Climate Change: Glaciers, People and Options

Lonnie G. Thompson

School of Earth Sciences and Byrd Polar Research Center, The Ohio State University

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Objectives

Introduction to global climate change
Glaciers as recorders of global climate change
Record of two large-scale ENSO events centered on 1789 to 1800 A.D.
and 1345 to 1360 A.D. recorded in two records separated 13,000 miles
Evidence for recent acceleration of the rate of glacier loss
Evidence that some glaciers like the Quelccaya ice cap are smaller than they have been in the last 6,000 years

Why B.F. Skinner became pessimistic about human beings.
"Immediate consequences outweigh delayed consequences"
"Consequences for the individual outweigh consequences for others" *P. Chance, 2007*

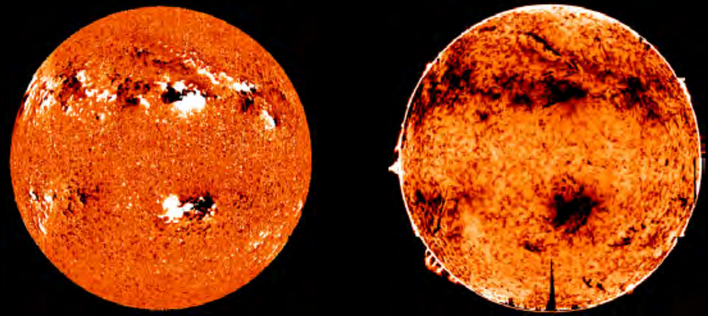
Our Options

Our greatest challenges in the 21st Century

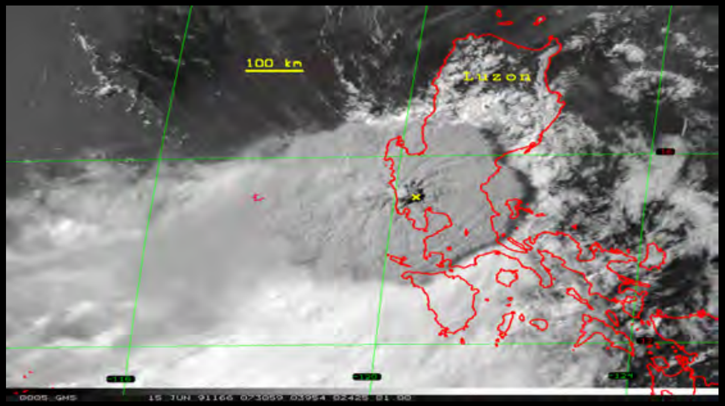
Natural mechanisms influence climate

Natural mechanisms

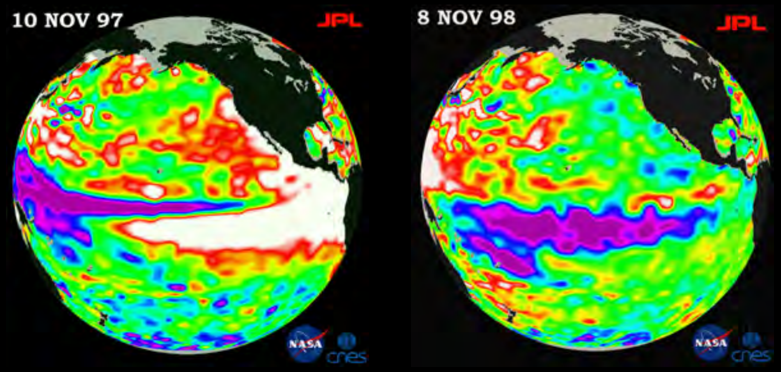
Changes in solar output



Changes in the amount of volcanic aerosols in the atmosphere



Internal variability of the coupled atmosphere-ocean system
(e.g., ENSO, monsoon systems, NAO)



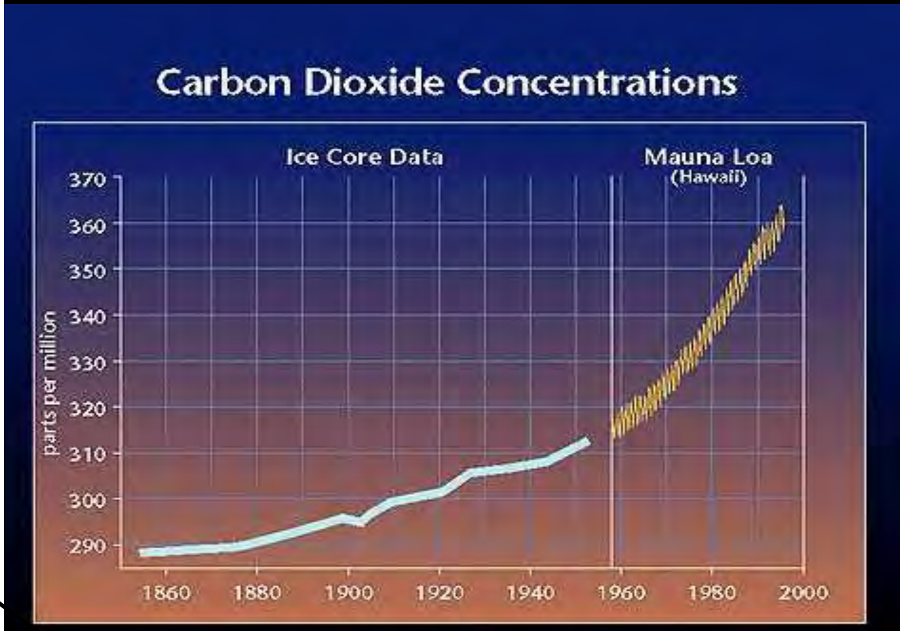
Human factors also influence climate

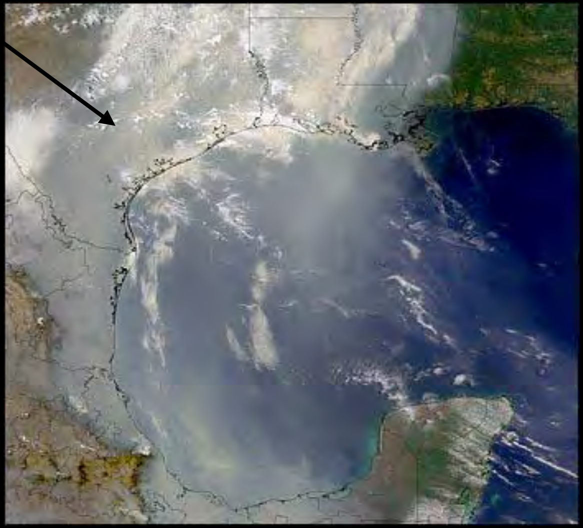
Non-natural mechanisms

Changes in the concentrations of atmospheric greenhouse gases

Changes in aerosols and particles from burning fossil fuels and biomass
- **coal (sulfate aerosols) – cooling**
- **biomass (black carbon) – warming**

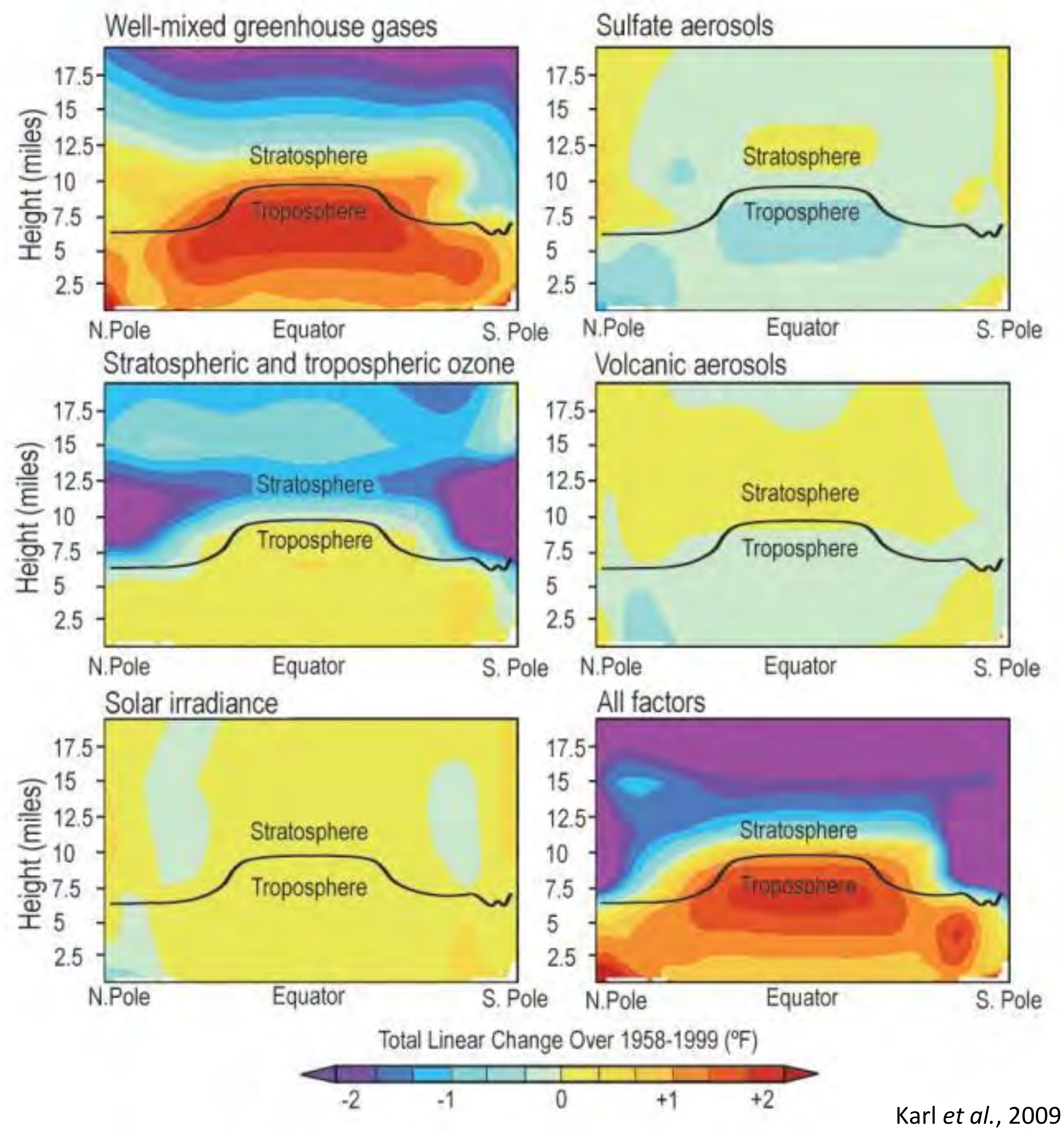
Changes in the reflectivity (albedo) of Earth's surface and the hydrologic cycle





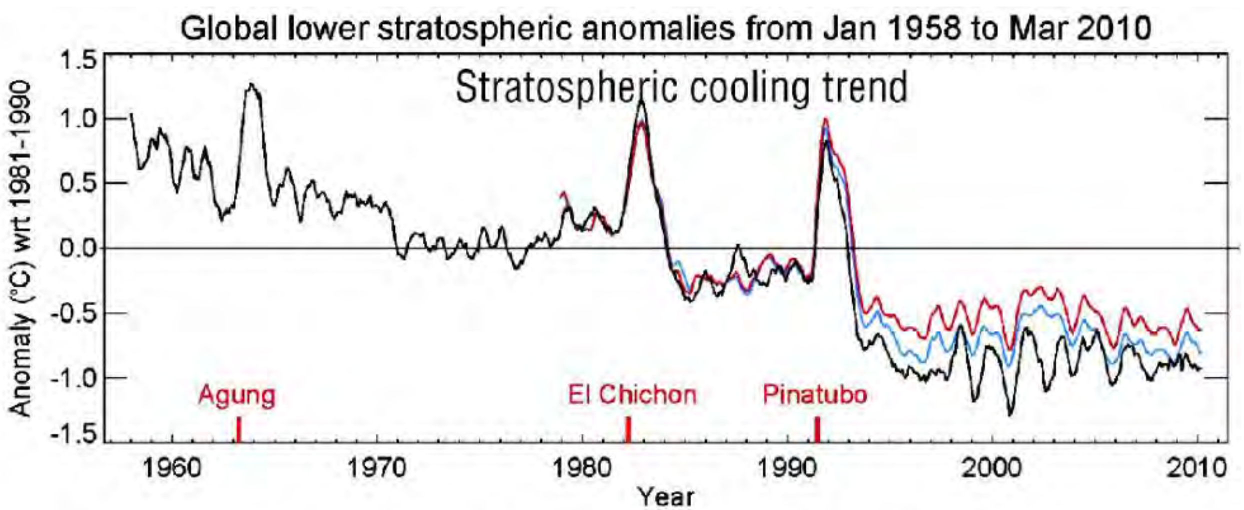
Smoke from fires in Guatemala and Mexico (May 14, 1998)

Climate Responses to Different Forcing Mechanisms

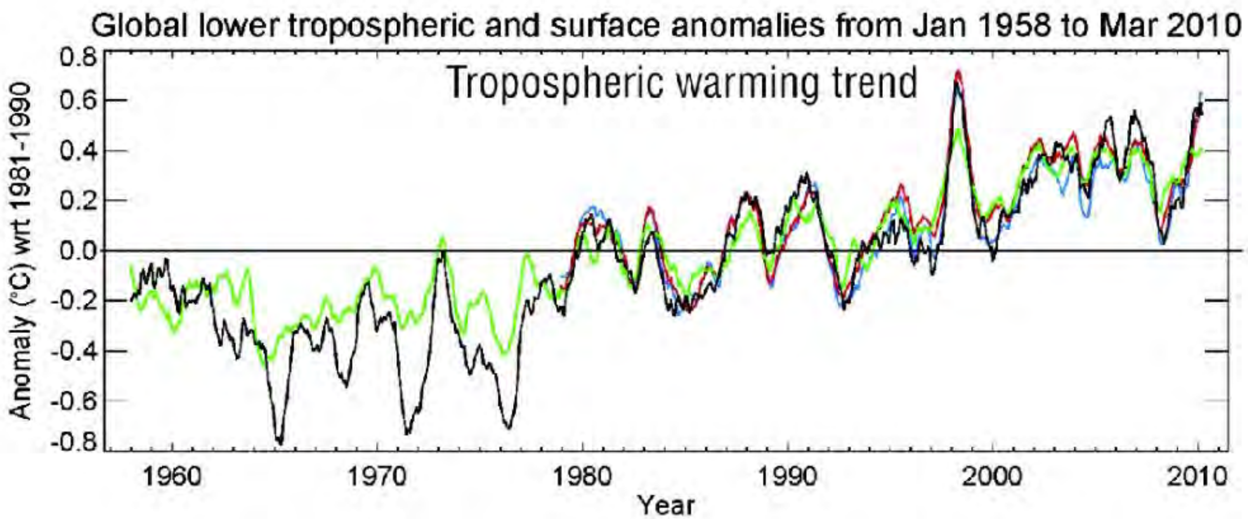


Karl *et al.*, 2009

Atmospheric temperatures since 1958



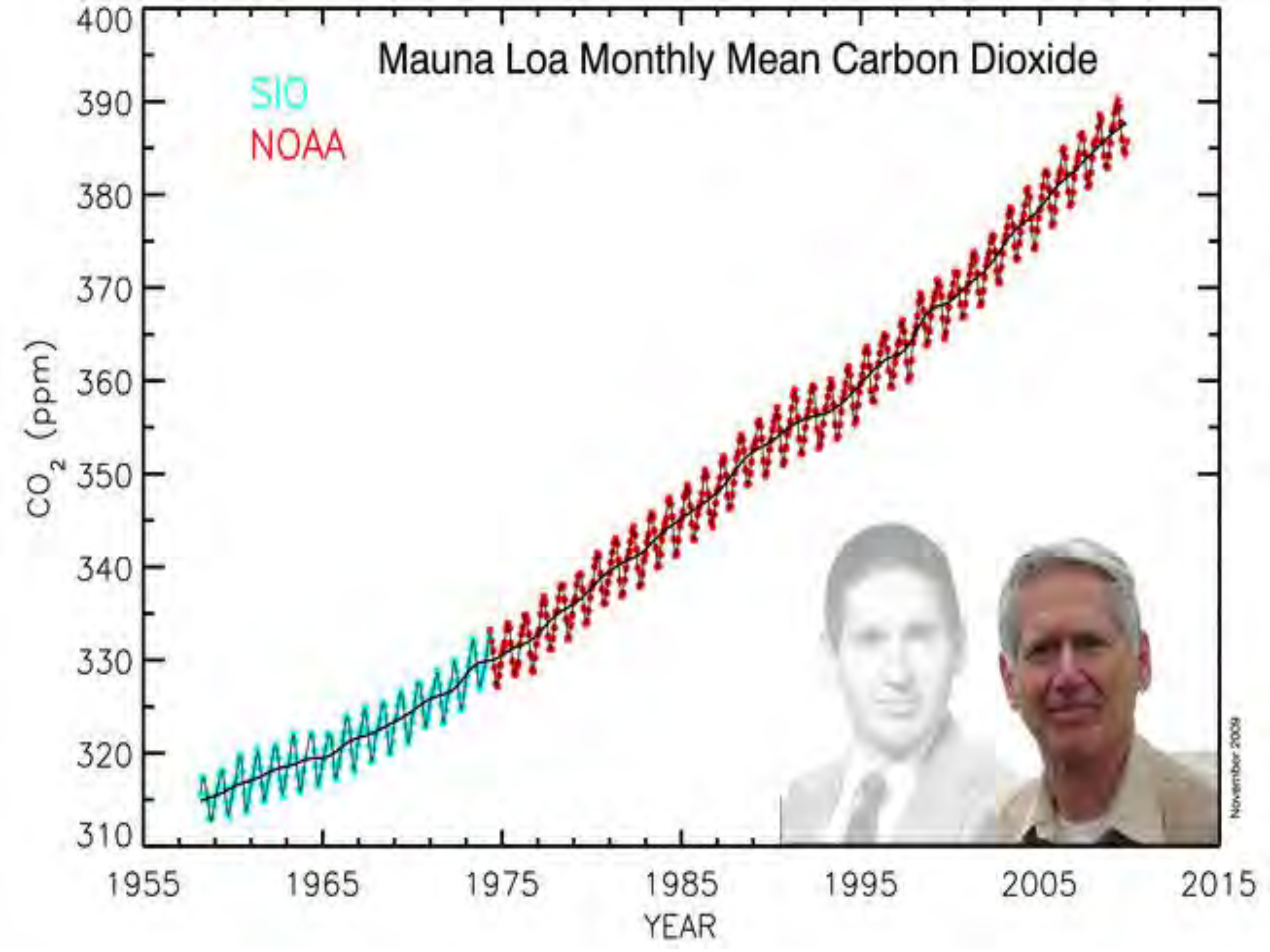
Stratosphere is cooling



Troposphere is warming

This response is expected from GHG forcing & is predicted by climate models. It is not forced by the sun!

