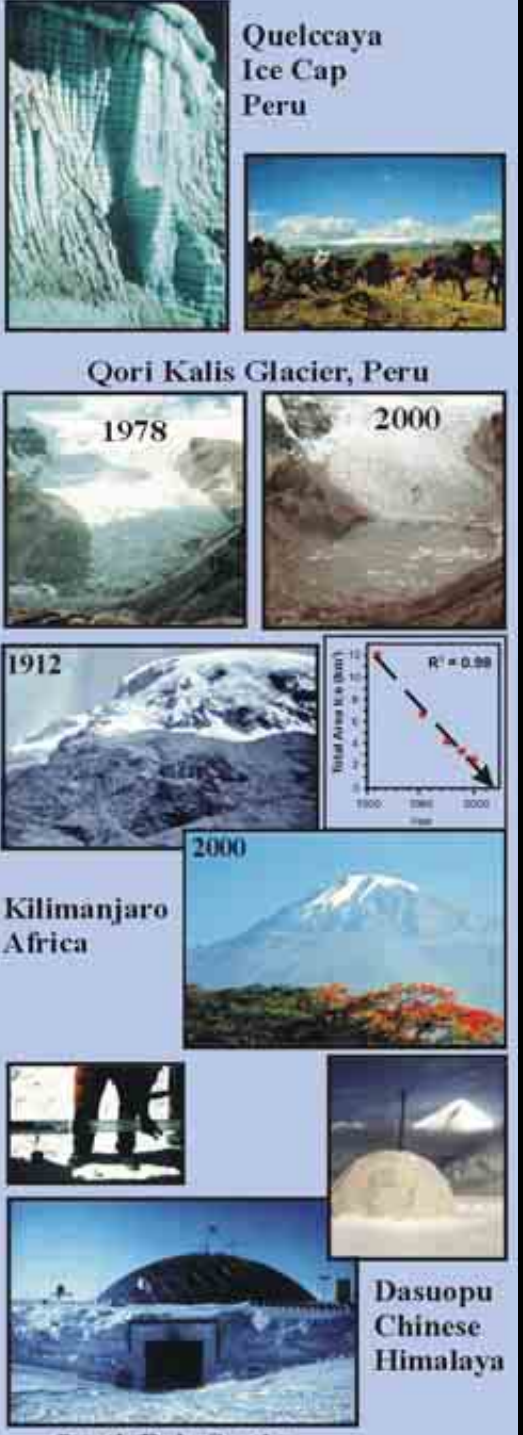

Glaciological Evidence of Abrupt Tropical Climate Change: Past, Present and Future

FERMILAB

May 18th, 2007

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NOAA: Paleoclimatology
Comer Foundation

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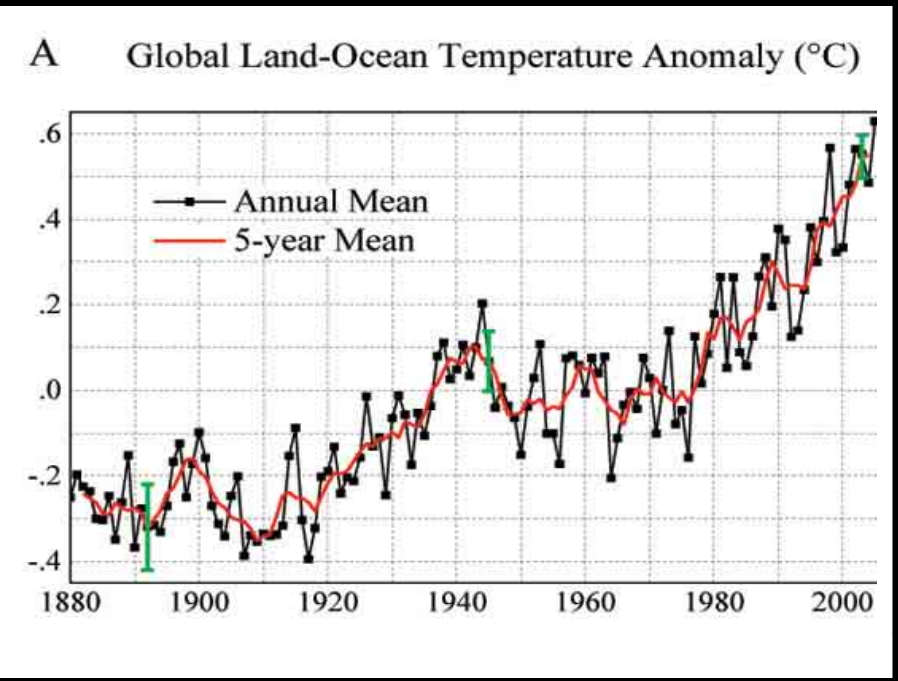
Objectives:

- **Introduction to climate change**
- **Evidence for asynchronous glaciation**
- **Glaciers our most visible evidence of global warming**
- **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**
- **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) (glacier retreat, ice shelf break up, ecosystem disruptions)**

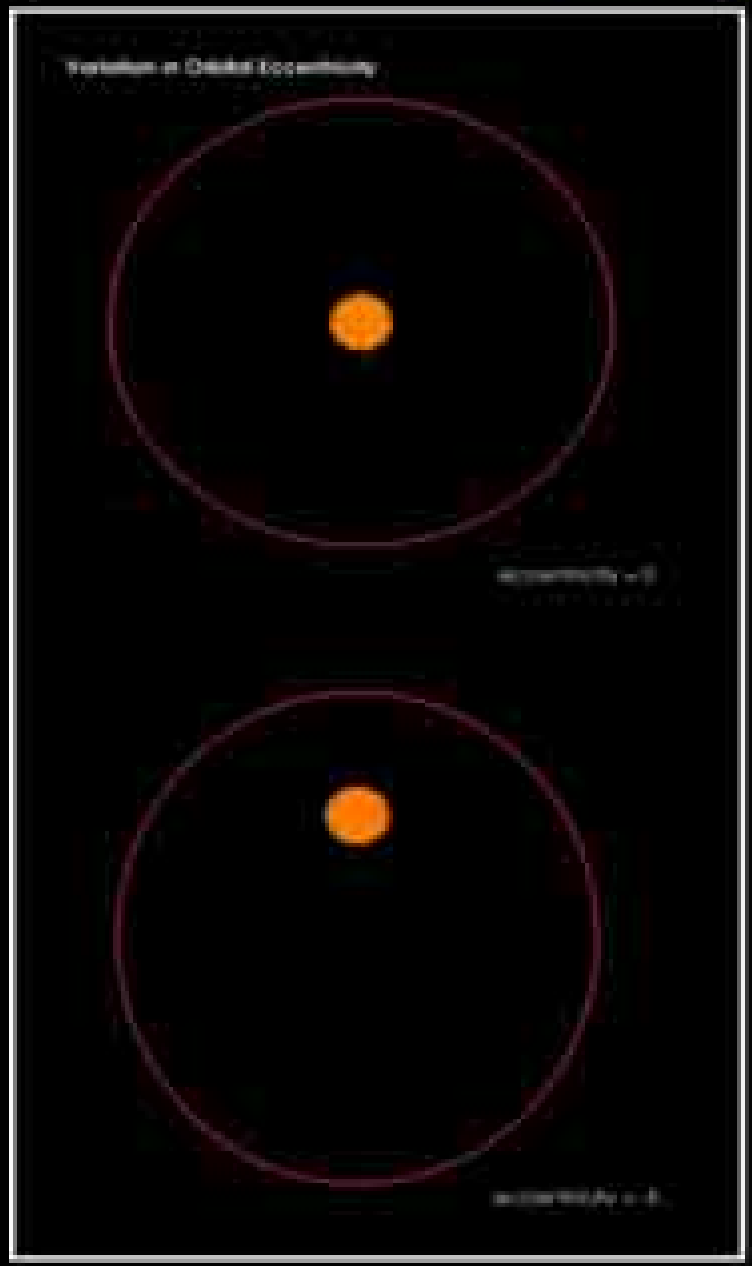


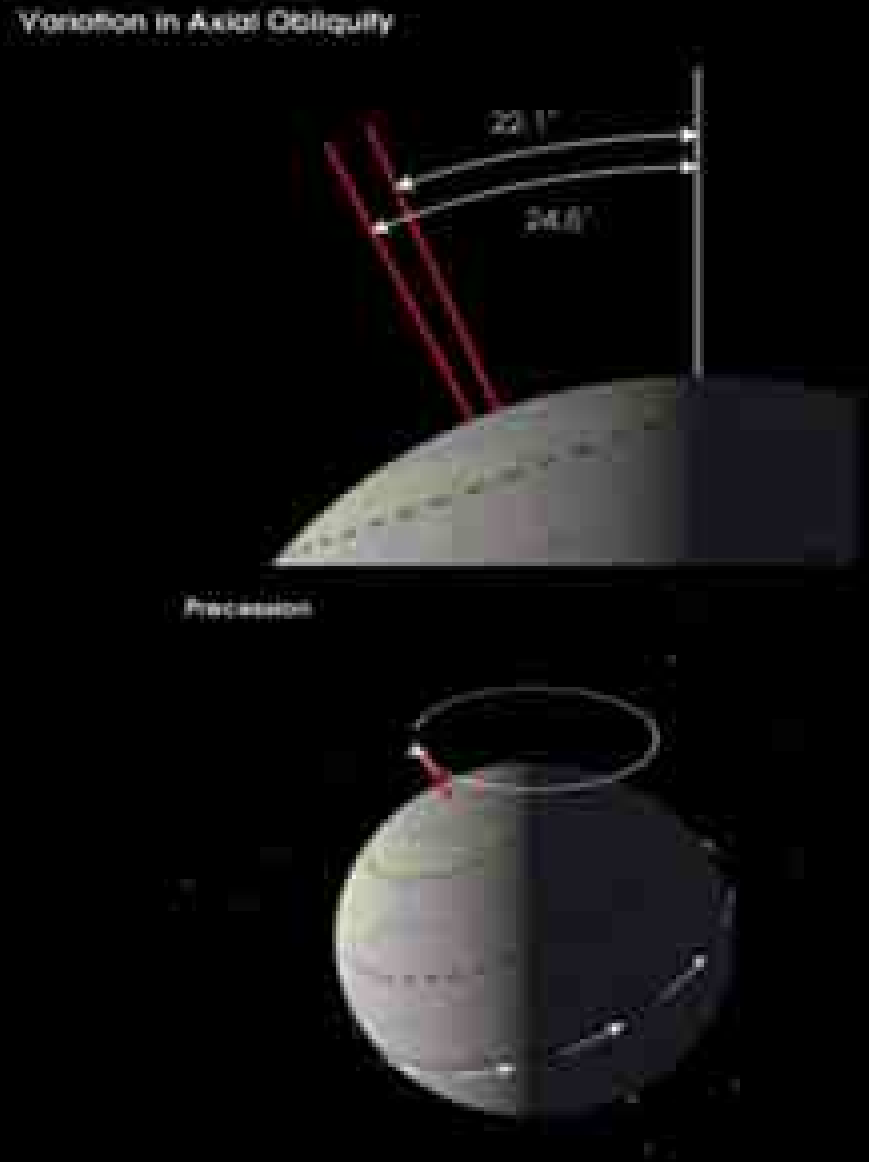
2005 warmest year on record

03/16/2007 NOAA – 2006 / 2007 warmest winter for N.H.

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

Earth's Orbital Parameters



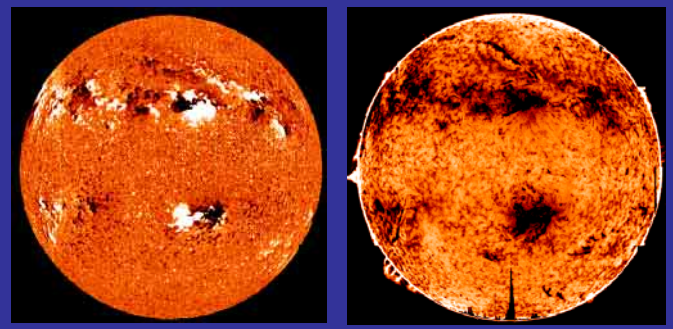


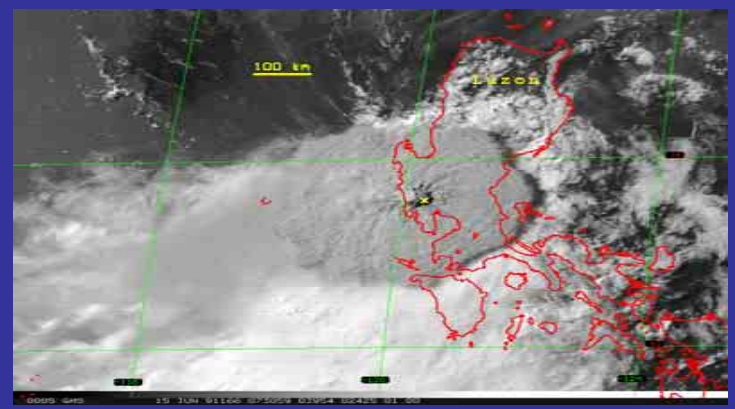
Source http://earthobservatory.nasa.gov/Library/Giants/Milankovitch/milankovitch_2.html

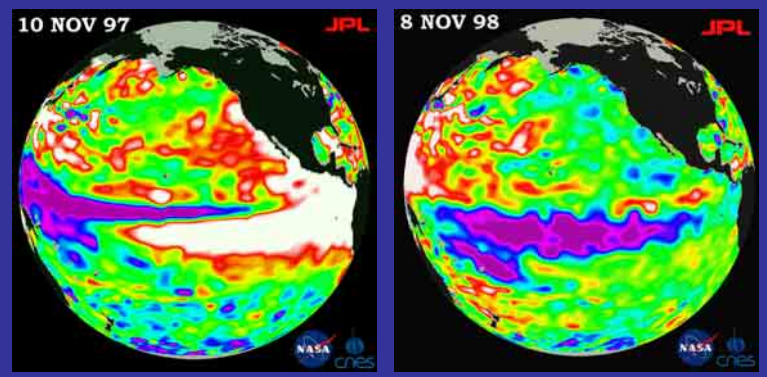
Natural mechanisms influence climate

Natural mechanisms

- Changes in the Sun
- Changes in the amount of volcanic dust in the atmosphere
- Internal variability of the coupled atmosphere-ocean system



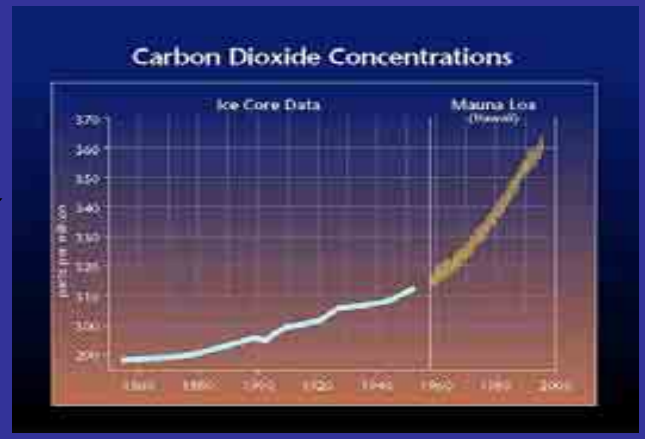


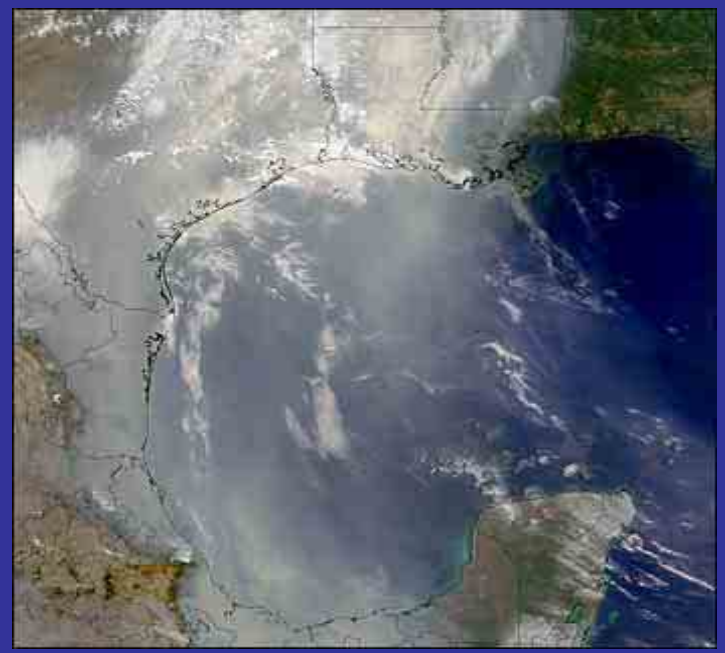


Human factors also influence climate

Non-natural mechanisms

- Changes in atmospheric concentrations of greenhouse gases
- Changes in aerosol particles from burning fossil fuels and biomass
- Changes in the reflectivity (albedo) of the Earth's surface





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

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

1977
Quelccaya Ice Cap, Peru

High temporal resolution

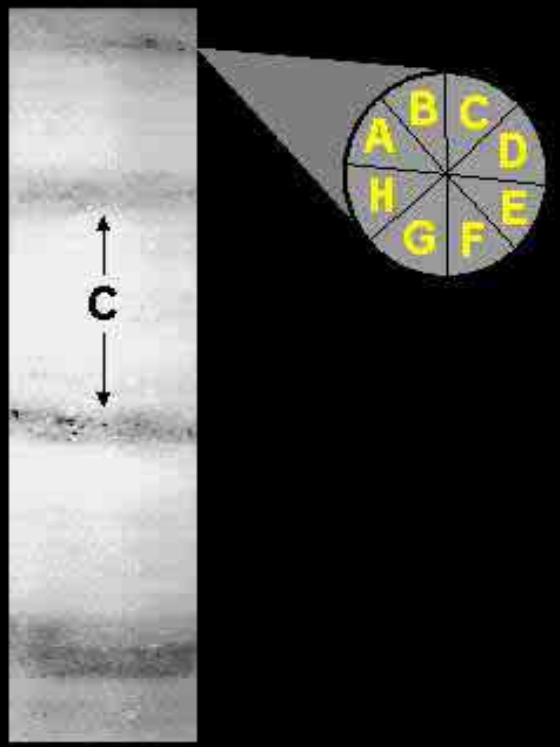
East Antarctica Plateau

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



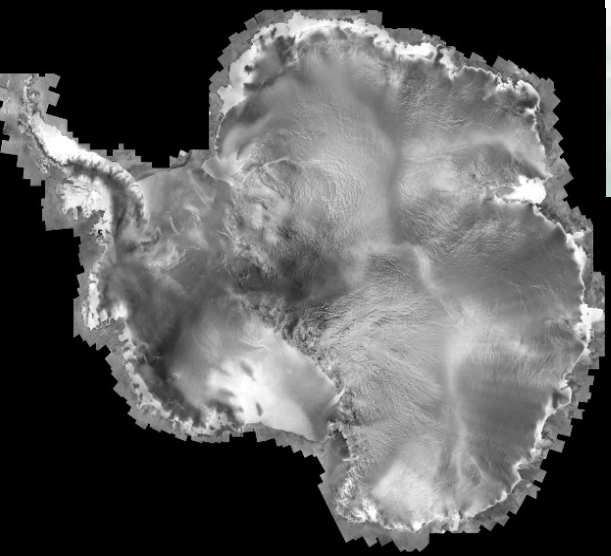
A Temperature ($\delta^{18}O$)
B Atmospheric Chemistry
C Net Accumulation
D Dustiness of Atmosphere
E Vegetation Changes
F Volcanic History
G Anthropogenic Emissions
H Entrapped Microorganisms

Guliya ice cap, Tibet

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

Huascarán, Peru

Dasuopu Glacier
Southern Tibet

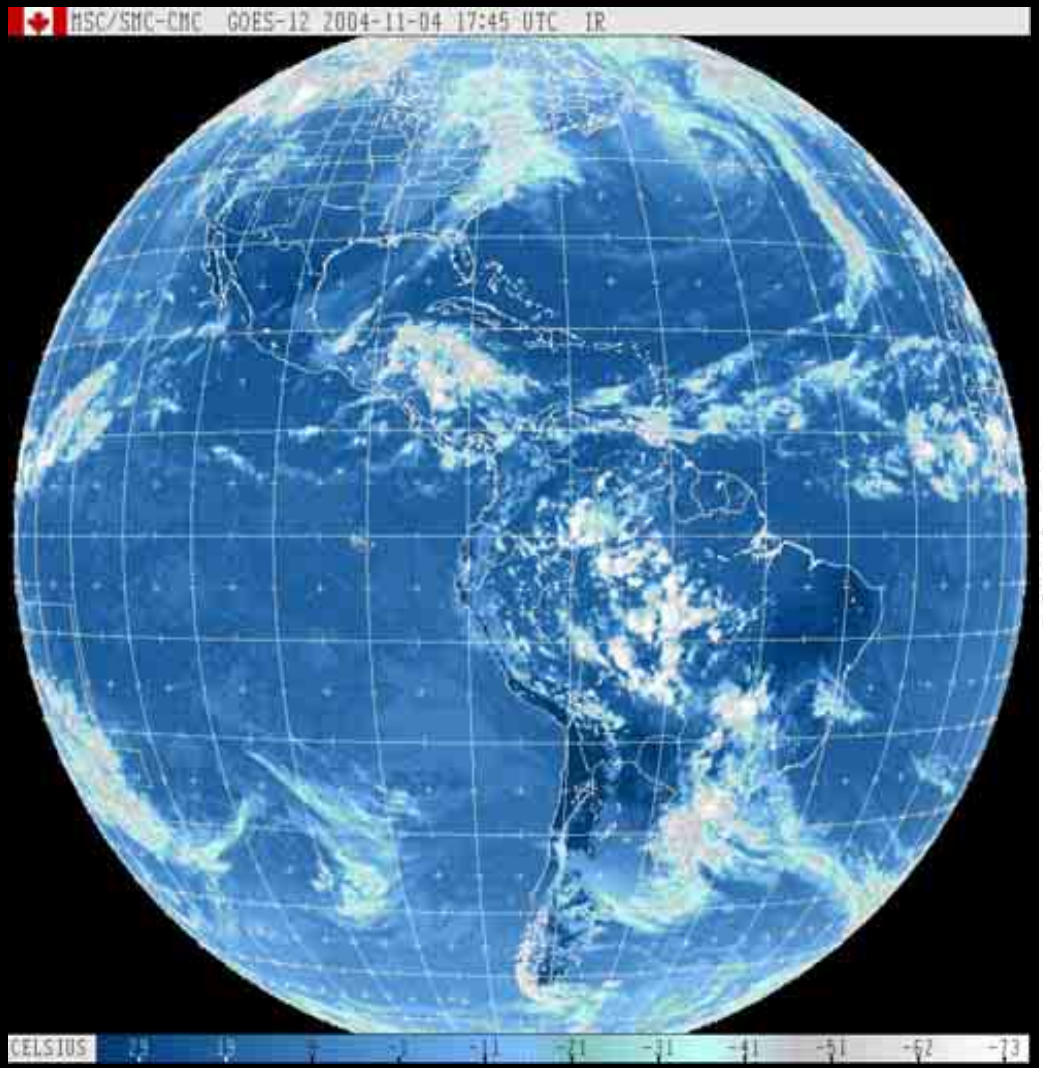


Class-100 clean room houses the equipment used to measure dust, isotopes and chemicals

