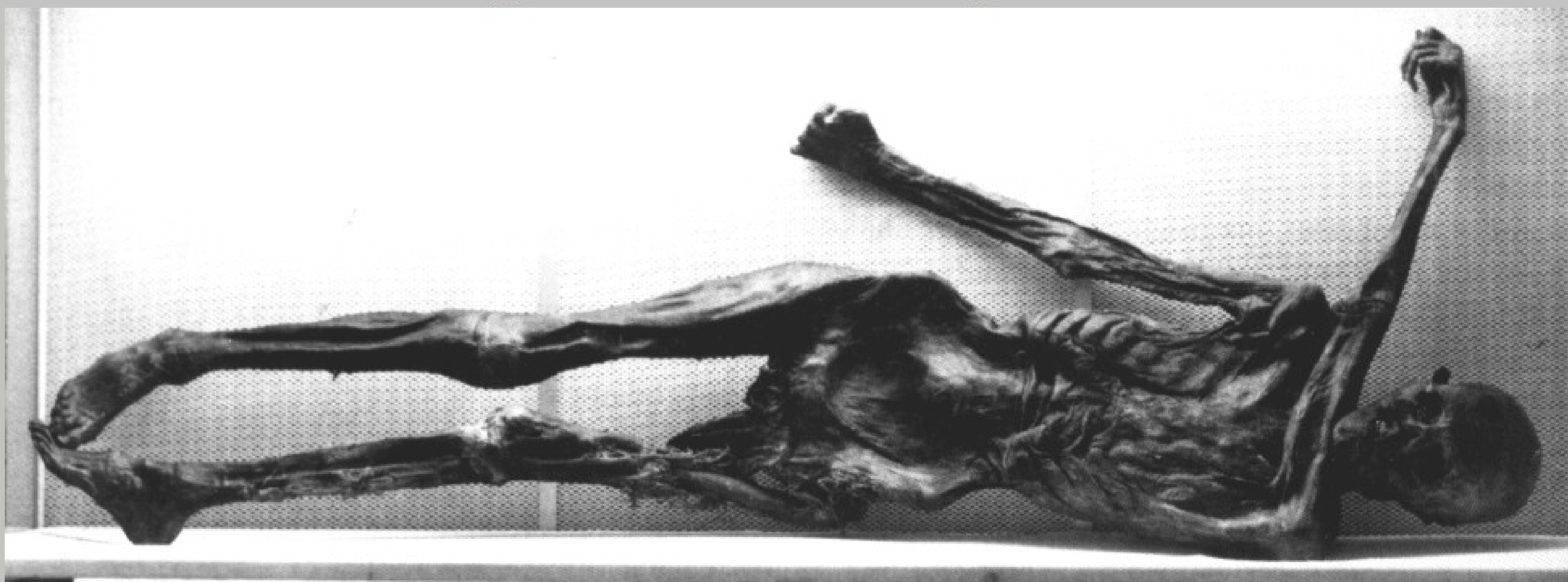



**Quelccaya Plant** **Modern**

**5177 ± 45 yr. B.P.**

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

## Age 5175 ± 125 years

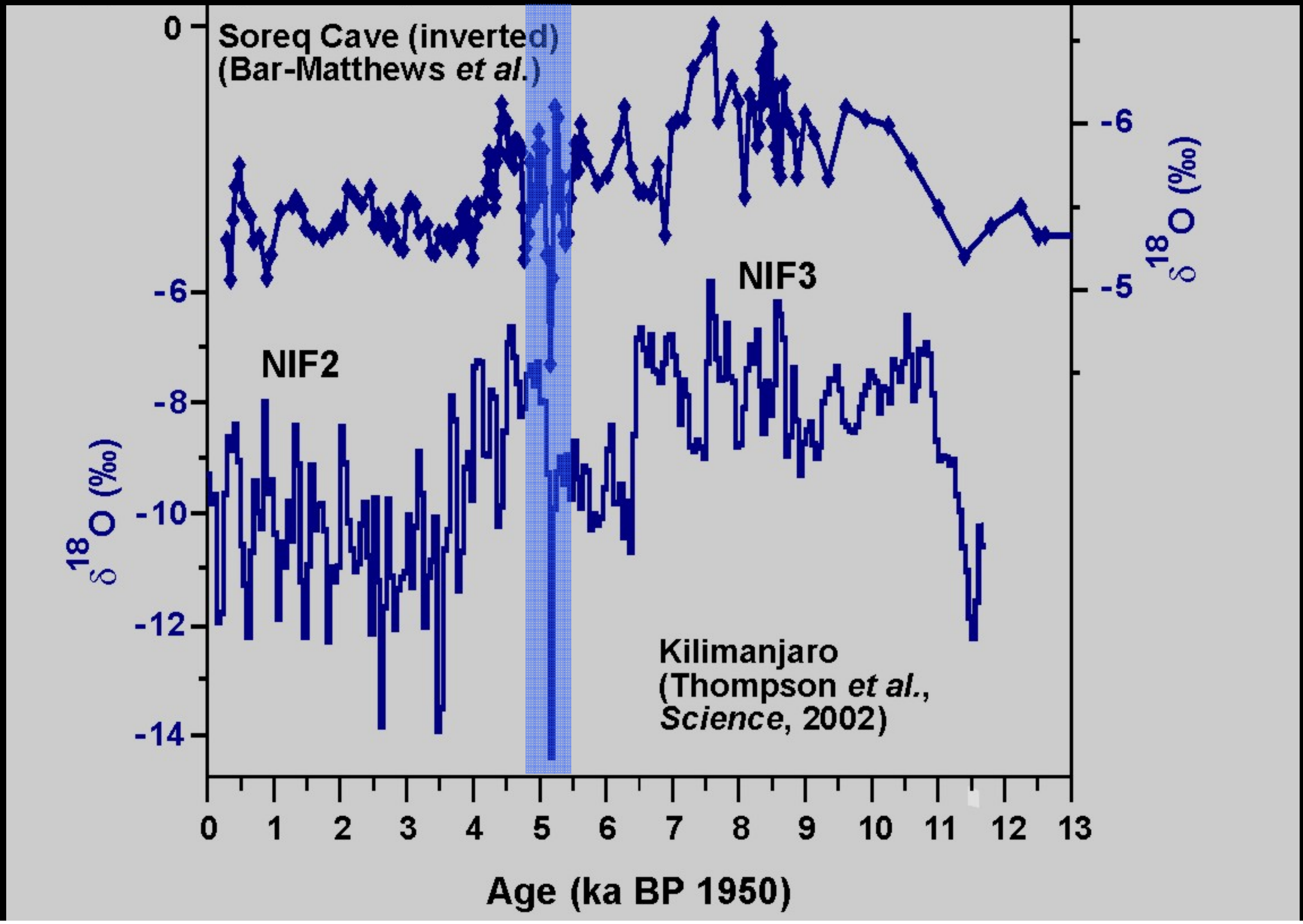


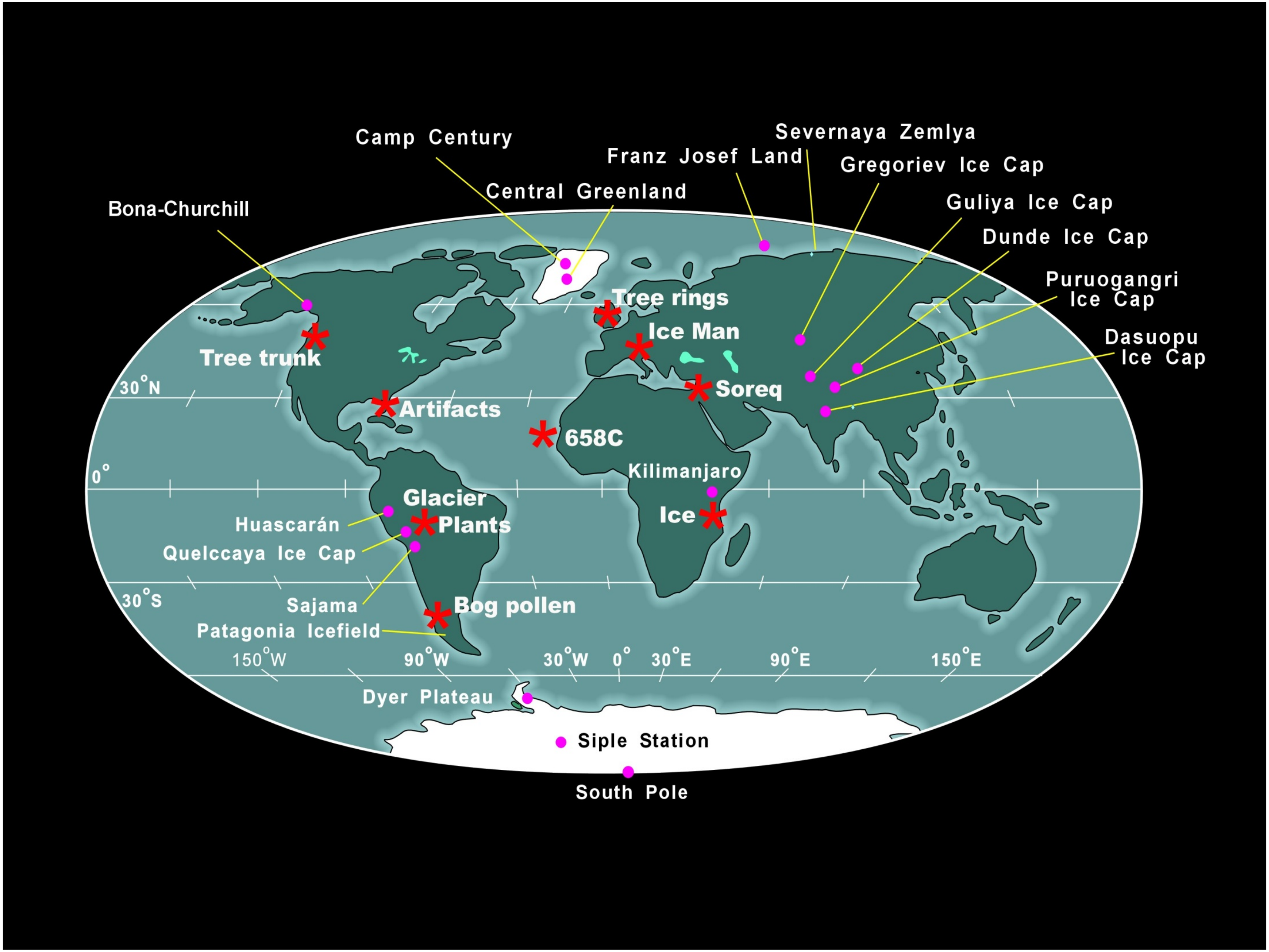
Source: http://info.uibk.ac.at/c/c5/c552/Forschung/Iceman/iceman-en.html#Finding

# 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

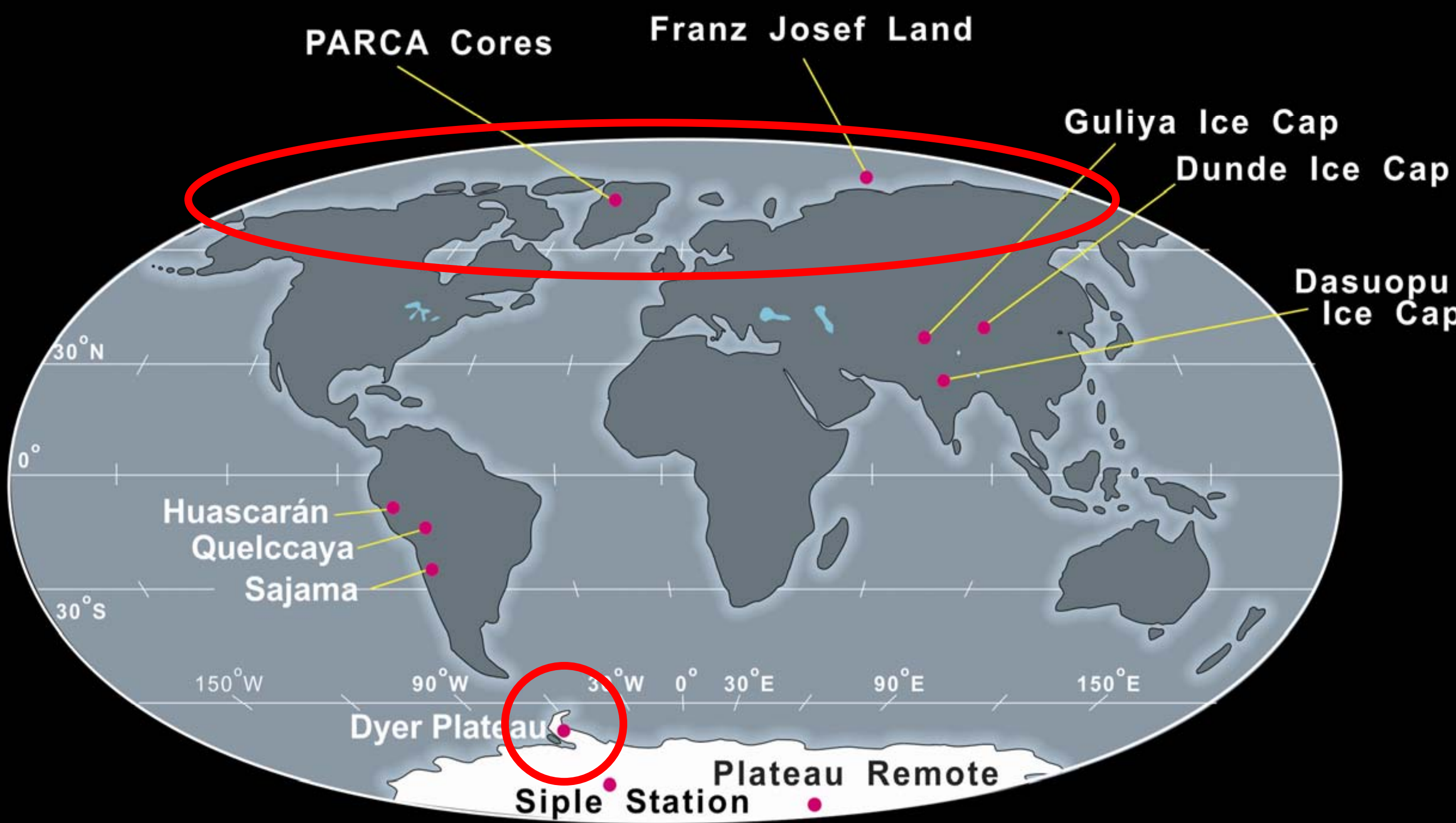
- Hierarchical societies formed in the overpopulated Nile Valley & Mesopotamia;