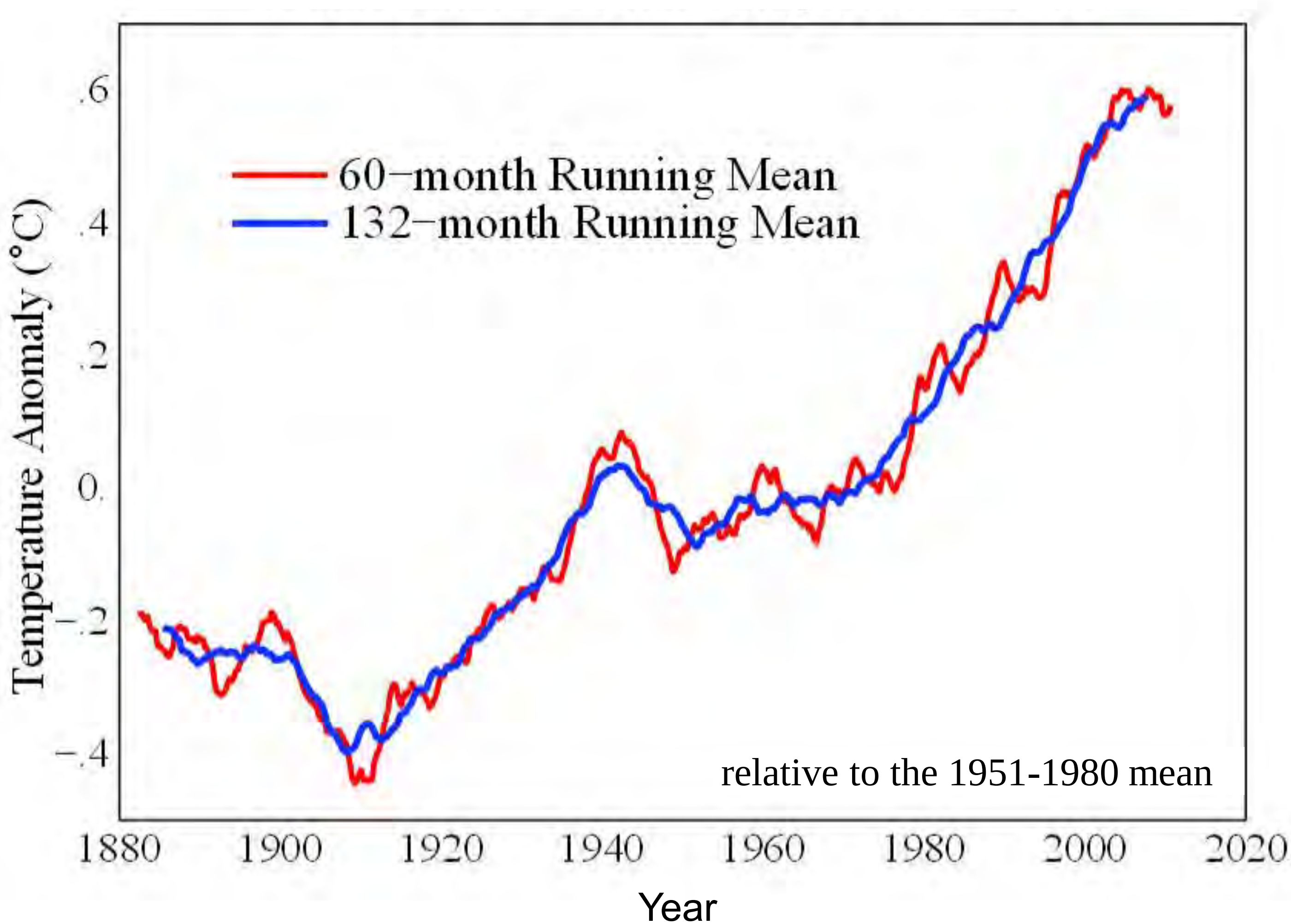
Source: Hadley Center (data available at http://hadobs.metoffice.com/hadat/images.html).



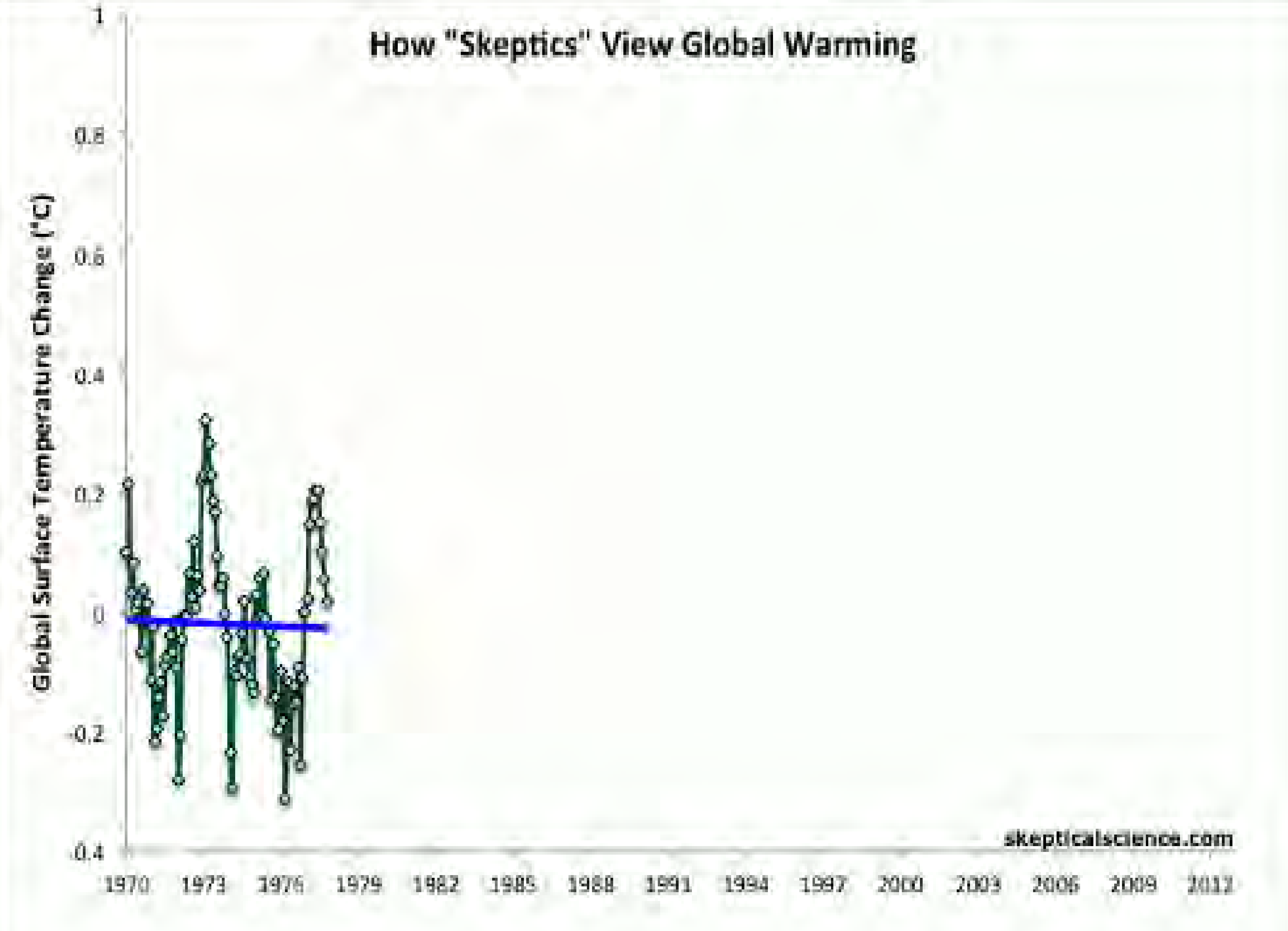
Mauna Loa Monthly Mean Carbon Dioxide
SIO
NOAA
CO2 (ppm)
400
390
380
370
360
350
340
330
320
310
1955
1965
1975
1985
1995
2005
2015
YEAR
November 2009

The Meteorological Record is Very Short

Globally averaged temperature (land & ocean)

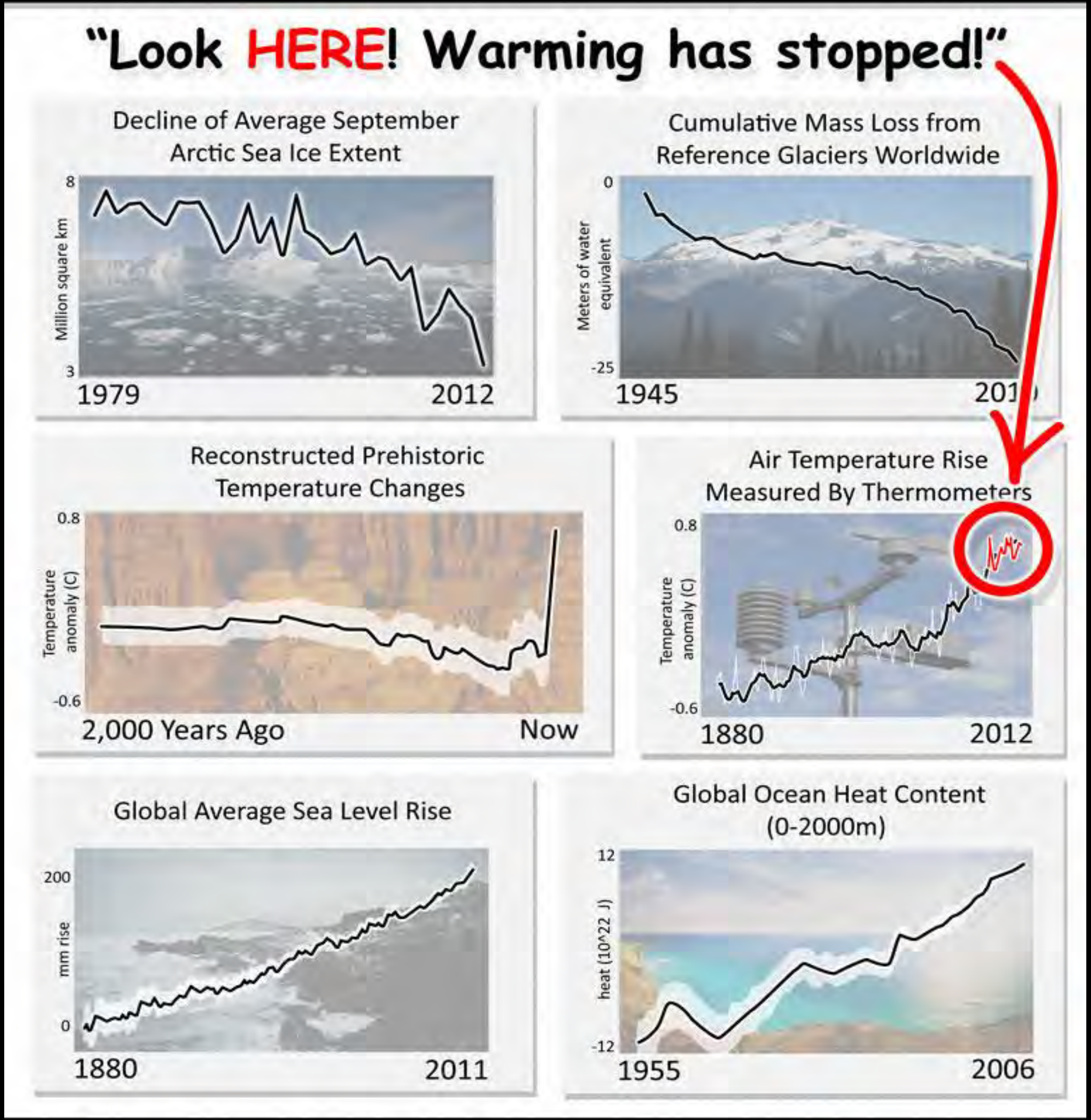


data.giss.nasa.gov/gistemp



How "Skeptics" View Global Warming
Global Surface Temperature Change (°C)
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006
2009
2012
skepticalscience.com

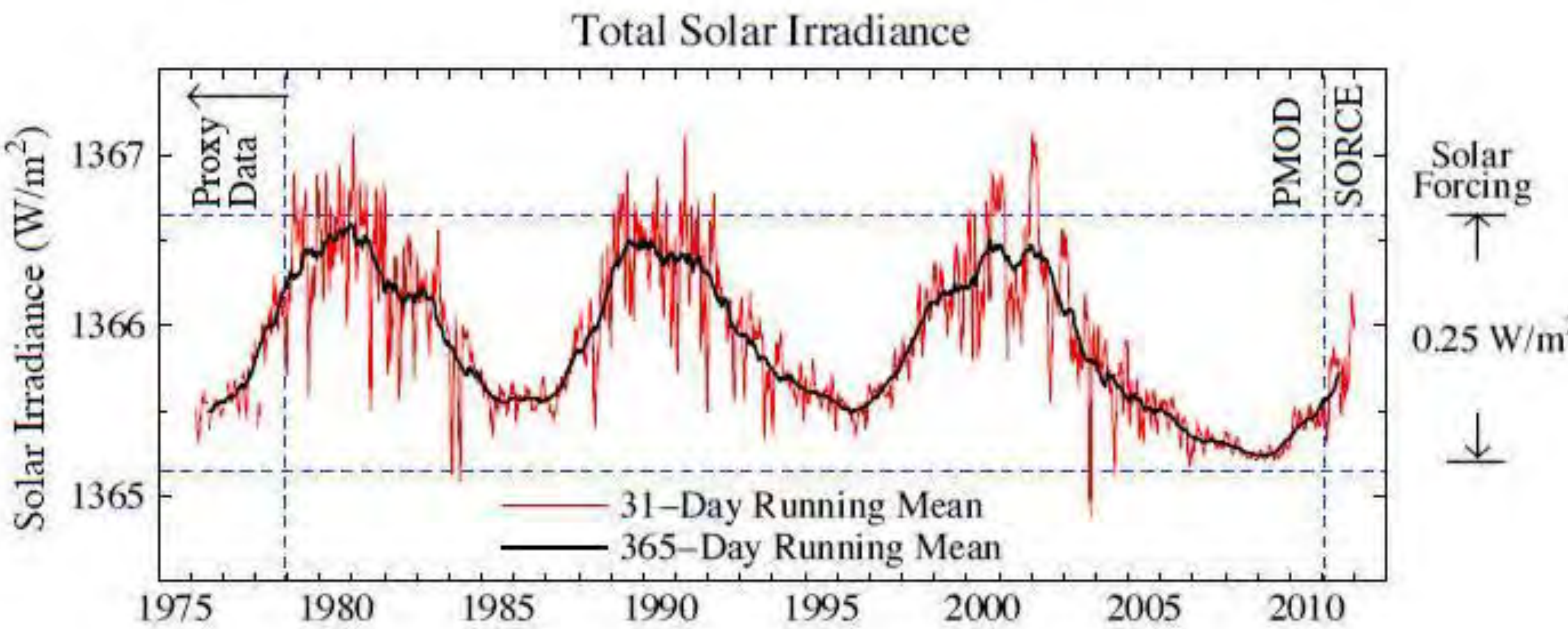
How "skeptics" want you to see climate change:



Be a Realist. Look at the whole picture.

Sources: Arctic ice, glaciers, sea level data: epa.gov/climatechange/science/indicators. Prehistoric temperatures: Marcott et al. (2013). Air temperatures: NASA GISTEMP Analysis. Ocean heat: Levitus et al. (2013). Based on a graphic from SkepticalScience.com.

climatenexus



Total Solar Irradiance
Solar Irradiance (W/m²)
1367
1366
1365
Proxy Data
PMOD
SORCE
Solar Forcing
0.25 W/m²
31–Day Running Mean
365–Day Running Mean
1975
1980
1985
1990
1995
2000
2005
2010

Various archival systems provide paleoclimate records

Ice Cores

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

Freezers for storage and cold rooms for physical property measurements

Machine shop for fabrication of our drills

Ice cores are powerful contributors to multi-proxy reconstructions:

1) they provide multiple lines of climatic & environmental evidence

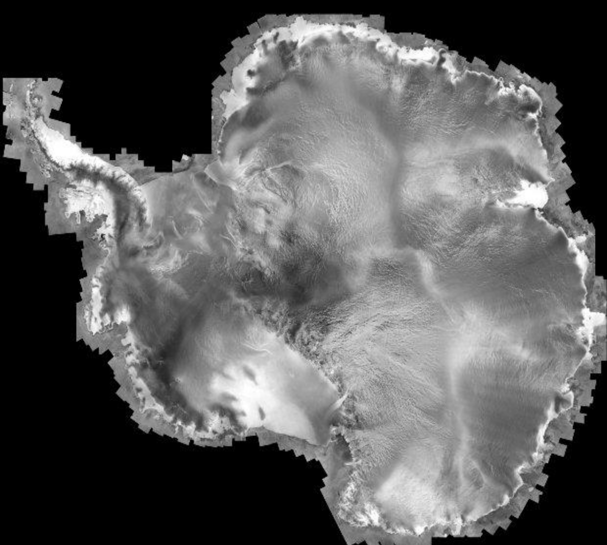
2) ideal for revealing rapid climate changes