Freezers for storage and cold rooms for physical property measurements

Machine shop for drill and equipment fabrication

Zonal Distribution of Annual Precipitation



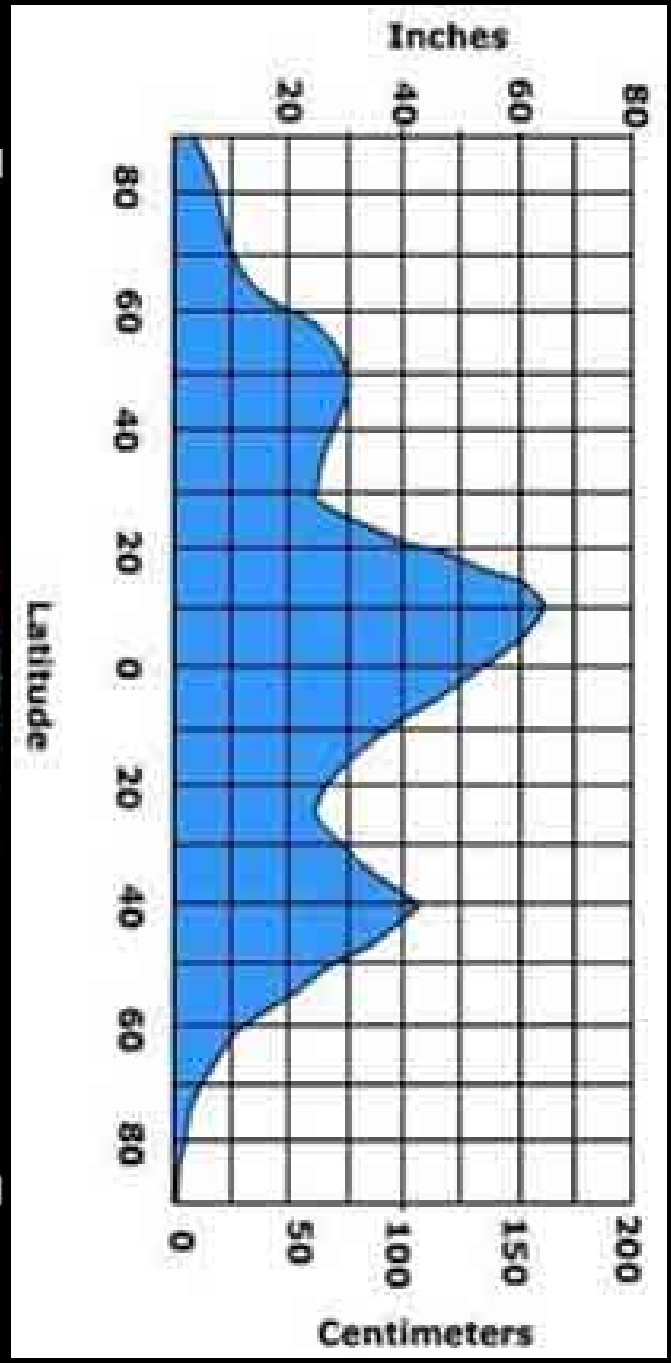
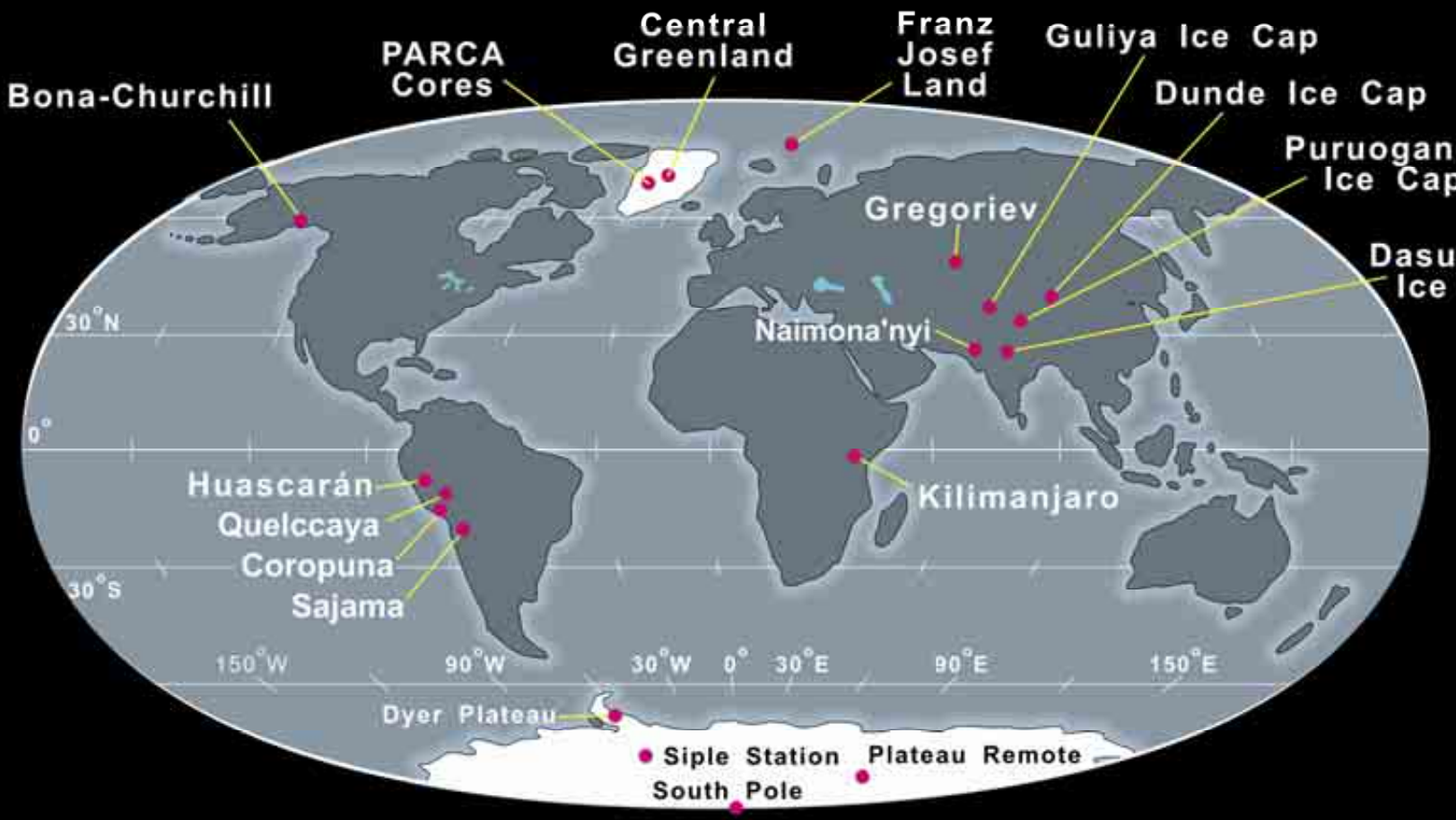
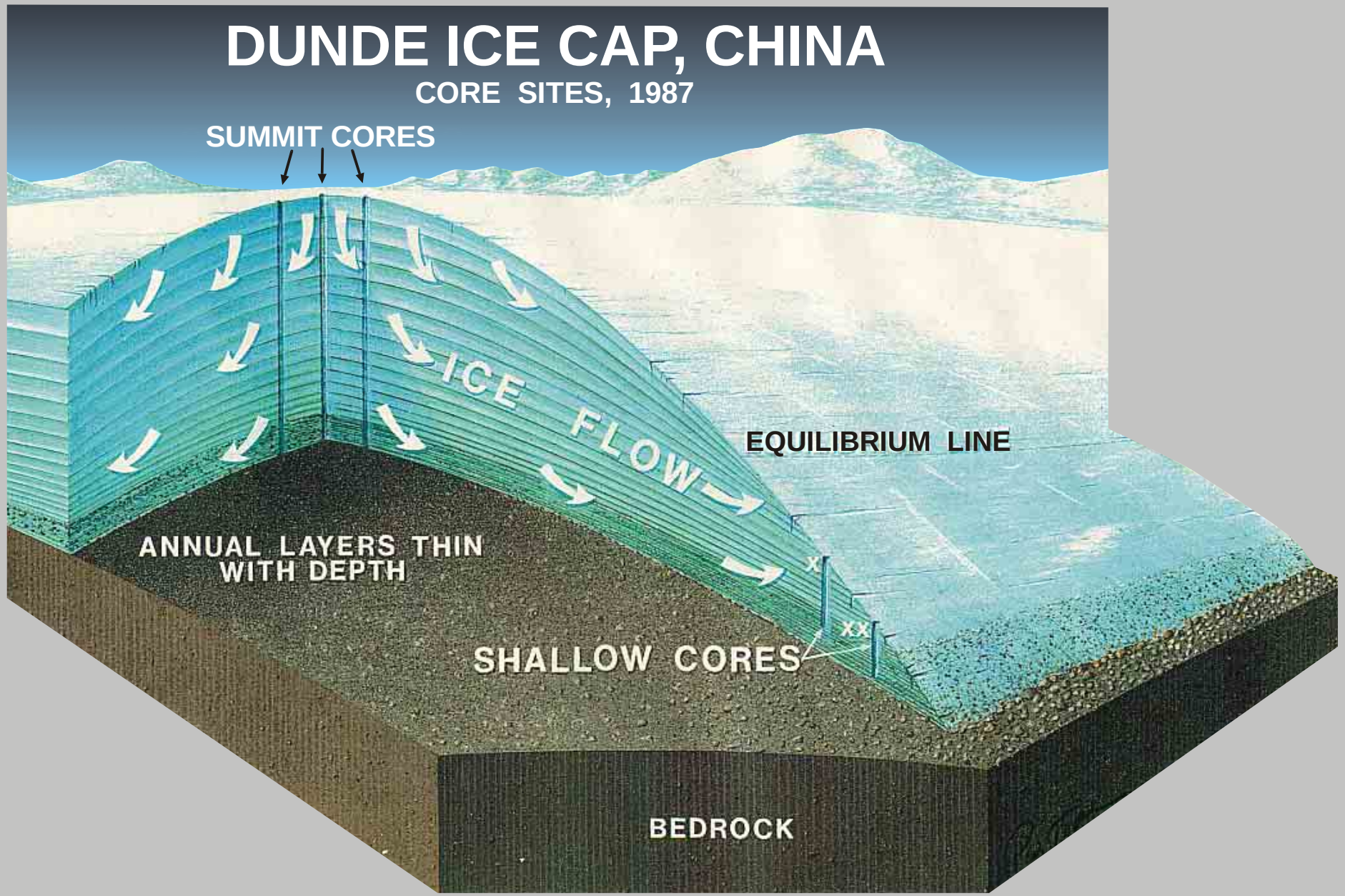


Image from GOES-12 Satellite Nov 4, 2004

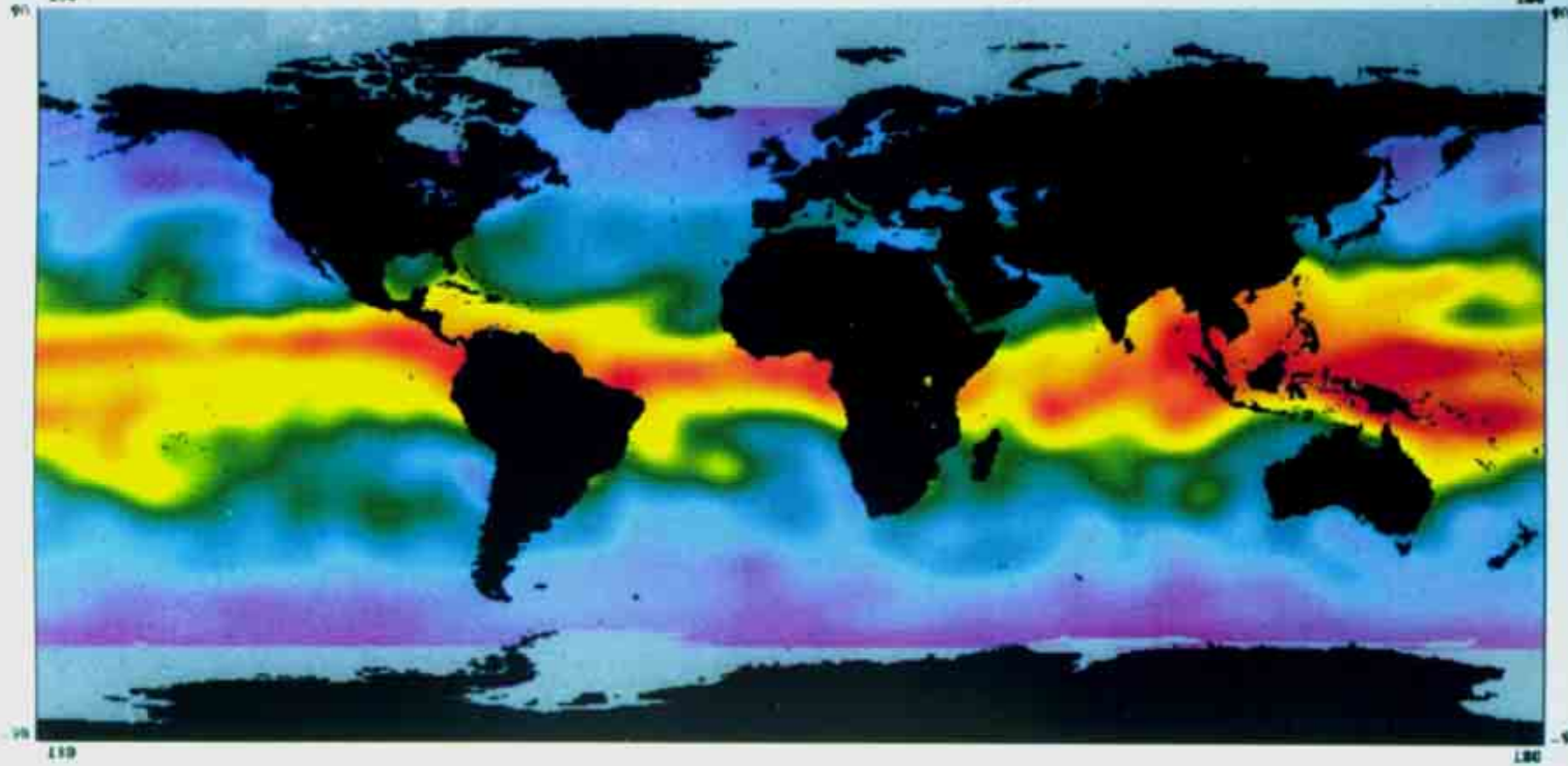
Sites where the OSU team has drilled ice cores




DUNDE ICE CAP, CHINA
CORE SITES, 1987
SUMMIT CORES
ICE FLOW
EQUILIBRIUM LINE
ANNUAL LAYERS THIN WITH DEPTH
X
XX
SHALLOW CORES
BEDROCK

96 / 85 / 82

Cycle 133.33



Water vapor

1 2 3 4 5

Grams per square centimeter

JPL

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

TOPEX/Poseidon

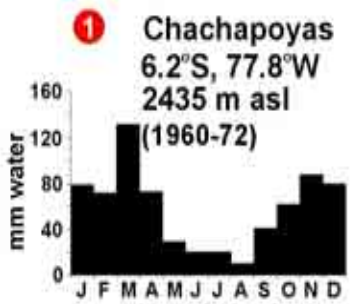
Produced at JPL with software developed at JPL and the University of Colorado, Boulder

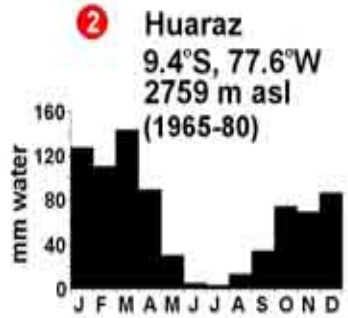
NASA

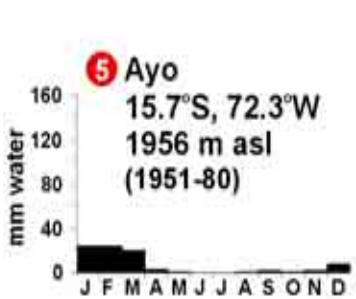
National Aeronautics and Space Administration

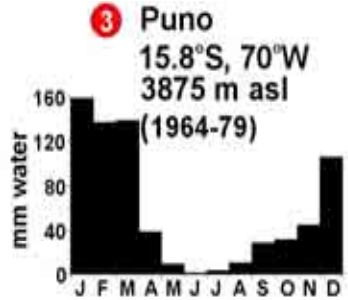
Wed Jan 17 20:25:44 1996

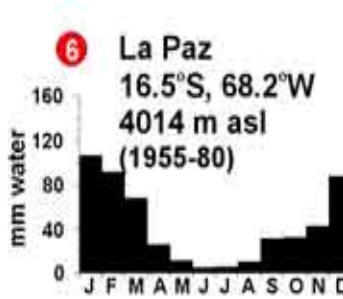

ECUADOR
PERU
Pucahirca
Huascarán
Huandoy
Copap
Caullaraju
Quelccaya
BOLIVIA
GLACIER
SITES
AWS 1991
Greater than 4000 m
Sajama
1
2
3
4
5
6

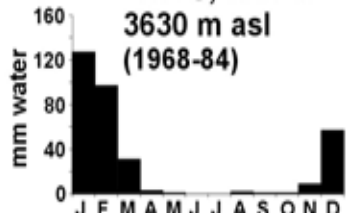

1 Chachapoyas
6.2°S, 77.8°W
2435 m asl
(1960-72)
mm water
160
120
80
40
0
J F M A M J J A S O N D

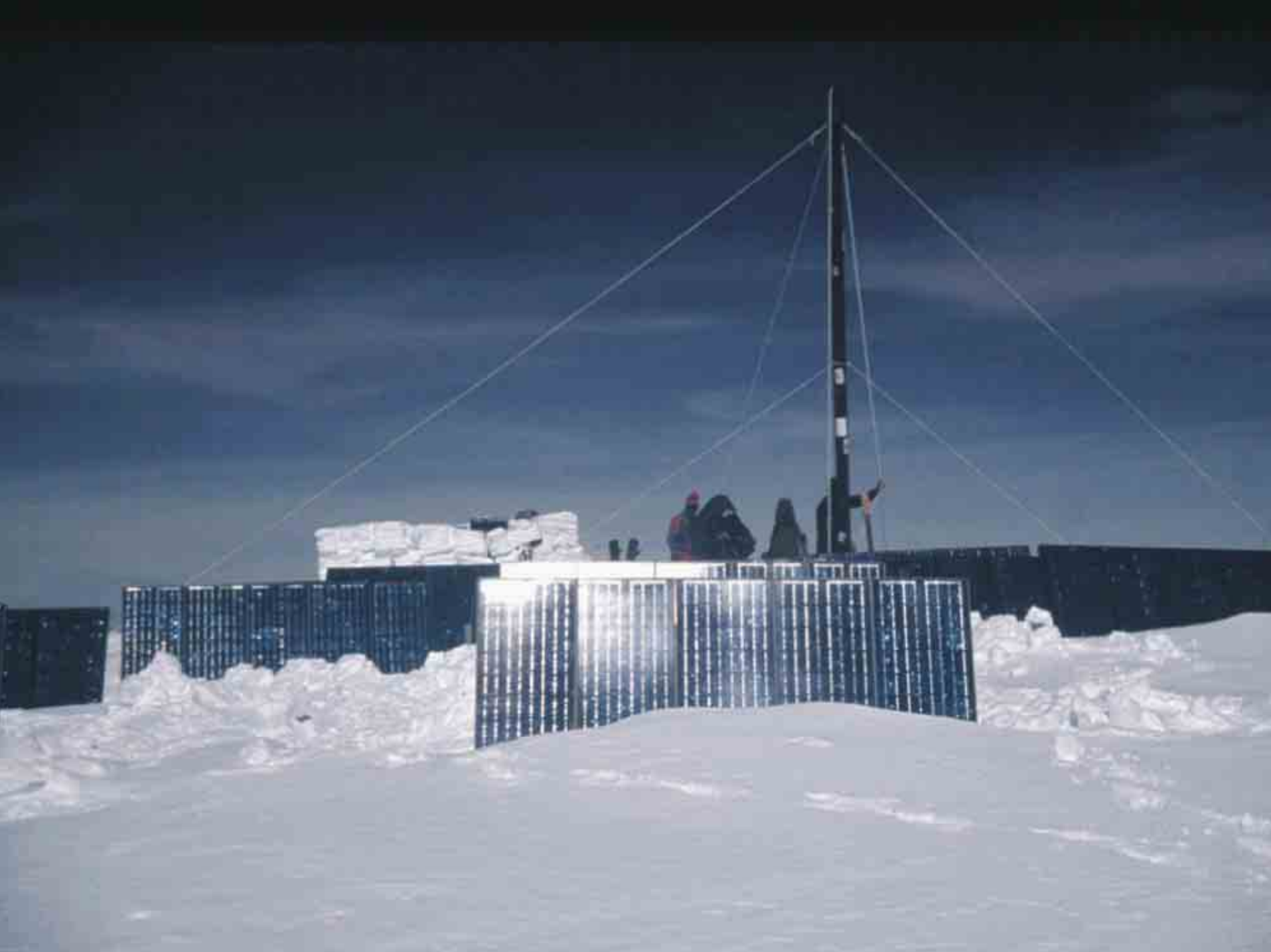

2 Huaraz
9.4°S, 77.6°W
2759 m asl
(1965-80)
mm water
160
120
80
40
0
J F M A M J J A S O N D

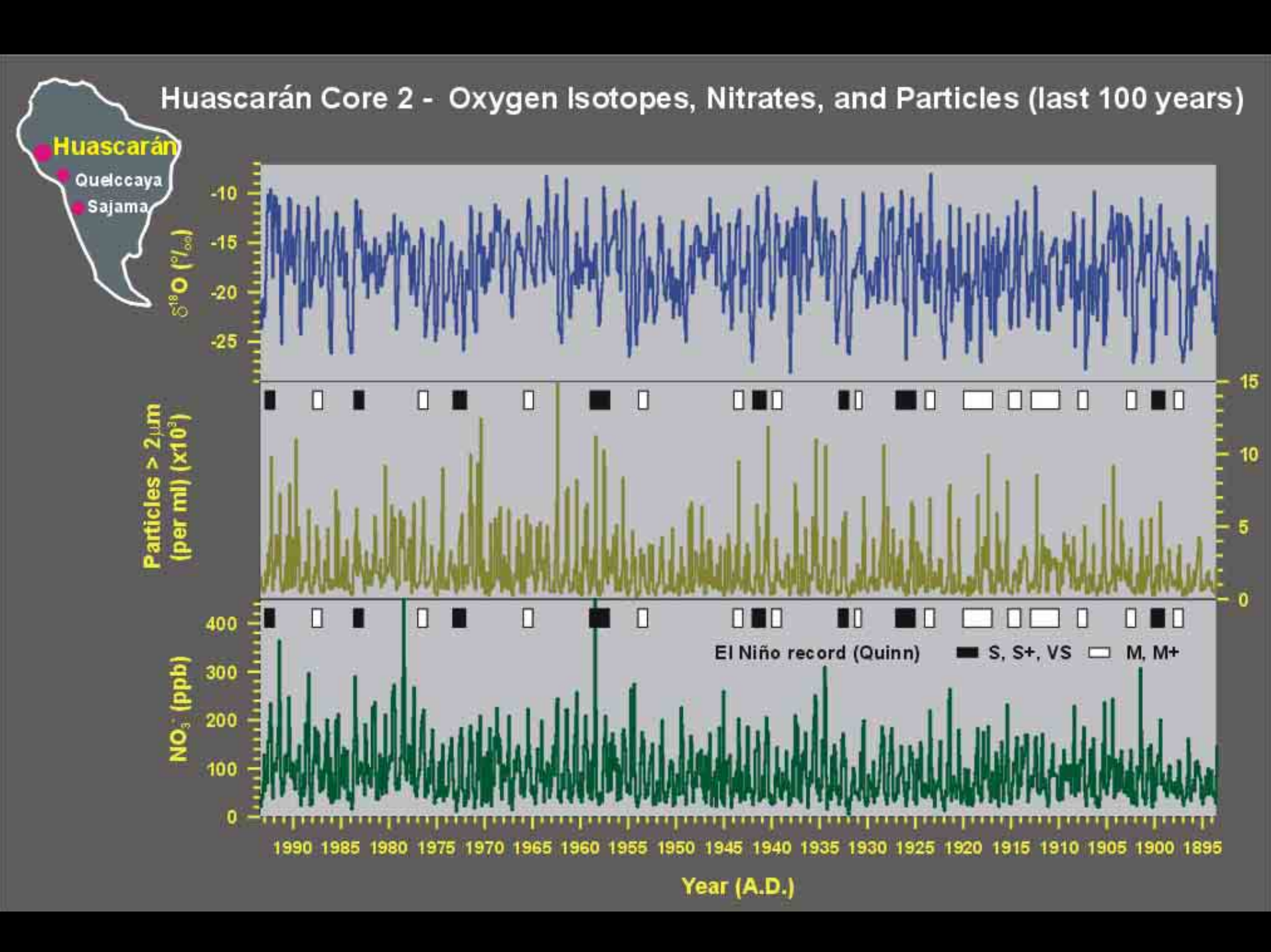

5 Ayo
15.7°S, 72.3°W
1956 m asl
(1951-80)
mm water
160
120
80
40
0
J F M A M J J A S O N D

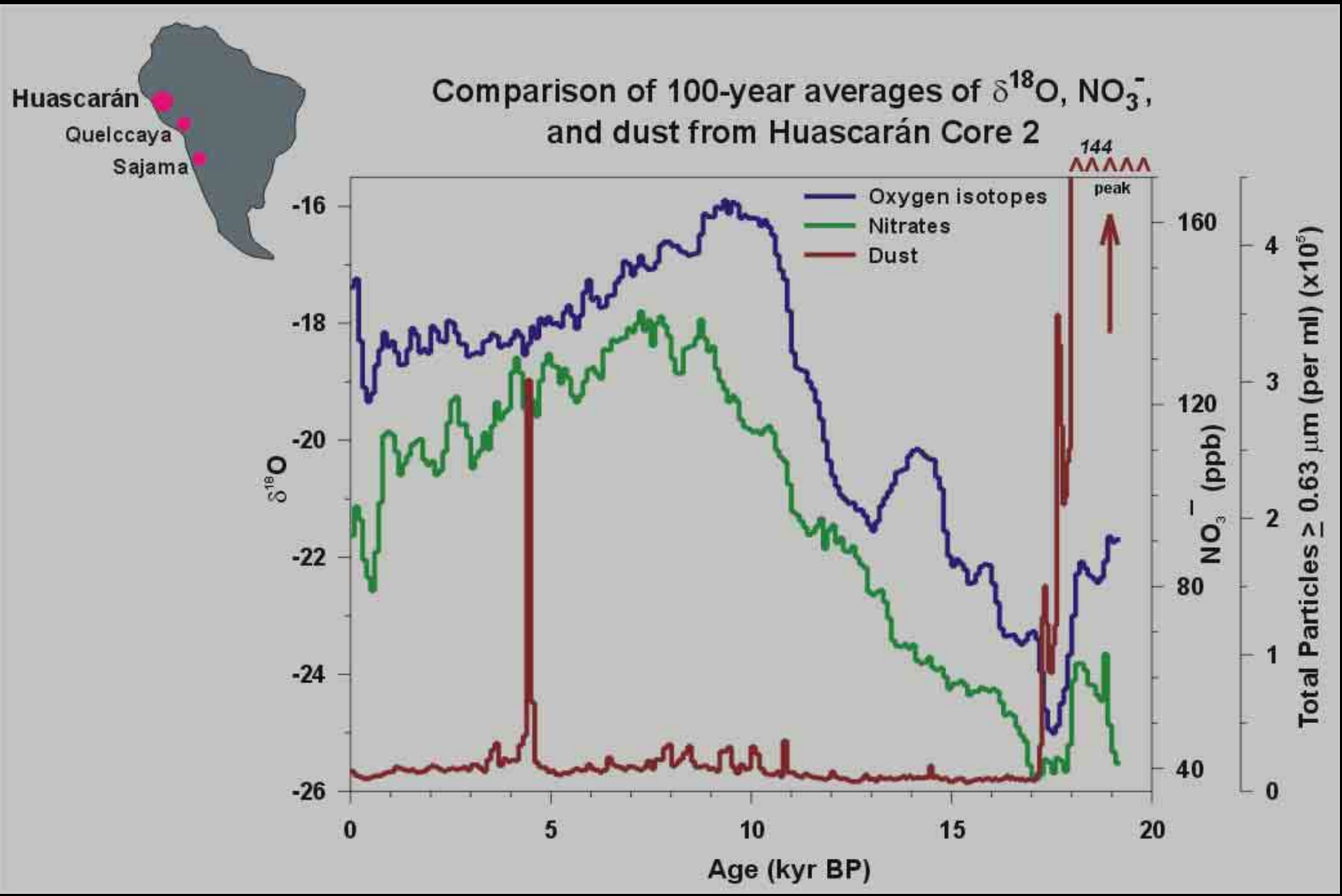

3 Puno
15.8°S, 70°W
3875 m asl
(1964-79)
mm water
160
120
80
40
0
J F M A M J J A S O N D

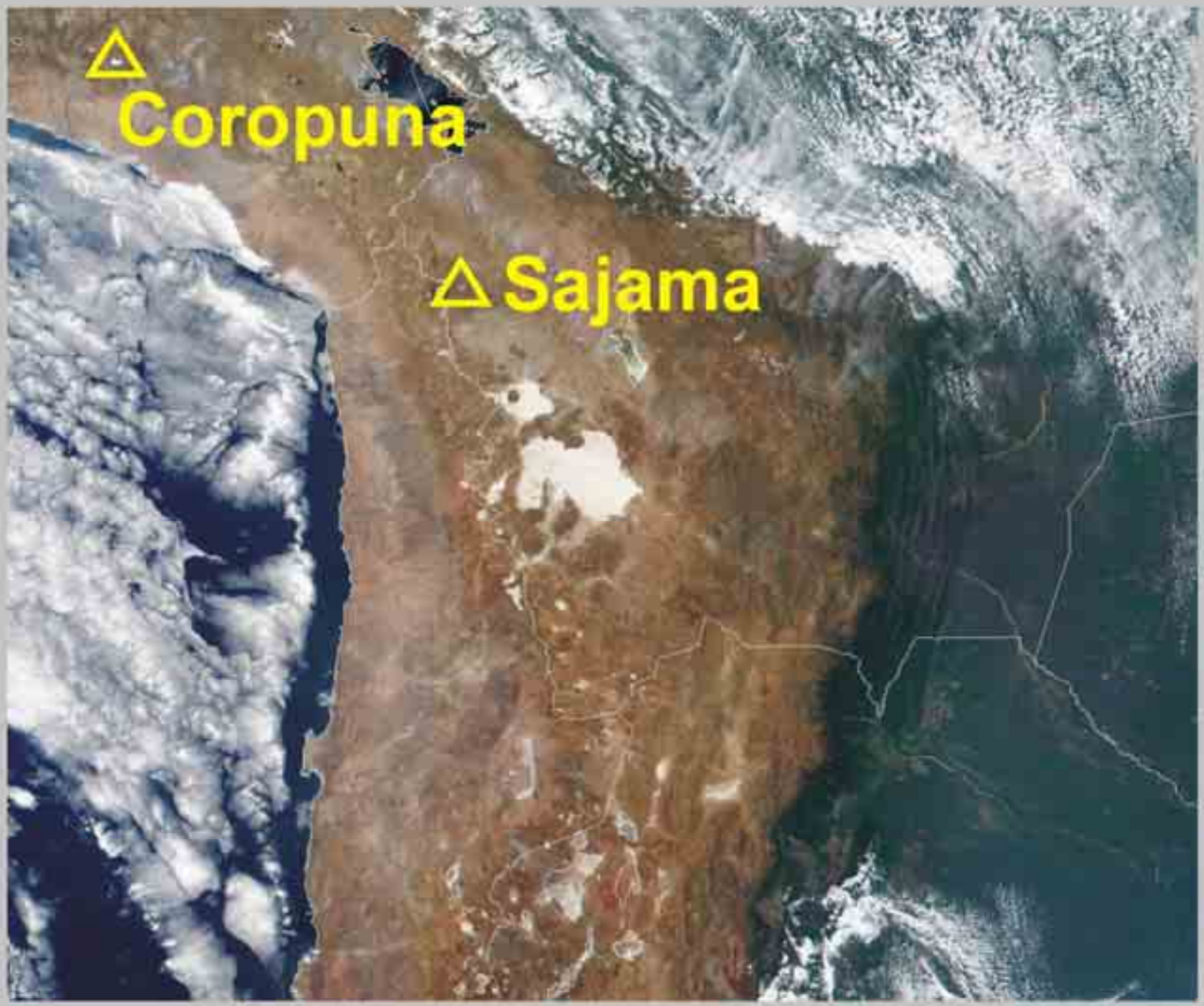

6 La Paz
16.5°S, 68.2°W
4014 m asl
(1955-80)
mm water
160
120
80
40
0
J F M A M J J A S O N D


4 Salinas de
G. Mendoza
19.6°S, 67.7°W
3630 m asl
(1968-84)
mm water
160
120
80
40
0
J F M A M J J A S O N D




Huascarán Core 2 - Oxygen Isotopes, Nitrates, and Particles (last 100 years)
Huascarán
Quelccaya
Sajama
δ18O (‰)
-10
-15
-20
-25
Particles > 2μm (per ml) (x10³)
15
10
5
0
NO3- (ppb)
400
300
200
100
0
El Niño record (Quinn)
S, S+, VS
M, M+
1990 1985 1980 1975 1970 1965 1960 1955 1950 1945 1940 1935 1930 1925 1920 1915 1910 1905 1900 1895
Year (A.D.)