- Neolithic settlements in the inner deserts of Arabia were abandoned

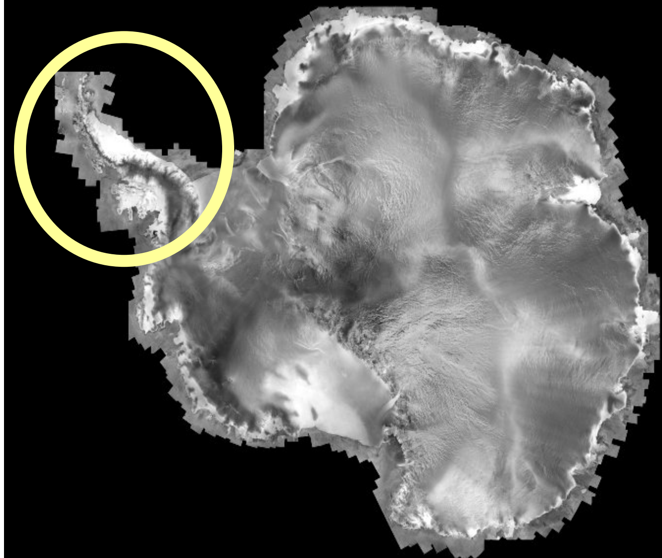




Camp Century
Severnaya Zemlya
Franz Josef Land
Gregoriev Ice Cap
Central Greenland
Guliya Ice Cap
Bona-Churchill
Dunde Ice Cap
Puruogangri Ice Cap
Tree rings
Ice Man
Dasuopu Ice Cap
Tree trunk
30°N
Soreq
Artifacts
658C
Kilimanjaro
0°
Glacier
Huascarán
Plants
Ice
Quelccaya Ice Cap
30°S
Sajama
Bog pollen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