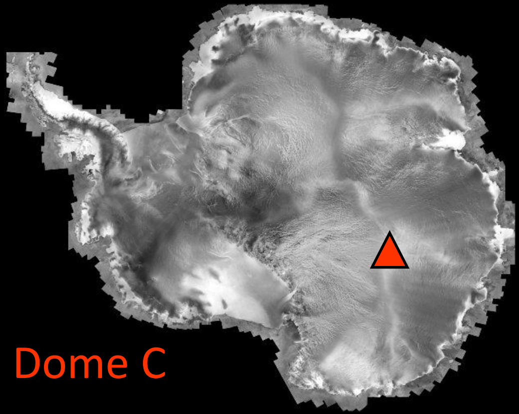
Guliya ice cap, Tibet

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

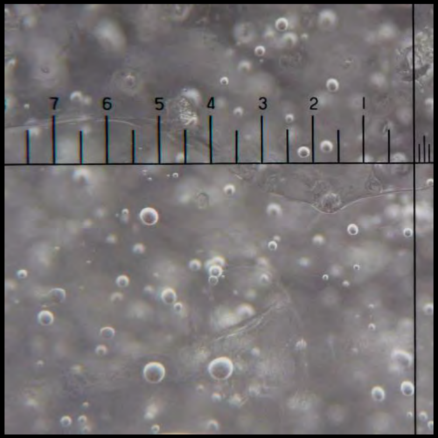
Huascarán, Peru

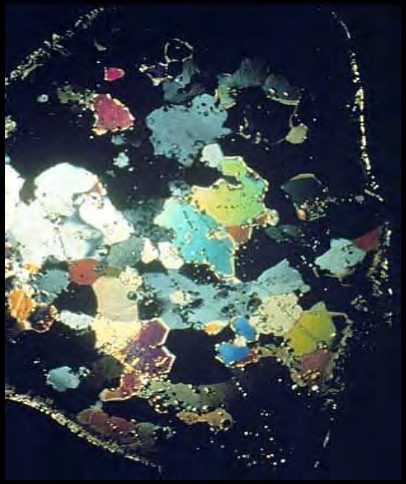
Dasuopu Glacier
Southern Tibet

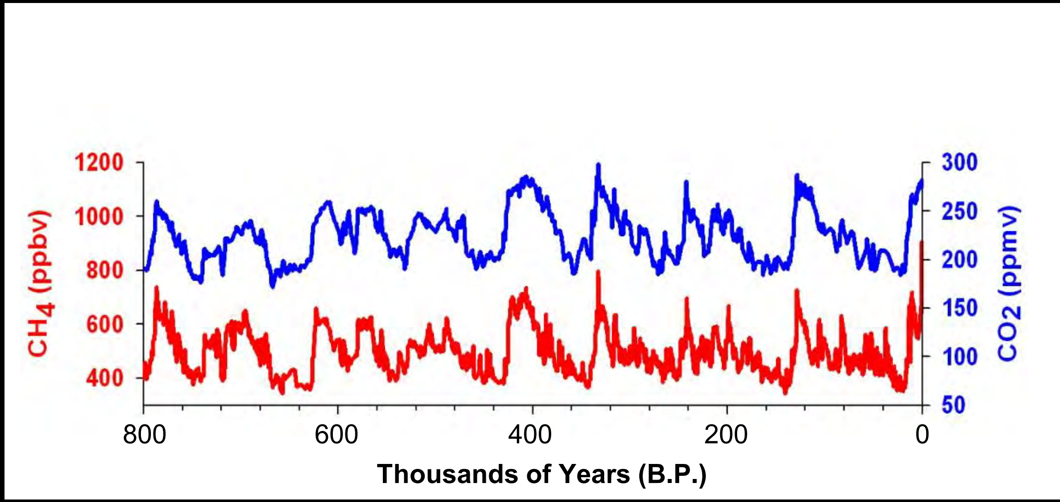




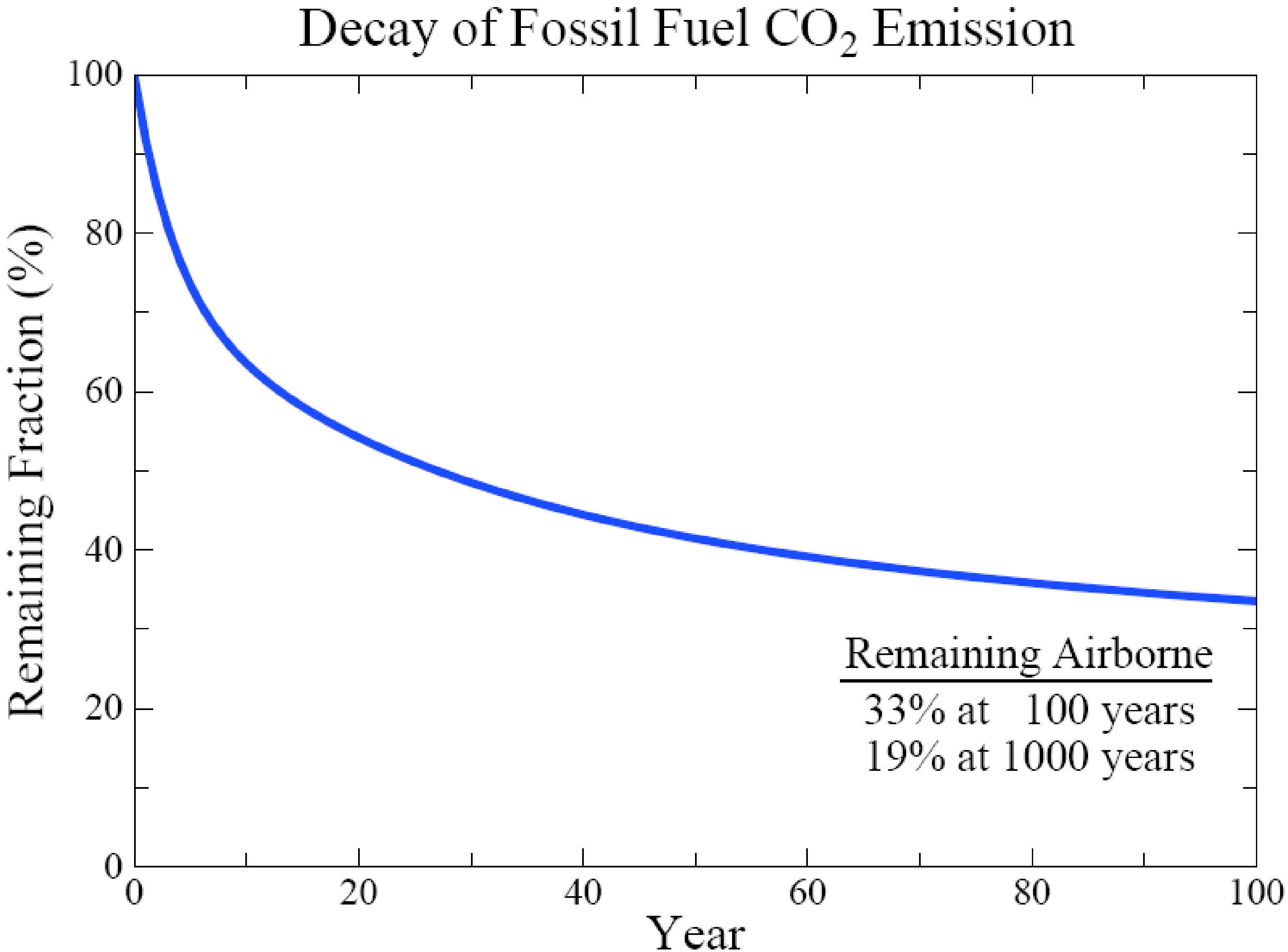
EPICA Dome C ice core extends back through eight glacial and interglacial stages (800,000 years) recording changes in the composition of Earth's atmosphere







Lüthi *et al.*, *Nature*, 2008



The fraction of CO_2 remaining in the air, after emission by fossil fuel burning, declines rapidly at first, but 1/3 remains in the air after a century and 1/5 after a millennium (*Atmos. Chem. Phys.* 7, 2287-2312, 2007).

Population

1.0 billion	in 1850
2.0 billion	in 1930
4.1 billion	in 1975
6.1 billion	in 2000
7.0 billion	in 2012
9.0 billion	by 2050

In 2012 we also need animals and crops

17 billion	Fowl
1.9 billion	Sheep and goats
1.4 billion	Cattle
1.0 billion	Pigs
400 million	Dogs
500 million	Cats

In contrast, the pre-exploitation number of American Bison:
60 - 80 million

Energy consumption growing

today

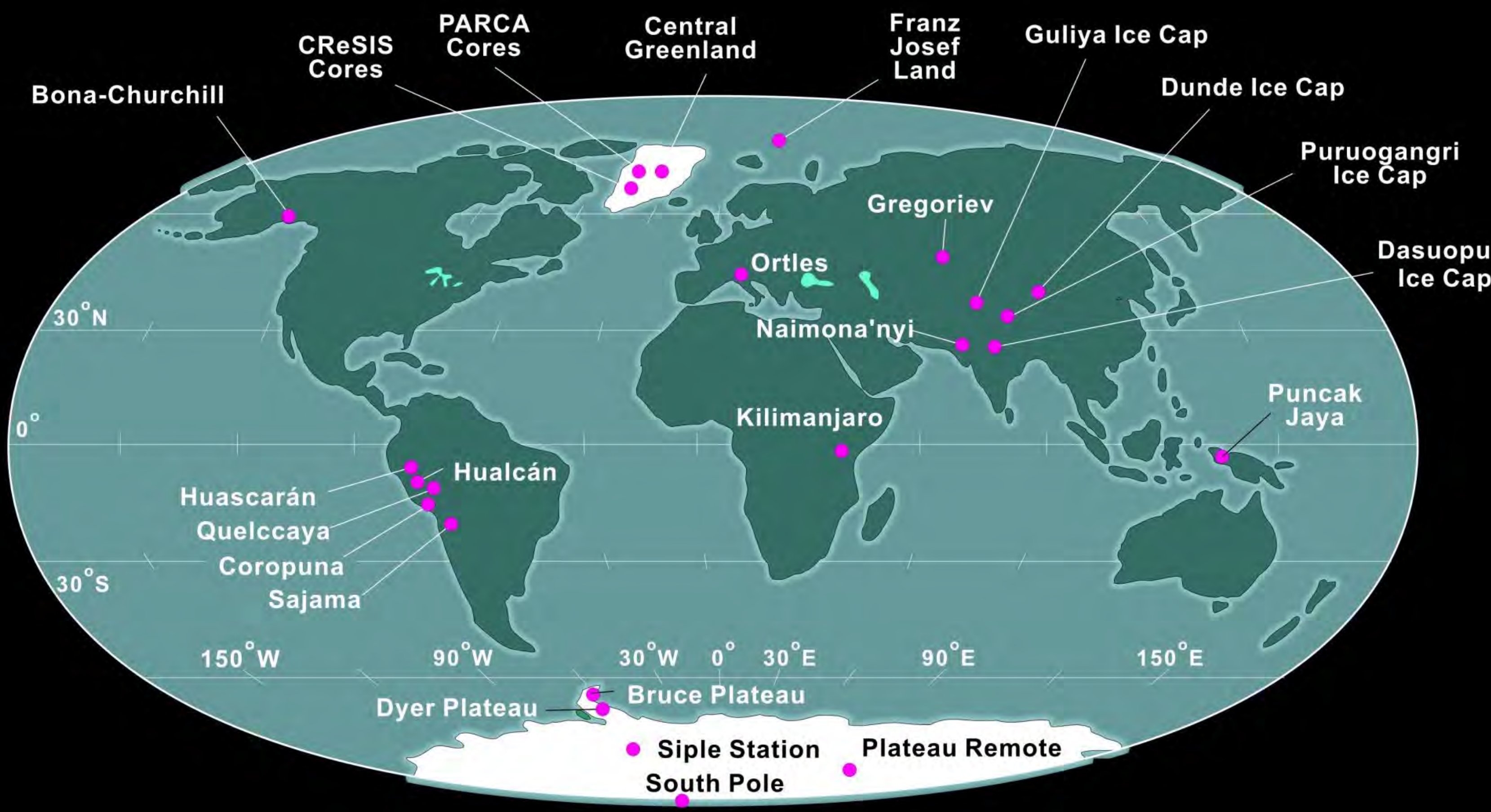
Coal – 40%
Natural gas – 20%
Renewables – 20%
Nuclear – 15%
Oil / Other Petroleum – 5%

World electricity 65% fossil fuels

… to unprecedented demands

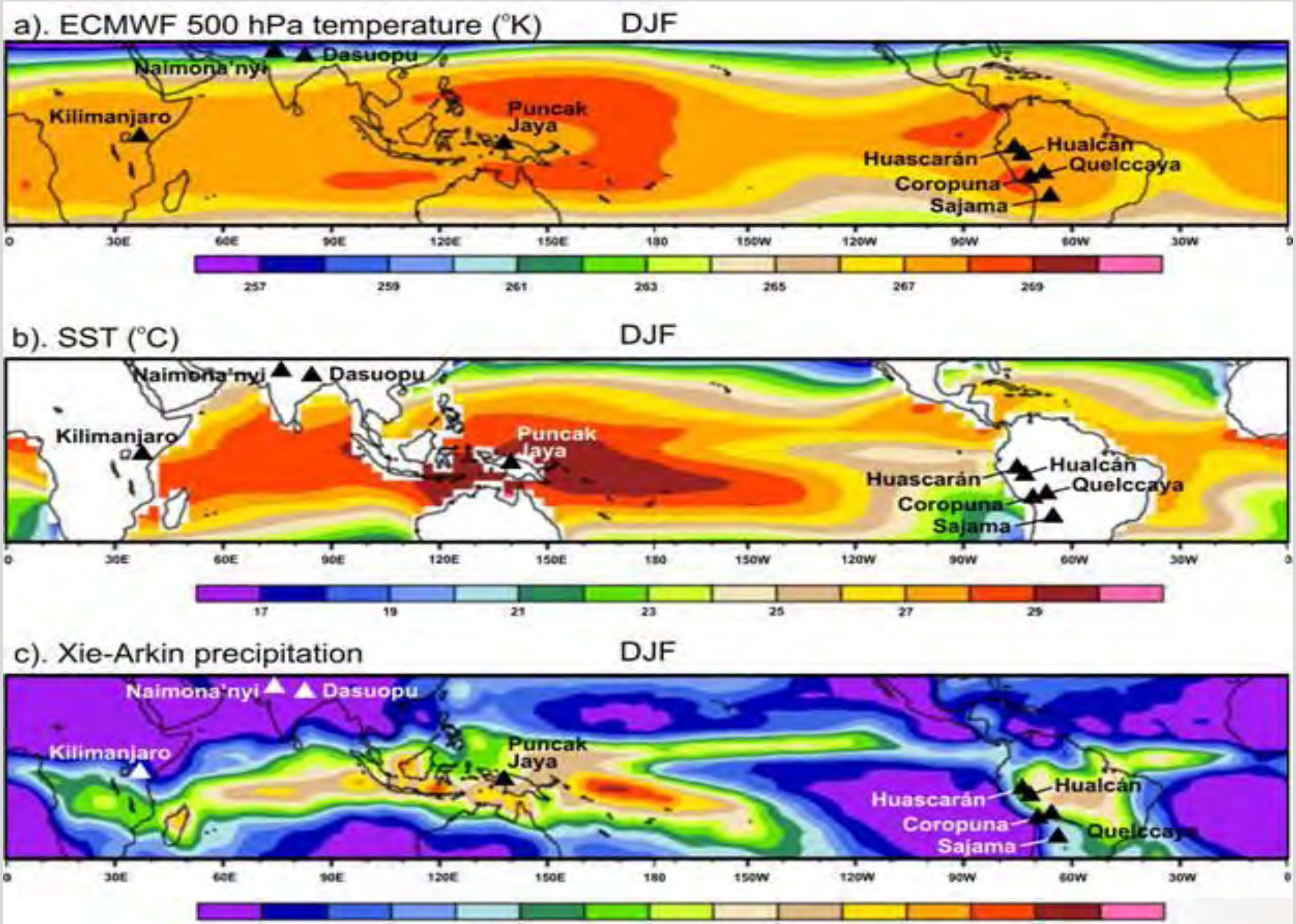
Looking ahead to 2030 … you can see sustained growth in global demand for electricity is inevitable. Demand is forecasted to more than double by 2030 (Energy Information Administration). Source: Mark Little, General Electric Global Research

Ohio State Ice Core Sites



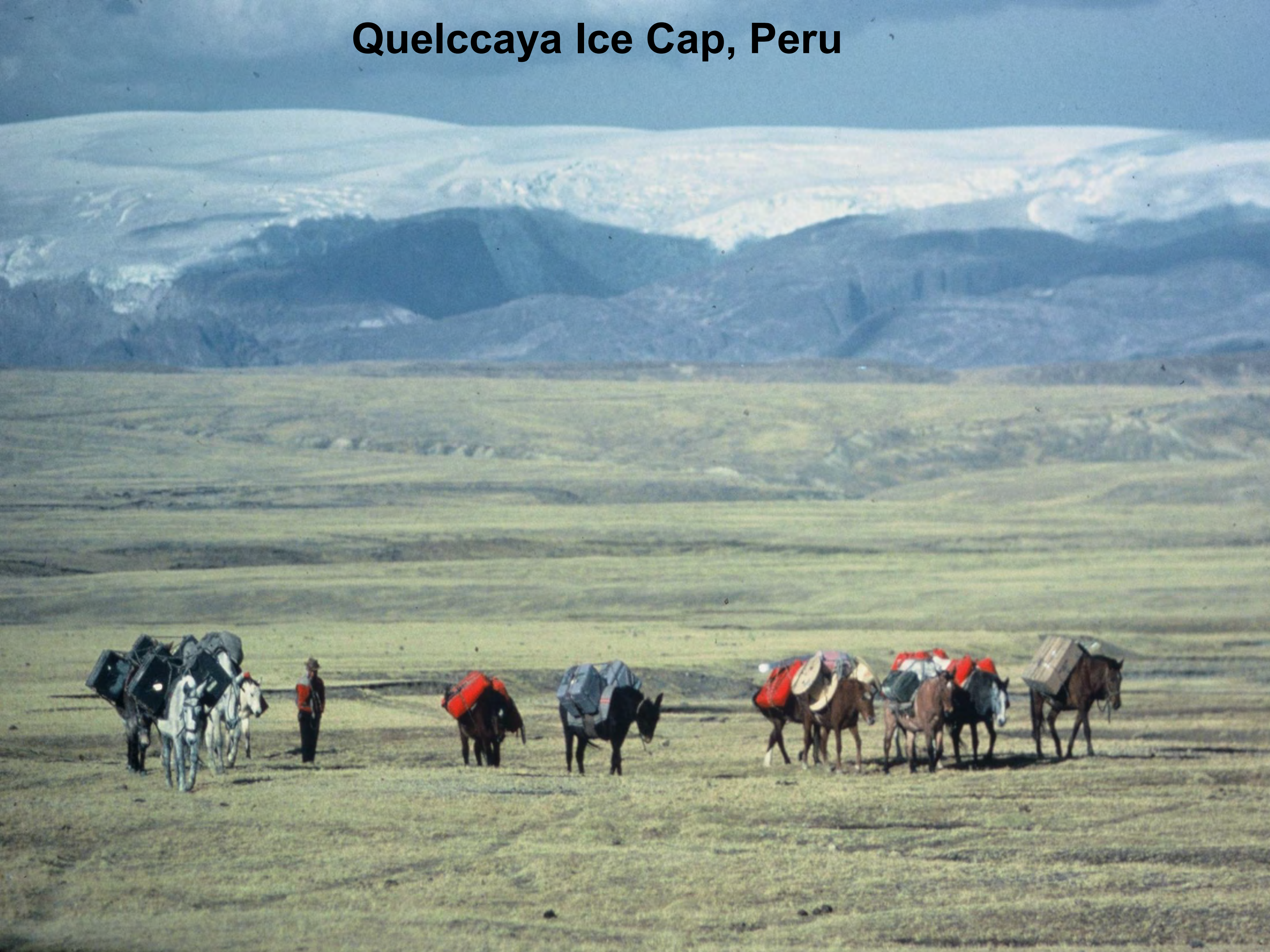
● *Ice Cores drilled by the OSU Ice Core Paleoclimatology Group*