Huascarán
Quelccaya
Sajama
Comparison of 100-year averages of $\delta^{18}O$, NO_3^-, and dust from Huascarán Core 2
144
peak
Oxygen isotopes
Nitrates
Dust
-16
-18
-20
-22
-24
-26
$\delta^{18}O$
160
120
80
40
NO_3^- (ppb)
4
3
2
1
0
Total Particles ≥ 0.63 μm (per ml) (x10^5)
0
5
10
15
20
Age (kyr BP)



source: http://visiblearth.nasa.gov/cgi-bin/viewrecord?7330

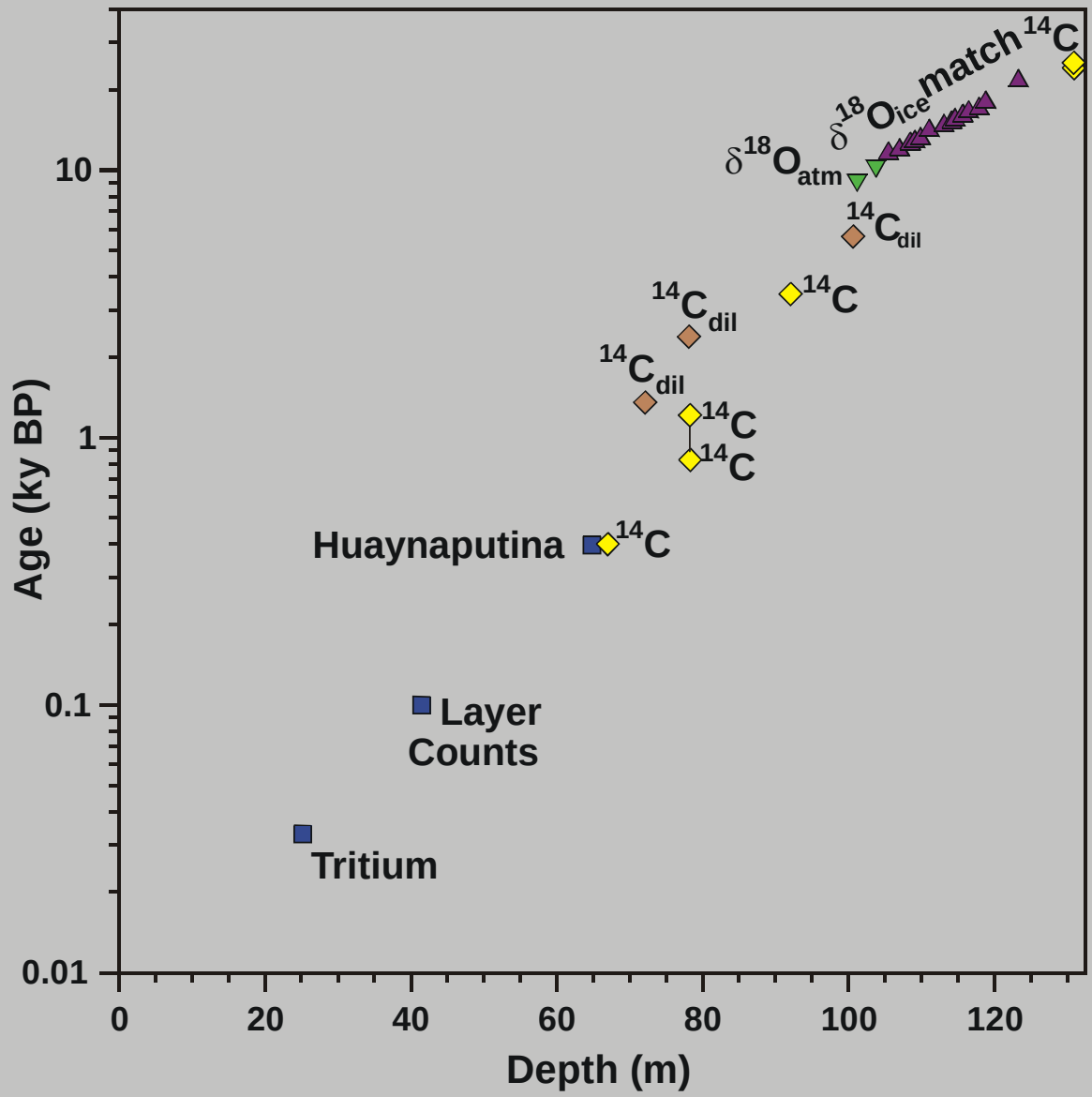
South American Altiplano

Sajama, Bolivia

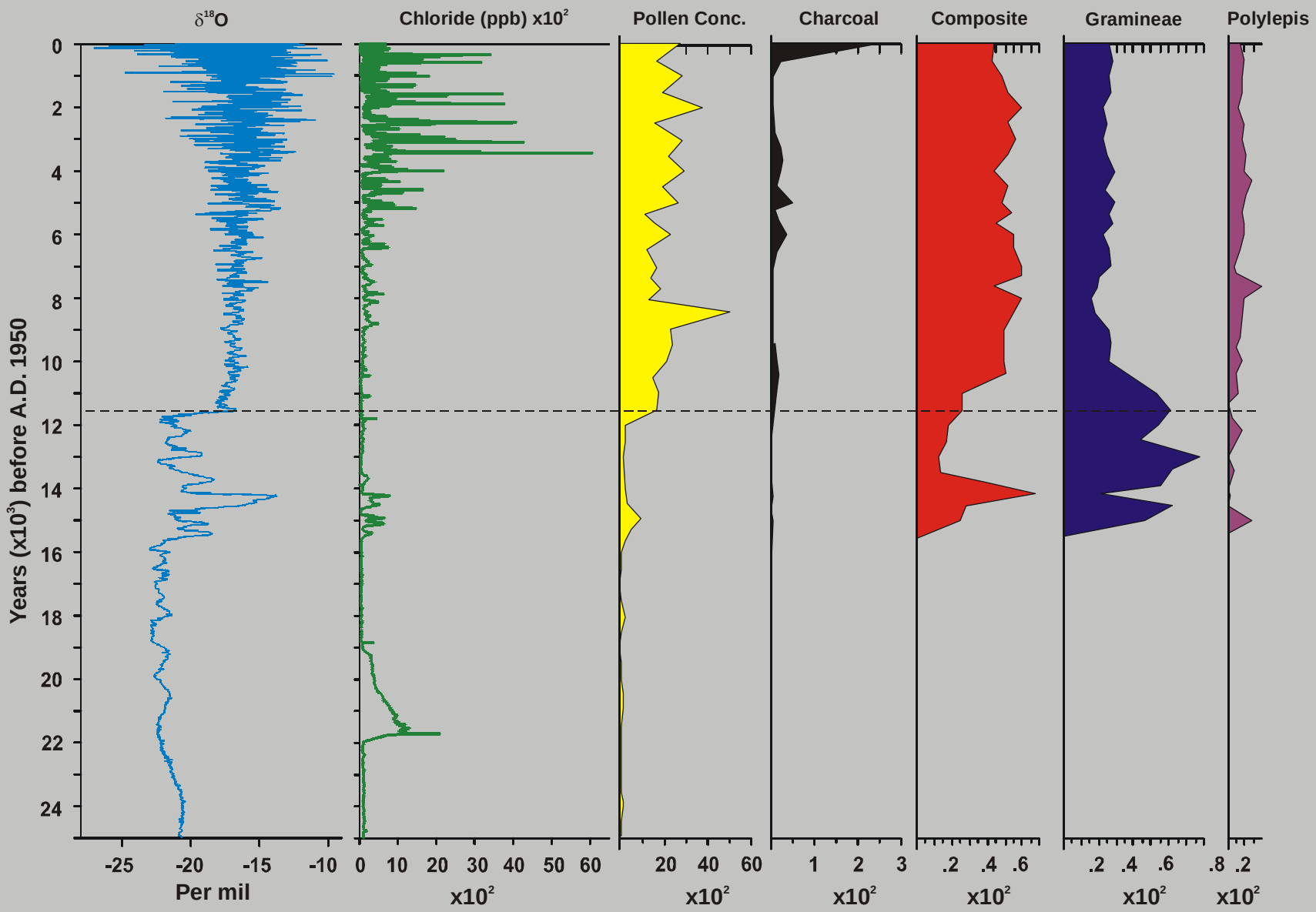
Ice began to accumulate on the top of an extinct volcano ~25,000 years ago

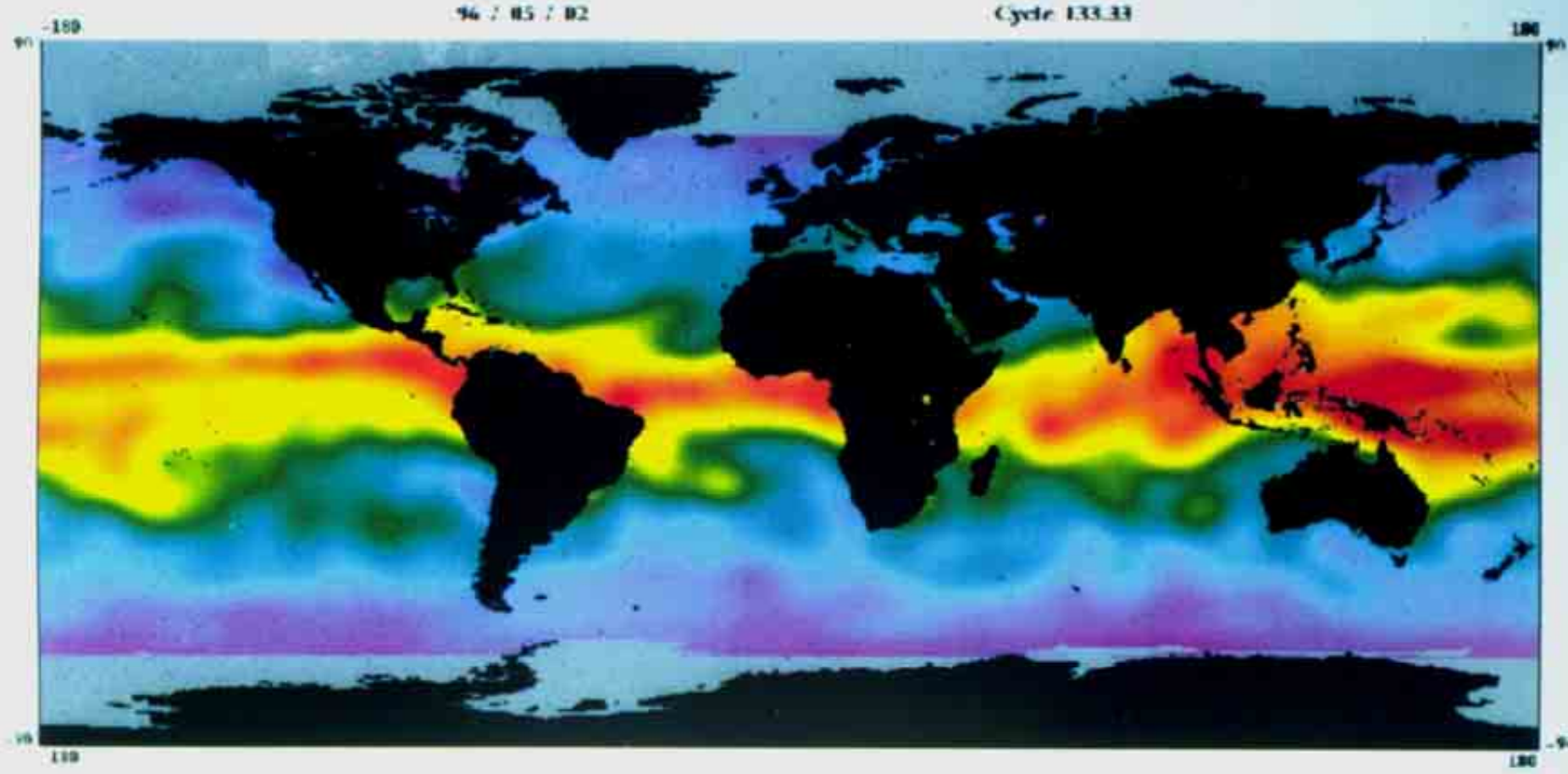
Sajama, Bolivia
Heteroptera
5620 ± 275 yr. B.P.
length: 2.0 mm

The Sajama ice core is the first to be carbon-14 dated



Sajama Ice Core





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Pasadena, California

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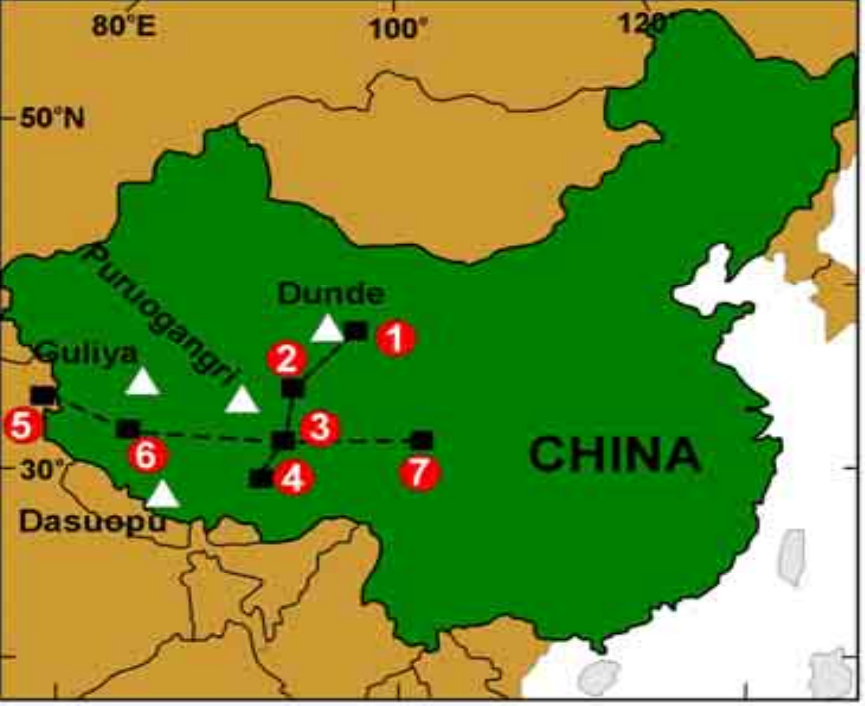
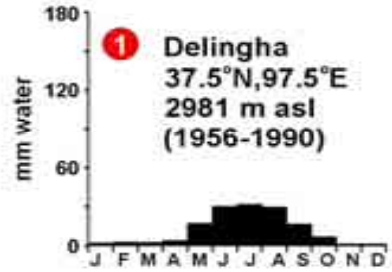
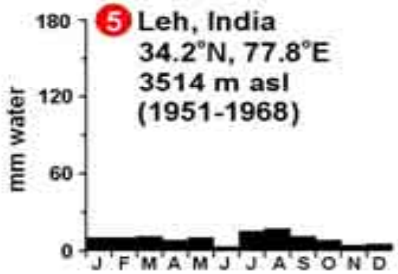
NASA

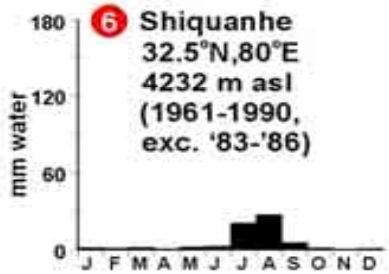
National Aeronautics
and Space Administration