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

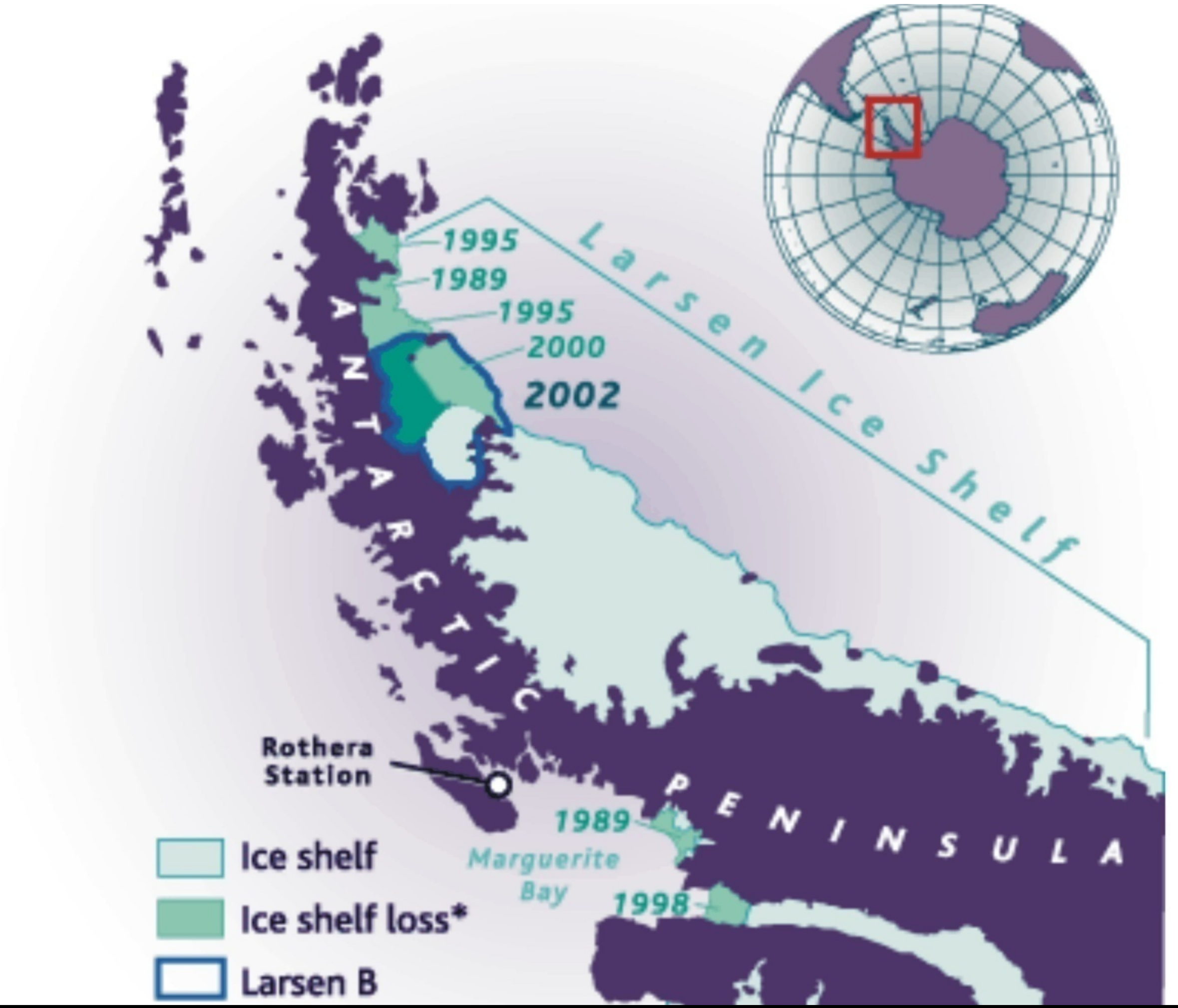




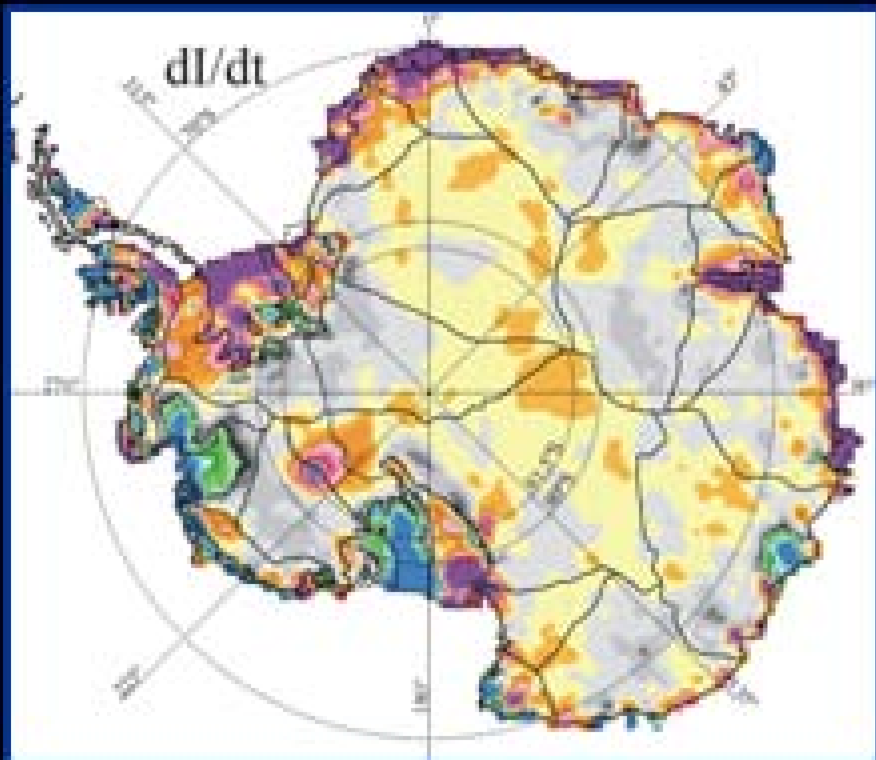
Earth's cold regions and their ice cover are well documented <u>indicators</u> of climate change

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

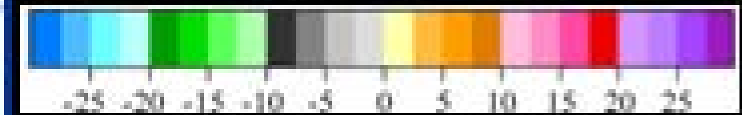
**Temperatures in the Peninsula region have warmed ~2.0$^{o}$C in the last 50 years.**