As of October 2011

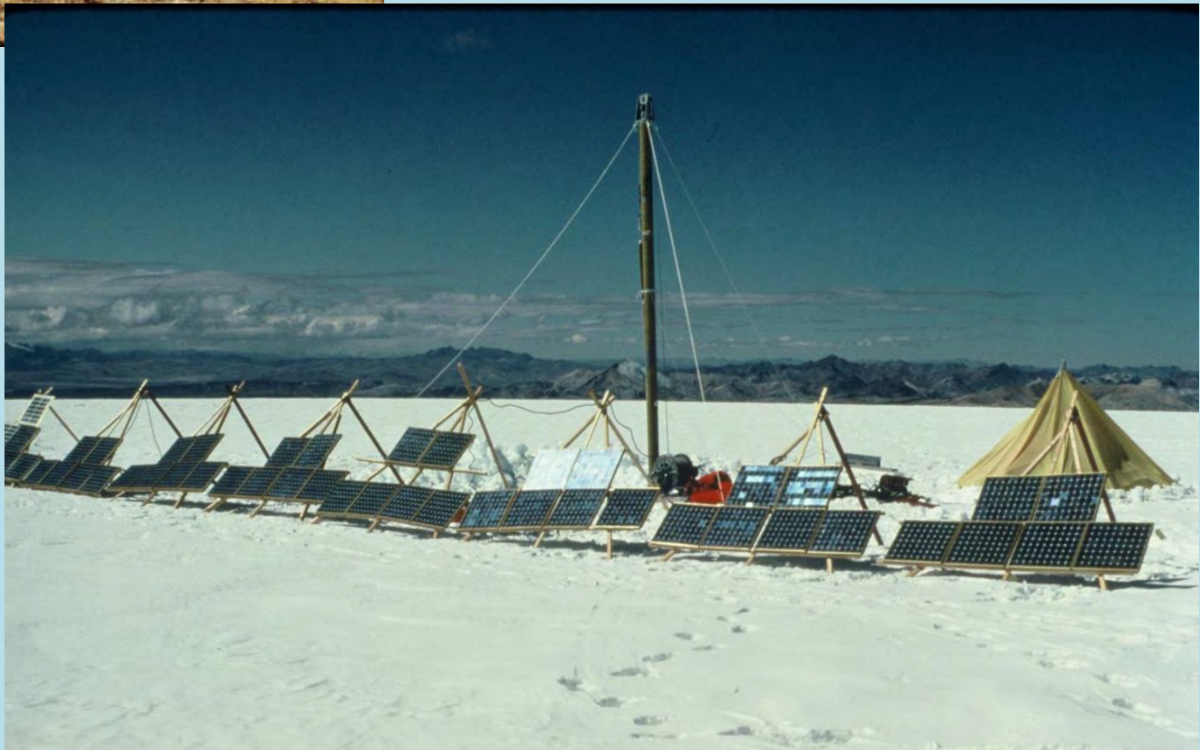


(Modified after Sobel, 2002)

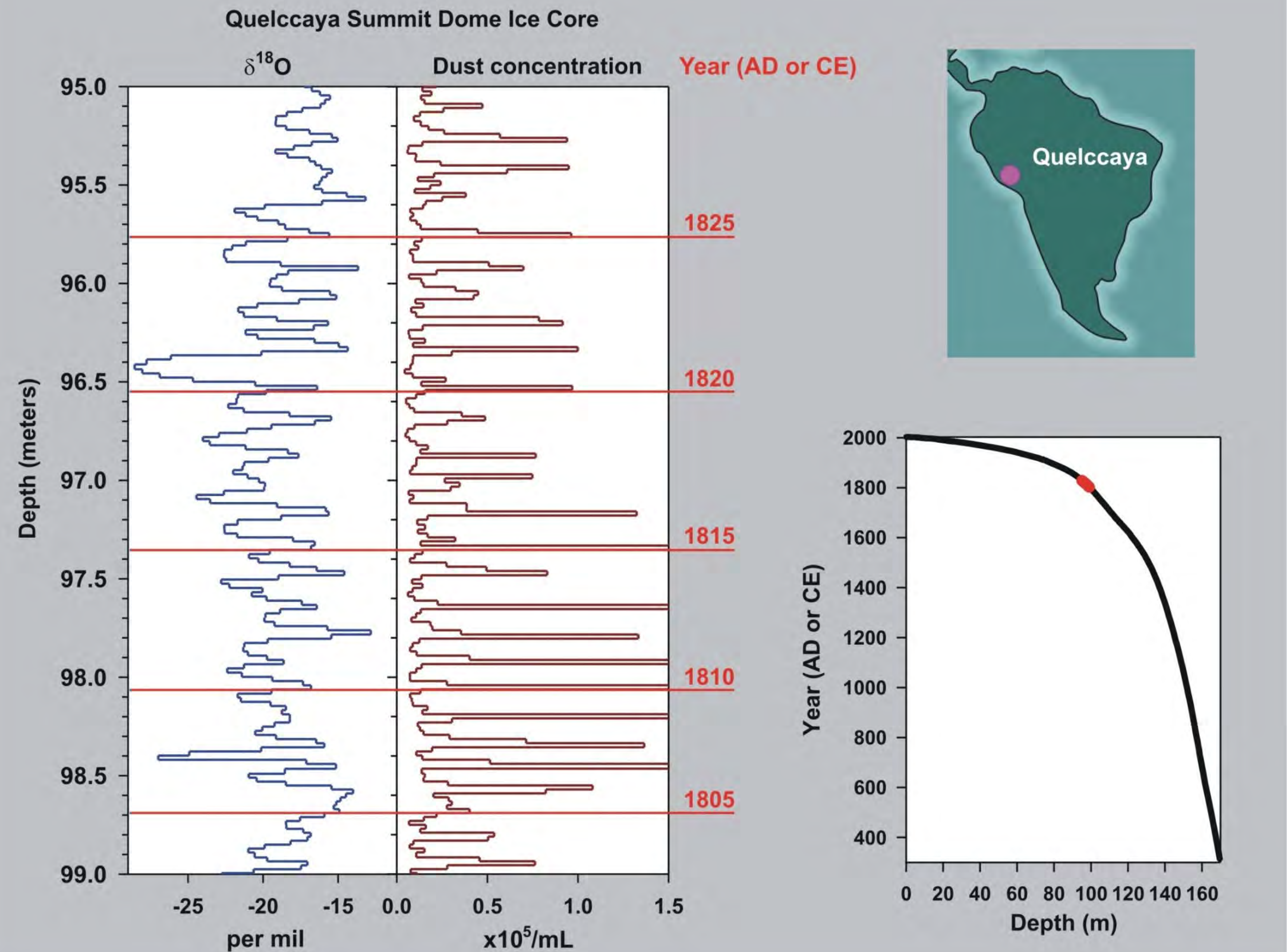
Quelccaya Ice Cap, Peru

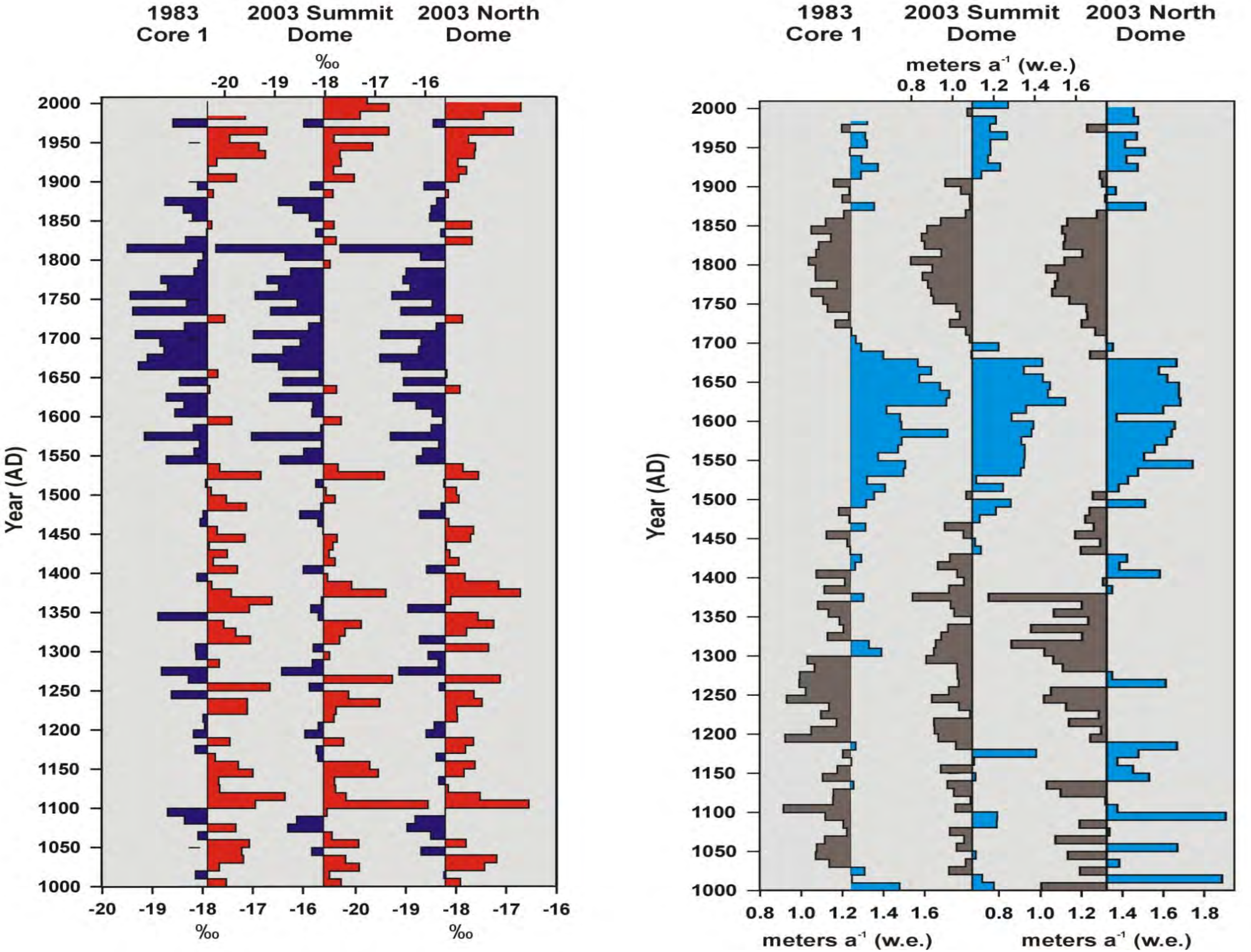



Quelccaya Ice Cap
1983




MOUNTAIN

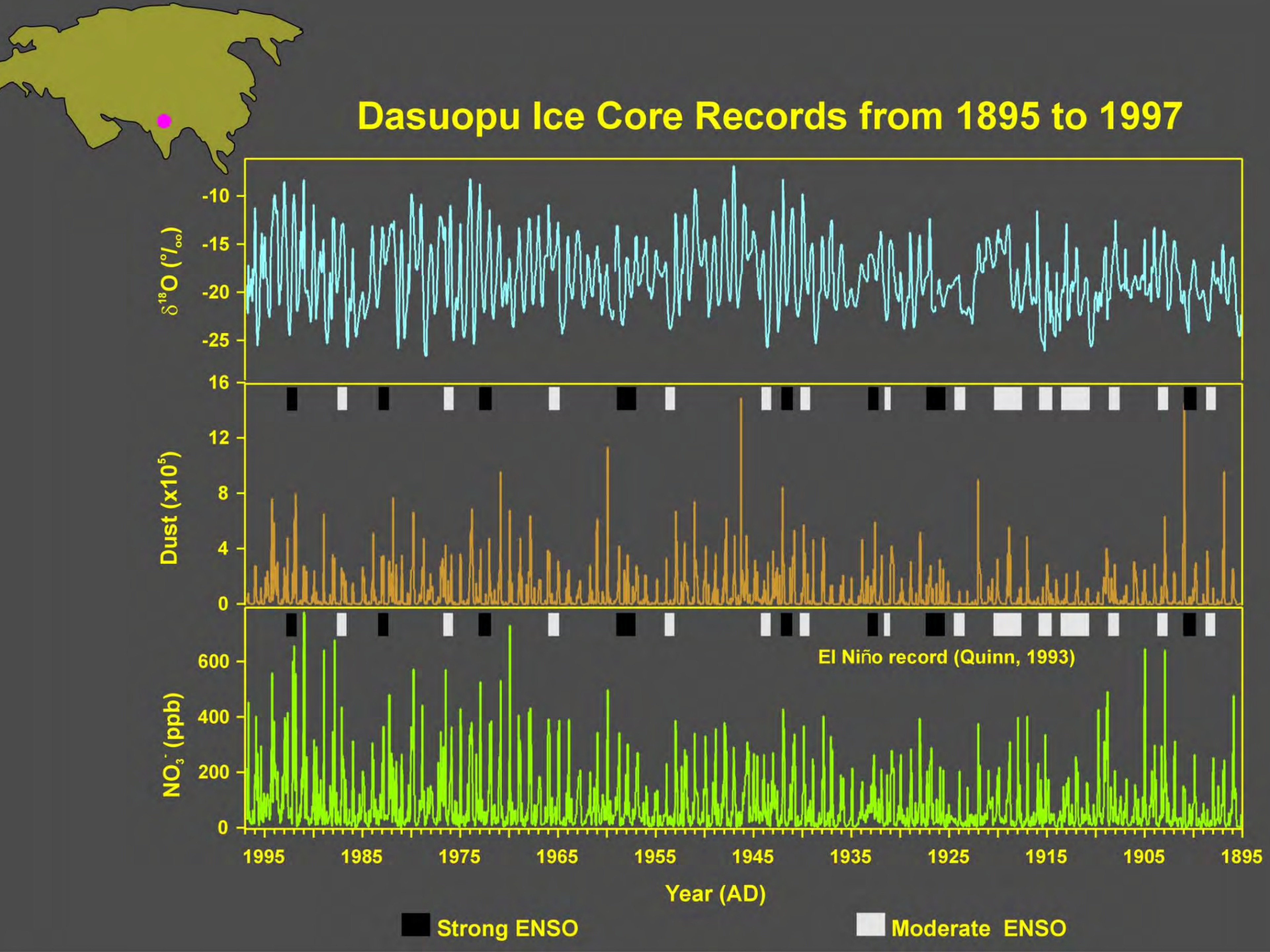

Quelccaya Summit Dome Ice Core
δ18O
Dust concentration
Year (AD or CE)
95.0
95.5
96.0
96.5
97.0
97.5
98.0
98.5
99.0
Depth (meters)
1825
1820
1815
1810
1805
-25
-20
-15
per mil
0.0
0.5
1.0
1.5
x10⁵/mL
Quelccaya
2000
1800
1600
1400
1200
1000
800
600
400
Year (AD or CE)
0
20
40
60
80
100
120
140
160
Depth (m)



1983 Core 1
2003 Summit Dome
2003 North Dome
‰
Year (AD)
meters a⁻¹ (w.e.)

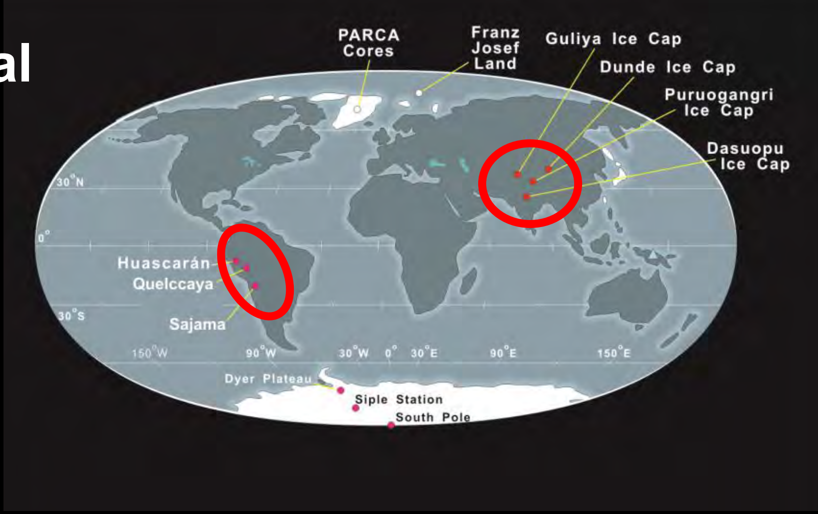
Dasuopu Glacier
Himalaya

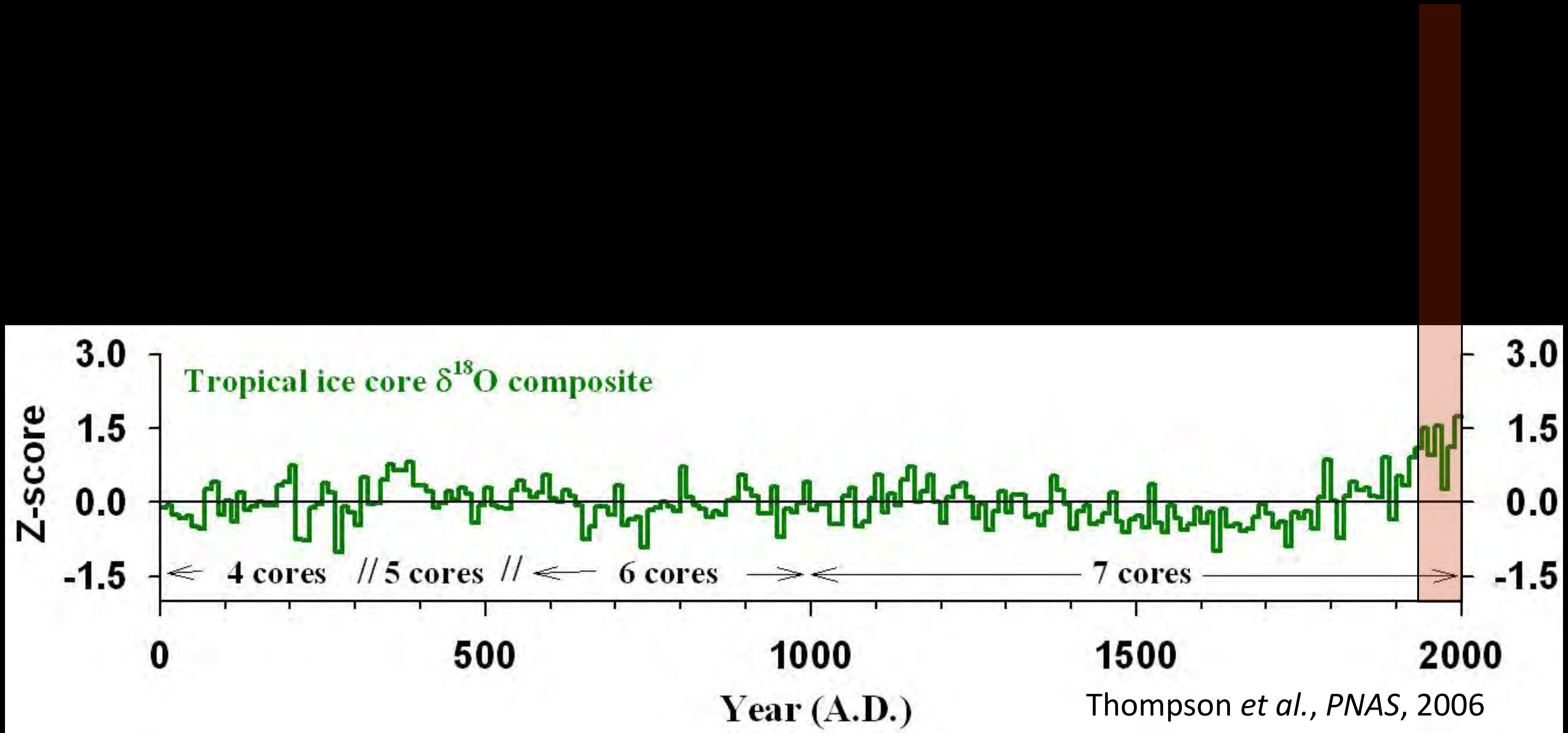
Dasuopu Ice Core Records from 1895 to 1997