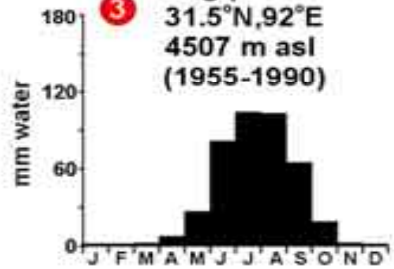

80°E
100°
120°
50°N
30°
Punuogangri
Dunde
Guliya
Dasuopu
CHINA
1
2
3
4
5
6
7

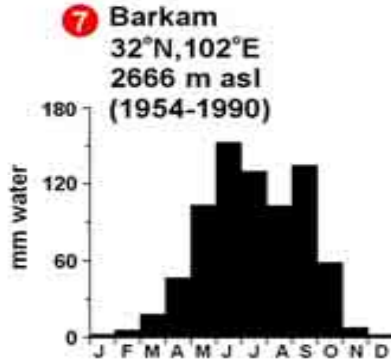

1 Delingha
37.5°N,97.5°E
2981 m asl
(1956-1990)
mm water
180
120
60
0
J F M A M J J A S O N D

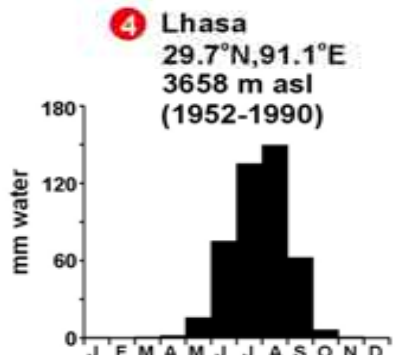

2 Tuotuohe
34°N,92.5°E
4535 m asl
(1957-1990)
mm water
180
120
60
0
J F M A M J J A S O N D

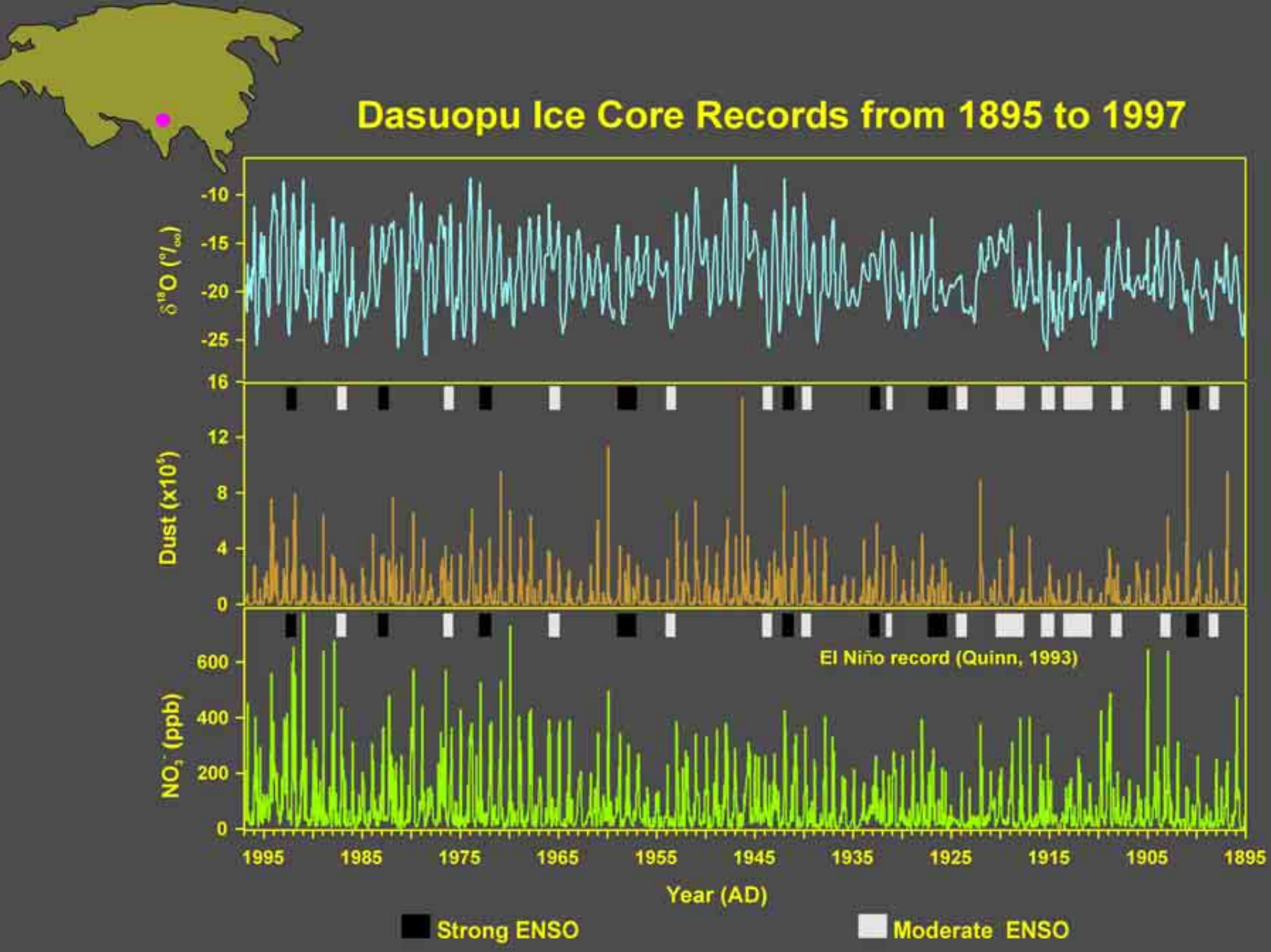

5 Leh, India
34.2°N, 77.8°E
3514 m asl
(1951-1968)
mm water
180
120
60
0
J F M A M J J A S O N D


6 Shiquanhe
32.5°N,80°E
4232 m asl
(1961-1990,
exc. '83-'86)
mm water
180
120
60
0
J F M A M J J A S O N D

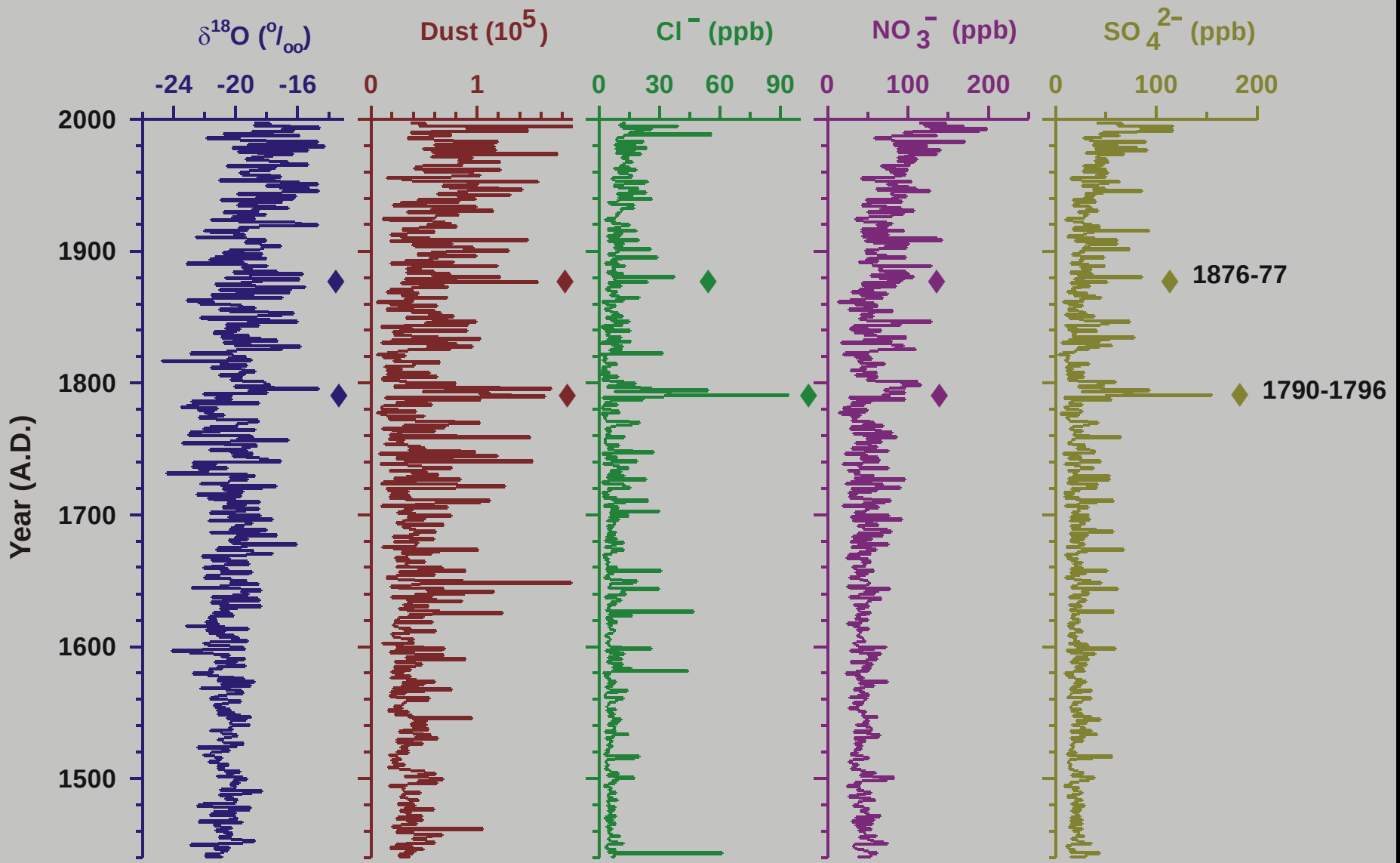

3 Nagqu
31.5°N,92°E
4507 m asl
(1955-1990)
mm water
180
120
60
0
J F M A M J J A S O N D


7 Barkam
32°N,102°E
2666 m asl
(1954-1990)
mm water
180
120
60
0
J F M A M J J A S O N D

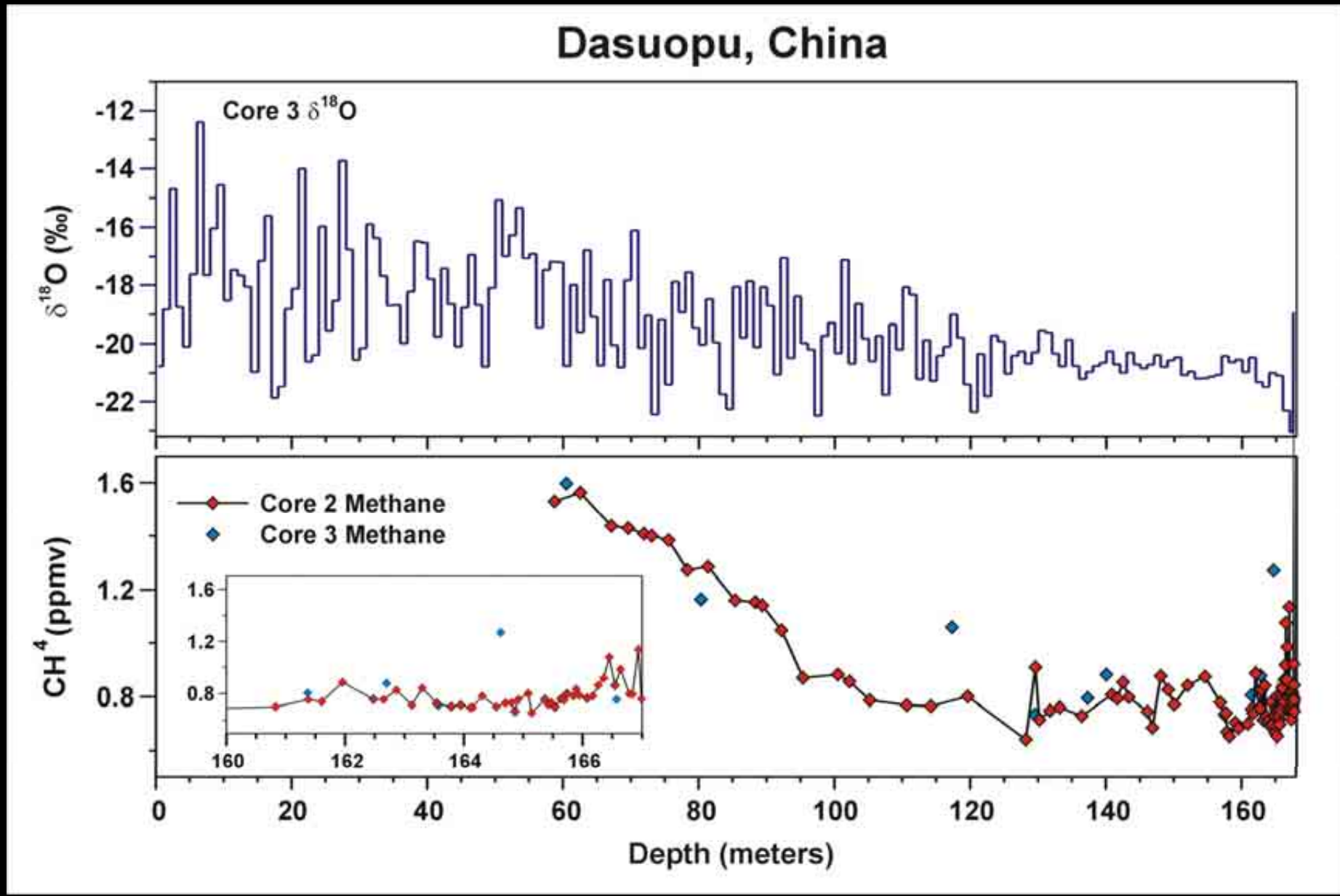

4 Lhasa
29.7°N,91.1°E
3658 m asl
(1952-1990)
mm water
180
120
60
0
J F M A M J J A S O N D


Dasuopu Ice Core Records from 1895 to 1997
δ18O (‰)
-10
-15
-20
-25
Dust (x10³)
16
12
8
4
0
El Niño record (Quinn, 1993)
NO3- (ppb)
600
400
200
0
1995
1985
1975
1965
1955
1945
1935
1925
1915
1905
1895
Year (AD)
Strong ENSO
Moderate ENSO

Dasuopu Glacier, Chinese Himalaya



Thompson *et al.*, *Science*, 2000

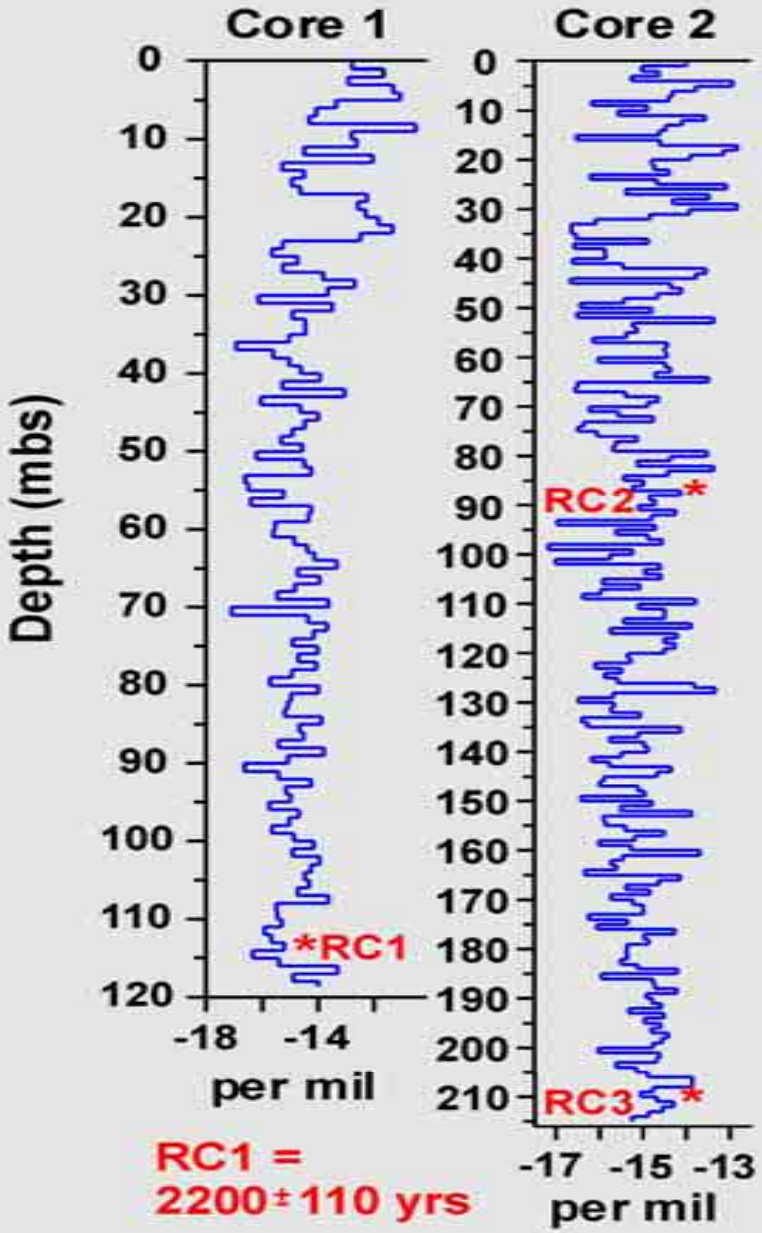

Dasuopu, China
Core 3 δ18O
δ18O (‰)
-12
-14
-16
-18
-20
-22
Core 2 Methane
Core 3 Methane
CH4 (ppmv)
1.6
1.2
0.8
160
162
164
166
0
20
40
60
80
100
120
140
160
Depth (meters)


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

Puruogangri Ice Cap, Central Tibet

△ Visible annual dust layers

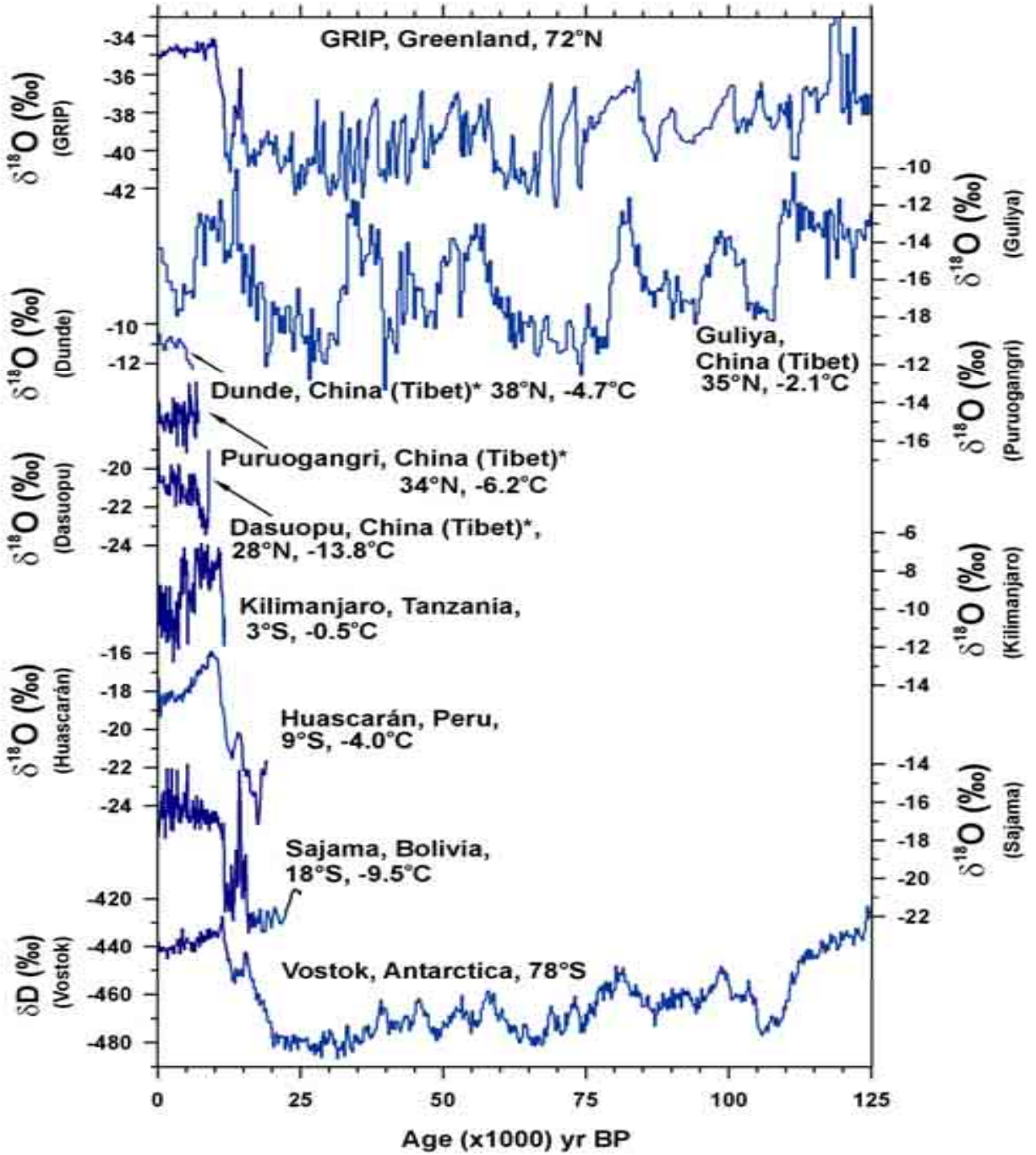
Puruogangri, Central Tibet



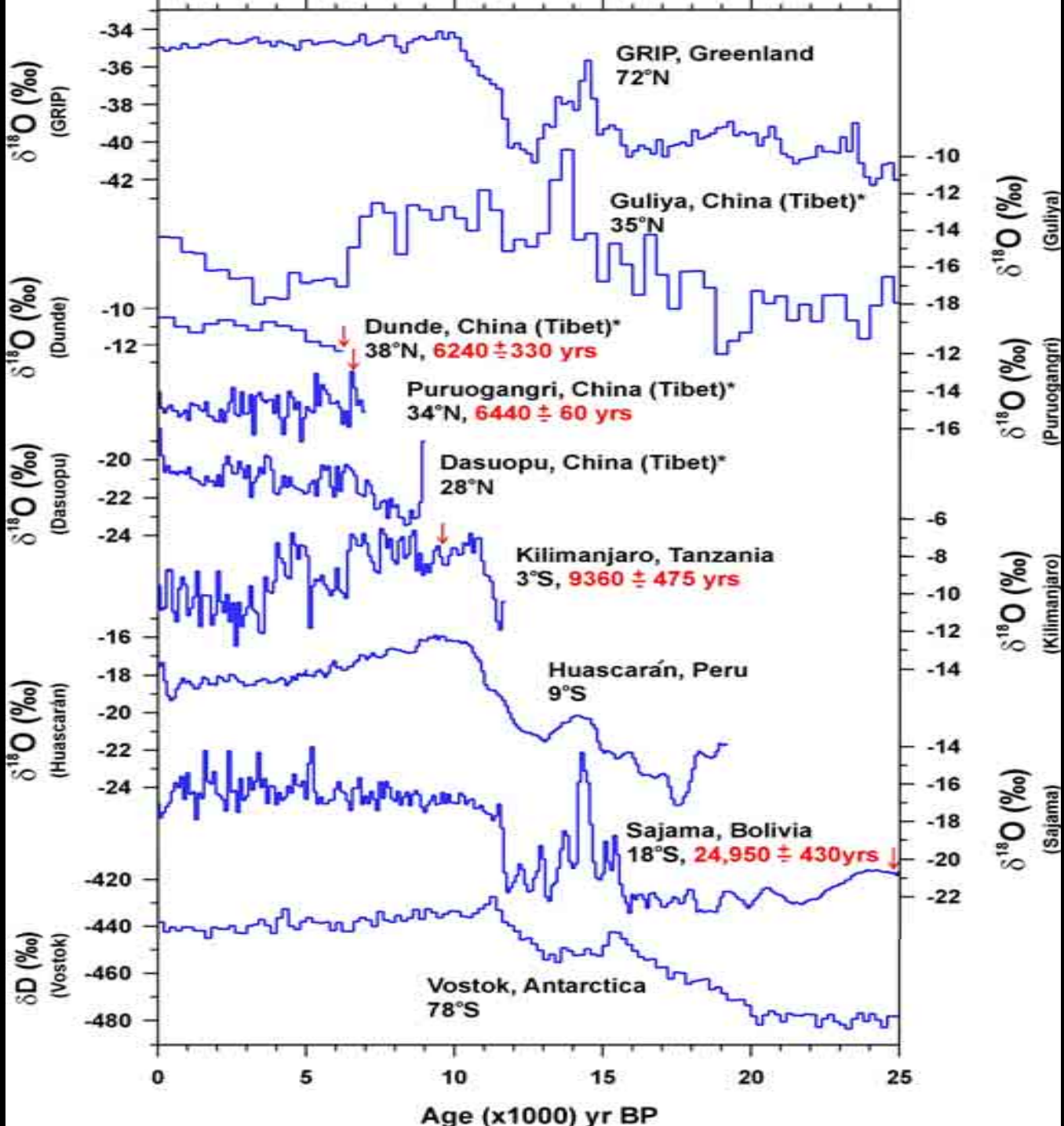
RC1 = 2200±110 yrs

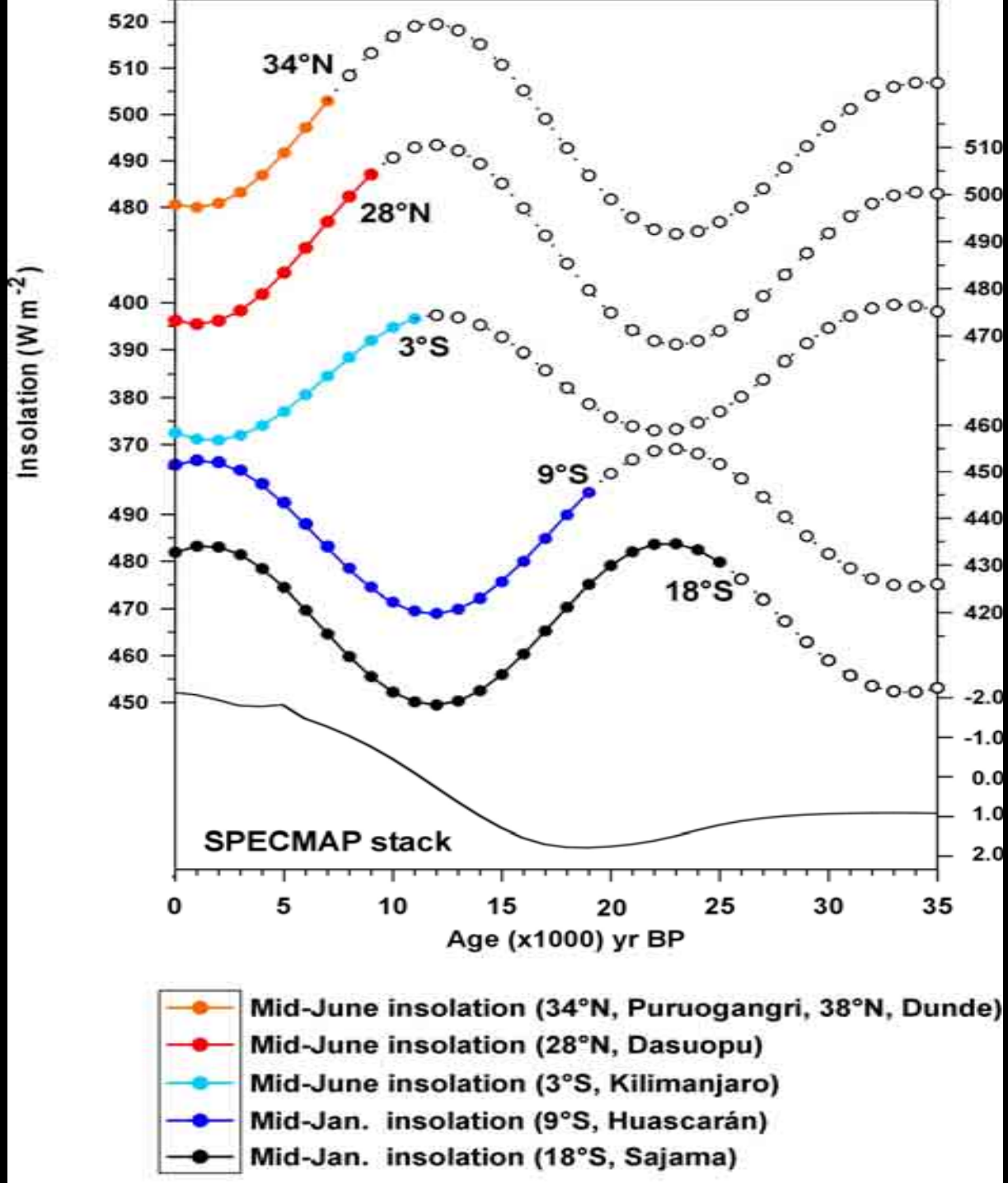
RC2 = 190±50 yrs

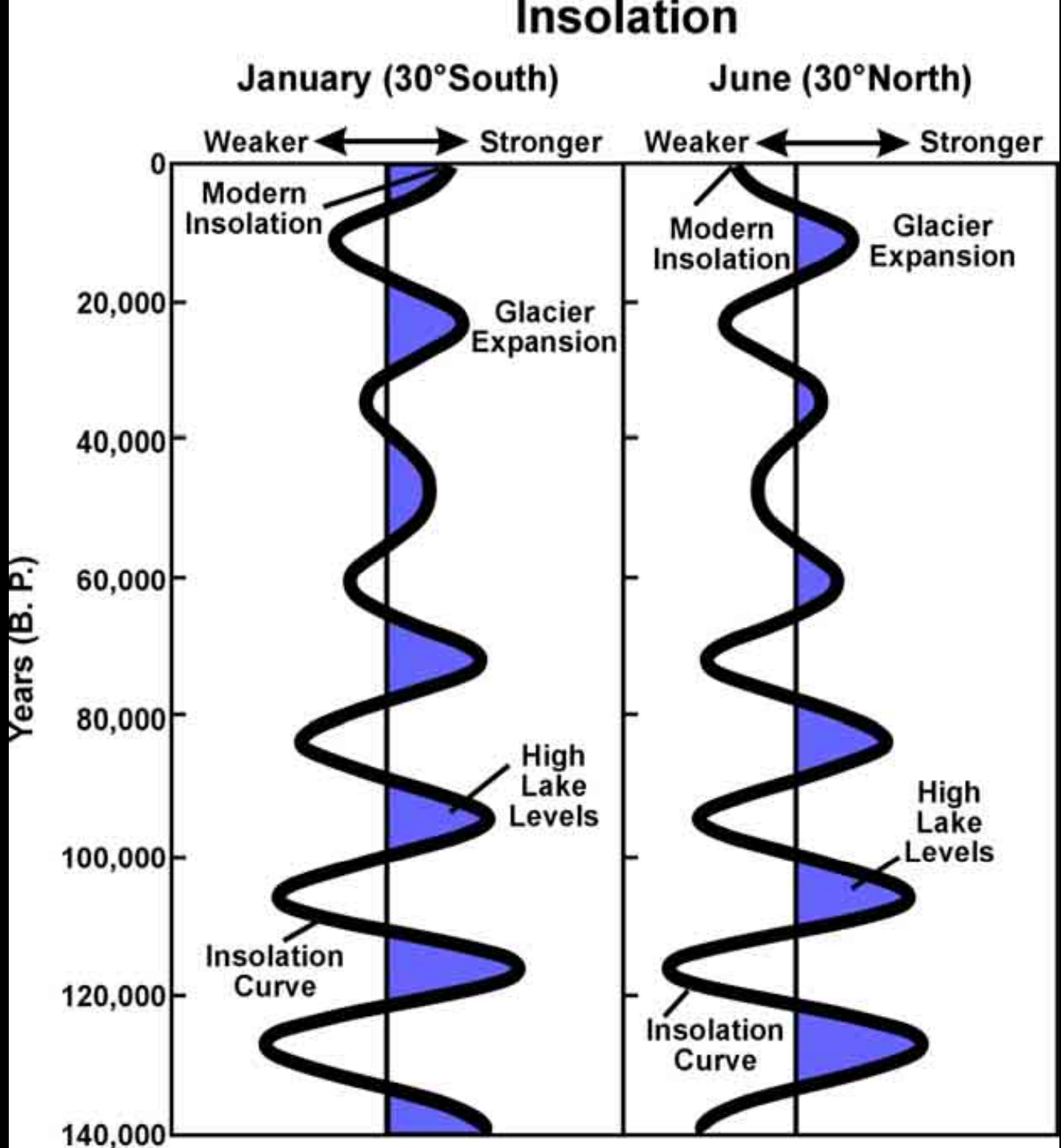
RC3 = 6440±60 yrs


GRIP, Greenland, 72°N
δ18O (‰) (GRIP)
-34
-36
-38
-40
-42
Guliya, China (Tibet) 35°N, -2.1°C
δ18O (‰) (Guliya)
-10
-12
-14
-16
-18
Dunde, China (Tibet)* 38°N, -4.7°C
δ18O (‰) (Dunde)
-10
-12
Puruogangri, China (Tibet)* 34°N, -6.2°C
δ18O (‰) (Puruogangri)
-12
-14
-16
Dasuopu, China (Tibet)*, 28°N, -13.8°C
δ18O (‰) (Dasuopu)
-20
-22
-24
Kilimanjaro, Tanzania, 3°S, -0.5°C
δ18O (‰) (Kilimanjaro)
-6
-8
-10
-12
-14
Huascarán, Peru, 9°S, -4.0°C
δ18O (‰) (Huascarán)
-16
-18
-20
-22
-24
Sajama, Bolivia, 18°S, -9.5°C
δ18O (‰) (Sajama)
-14
-16
-18
-20
-22
Vostok, Antarctica, 78°S
δD (‰) (Vostok)
-420
-440
-460
-480
0
25
50
75
100
125
Age (x1000) yr BP

Core:	Modern (0-1 ka)	Early Holocene (EH) (6.8 - 10.0 ka)	Last Glacial Maximum (LGM) (18.0-21.2 ka)	LGM-Modern (‰)	LGM-EH (‰)
Sajama (Bolivia)	-16.8	-16.7	-22.1	5.4	5.4
Huascarán (Peru)	-18.5	-16.6	-22.9	4.4	6.3
GISP2 (Greenland)	-35.0	-34.6	-39.7	4.7	5.1
Guliya (W. China)	-14.4	-13.1	-18.5	4.1	5.4
Byrd (Antarctica)	-32.8	-33.9	-40.5	7.6	6.6
Vostok (Antarctica)	-441(-56.4)	-436(-55.7)	-472(-60.2)	3.9	4.5
Vostok (21.0 - 24.2 ka)	-441(-56.4)	-436(-55.7)	-479(-61.1)	4.8	5.4


GRIP, Greenland
72°N
Guliya, China (Tibet)*
35°N
Dunde, China (Tibet)*
38°N, 6240 ± 330 yrs
Puruogangri, China (Tibet)*
34°N, 6440 ± 60 yrs
Dasuopu, China (Tibet)*
28°N
Kilimanjaro, Tanzania
3°S, 9360 ± 475 yrs
Huascarán, Peru
9°S
Sajama, Bolivia
18°S, 24,950 ± 430yrs
Vostok, Antarctica
78°S
δ18O (‰) (GRIP)
δ18O (‰) (Dunde)
δ18O (‰) (Dasuopu)
δ18O (‰) (Huascarán)
δD (‰) (Vostok)
δ18O (‰) (Guliya)
δ18O (‰) (Puruogangri)
δ18O (‰) (Kilimanjaro)
δ18O (‰) (Sajama)
Age (x1000) yr BP


34°N
28°N
3°S
9°S
18°S
SPECMAP stack
Insolation (W m-2)
Age (x1000) yr BP
Mid-June insolation (34°N, Puruogangri, 38°N, Dunde)
Mid-June insolation (28°N, Dasuopu)
Mid-June insolation (3°S, Kilimanjaro)
Mid-Jan. insolation (9°S, Huascarán)
Mid-Jan. insolation (18°S, Sajama)