# 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)

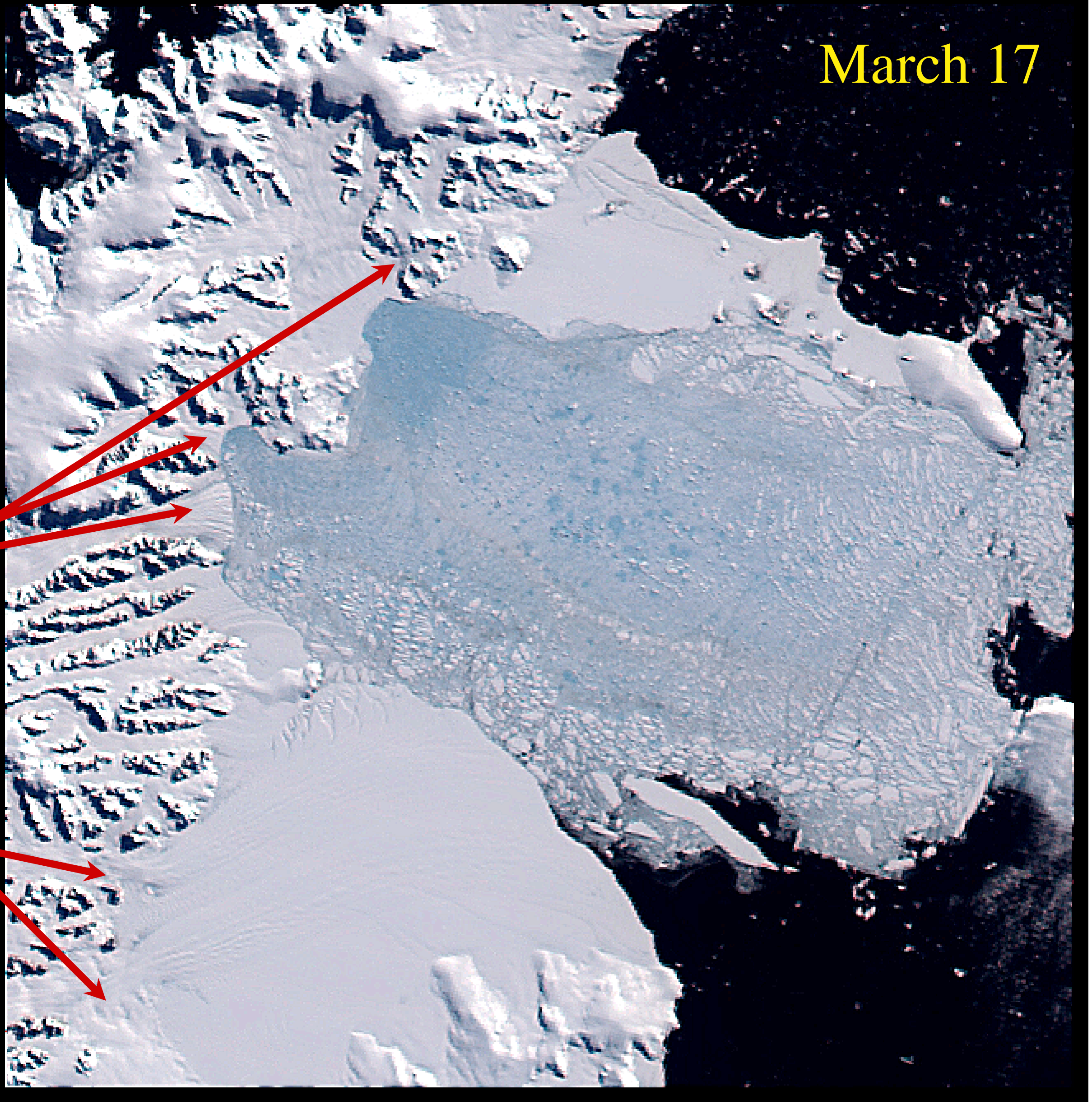
# Ice Shelves and the Buttressing Effect

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

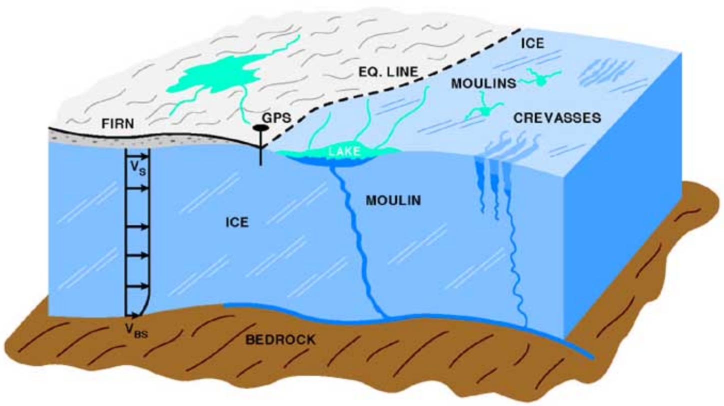
**Land based glaciers increased their flow speed up to 8-fold**

**Some have thinned by as much as 40 m in 6 months**

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



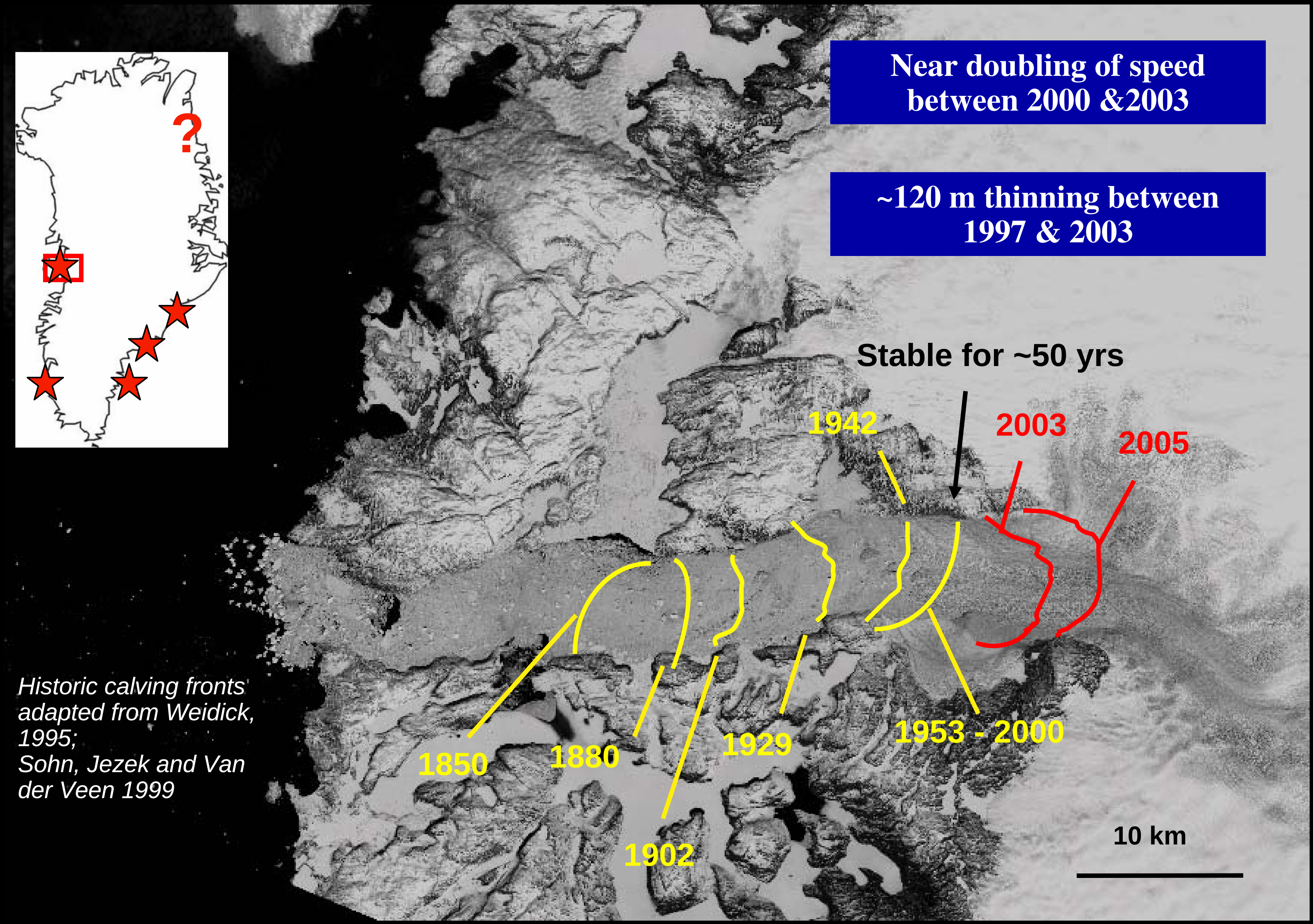
**The warming in the Arctic is now well-documented .....**
**Arctic Climate Impact Assessment available at http://www.acia.uaf.edu/**