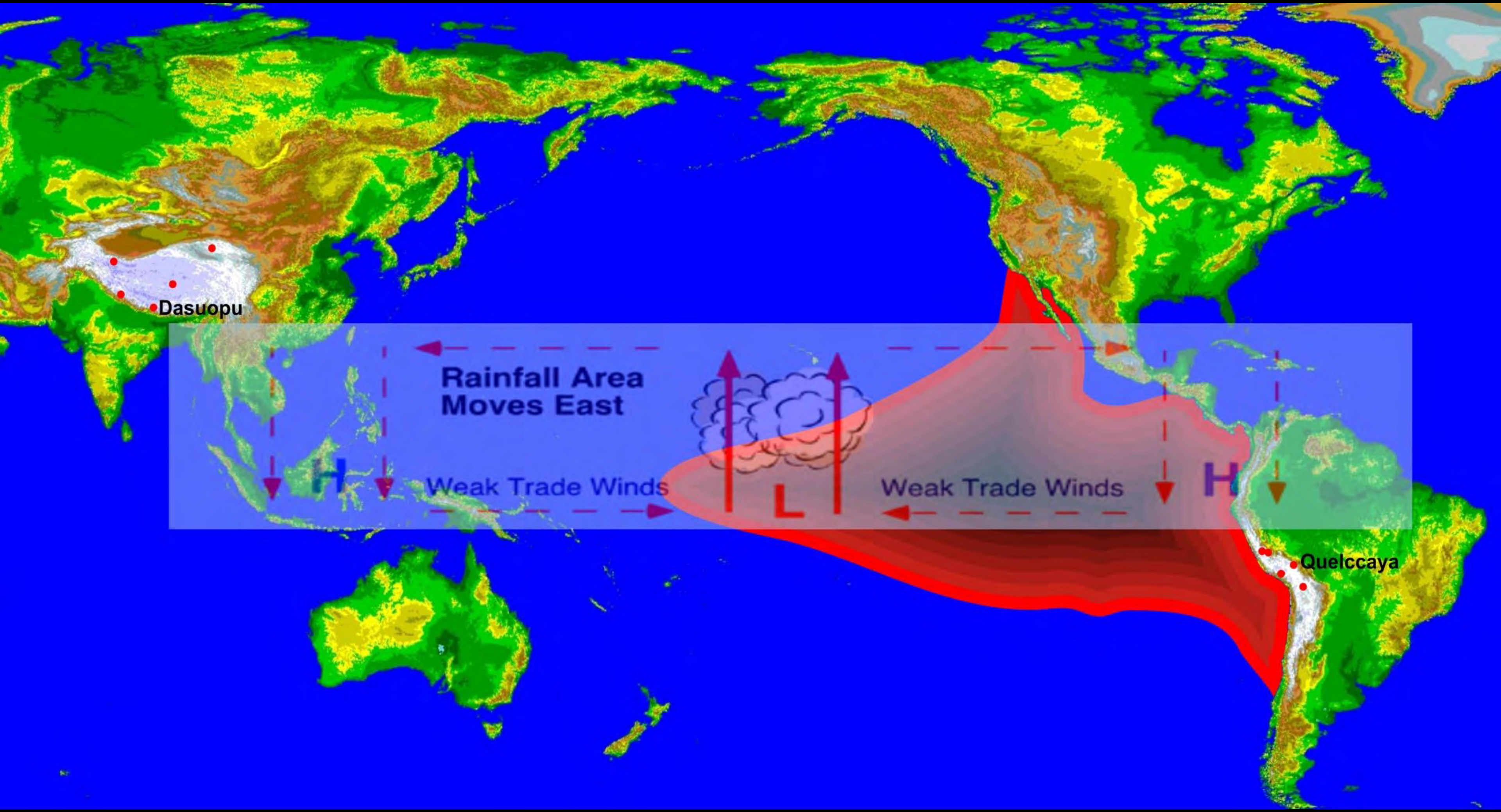
High elevation, low latitude ice cores reveal

- regional differences
- larger scale changes





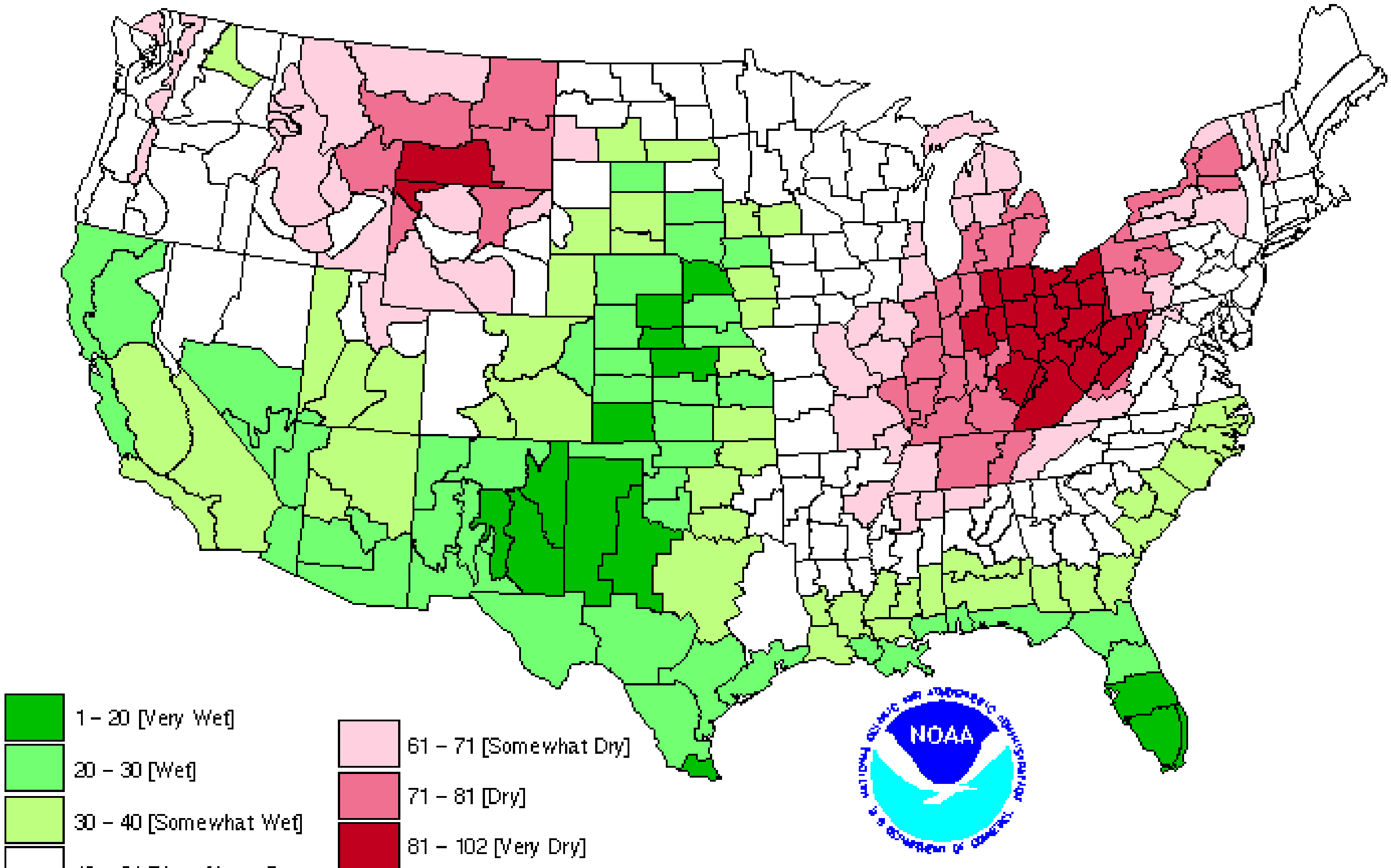
Thompson *et al.*, *PNAS*, 2006


Dasuopu
Rainfall Area
Moves East
Weak Trade Winds
Weak Trade Winds
H
L
H
Quelccaya

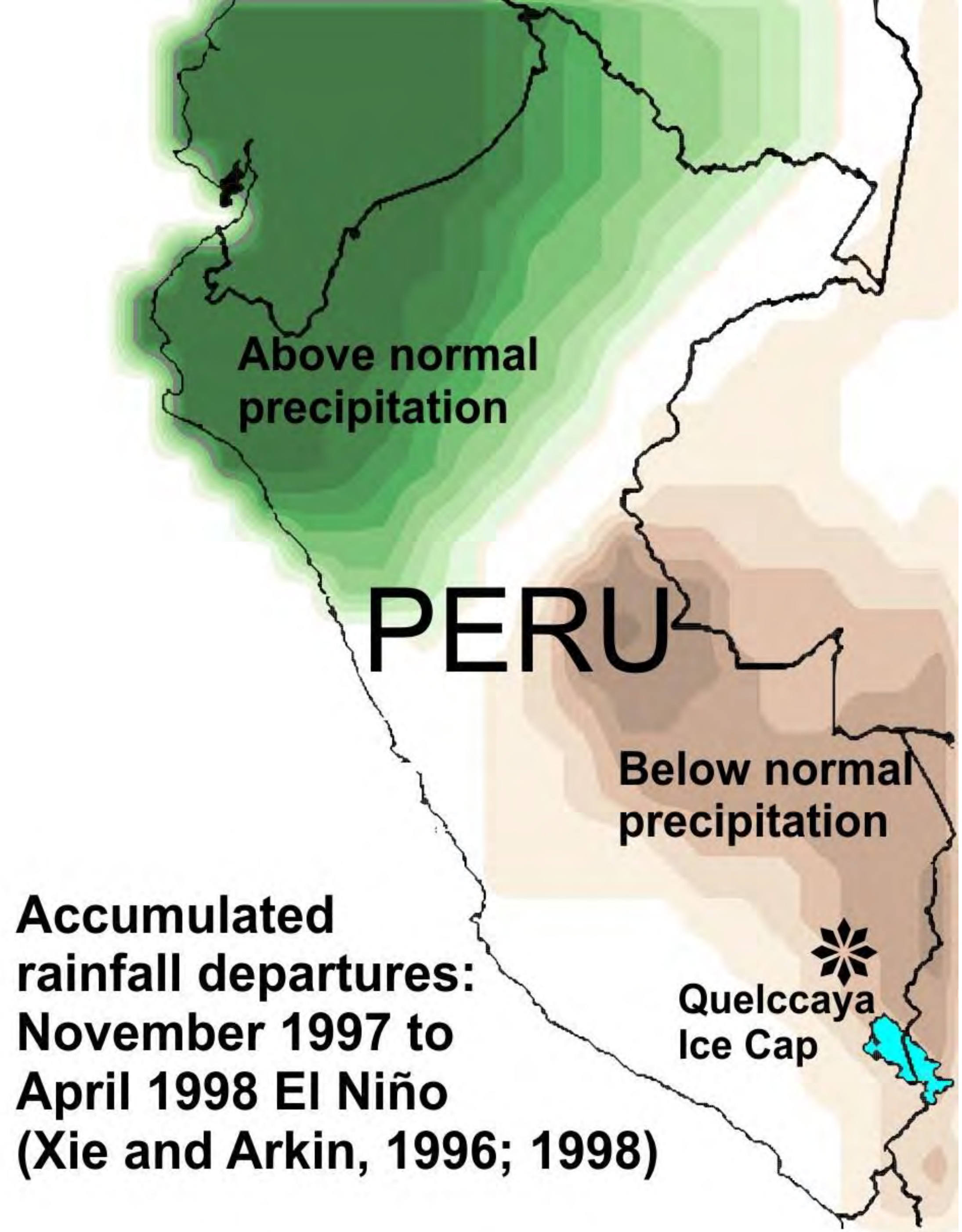
AVERAGE JANUARY - MARCH [3-month] PRECIPITATION RANKINGS DURING ENSO EVENTS

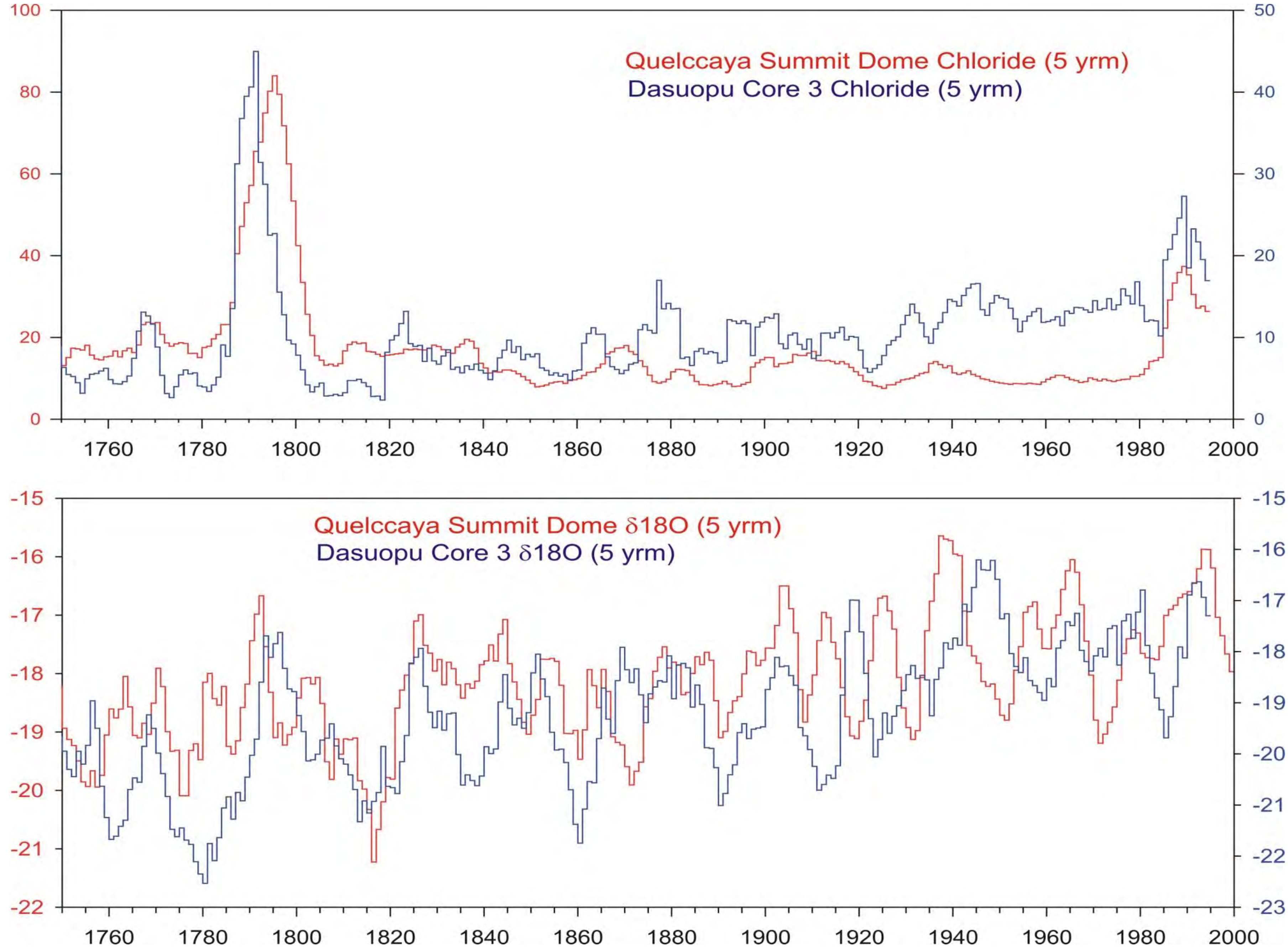
1915 1919 1941 1958 1966 1969 1973 1983 1987 1992