Insolation
January (30°South)
June (30°North)
Weaker
Stronger
Weaker
Stronger
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
Years (B. P.)
Modern Insolation
Glacier Expansion
High Lake Levels
Insolation Curve
Modern Insolation
Glacier Expansion
High Lake Levels
Insolation Curve

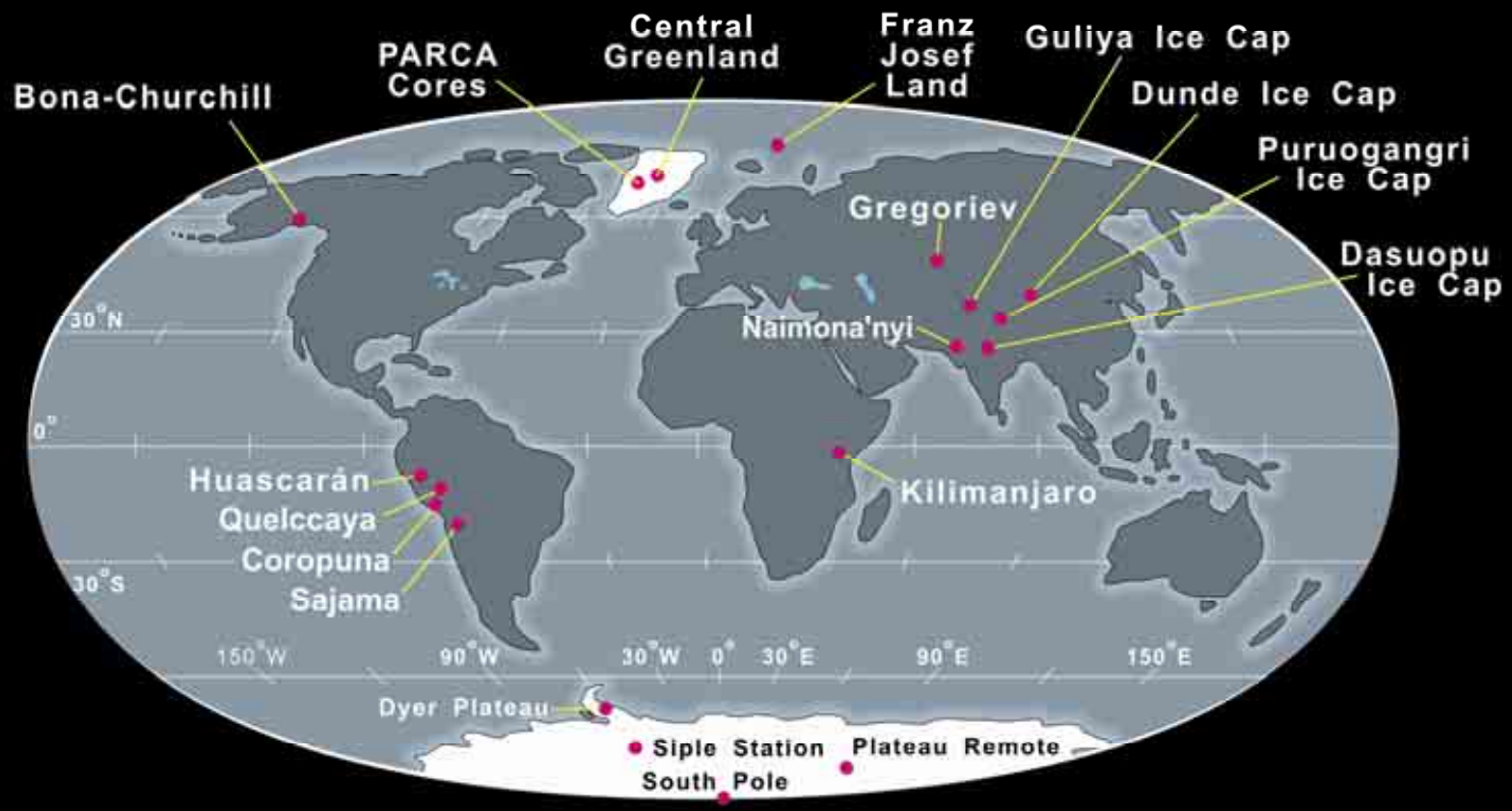
- **The $\delta^{18}O$ changes at the end of the Last Glacial Stage (where recorded) appear of comparable magnitude.**

- **The lack of glacial-stage ice at the bottom of the Kilimanjaro, Dasuopu and Puruogangri ice cores suggests the importance of summer monsoon precipitation for existence of low-latitude glaciers and ice caps.**

- **Asynchronous growth of low latitude mountain glaciers may result from precession–driven changes in water vapor.**

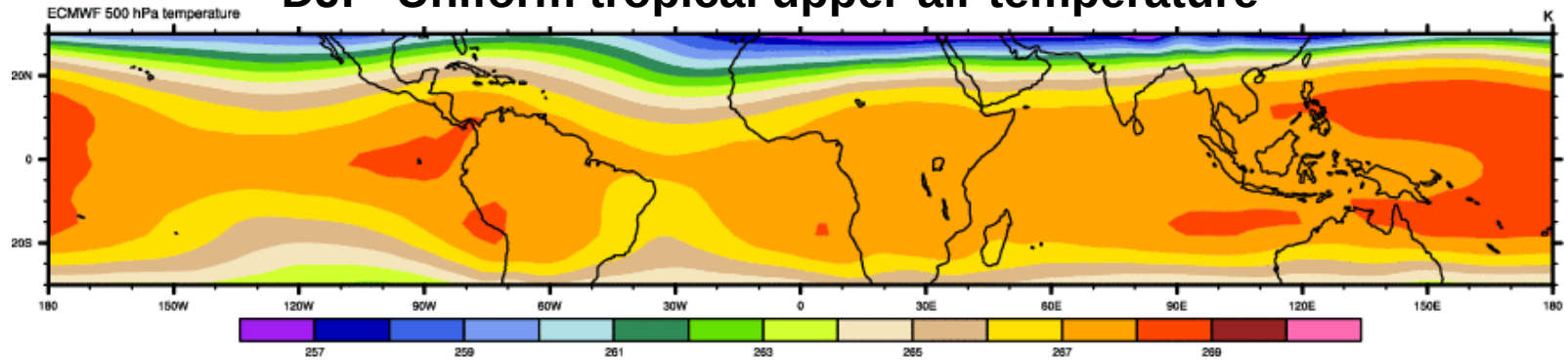
- **The last glaciation (here defined as the presence or absence of ice) is not globally synchronous, but more likely transitory in space and time.**

Sites where the OSU team has drilled ice cores

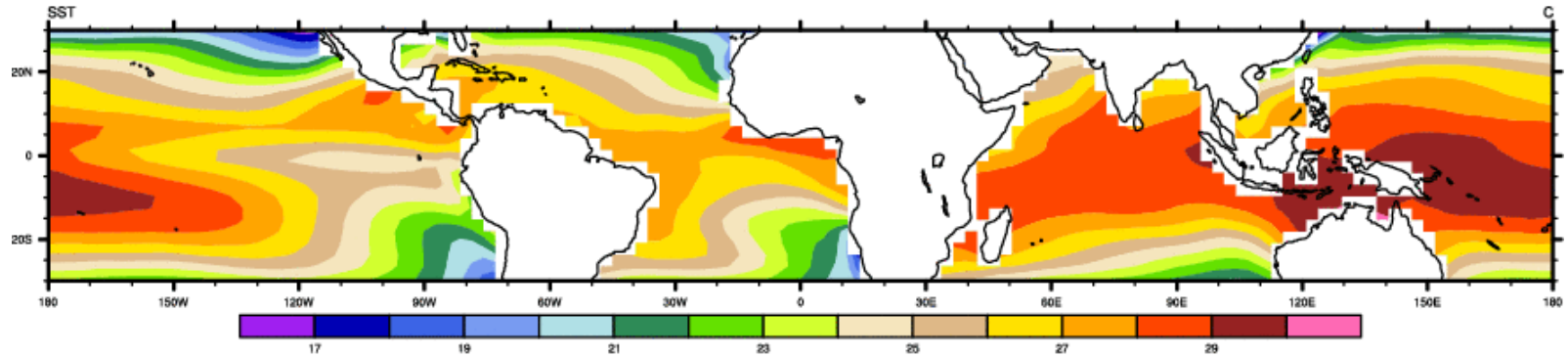


Ice core drilling on the Coropuna Ice Cap, Peru (2003)

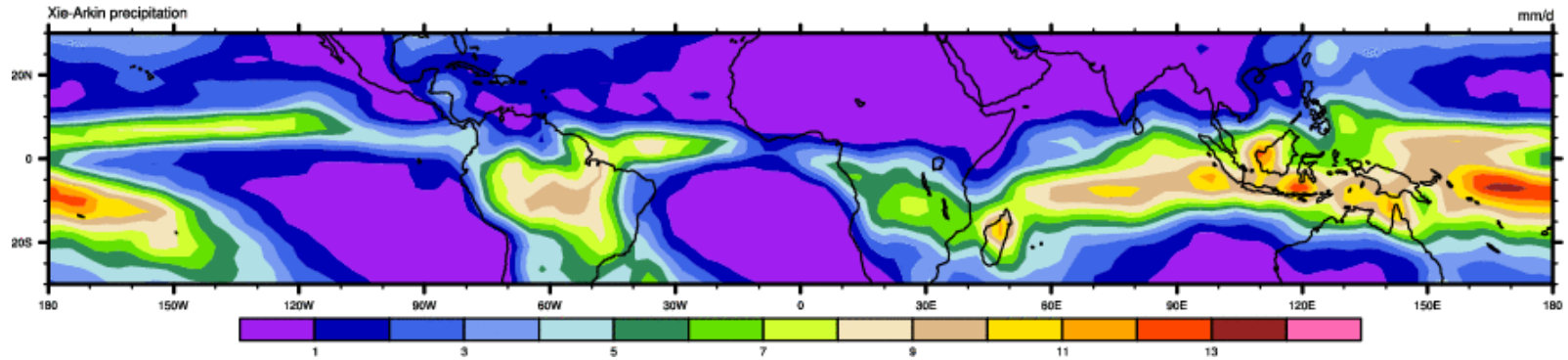
DJF Uniform tropical upper-air temperature



DJF Larger SST variations



DJF Rainfall roughly follows warm SST



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

Ecuador

Peru

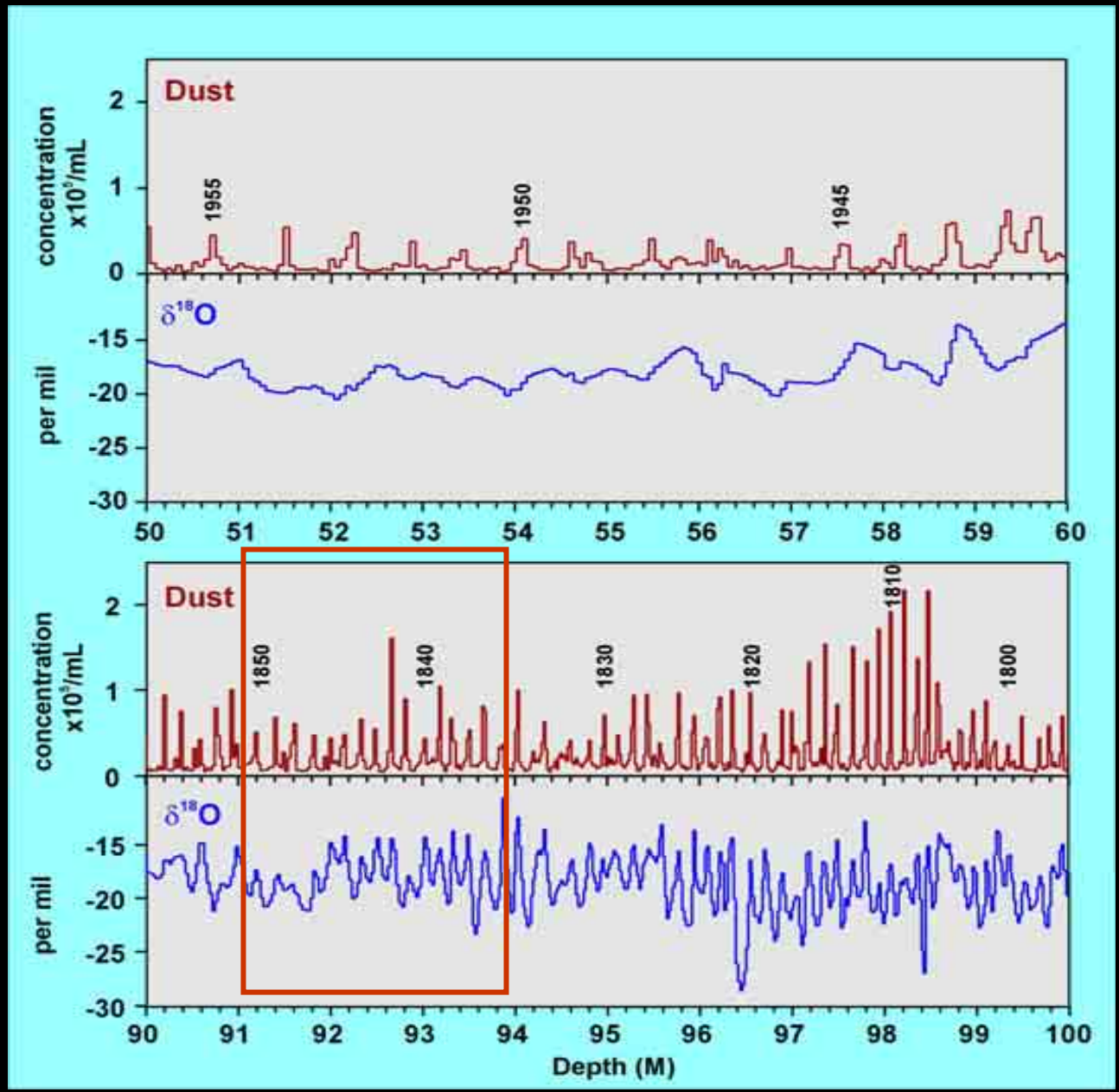
Lima

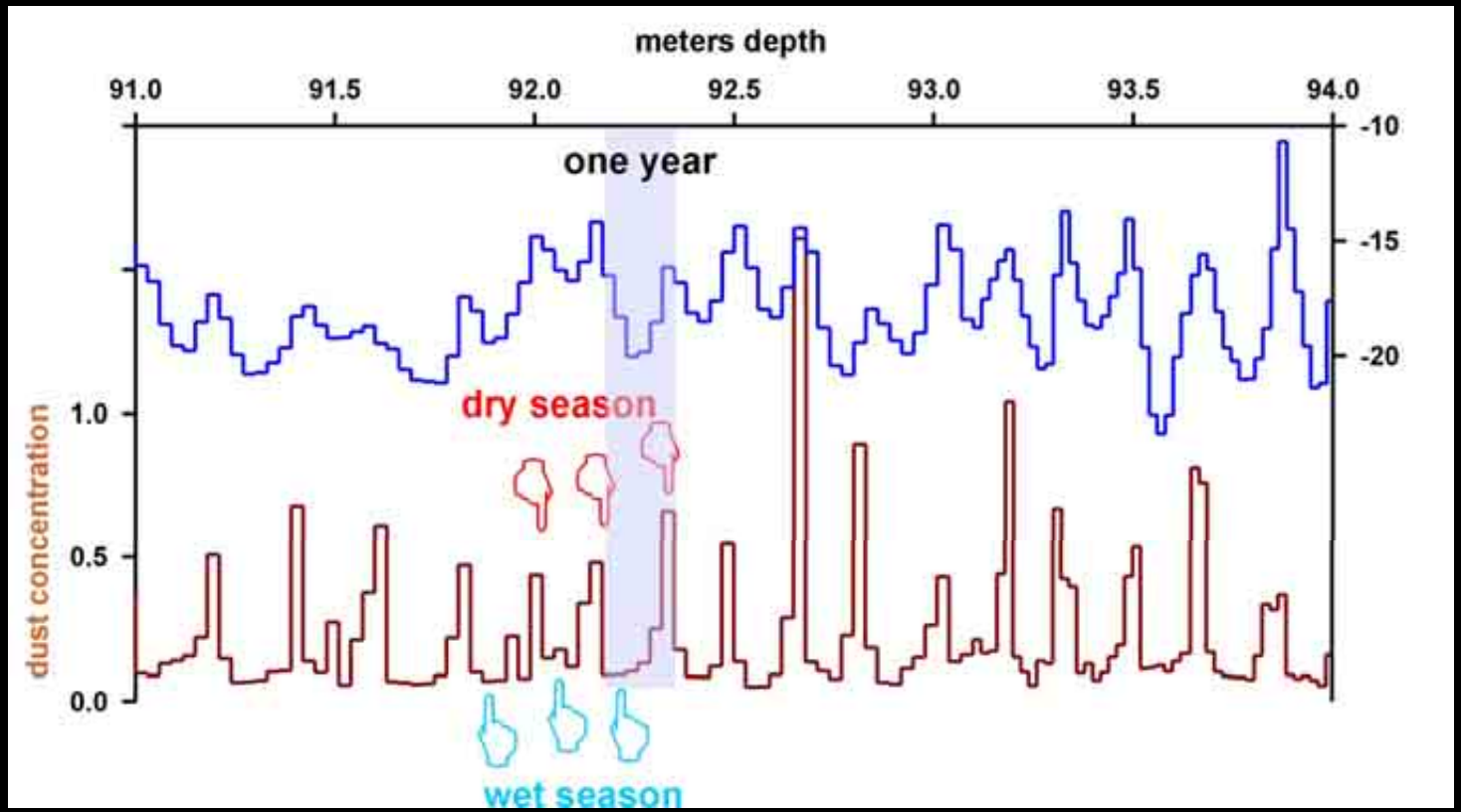
Quelccaya

Coropuna

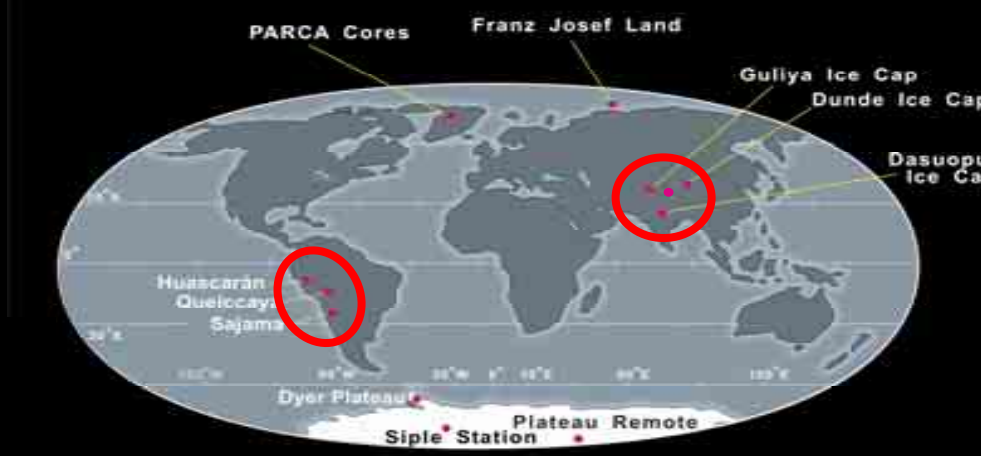
Side of Quelccaya ice cap, Peru

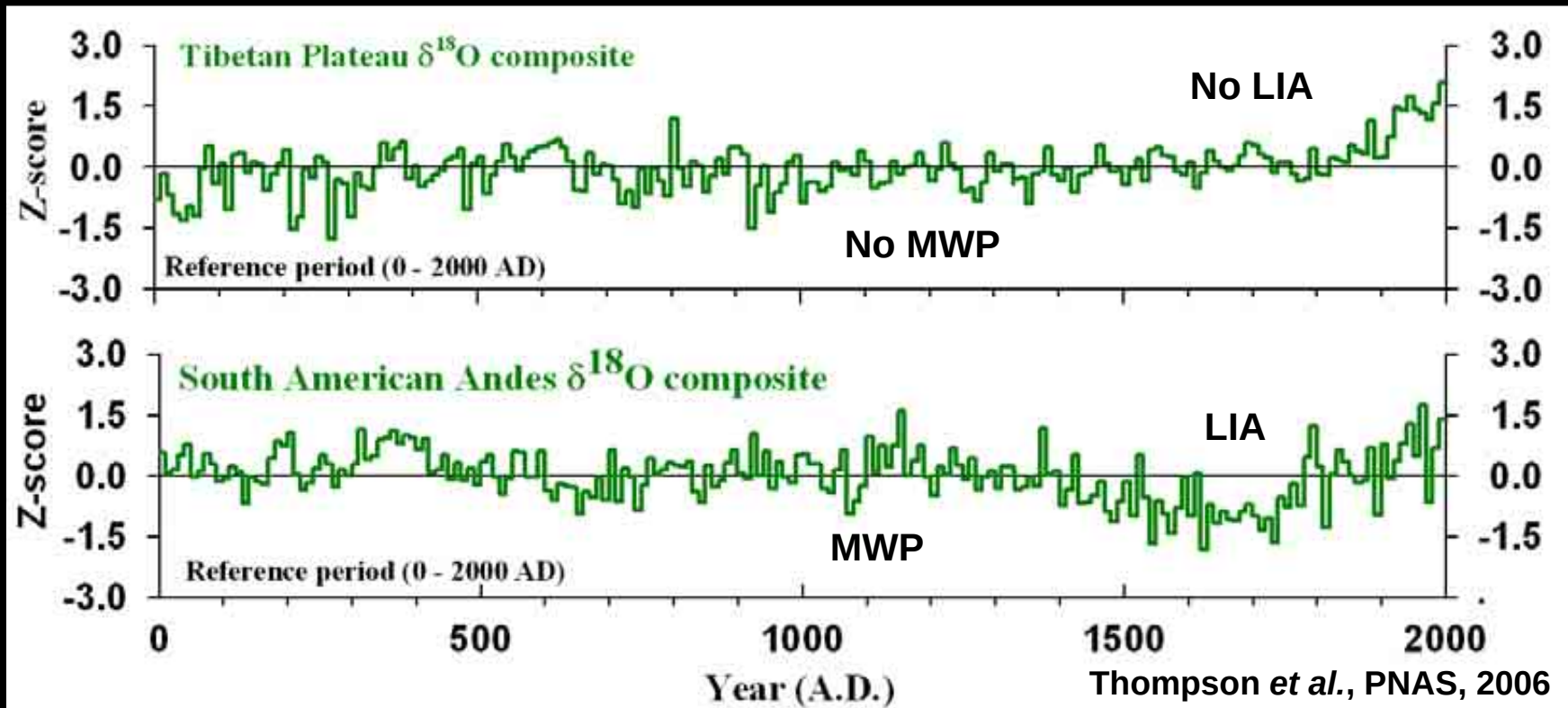
Annual layers


Dust
concentration x10⁵/mL
2
1
0
1955
1950
1945
δ¹⁸O
per mil
-15
-20
-25
-30
50
51
52
53
54
55
56
57
58
59
60
Dust
concentration x10⁵/mL
2
1
0
1850
1840
1830
1820
1810
1800
δ¹⁸O
per mil
-15
-20
-25
-30
90
91
92
93
94
95
96
97
98
99
100
Depth (M)


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

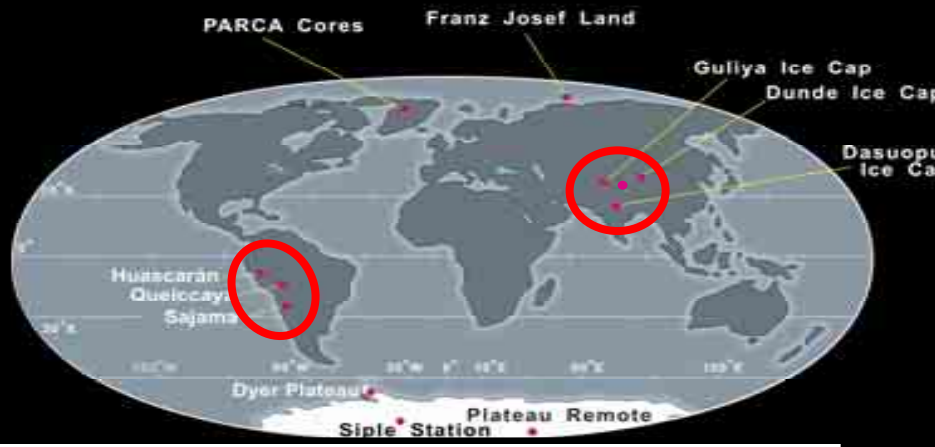
High elevation, low latitude ice cores record
- large-scale climate changes
- regional differences