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

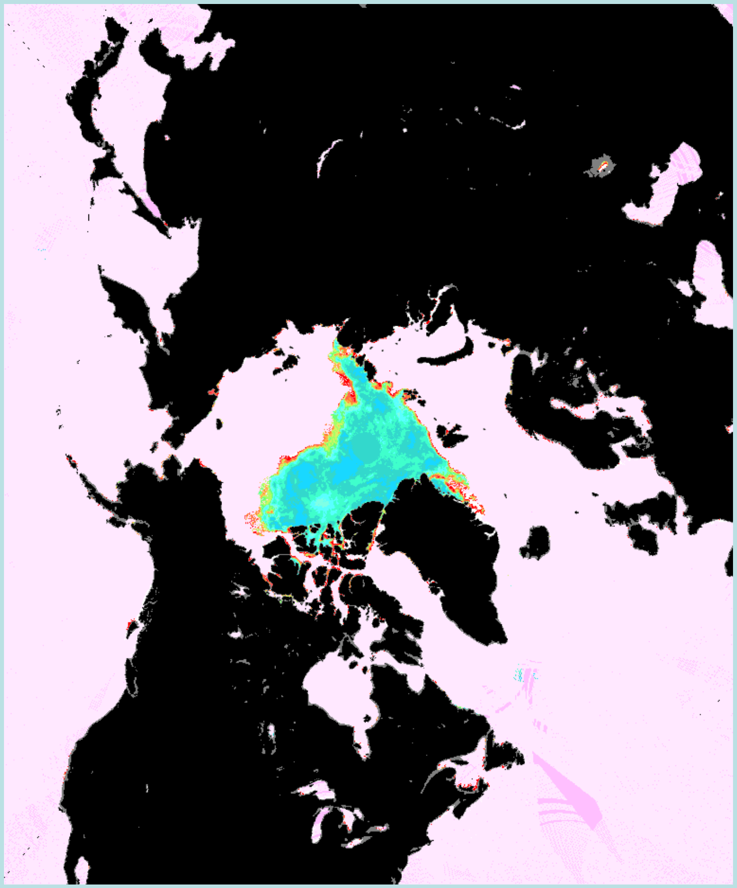
Photo by Roger J. Braithwaite

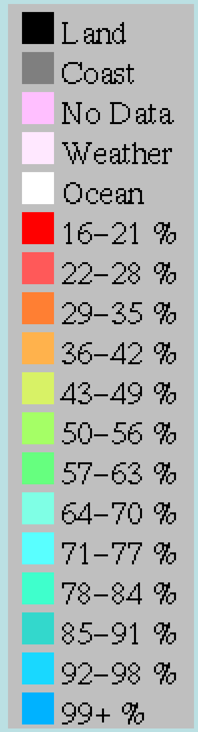
# Retreat of the Jakobshavn Ice Stream

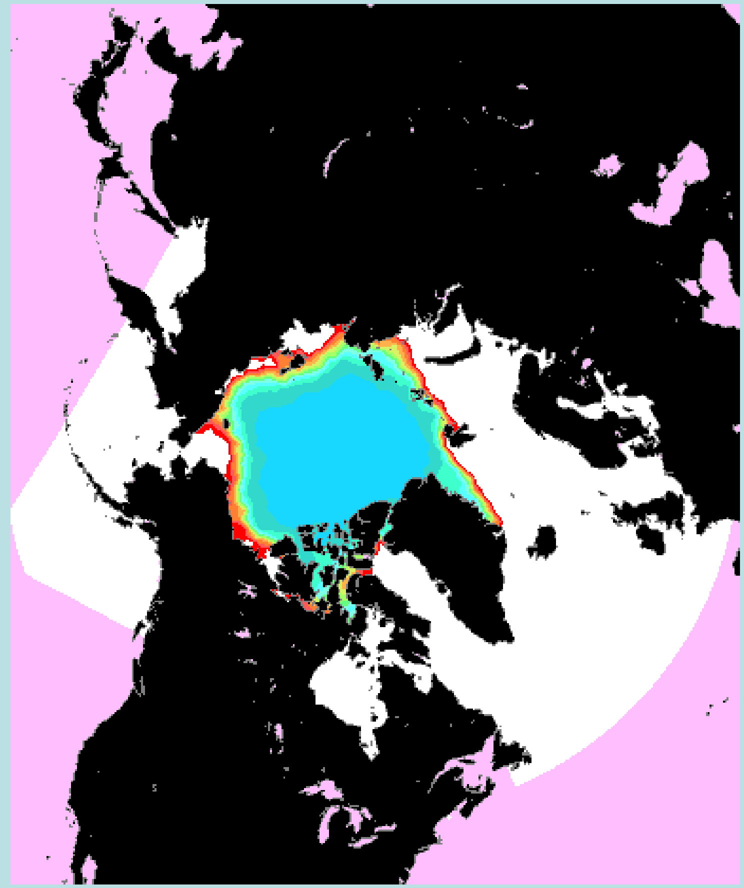



*Historic calving fronts adapted from Weidick, 1995; Sohn, Jezek and Van der Veen 1999*