Based on 1895-1997



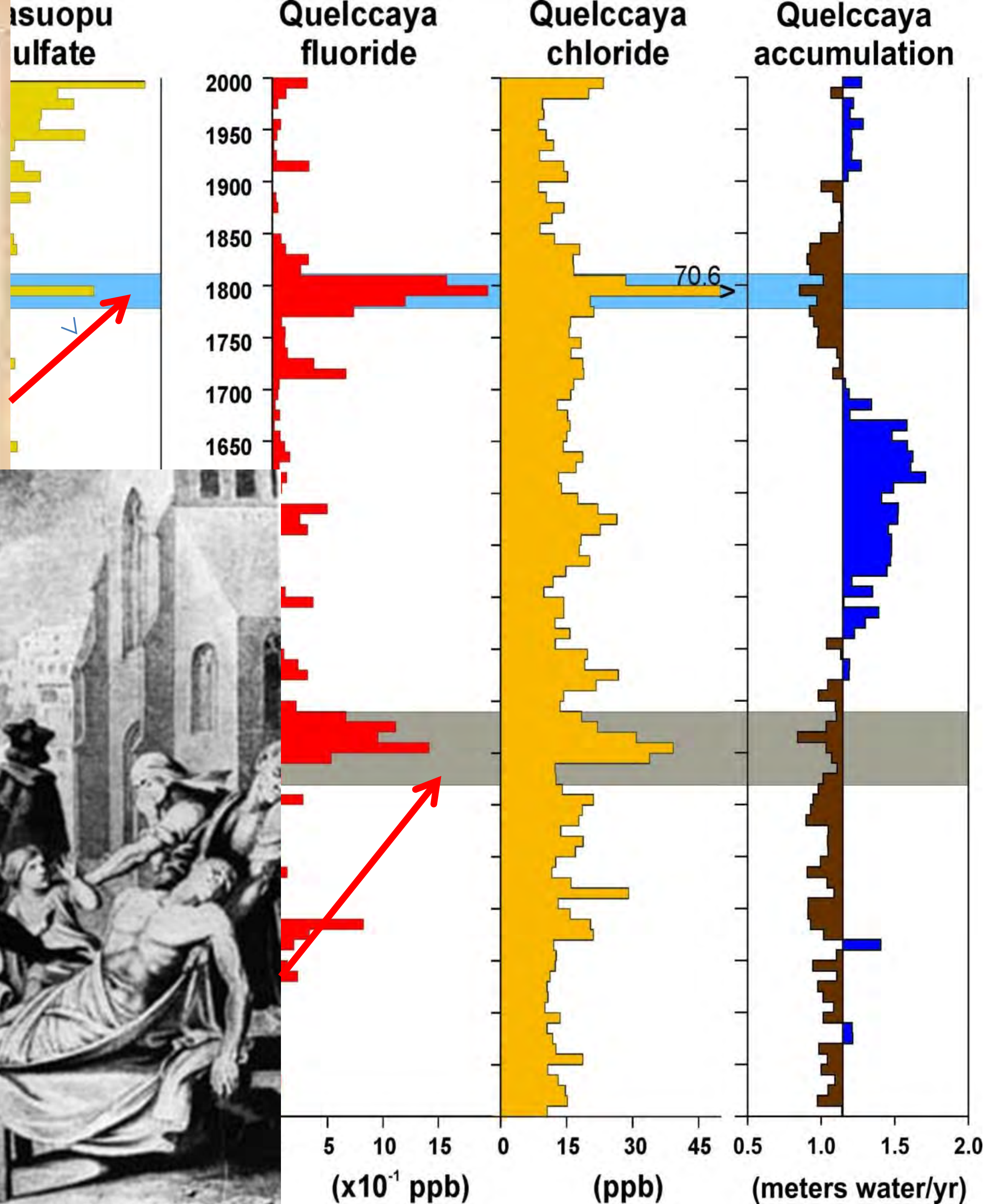
CLIMATE PREDICTION CENTER, NOAA


Above normal
precipitation
PERU
Below normal
precipitation
Quelccaya
Ice Cap
Accumulated
rainfall departures:
November 1997 to
April 1998 El Niño
(Xie and Arkin, 1996; 1998)


Quelccaya Summit Dome Chloride (5 yrm)
Dasuopu Core 3 Chloride (5 yrm)
100
80
60
40
20
0
50
40
30
20
10
0
1760
1780
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
Quelccaya Summit Dome δ18O (5 yrm)
Dasuopu Core 3 δ18O (5 yrm)
-15
-16
-17
-18
-19
-20
-21
-22
-15
-16
-17
-18
-19
-20
-21
-22
-23
1760
1780
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000


INDIA in 1795.
20.
Region of the
Doji Bara famine
1791-92
OUDH
MAHRATTA


Hulton Archive

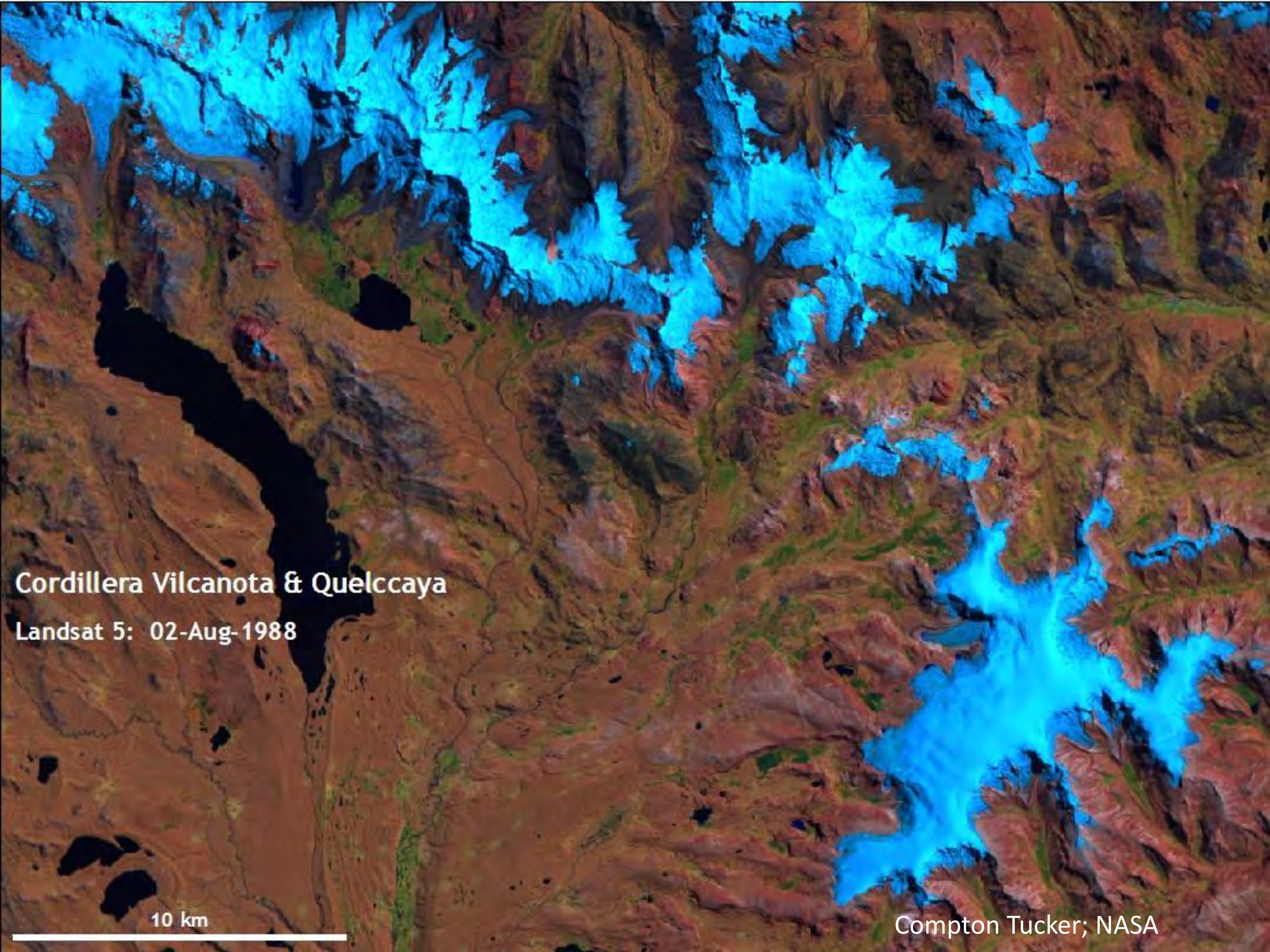

ulfate
Quelccaya
fluoride
Quelccaya
chloride
Quelccaya
accumulation
2000
1950
1900
1850
1800
1750
1700
1650
70.6
5
10
15
0
15
30
45
0.5
1.0
1.5
2.0
(x10^-1 ppb)
(ppb)
(meters water/yr)

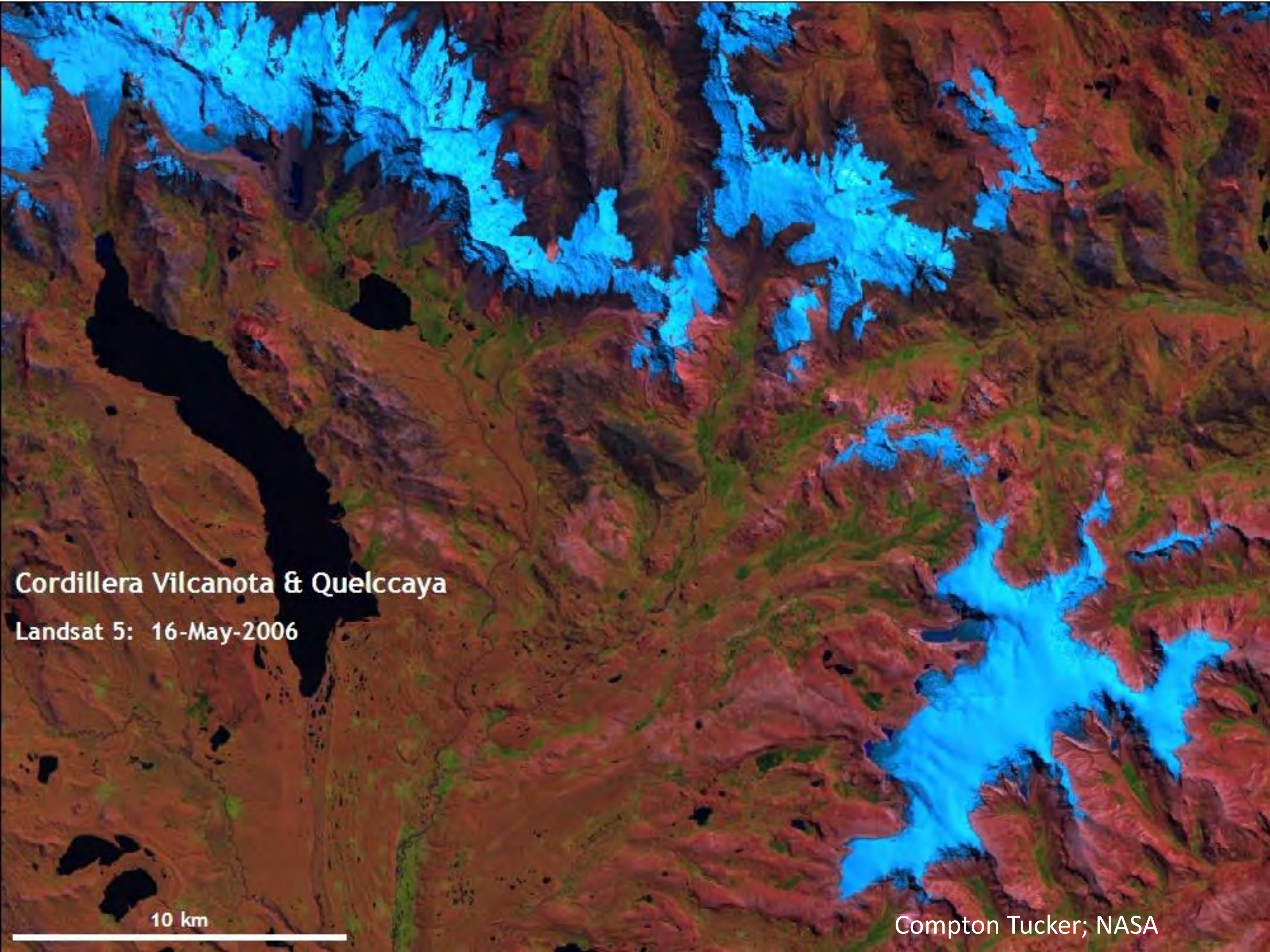
Nature's best thermometer, perhaps its most sensitive and unambiguous indicator of climate change, is ice.

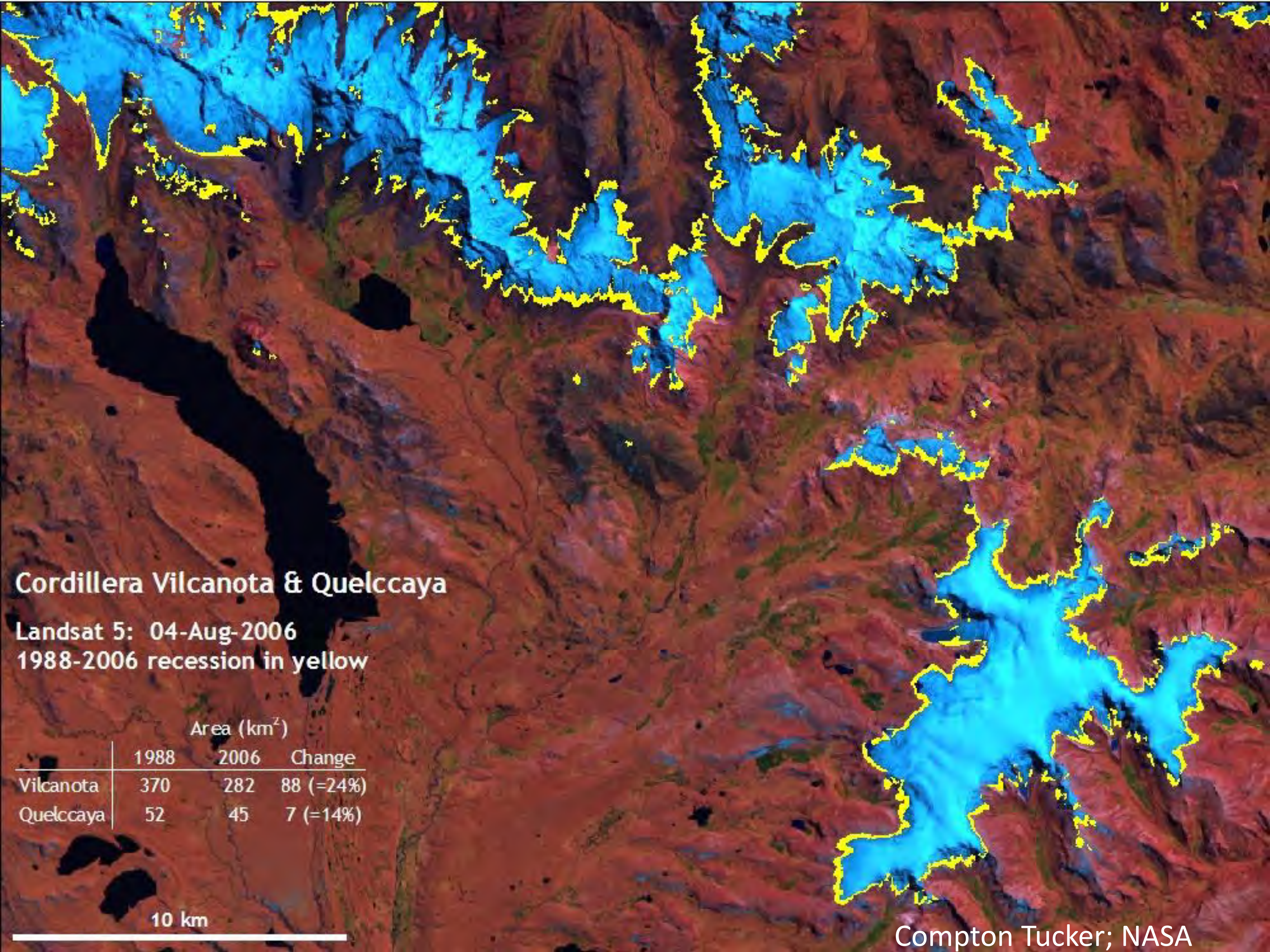
"Ice asks no questions,
presents no arguments,
reads no newspapers
listens to no debates.
It is not burdened by ideology and carries
no political baggage as it changes
from solid to liquid. It just melts."

From *A World Without Ice* by Henry Pollack, 2009

1977


Cordillera Vilcanota & Quelccaya
Landsat 5: 02-Aug-1988
10 km
Compton Tucker; NASA


Cordillera Vilcanota & Quelccaya
Landsat 5: 16-May-2006
10 km
Compton Tucker; NASA



Cordillera Vilcanota & Quelccaya
Landsat 5: 04-Aug-2006
1988-2006 recession in yellow
Area (km2)
1988 2006 Change
Vilcanota 370 282 88 (=24%)
Quelccaya 52 45 7 (=14%)
10 km
Compton Tucker; NASA