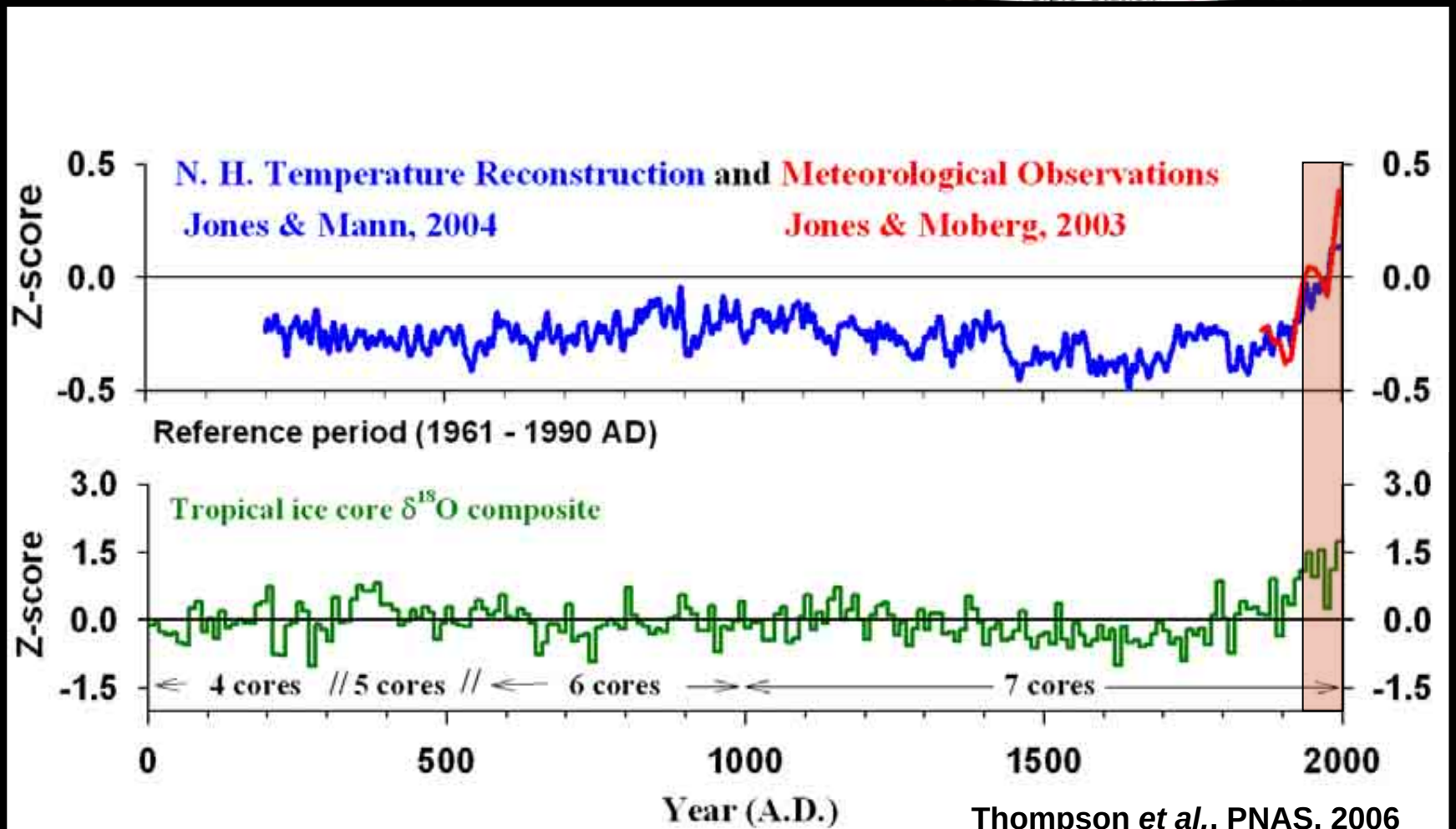




Thompson *et al.*, PNAS, 2006

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

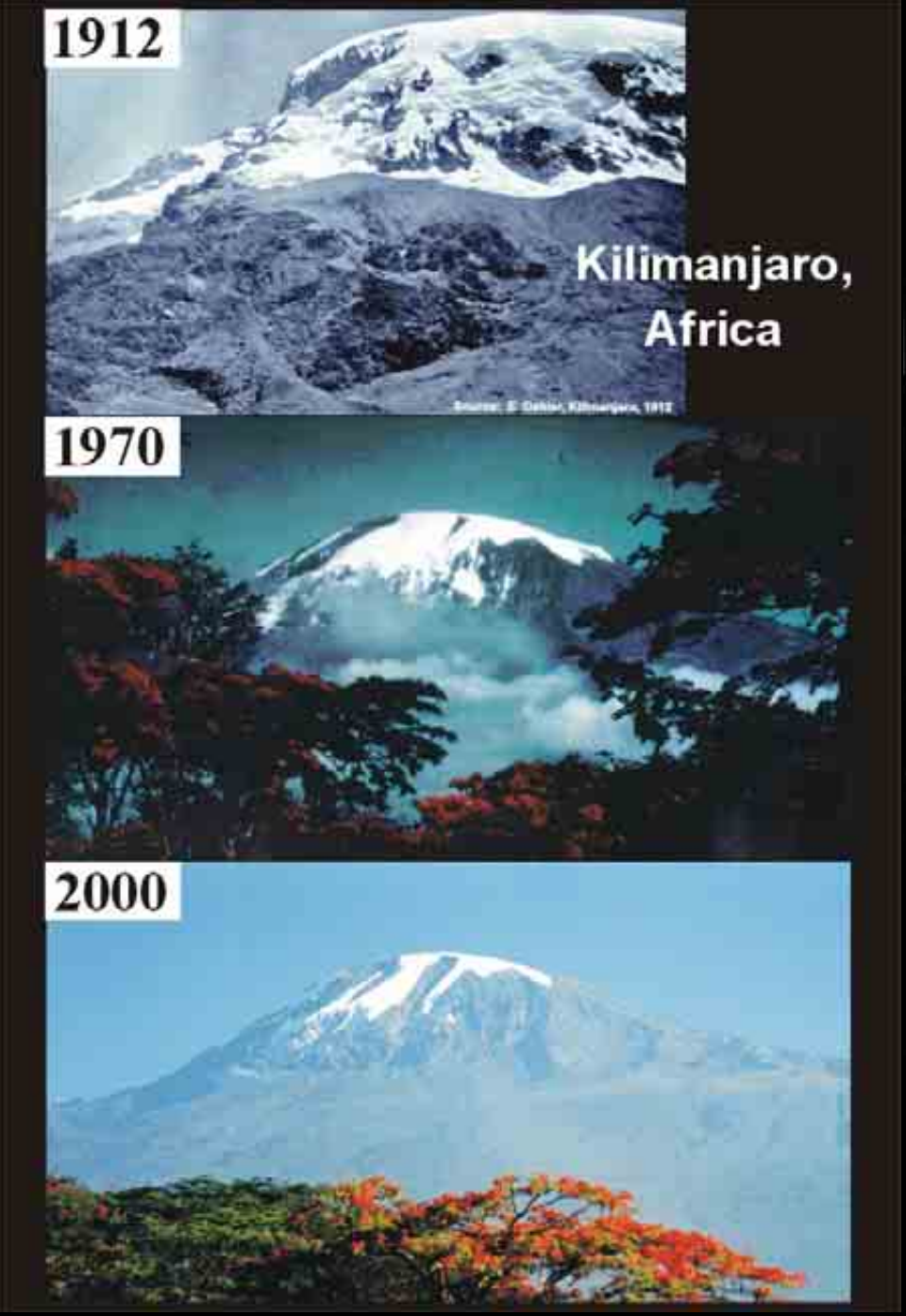
Glacier National Park, Boulder Glacier

Photo: George Grant, Glacier National Park archives

Photo: Jerry DeSanto, National Park Service

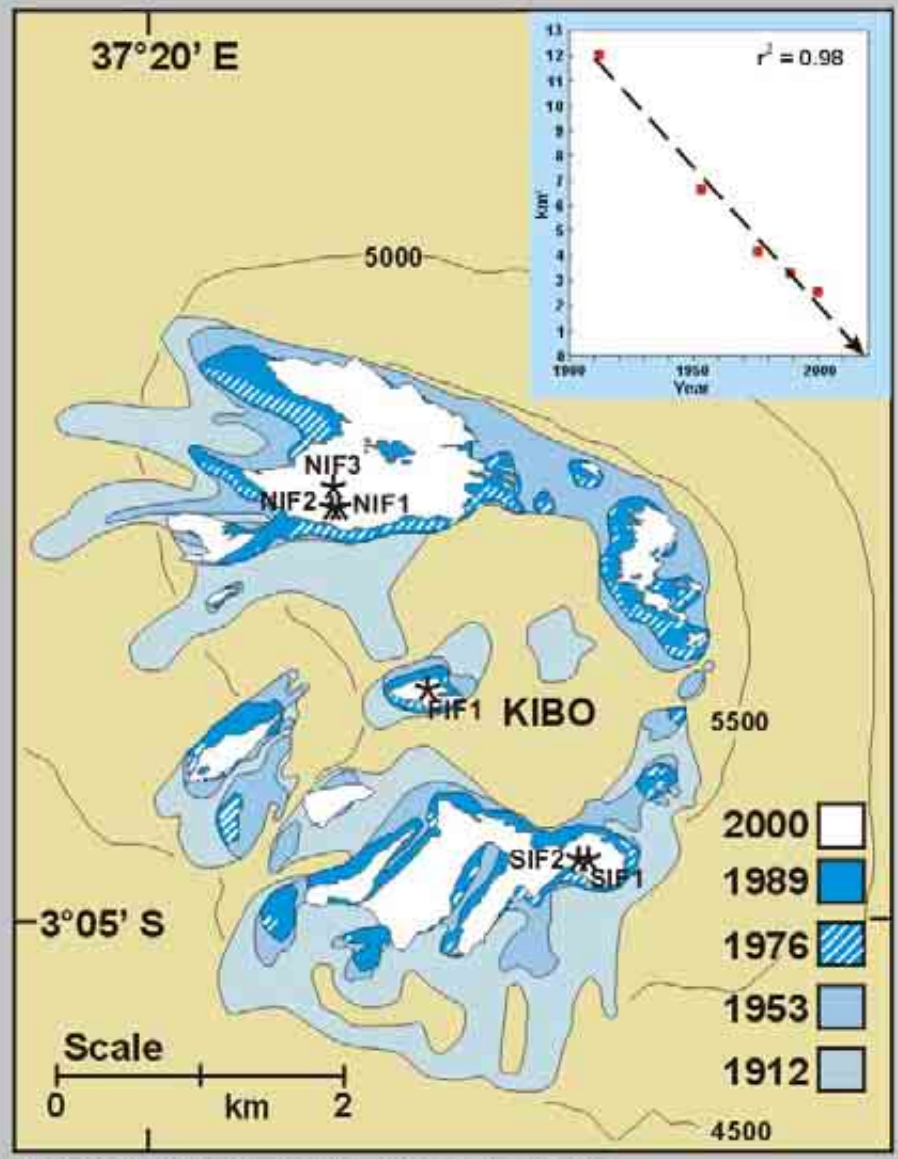
Source: *BioScience*, Vol. 53 No. 2, Feb 2003

Glaciar Lanín Norte



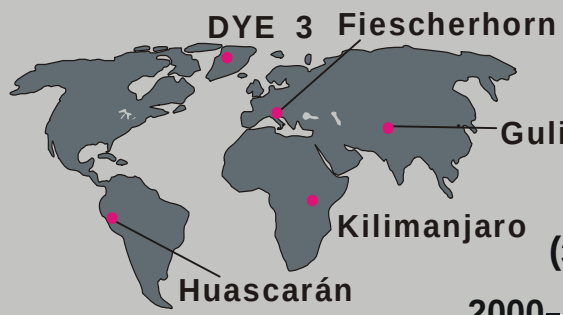
Aerial photo in 2000

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

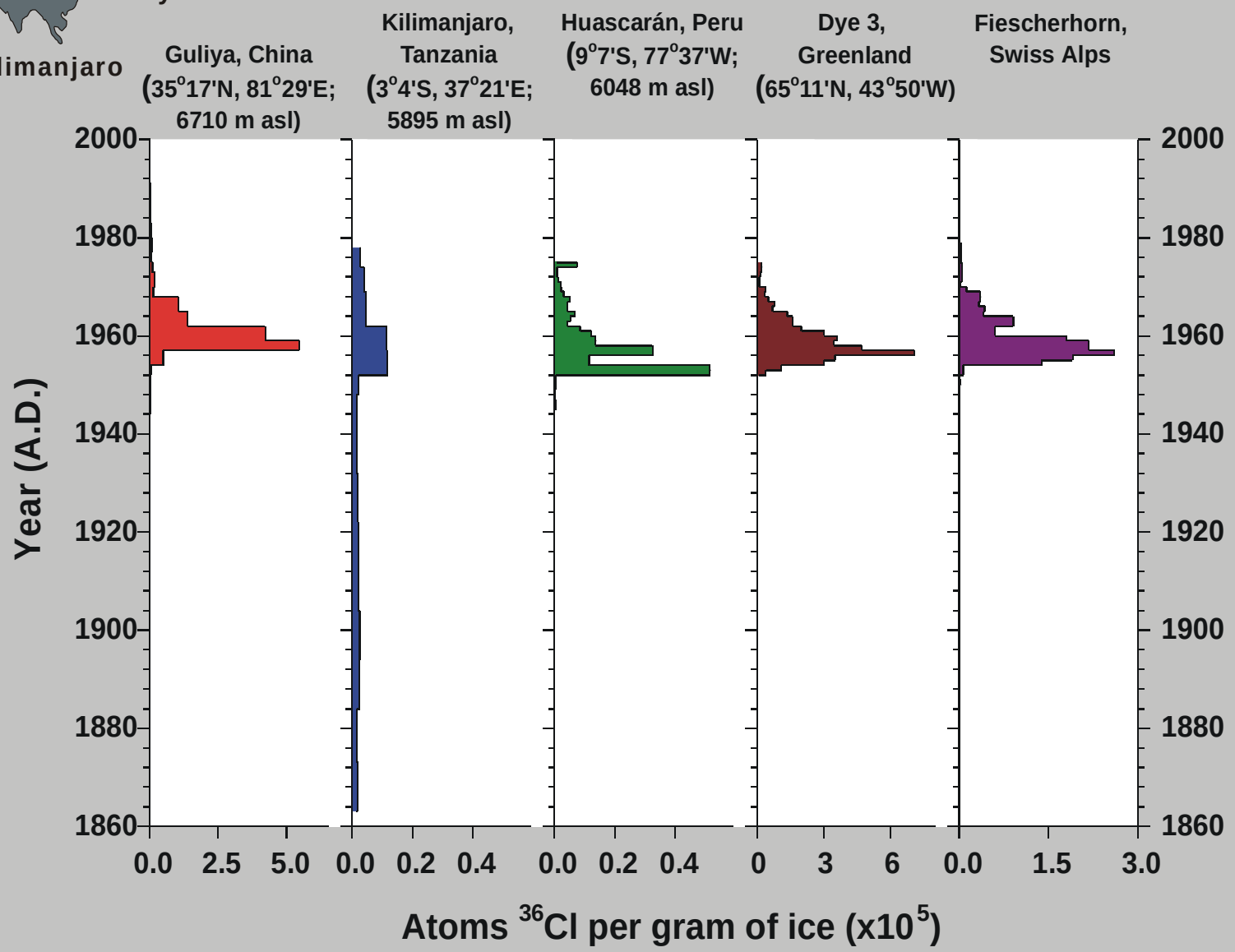


1912 - 1989 after Hastenrath and Greischar, *J. Glaciol.*, 1997
2000 after Thompson *et al.*, *Science*, 2002

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


DYE 3
Fiescherhorn
Guliya
Kilimanjaro
Huascarán

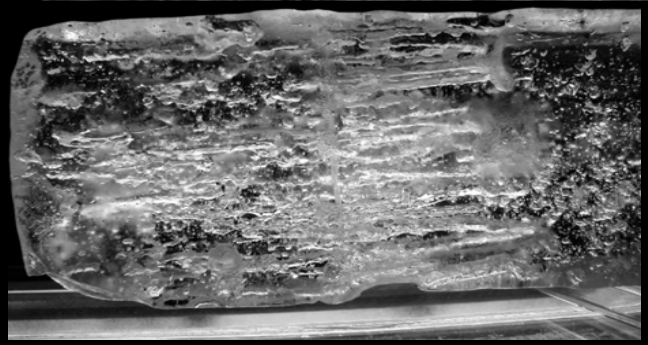
Ivy Test


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
Year (A.D.)
2000
1980
1960
1940
1920
1900
1880
1860
0.0 2.5 5.0
0.0 0.2 0.4
0.0 0.2 0.4
0 3 6
0.0 1.5 3.0
Atoms ^{36}Cl per gram of ice (x10^{5})

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

Drill shelter on Northern Ice Field, Kilimanjaro in 2000

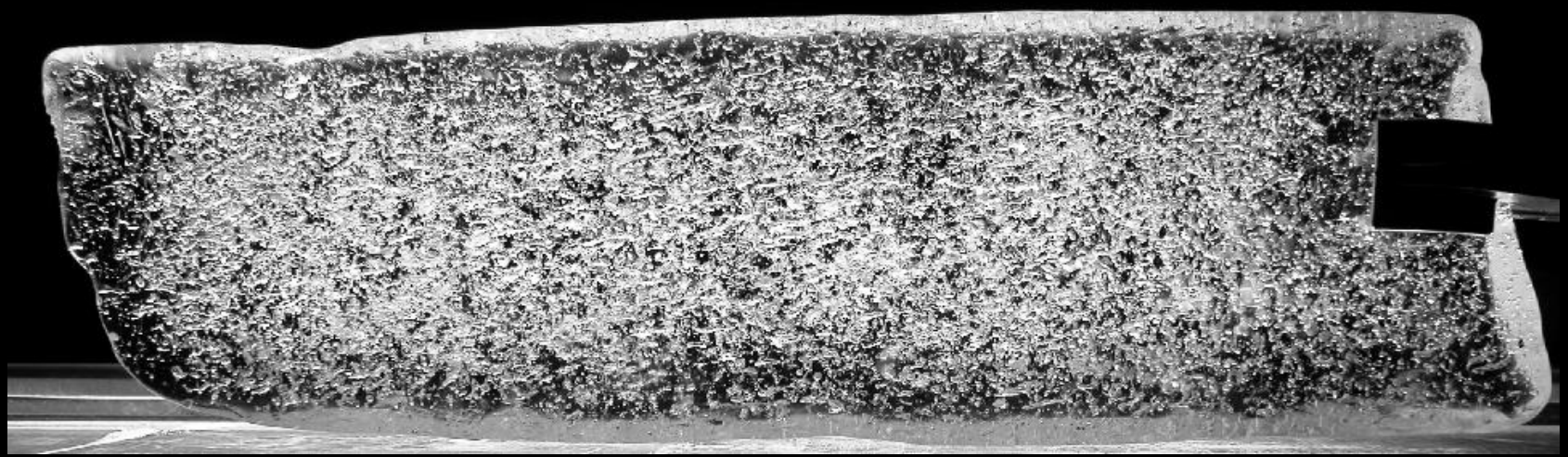
Kilimanjaro (2000) Northern Ice Field Core 3



Tube 1: top: 0.00 m

Elongated bubbles

Tube 43: top: 42.84 m

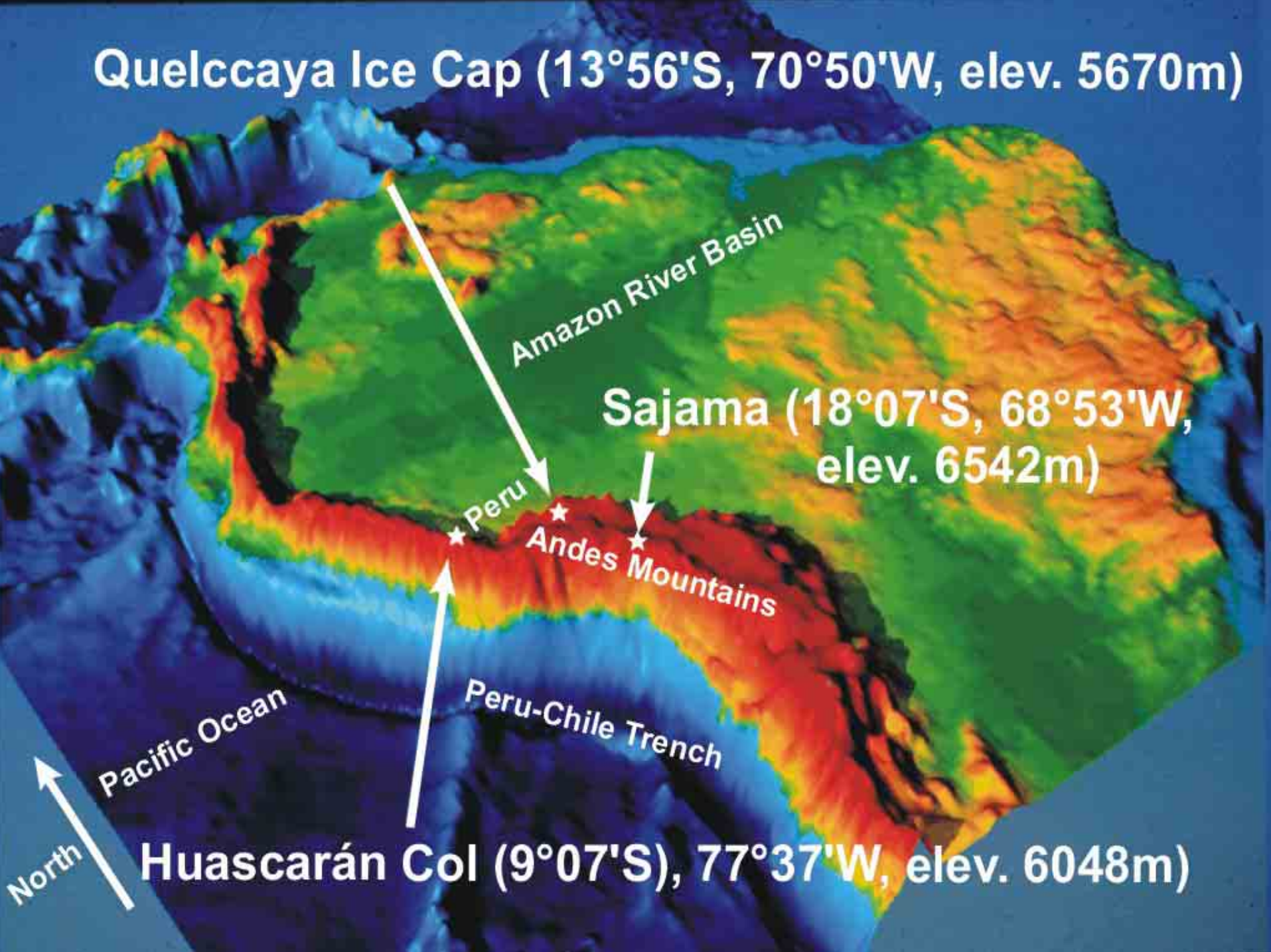


•Kilimanjaro

Feb 2000

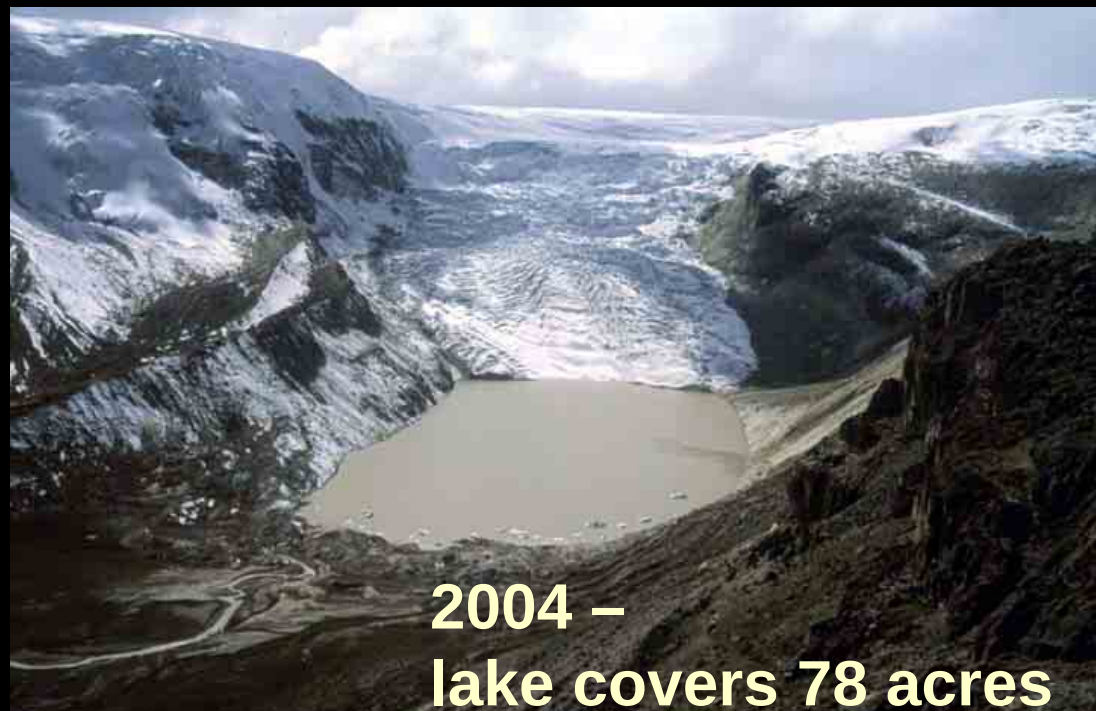
Jan 2006

•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

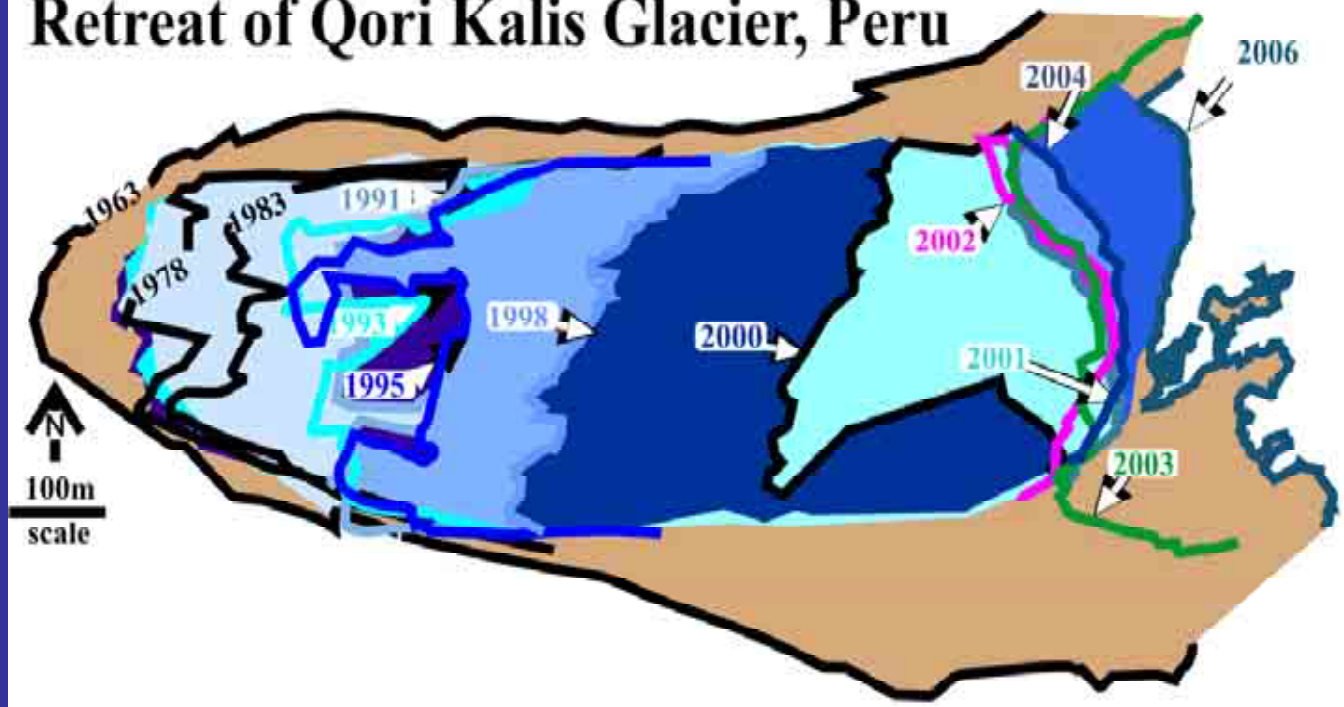


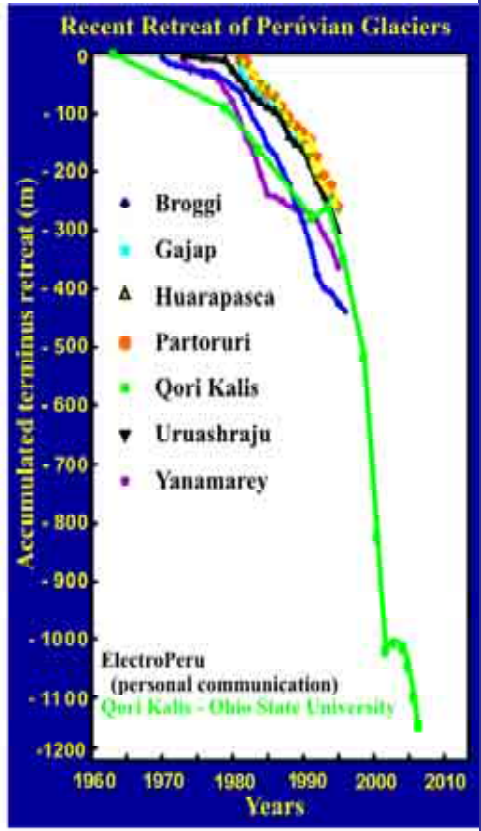
2004 –
lake covers 78 acres


Qori Kalis July 2005


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

Retreat of Qori Kalis Glacier, Peru





1000m

1978

1991

1998

2000

2006


1977


2006


Boulder, 1978


Boulder, 2006

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).