## 2007 Arctic Sea Ice Cover at a Record Low, September 13, 2007





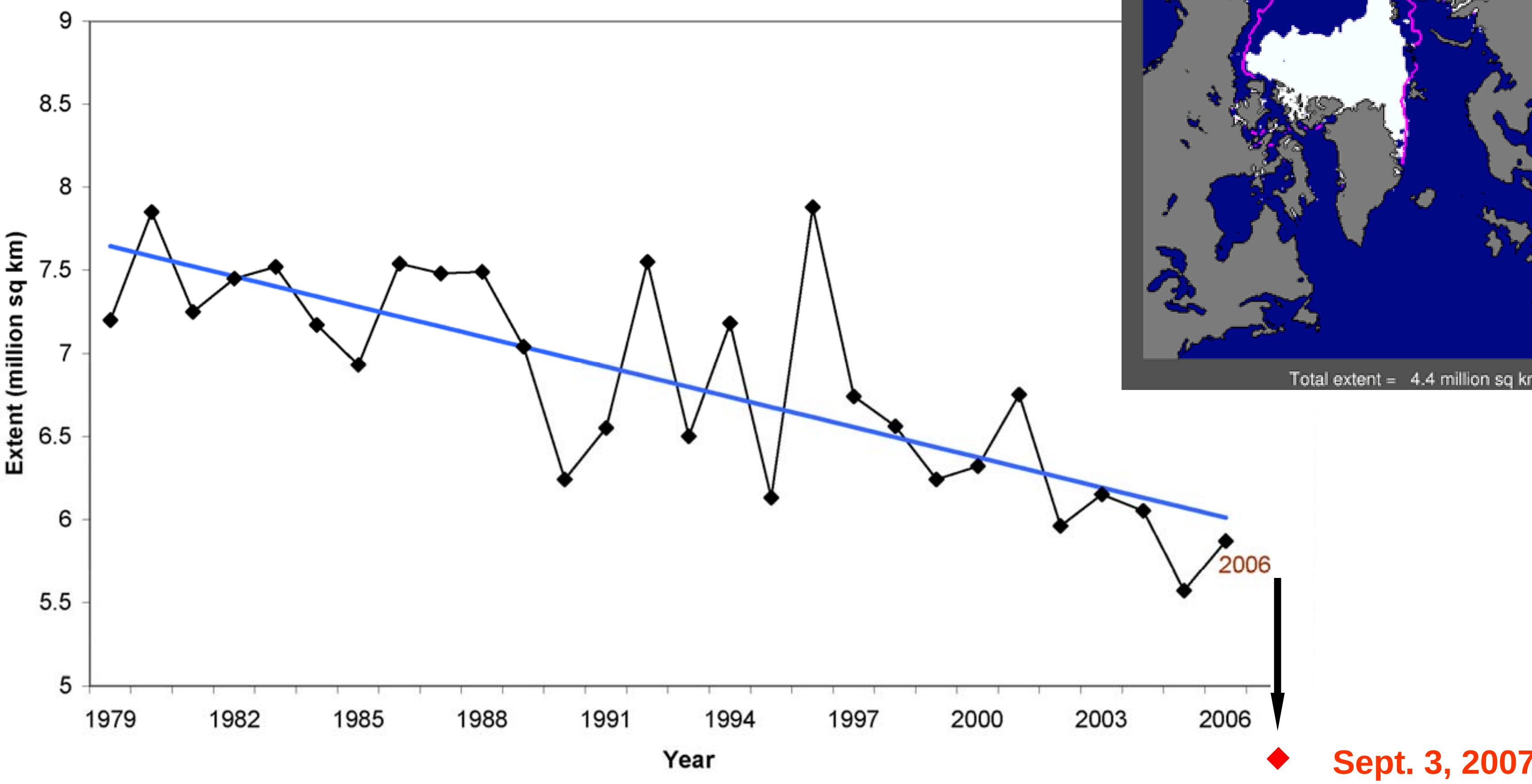



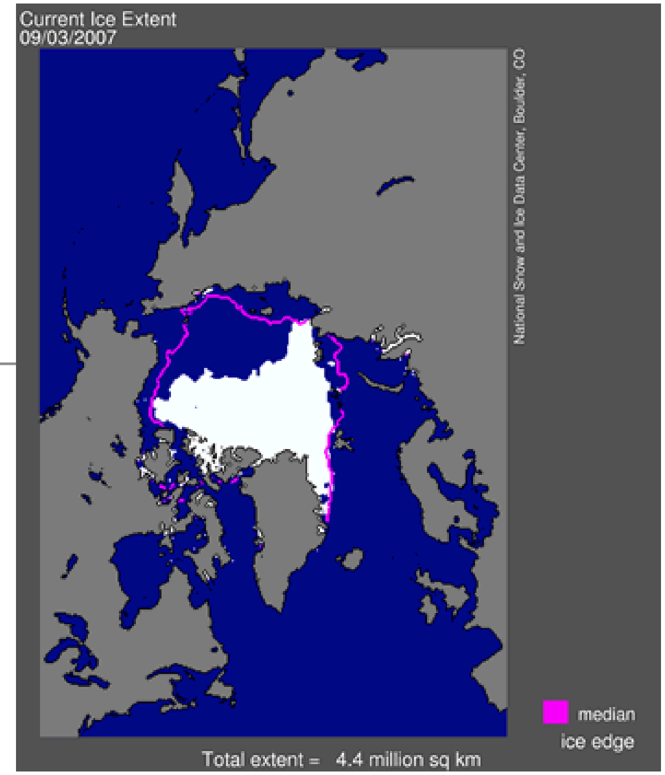
September 13, 2007

September 30 average
1901 – 1990
(climatology)

**Source: NOAA**
**http://polar.ncep.noaa.gov/seaice/hires/nh.xml**

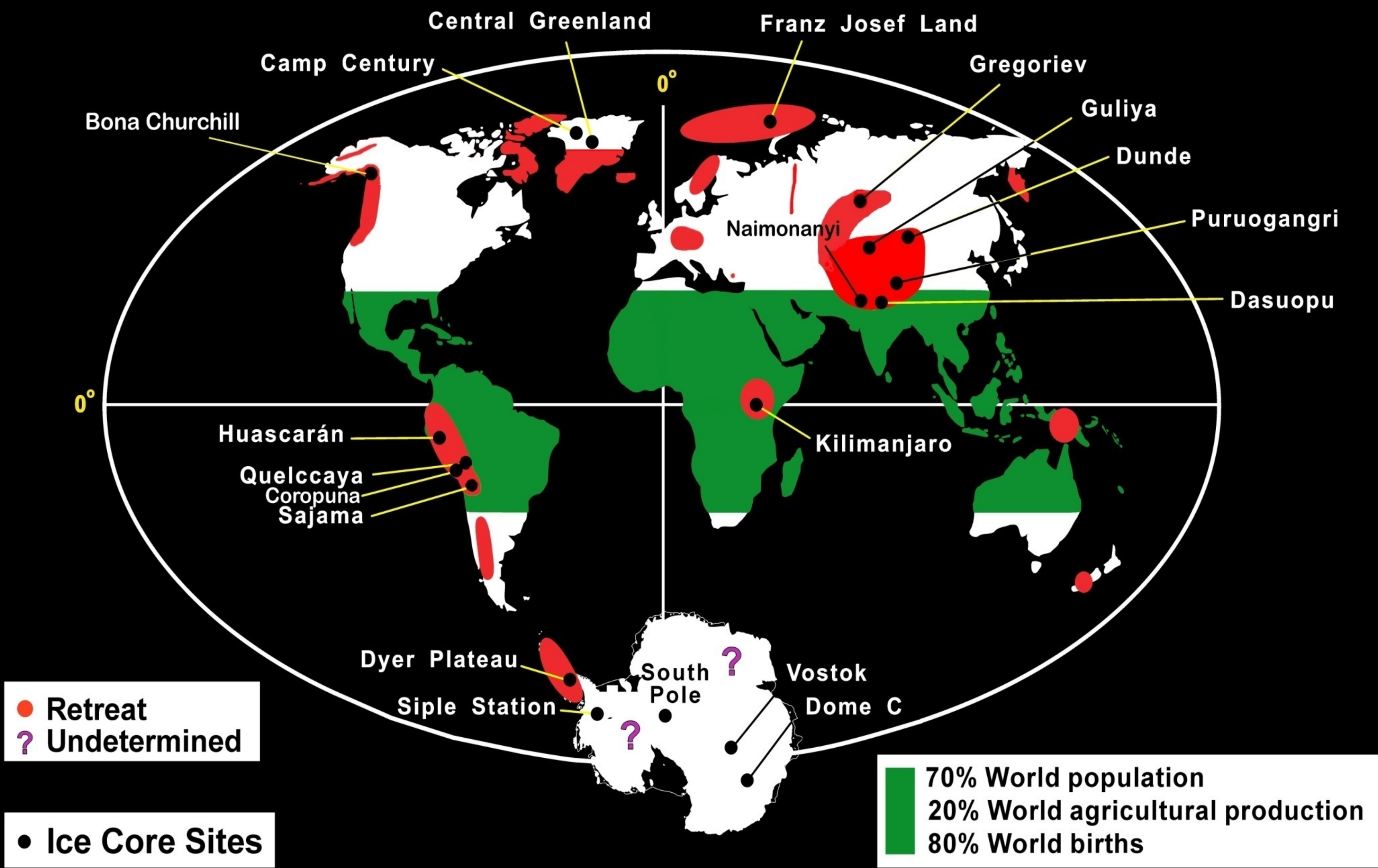
## Minimum Sea Ice Extent Each Year Since 1979
## As Measured by Satellite at the End of September




**Source: National Snow and Ice Data Center**
**http://nsidc.org/**

# 20th and 21st Century Changes in Ice Cover

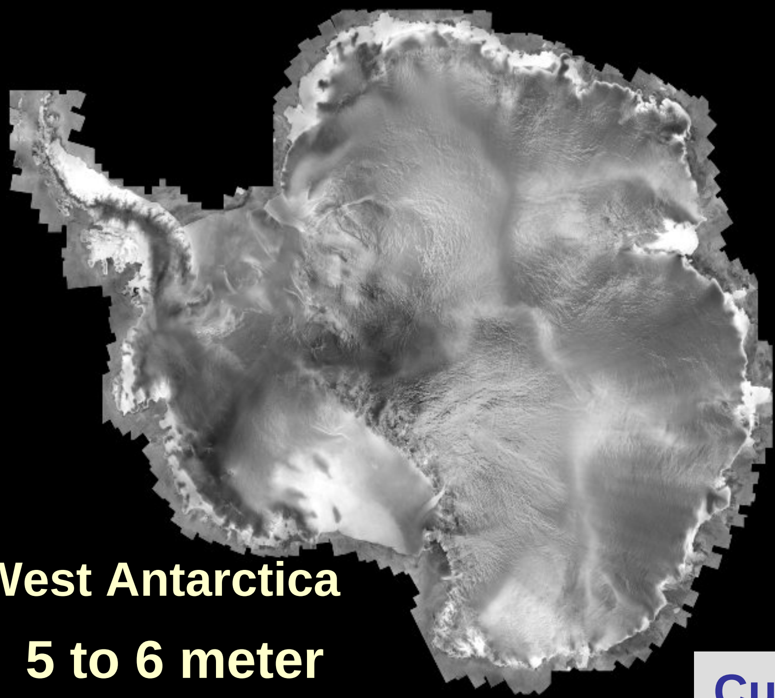



•*Climatologically we are in unfamiliar territory, and the world's ice cover is responding dramatically*.