Quelccaya, Peru

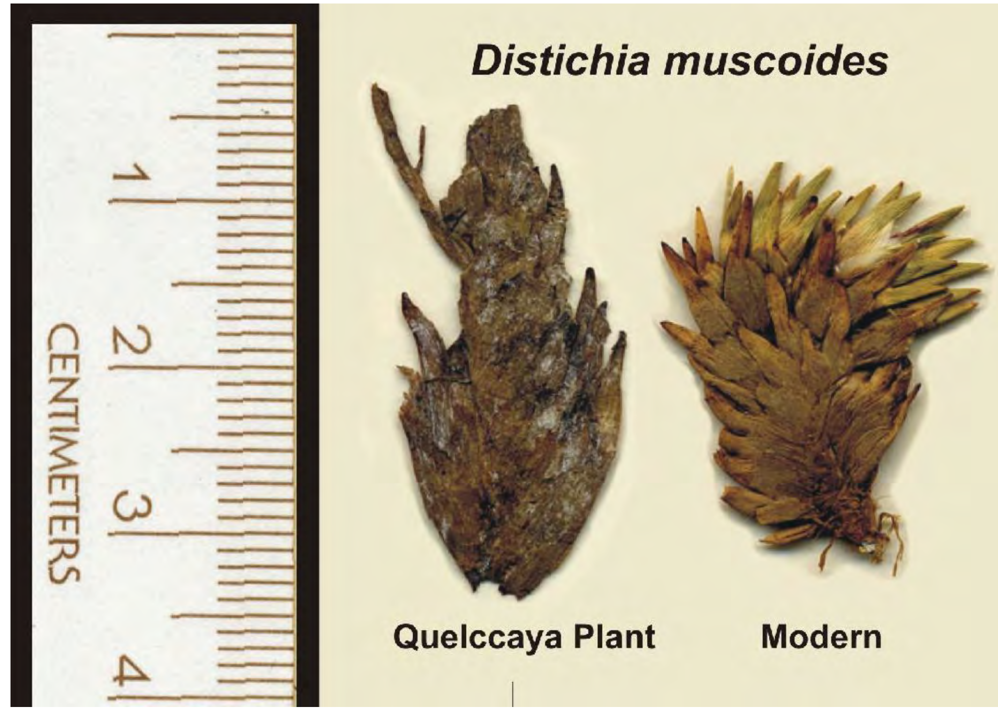
1977

2002

Quelccaya Ice Cap, Peru

Plant

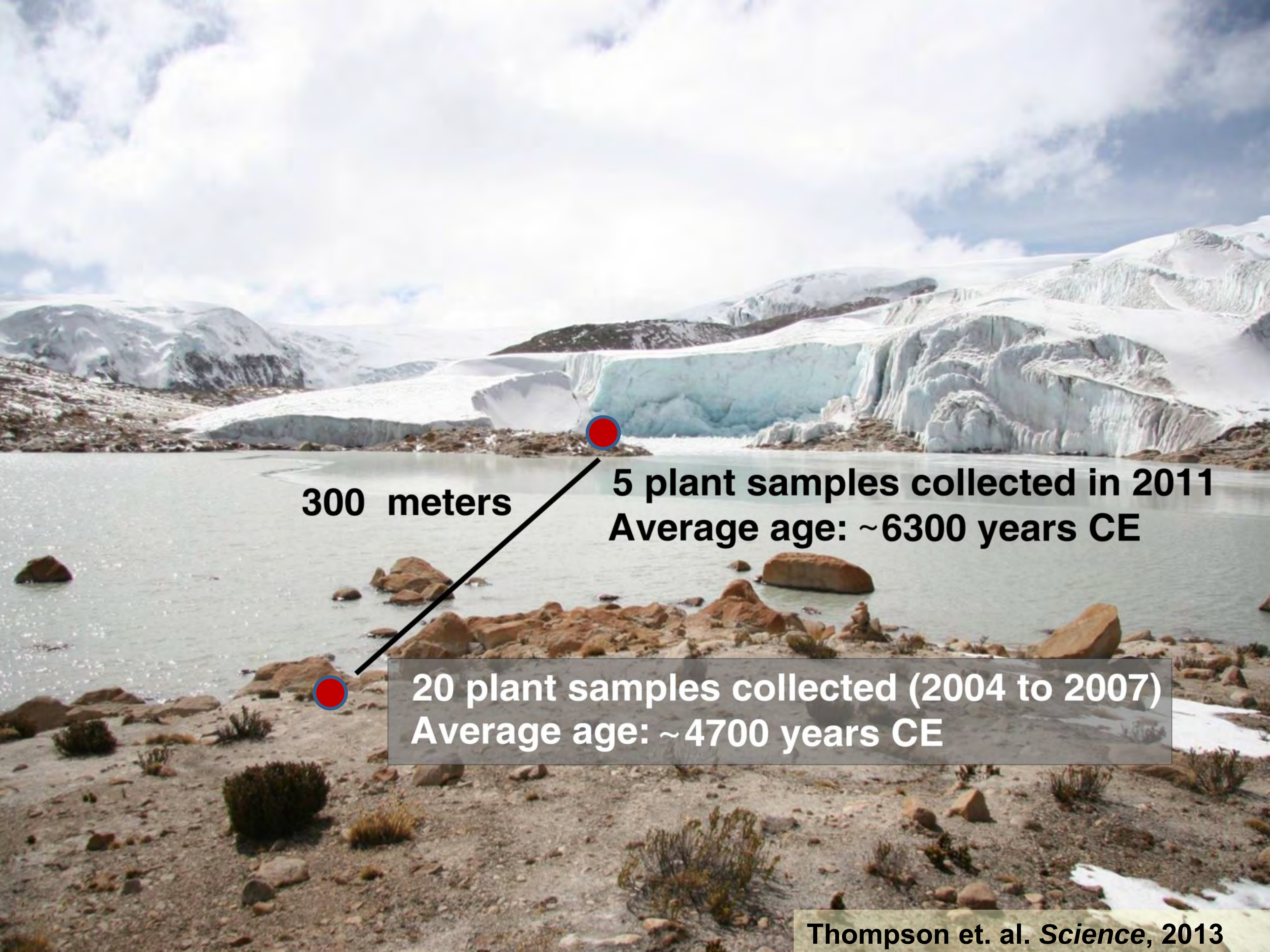
2002



5177 ± 45 yr. BP

200 - 400 m above its modern range

2005


300 meters
5 plant samples collected in 2011
Average age: ~6300 years CE
20 plant samples collected (2004 to 2007)
Average age: ~4700 years CE
Thompson et. al. *Science*, 2013

Muir Glacier, SE Alaska

August, 1941 (photo by William Field)

August, 2004 (photo by Bruce Molnia)

Kyetrak Glacier, Eastern Himalayas

Courtesy of the Royal Geographical Society

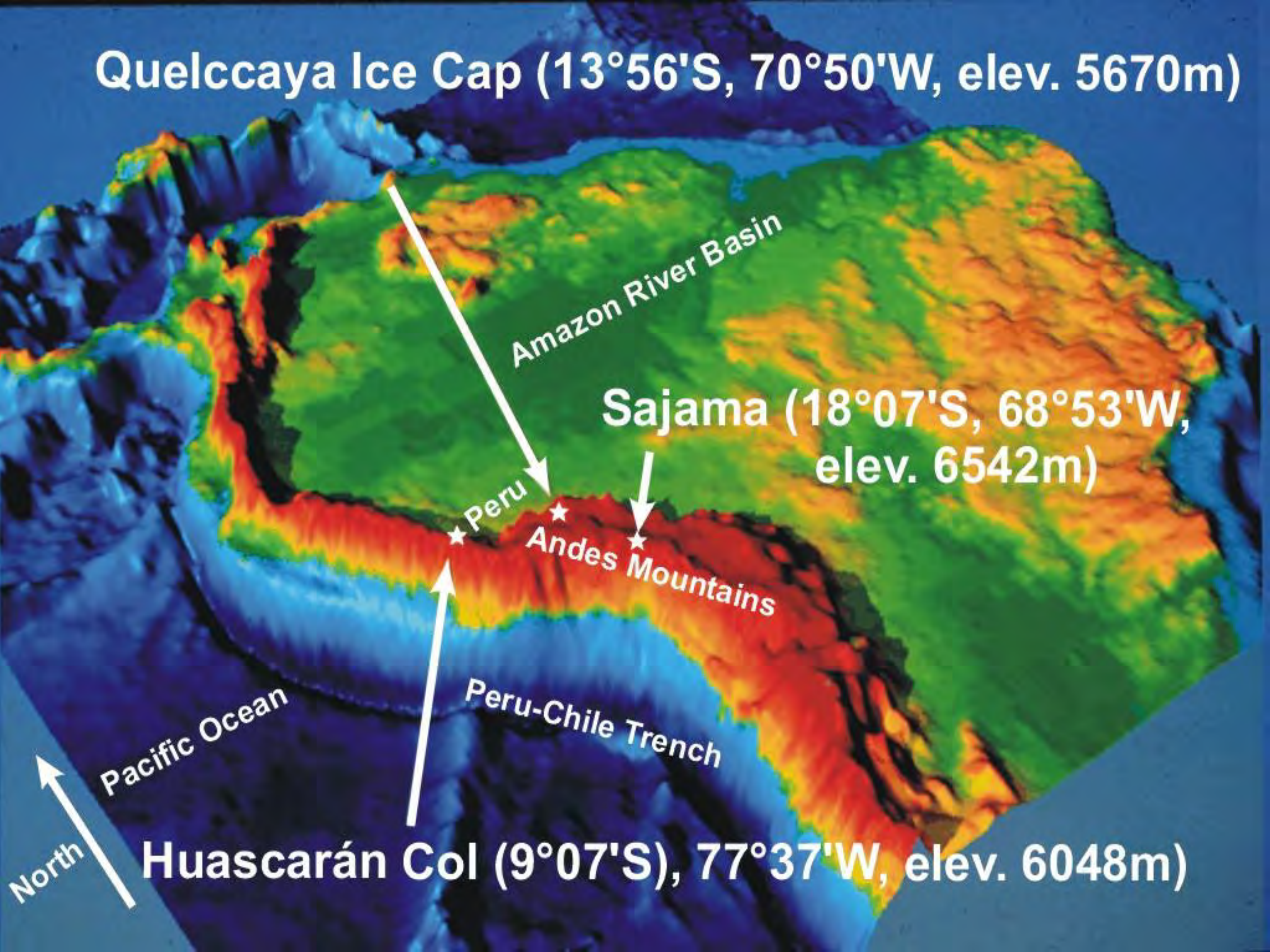
1921

Courtesy of Glacier Works

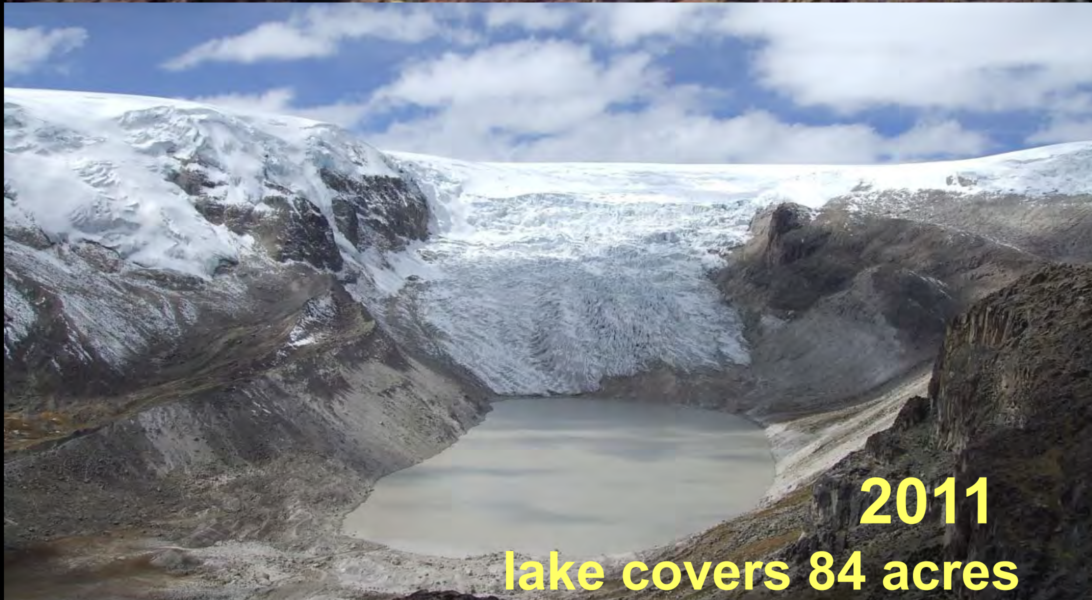
2009

Ghiacciai della Lobbia e dell'Adamello/Mandrone

(*102 anni*)


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)

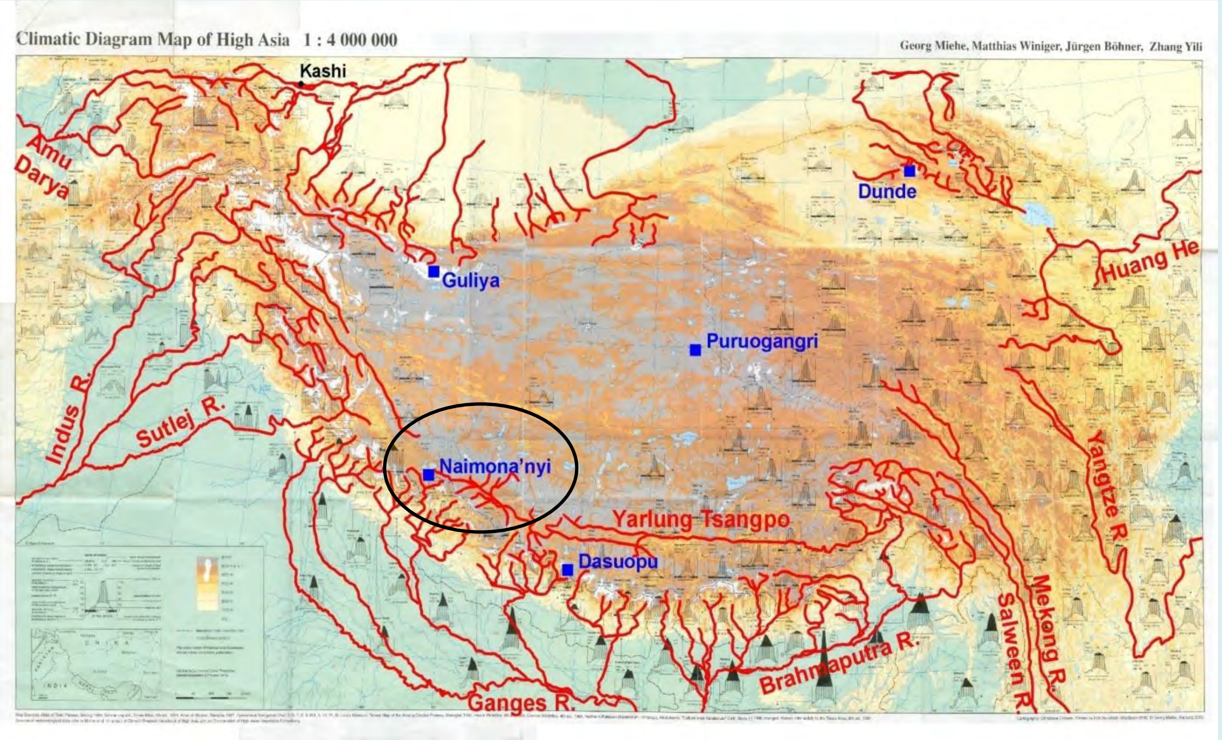
Retreat of the Qori Kalis Glacier (Peru)



Qori Kalis Glacier, Quelccaya Ice Cap, Peru

The Third Pole … high, cold, remote & threatened by climate change

- Centered on the Tibetan Plateau & Himalayas
- Covers 5 million km^2
- One of the largest glacial stores of fresh water over 46,000 glaciers (Asia's water tower)
- Glaciers feed Asia's largest rivers
- Help sustain 1.5 billion people in 10 countries



Naimona’nyi Glacier, southwestern Himalaya (Tibet)


Recovered three ice cores to bedrock in 2006
157.5, 137.8, 113.7 meters
Photo: Lonnie G Thompson

Naimona'nyi Glacier, Himalaya - 2006

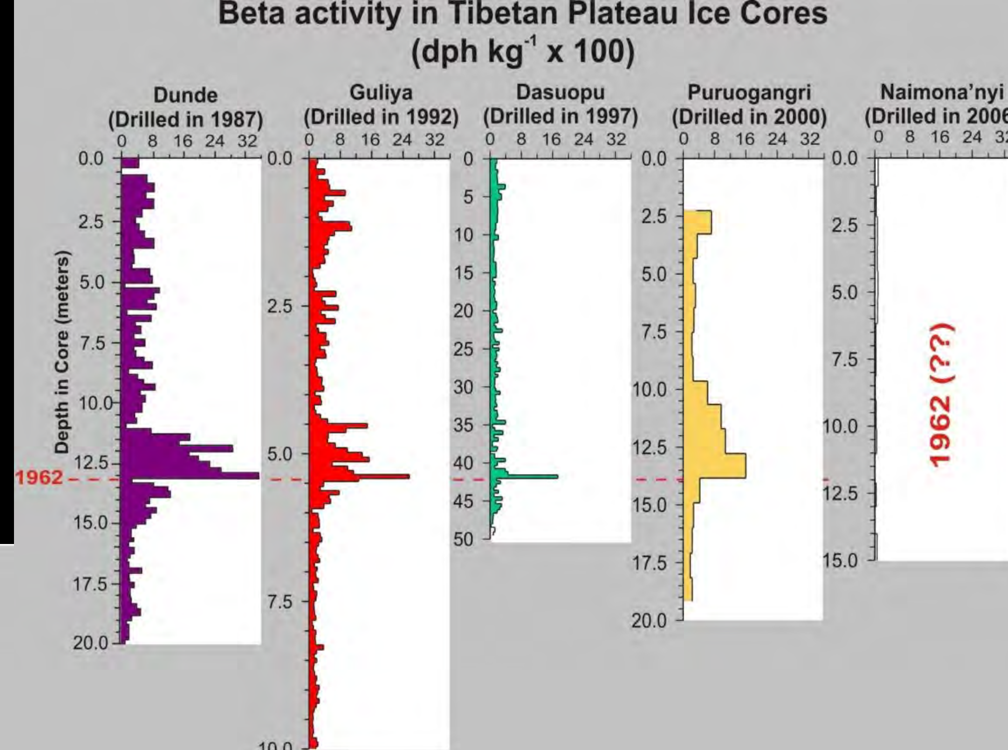
Naimona'nyi Glacier, Himalaya - 2006

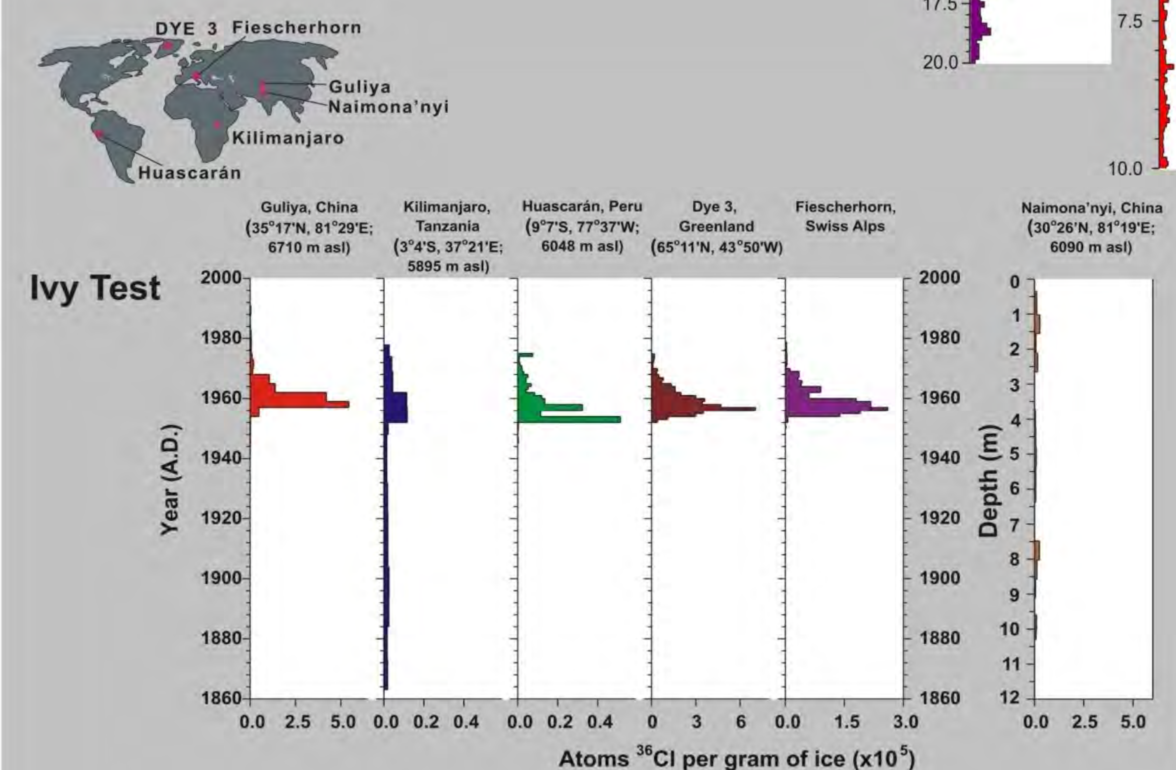
Naimona'nyi Glacier, Himalaya - 2006

Beta activity from nuclear weapons testing in the early 1960s is present in four of the Third Pole cores, but not in Naimona'nyi.