Martin Chambi J. Mid-1930's

Qoyllur Rit'i, Peru 2006

In 1915 Ernest Shackleton stated ……

“What the Ice Gets, the Ice Keeps”

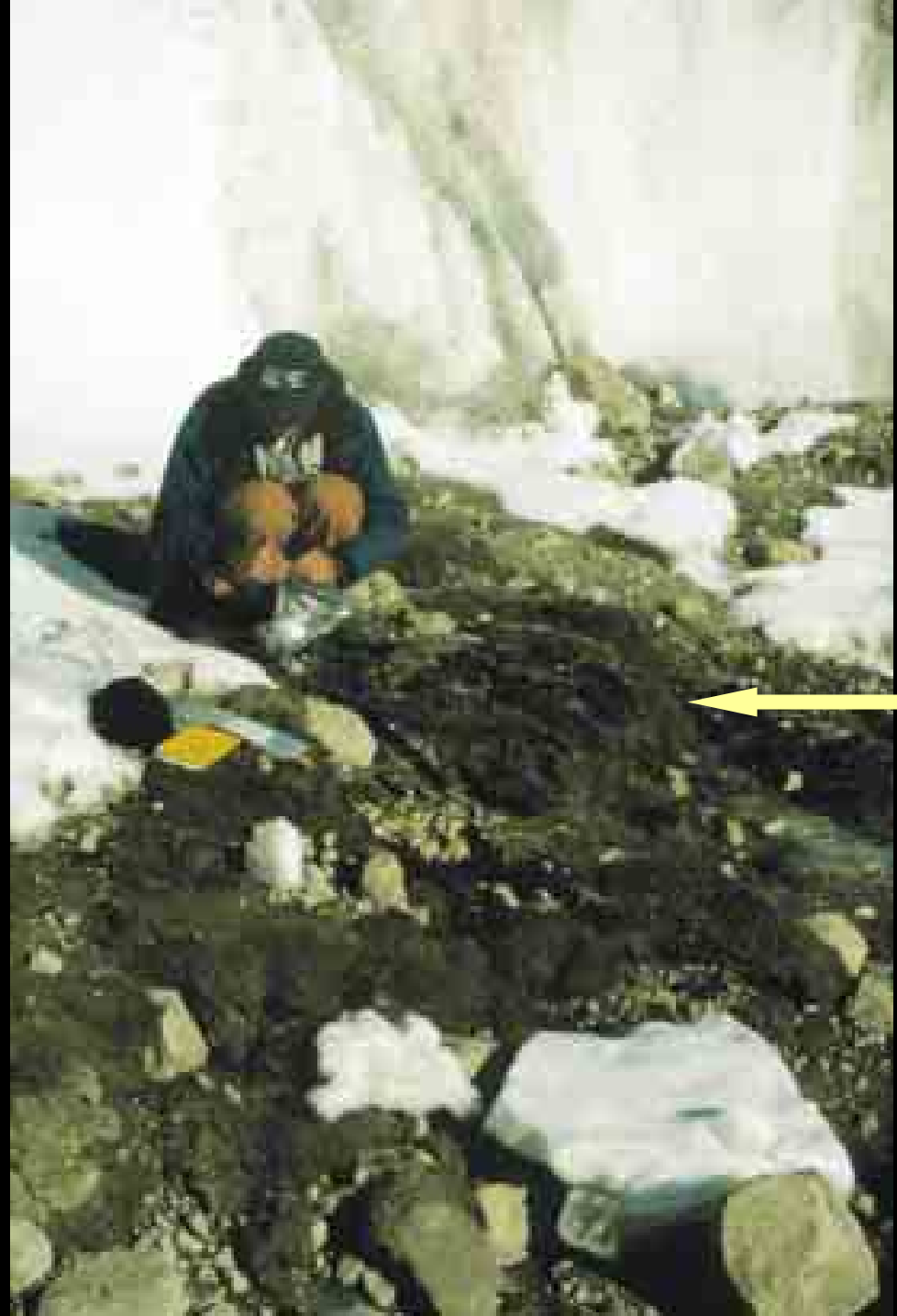
But today the retreating ice
is giving up long-buried secrets …..

Quelccaya, Peru

1977

2002

Quelccaya Ice Cap, 2002



200 – 400 m above its modern range

Distichia muscoides

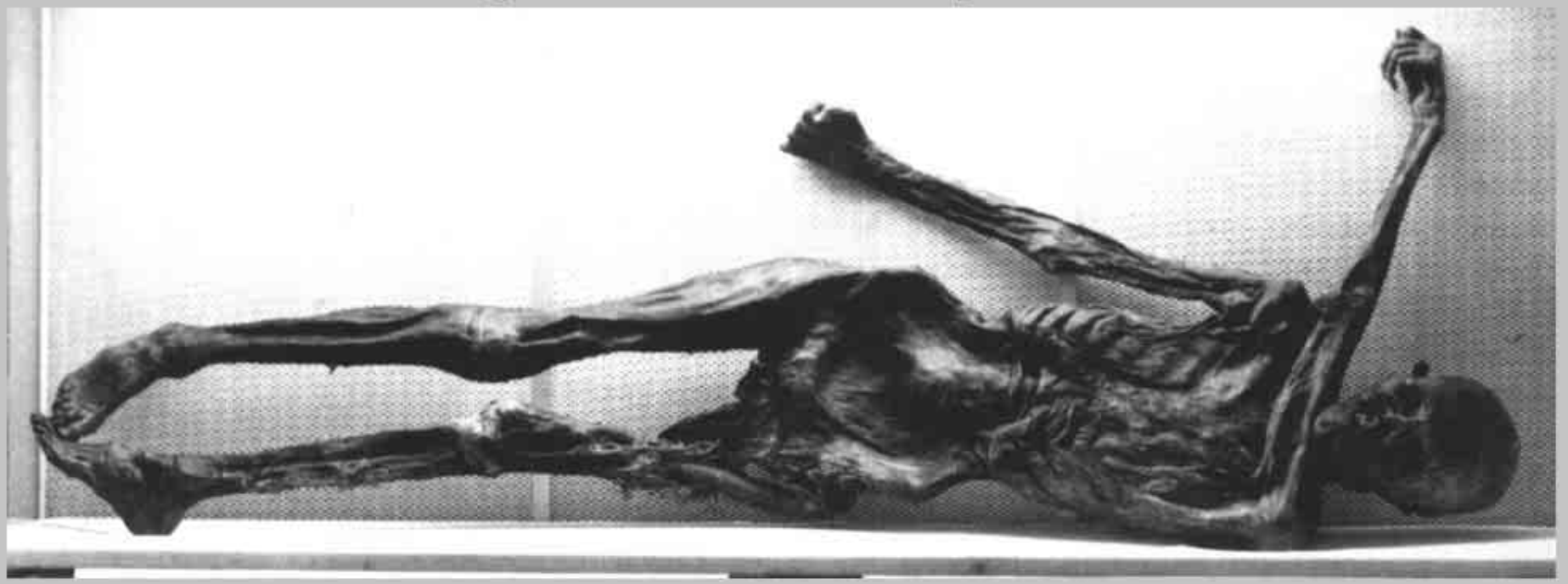
Quelccaya Plant

Modern

5177 ± 45 yr. B.P.

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

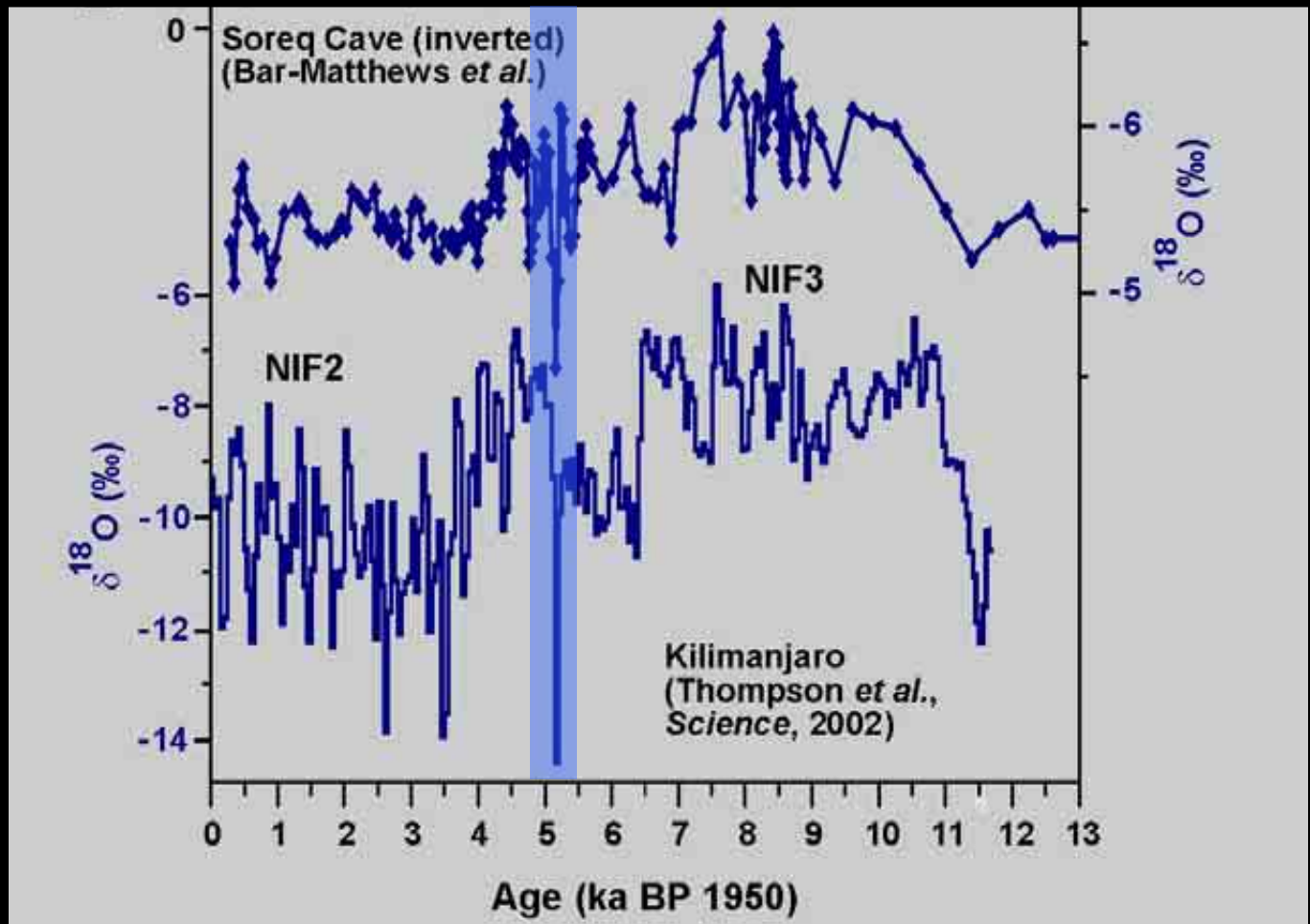
Age 5175 ± 125 years

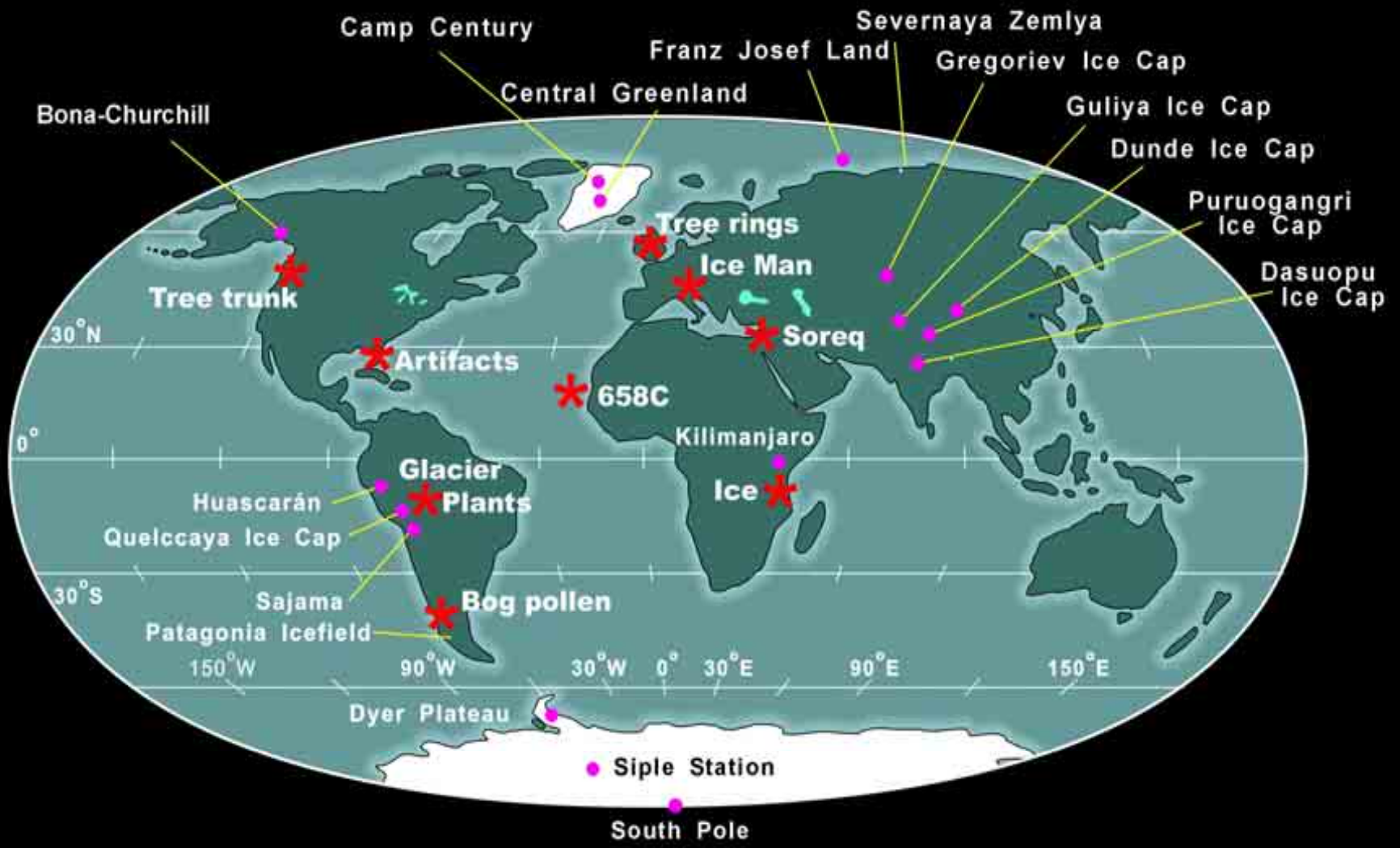


Source: http://info.uibk.ac.at/c/c5/c552/Forschung/Iceman/iceman-en.html#Finding

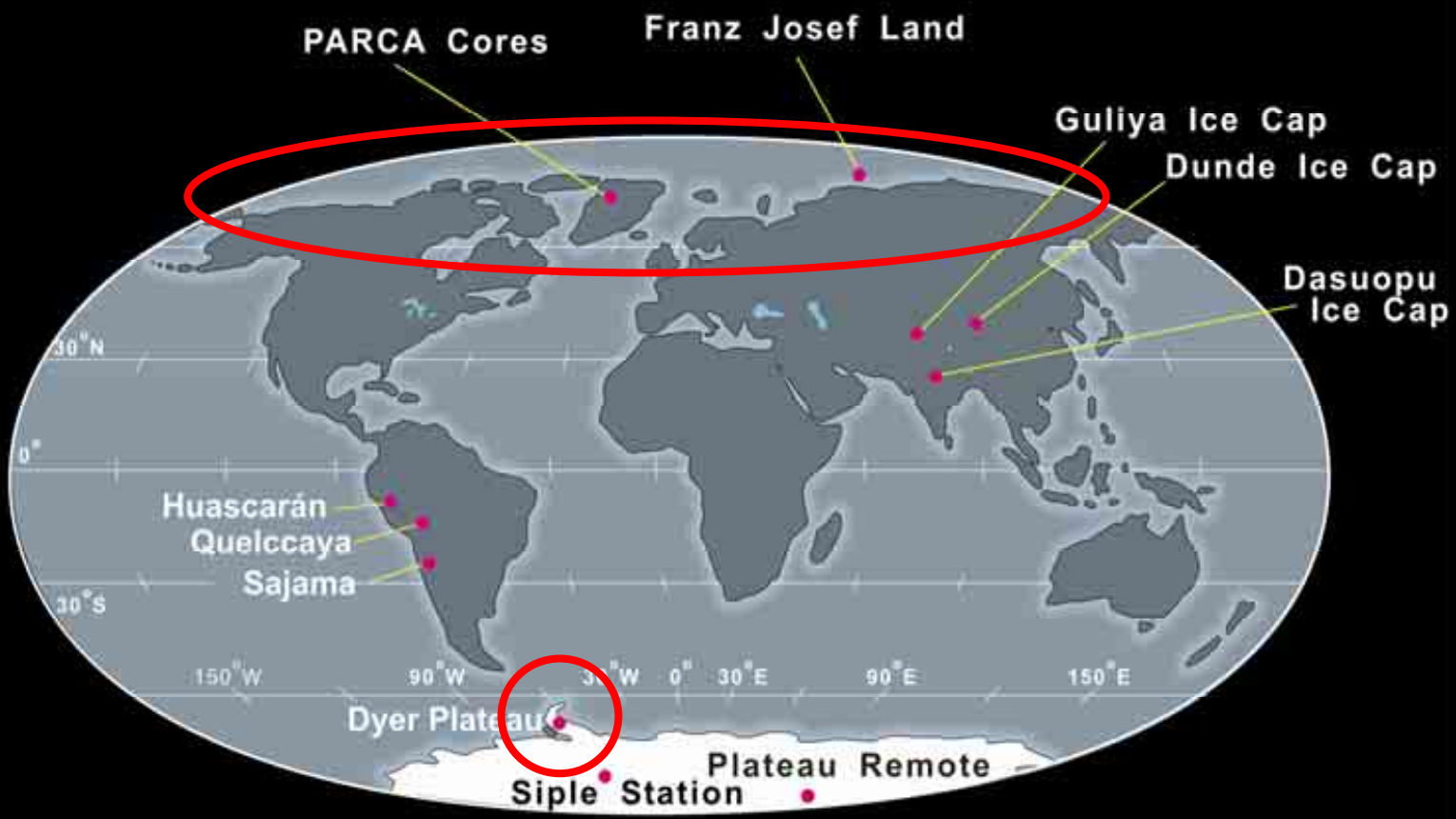
The Kilimanjaro ice cores provide a record ~ 11,000 years long

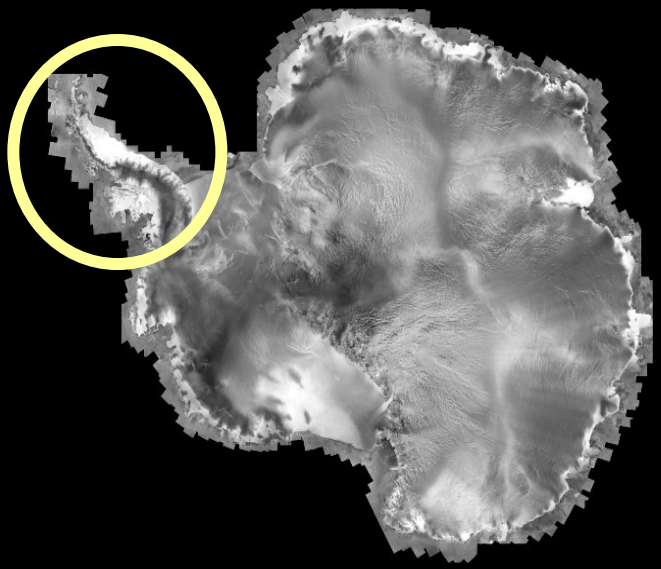
This abrupt cooling event 5,200 years ago was contemporaneous with the reorganization of societal structures – Late Uruk abrupt climate change
- **Hierarchical societies formed in the overpopulated Nile Valley & Mesopotamia;**
- **Neolithic settlements in the inner deserts of Arabia were abandoned**




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
Soreq
30°N
Artifacts
658C
0°
Kilimanjaro
Glacier
Ice
Plants
Huascarán
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

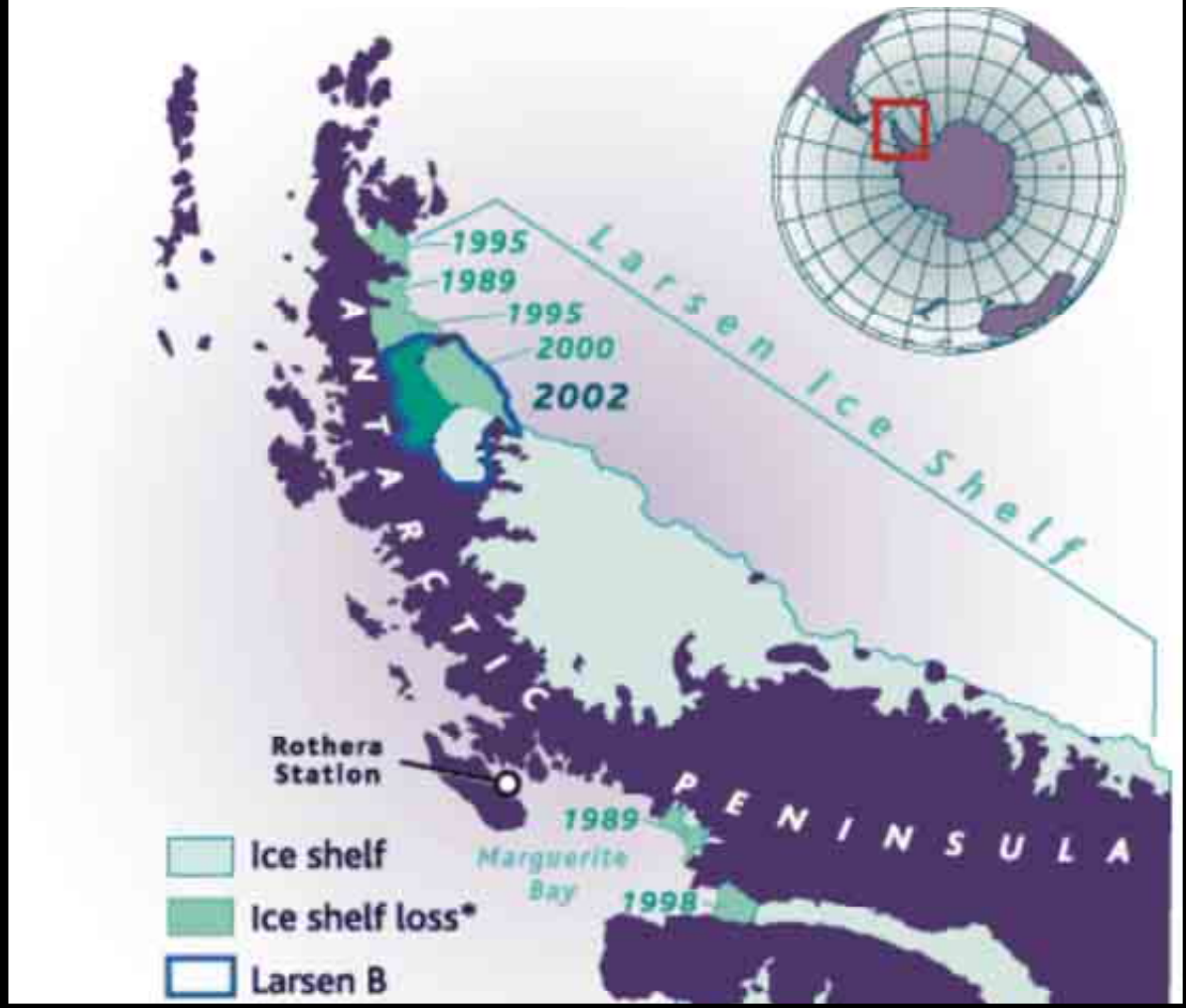




•Earth’s cold regions and their icy cover are well documented <u>indicators</u> of climate change

•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.