**Sea level is currently rising 3.1 ± 0.7 mm per 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**

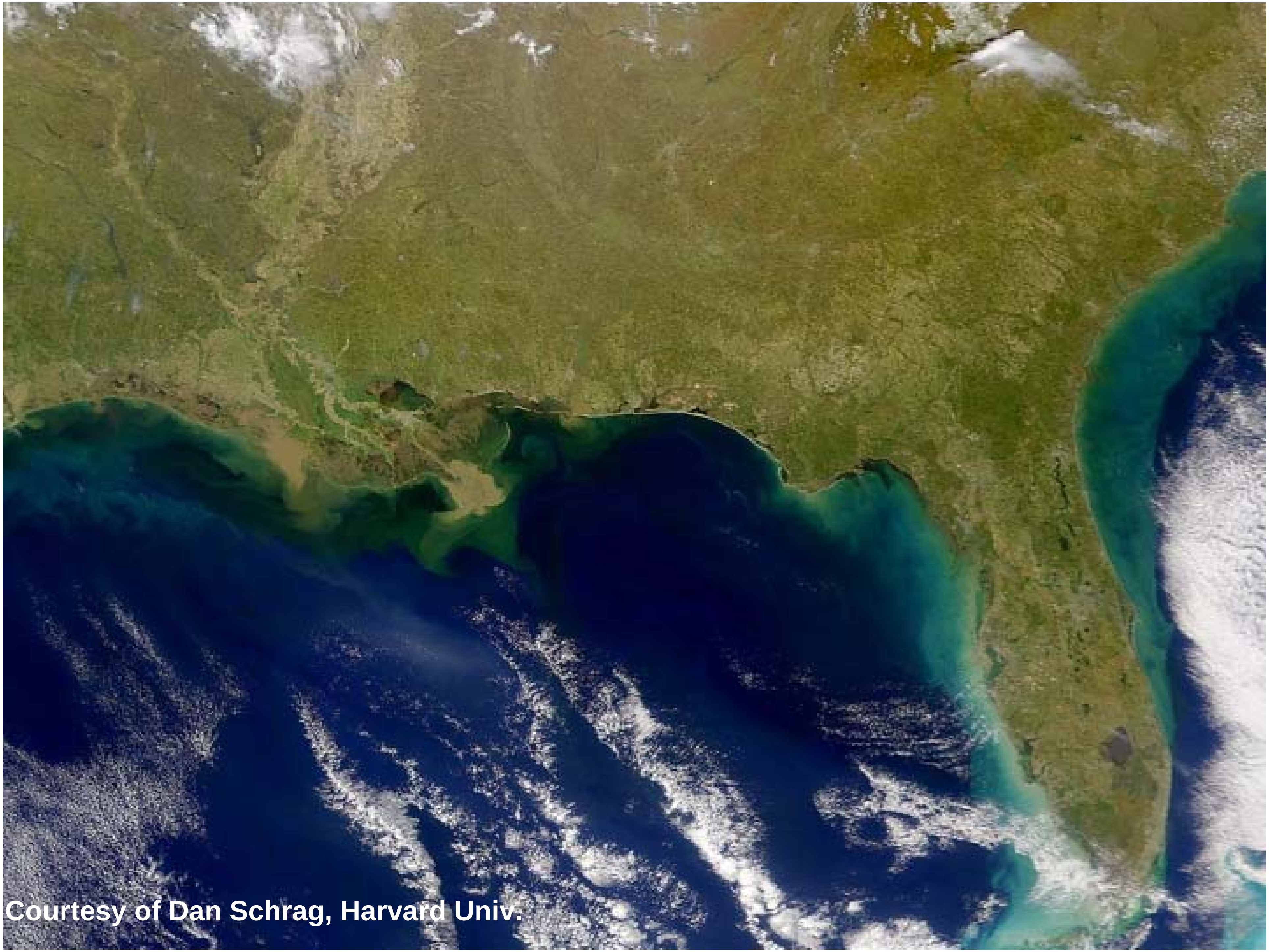
**East Antarctica**

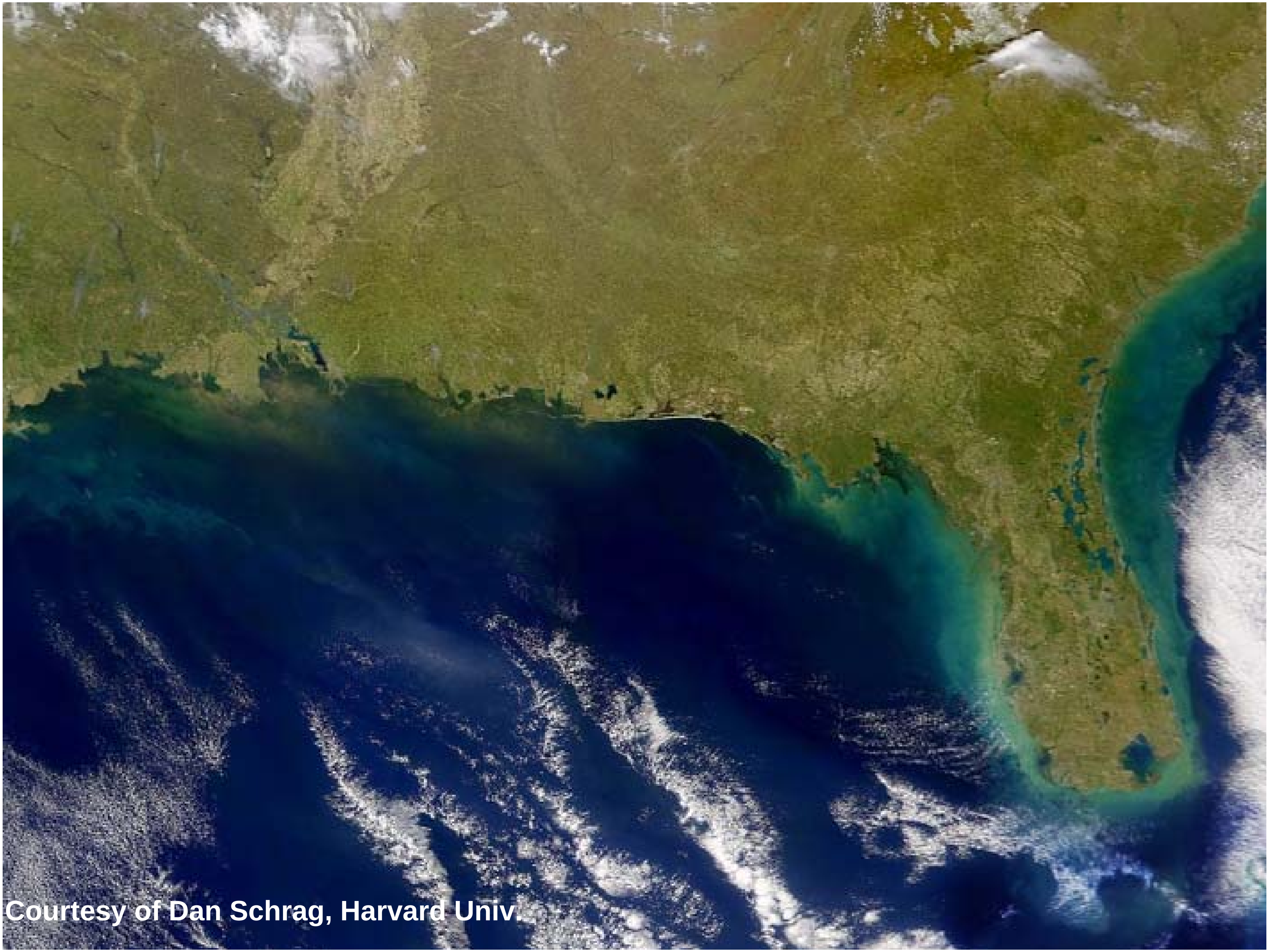
**55 to 60 meter sea level rise equivalent**

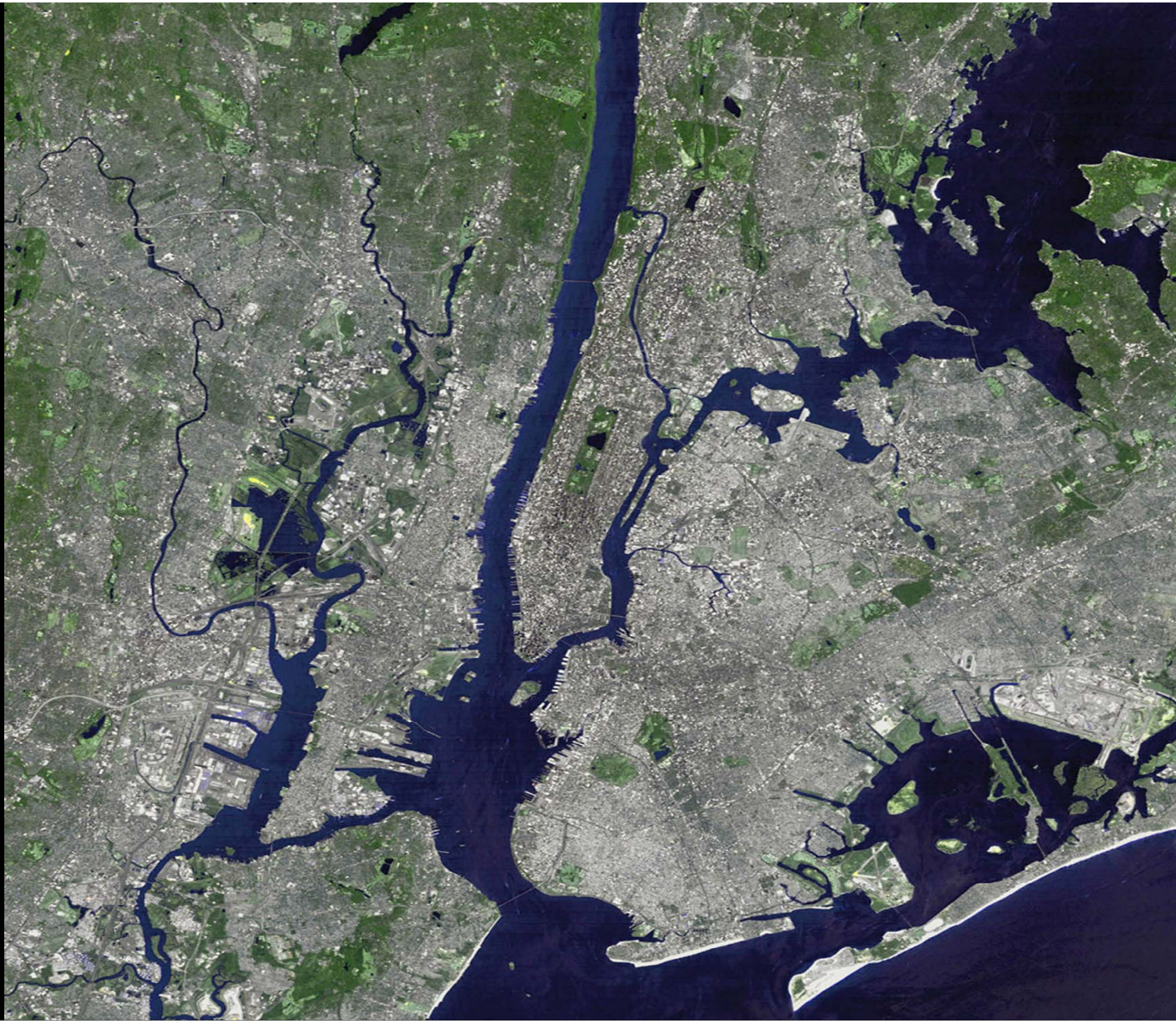
**Greenland**

**6 to 7 meter sea level rise equivalent**

**Currently, 60% of the ice loss is from glaciers and ice caps rather than the two ice sheets. The loss of mountain glaciers may raise sea level ~ 0.25 meters by 2100. (Meier *et al. Science, 2007*)**


Courtesy of Dan Schrag, Harvard Univ.


Courtesy of Dan Schrag, Harvard Univ.



# 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.**

# 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!**

## Food for Thought!

**"We are now faced with the fact that tomorrow is today. We are confronted with the fierce urgency of now. In this unfolding conundrum of life and history there is such a thing as being too late. Procrastination is still the thief of time. Life often leaves us standing bare, naked and dejected with lost opportunity. The 'tide in the affairs of men' does not remain at the flood; it ebbs. We may cry out desperately for time to pause in her passage, but time is deaf to every plea and rushes on. Over the bleached bones and jumbled residue of numerous civilizations are written the pathetic words…. <u>too late.</u>"**

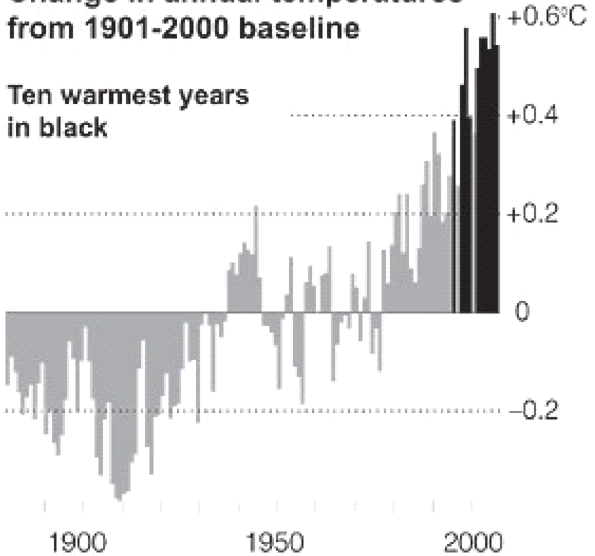
**Reverend Dr. Martin Luther King, Jr.**

## 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**

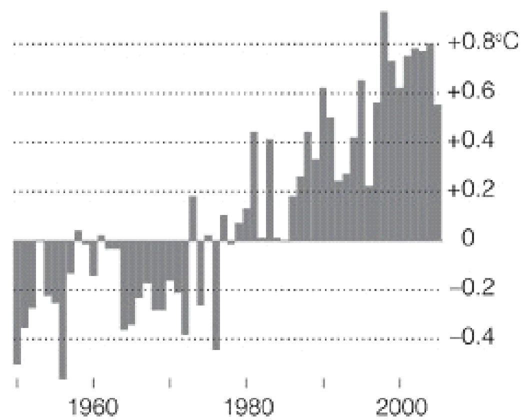
**Ten warmest years in black**




## . . . And Understanding The Reasons for It

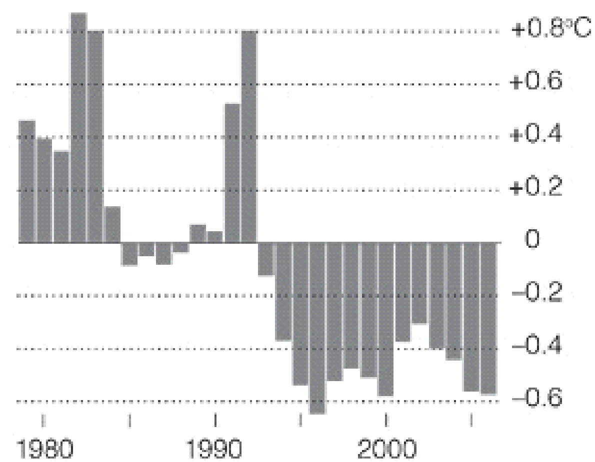
The global warming trend does not necessarily prove that human-generated greenhouse gases are heating the planet. Scientists find stronger clues in patterns of temperature changes, including a recent trend toward warmer nights.

**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, past and the present (the only way to replicate the remarkable warming, and extraordinary Arctic warming, of the recent decades is to add greenhouse gases.**