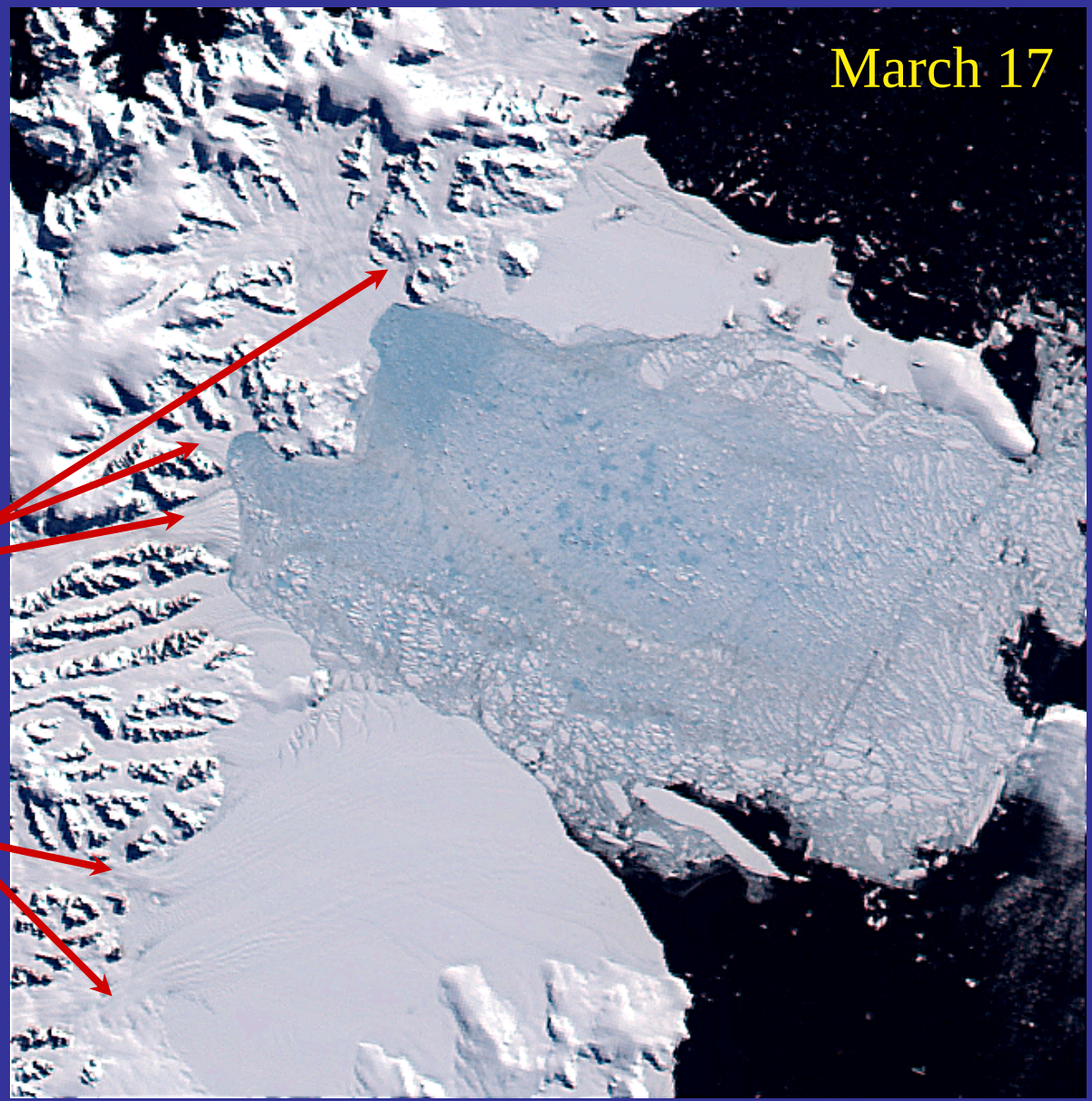


Ice Shelves and the Buttressing Effect

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

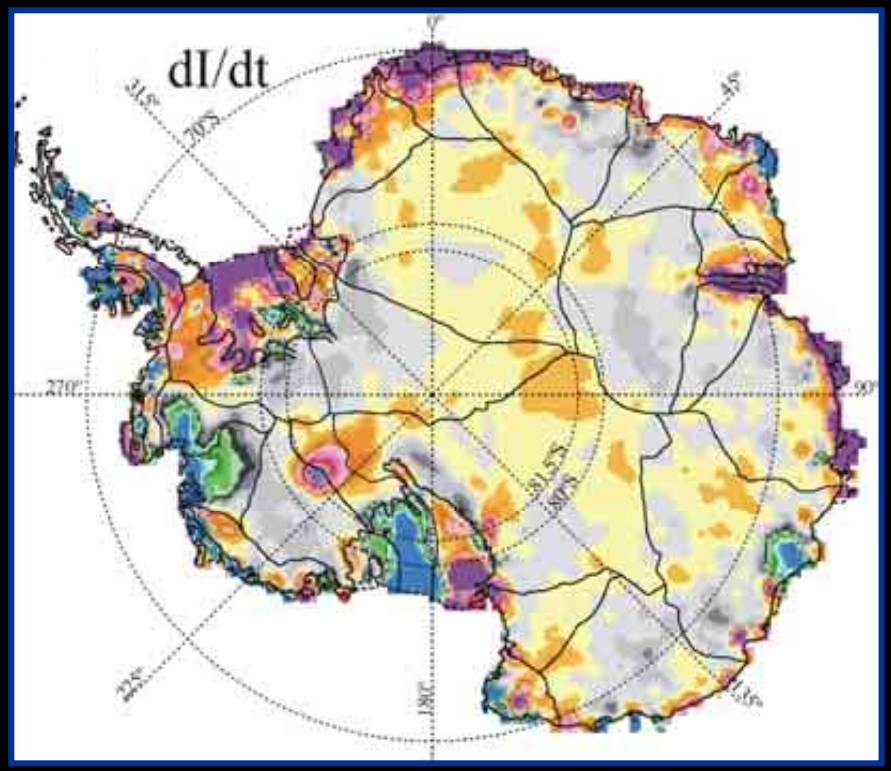
- Increase in flow speed up to 8-fold
- Thinning by as much as 40 m in six months

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

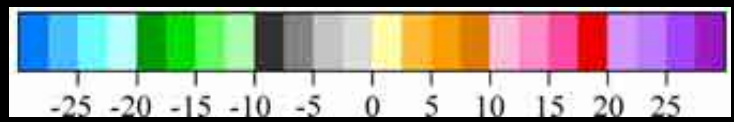


Ted Scambos, NSIDC

Antarctic Ice Sheet Elevation



Ice Thickness Change From Altimetry

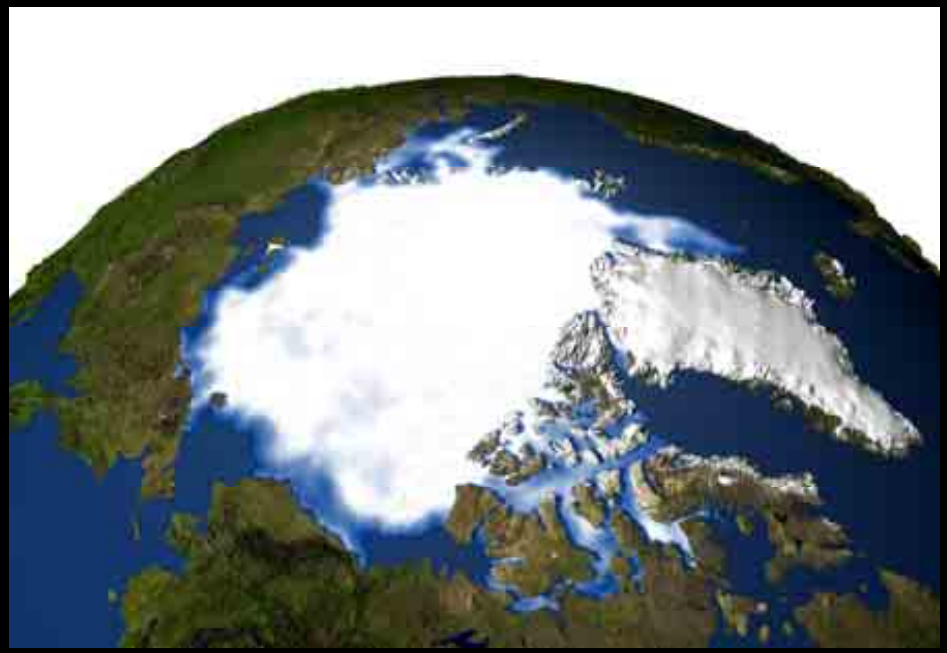


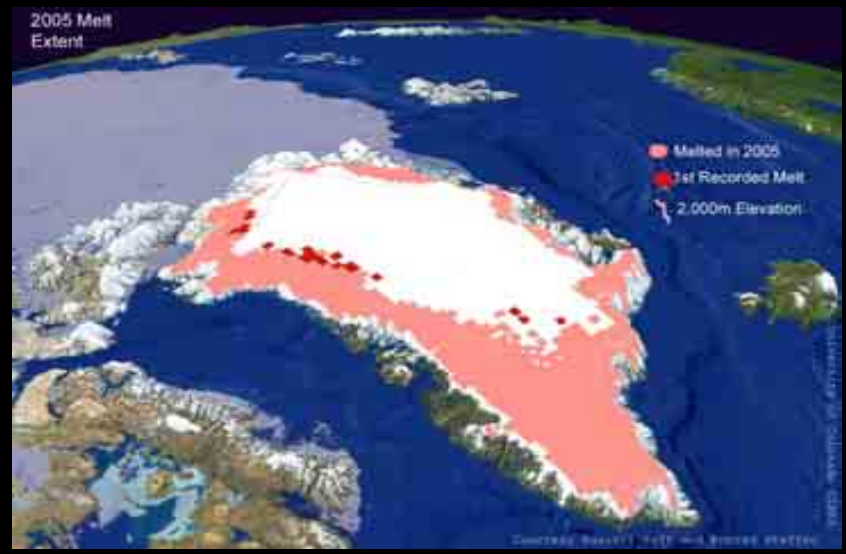
(cm/yr)

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



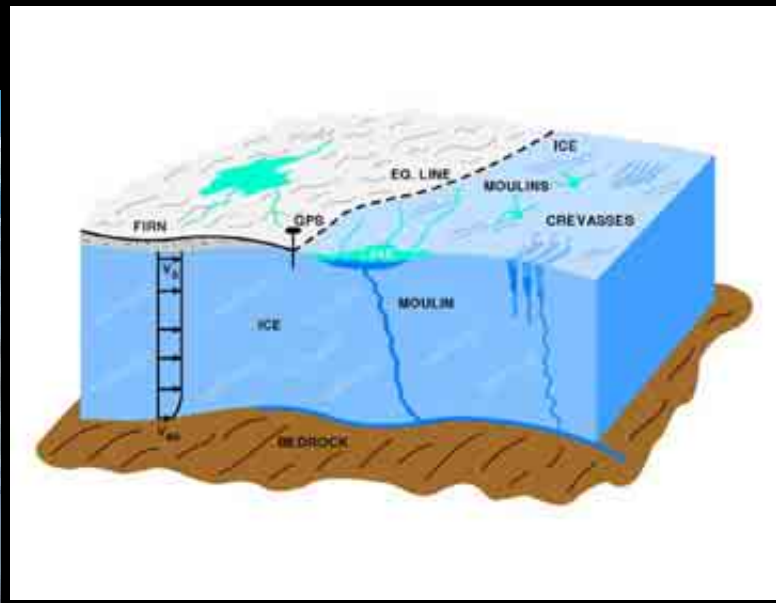


- 7 m sea level equivalent
- Unlike Antarctica, experiences substantial surface melt in the summer time over much of its area
- Rimmed by outlet glaciers with some floating ice tongues; ice shelves are absent

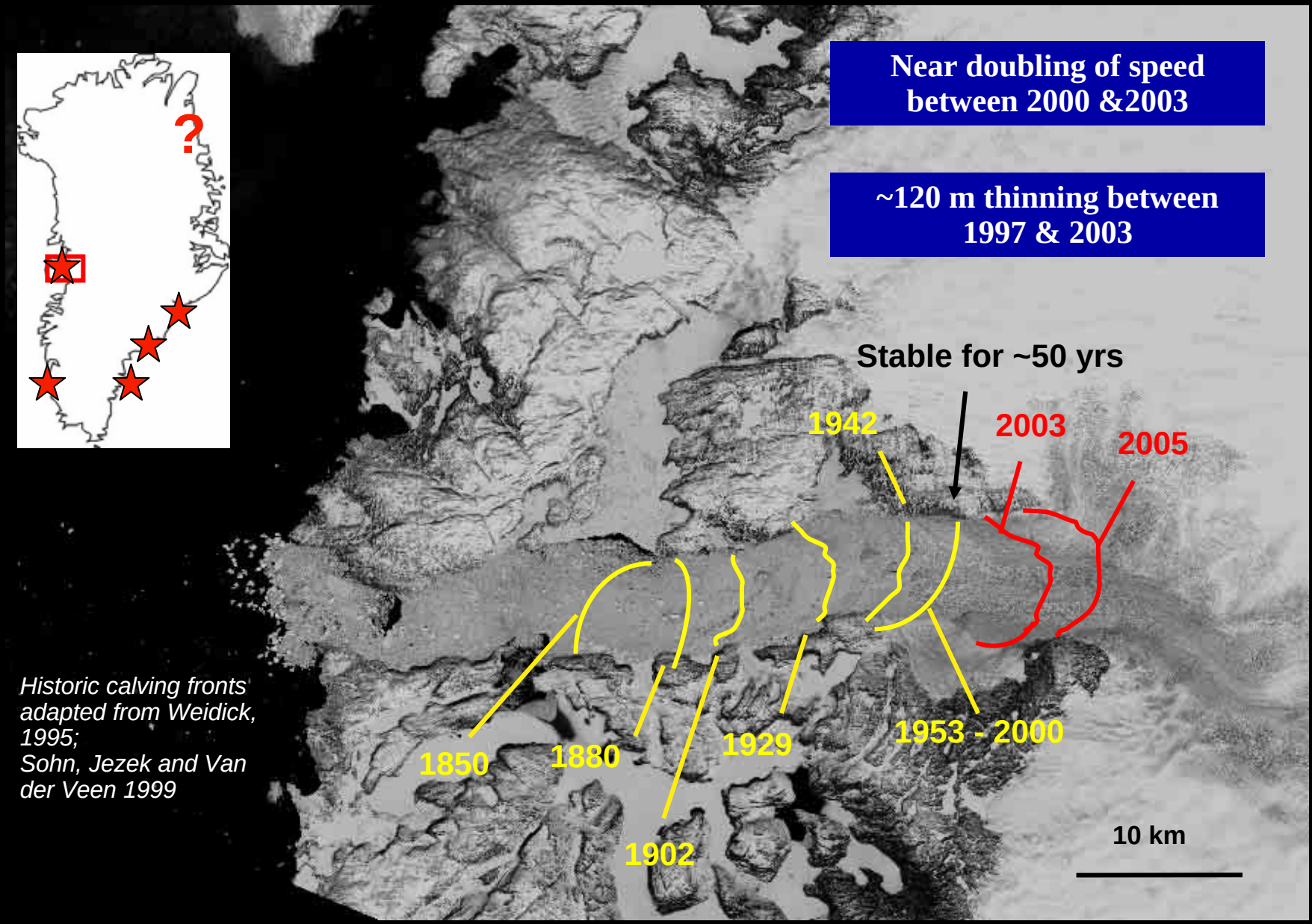
The warming in the Arctic is now well-documented …..
Arctic Climate Impact Assessment
available at http://www.acia.uaf.edu/

East Greenland: summer melt water running into a moulin

Photo by Roger J. Braithwaite



Retreat of the Jakobshavn Ice Stream



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

Arctic Sea Ice Decline Intensifies

1979-2000 Blue – March
Red – Sept

Extent (million sq km)

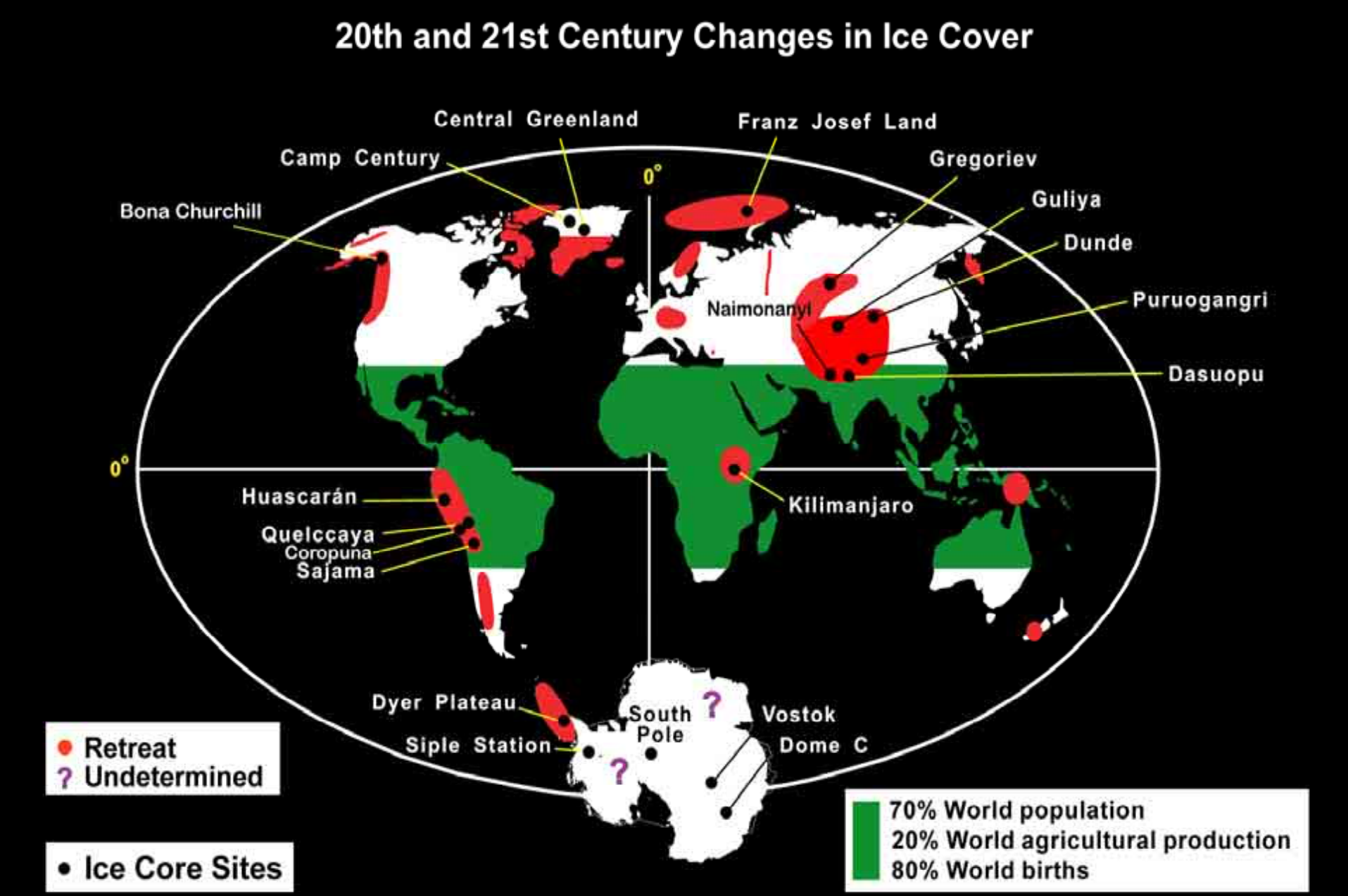
9
8.5
8
7.5
7
6.5
6
5.5
5

1978
1983
1988
1993
1998
2003

Year

2006
2005

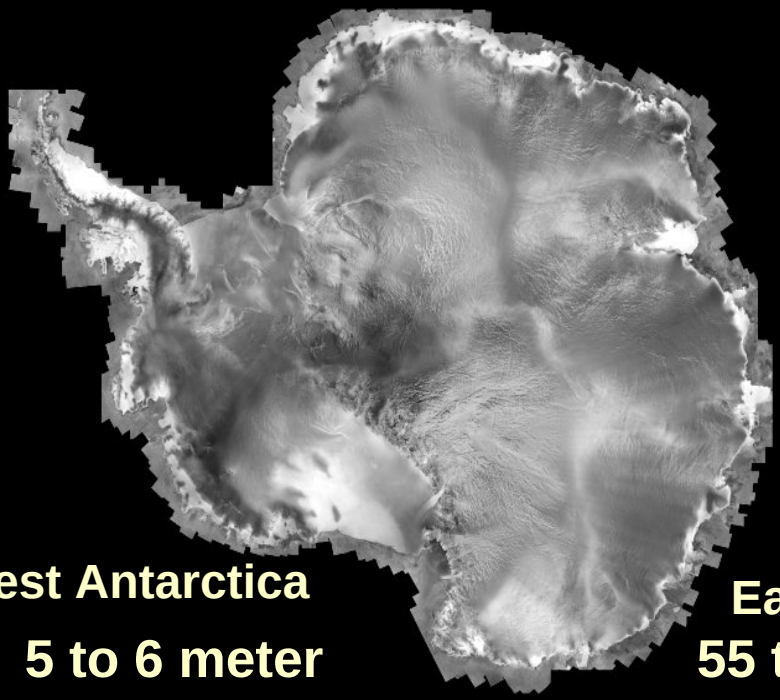
For detailed discussion see Serreze *et al*., *Science*, March 16, 2007



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

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

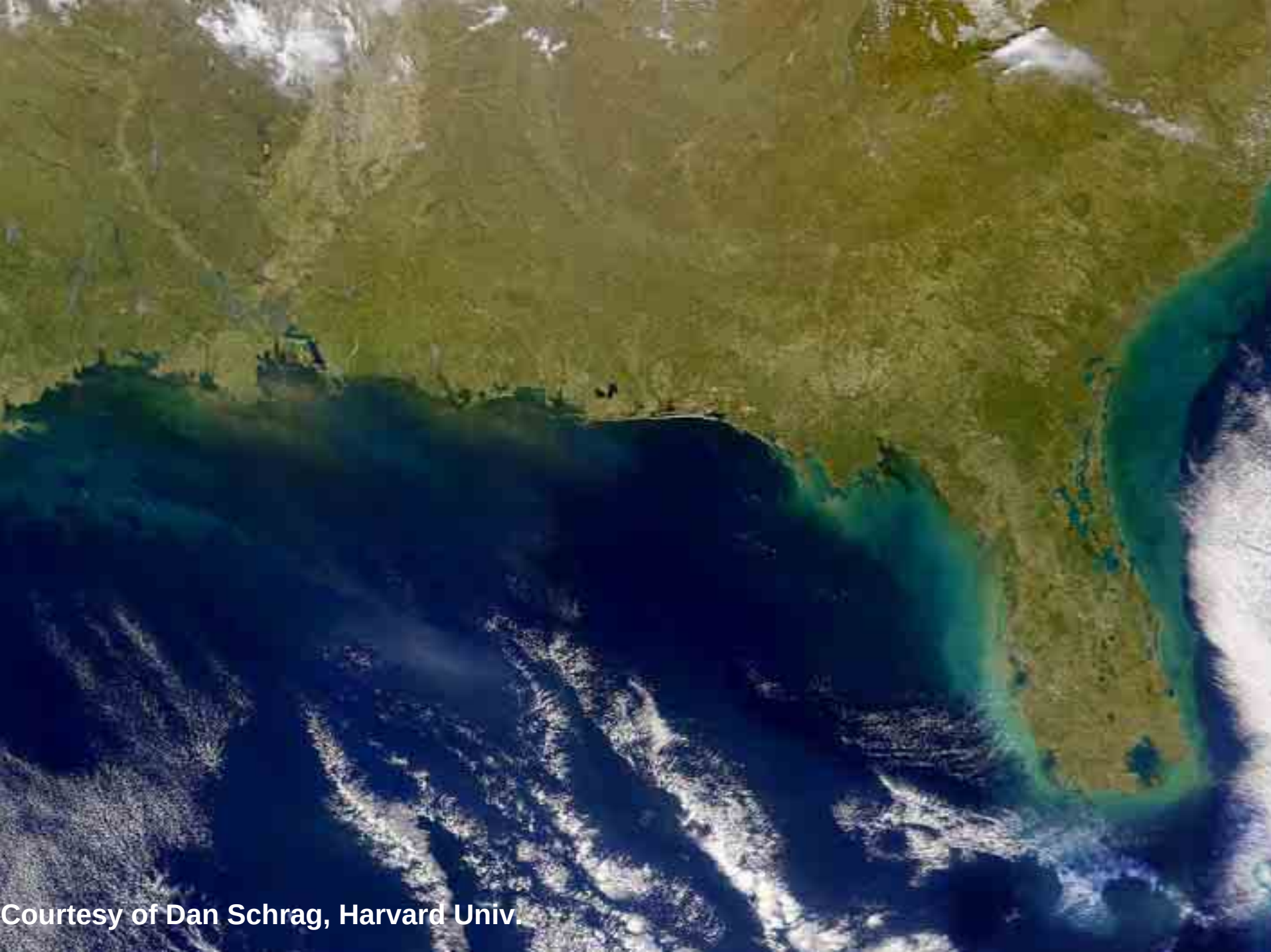
East Antarctica

55 to 60 meter sea level rise equivalent

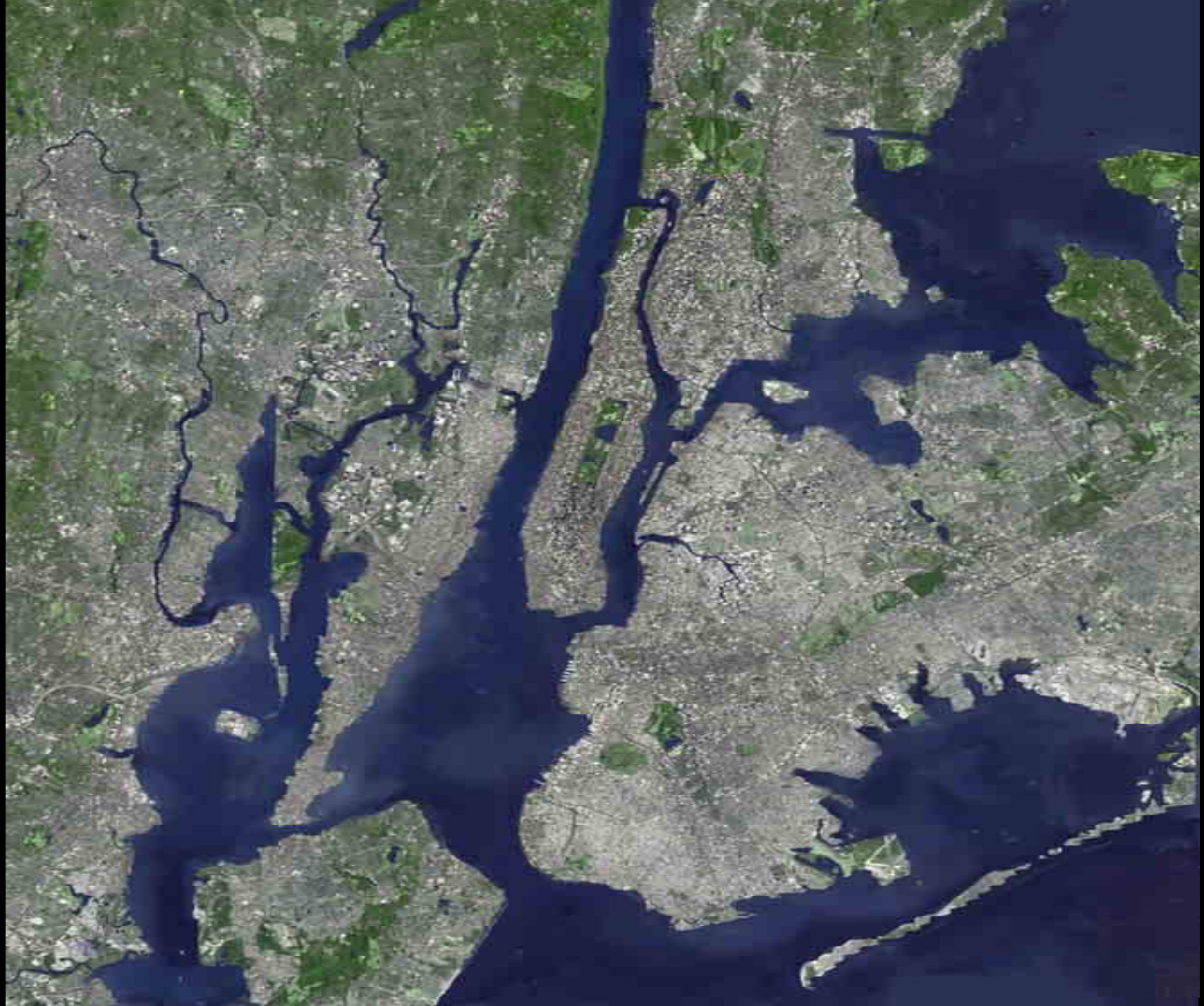
6 to 7 meter sea level rise equivalent

Greenland

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".

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…. too late."

Reverend Dr. Martin Luther King, Jr.

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