^{36}Cl from nuclear weapons testing in the South Pacific (1952-1958) is present in many glaciers around the world, but not in Naimona'nyi.

The lack of these species in Naimona'nyi indicates that at least the most recent half century of the record is missing.



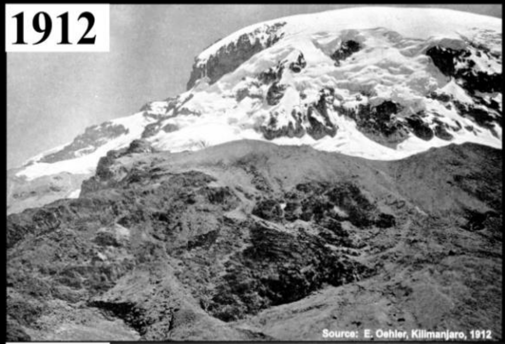


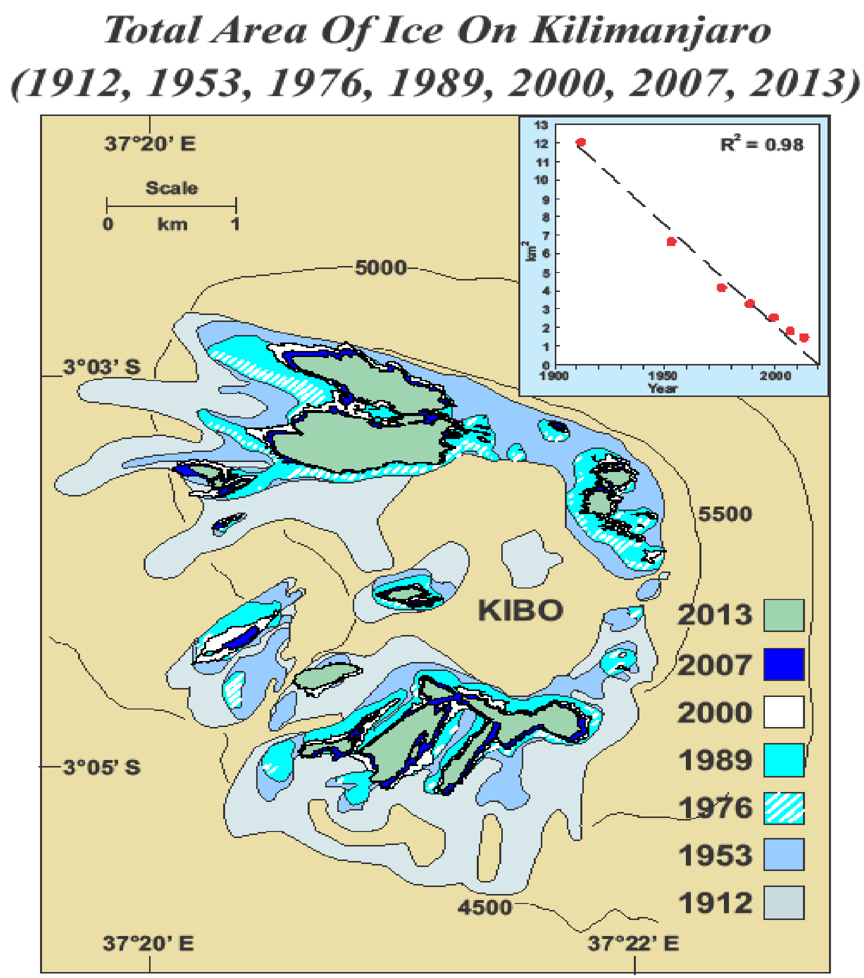
Lanong glacier southern Tibet and Guoqu glacier in central Tibet has loss these marker peaks (Qiu, September 17th, 2013 *Nature)*

Kehrwald, N.M. *et al.* (2008) Mass loss on Himalayan glacier endangers water resources. *Geophys. Res. Lett*. 35, doi:10.1029/2008GL035556

88.3% of the ice present in 1912 has disappeared
40% of the ice present in 2000 had disappeared by 2013

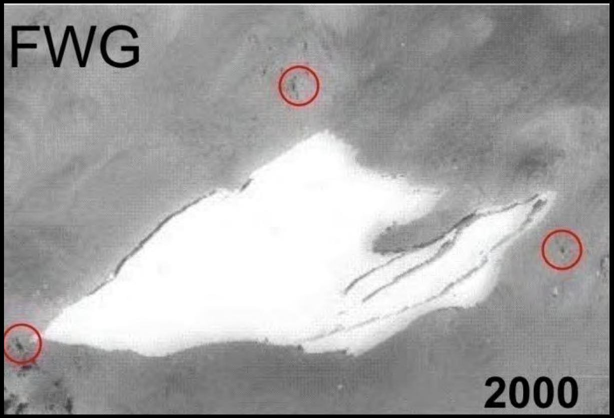
Kilimanjaro, Africa



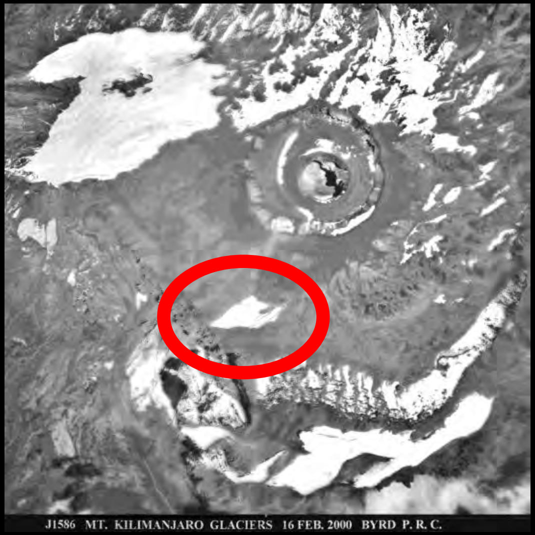


1912 - 1989 after Hastenrath and Greischar, *J. Glaciol.*, 1997
2000 after Thompson *et al.*, *Science*, 2002; 2007 from Thompson (OSU)

Furtwängler Glacier



16 Feb 2000



Thompson *et al*. , *PNAS*, 2009

From 2000 to 2007

- **Northern Ice Field surface lowered 1.9 meters**
- **Furtwängler Glacier surface lowered 3.1 m**
- **Southern Ice Field surface lowered 5.1 m**

Thompson *et al., PNAS,* 2009

Photo: Lonnie Thompson
January

Furtwängler Glacier,

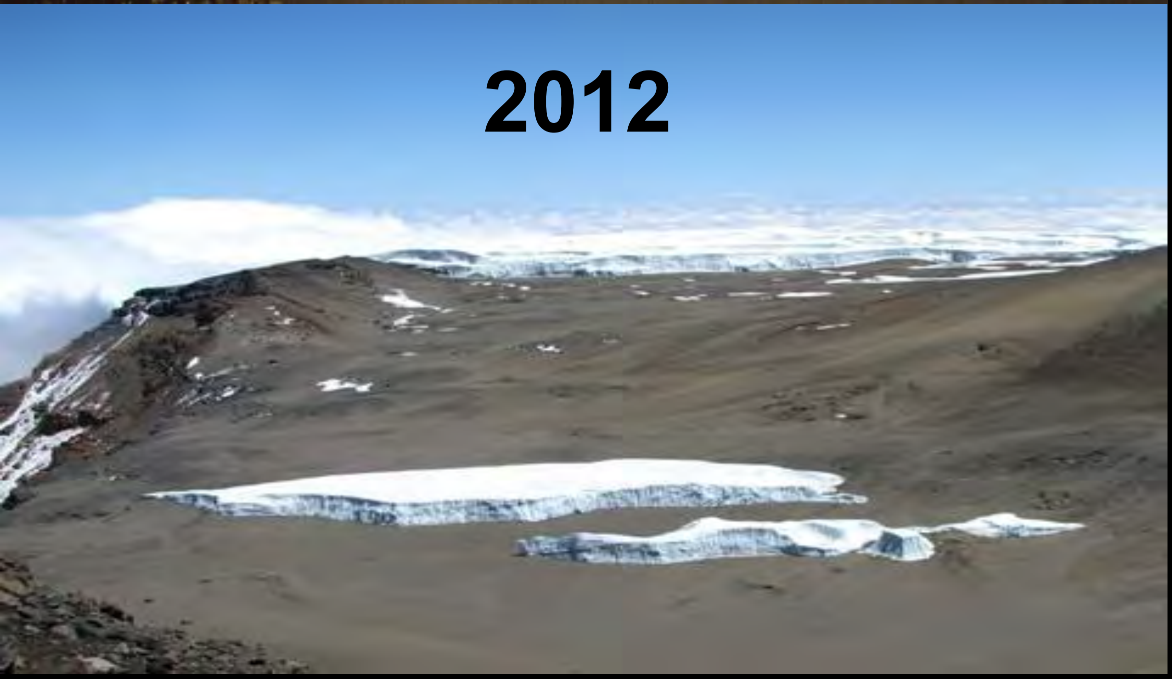
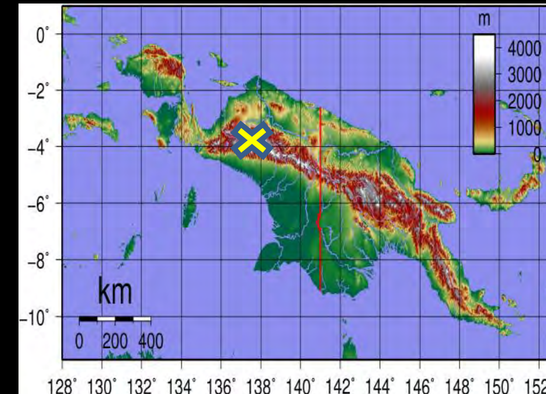


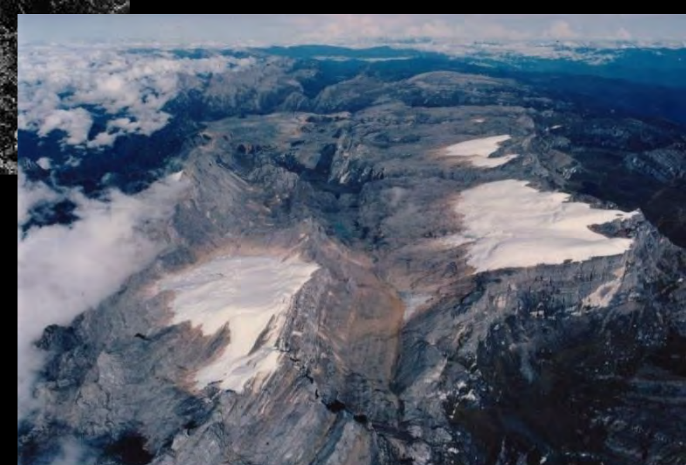
Photo: Michael O'Toole
September

Ice Fields near Puncak Jaya, Papua, Indonesia drilled 2010



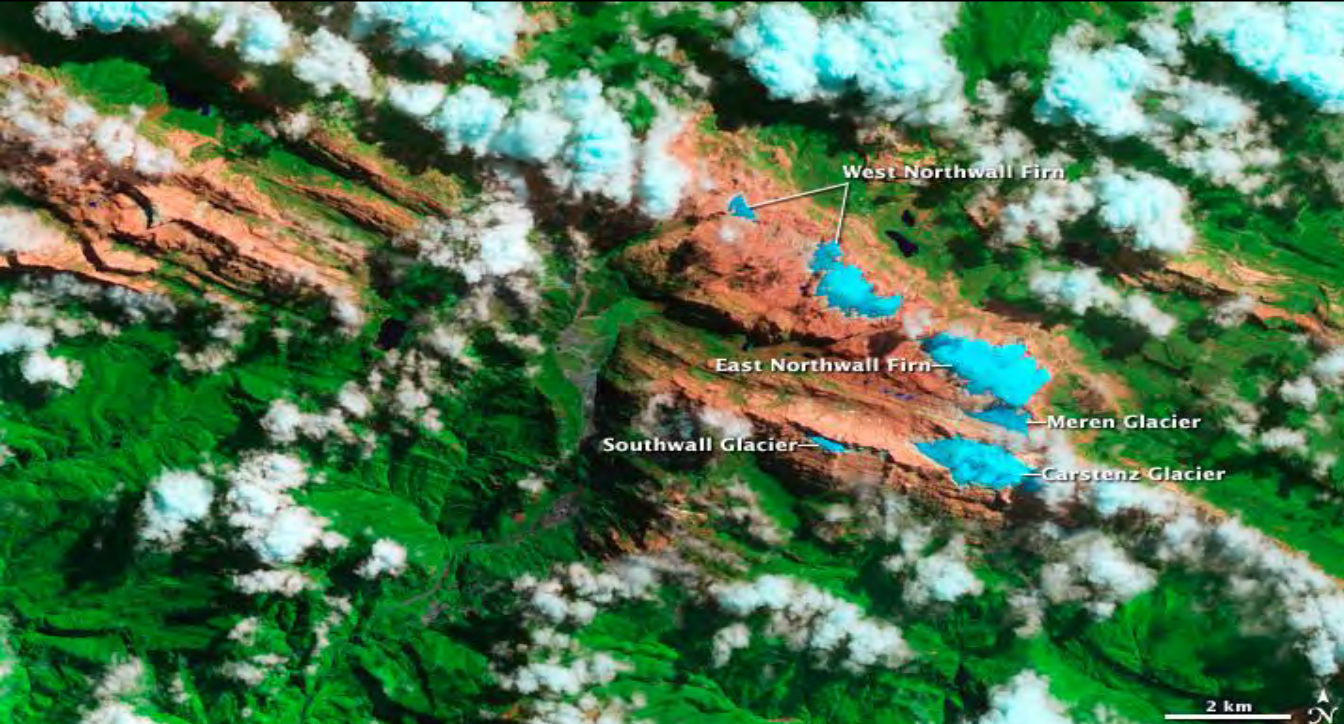
1936

1991



2001

Papua, Indonesia (New Guinea)



May 26, 1989

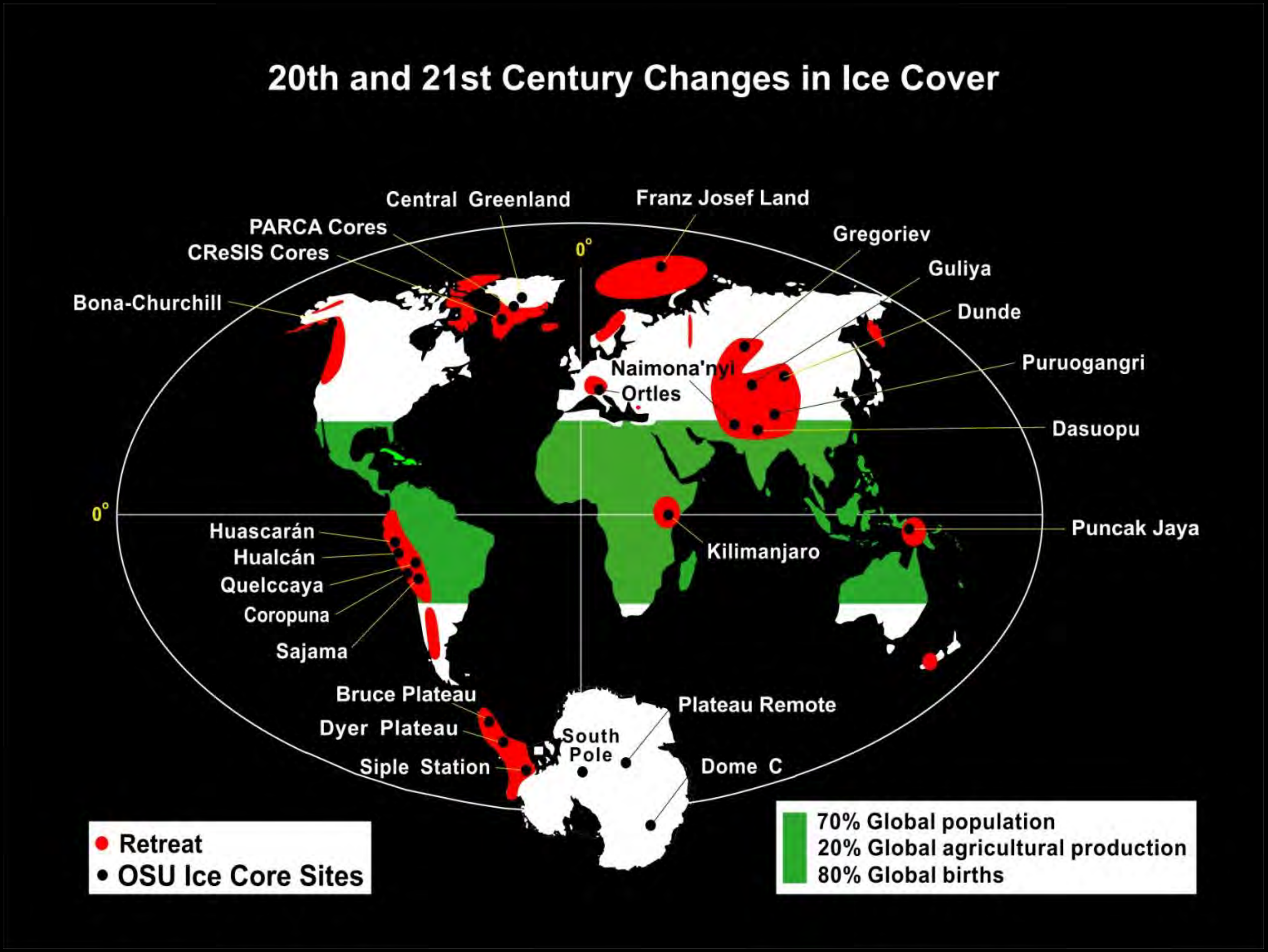
October 29, 2009

Adam Voiland Writer

NASA's Earth Observatory

East Northwall Firn, 2010
Papua, Indonesia
(New Guinea)

Recent and rapid melting of glaciers around the world



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

Courtesy of Dan Schrag, Harvard Univ.


Courtesy of Dan Schrag, Harvard Univ.

How to manage a world with threats from climate change, rising sea levels and rising energy consumption?

Perfect Storm is Brewing

Ingredients for a Perfect Disaster:

- 1000-year CO_2 Lifetime
- Climate System Inertia
- Positive (Amplifying) Feedbacks
- Fossil Fuel Addiction

Alternative: A Brighter Future

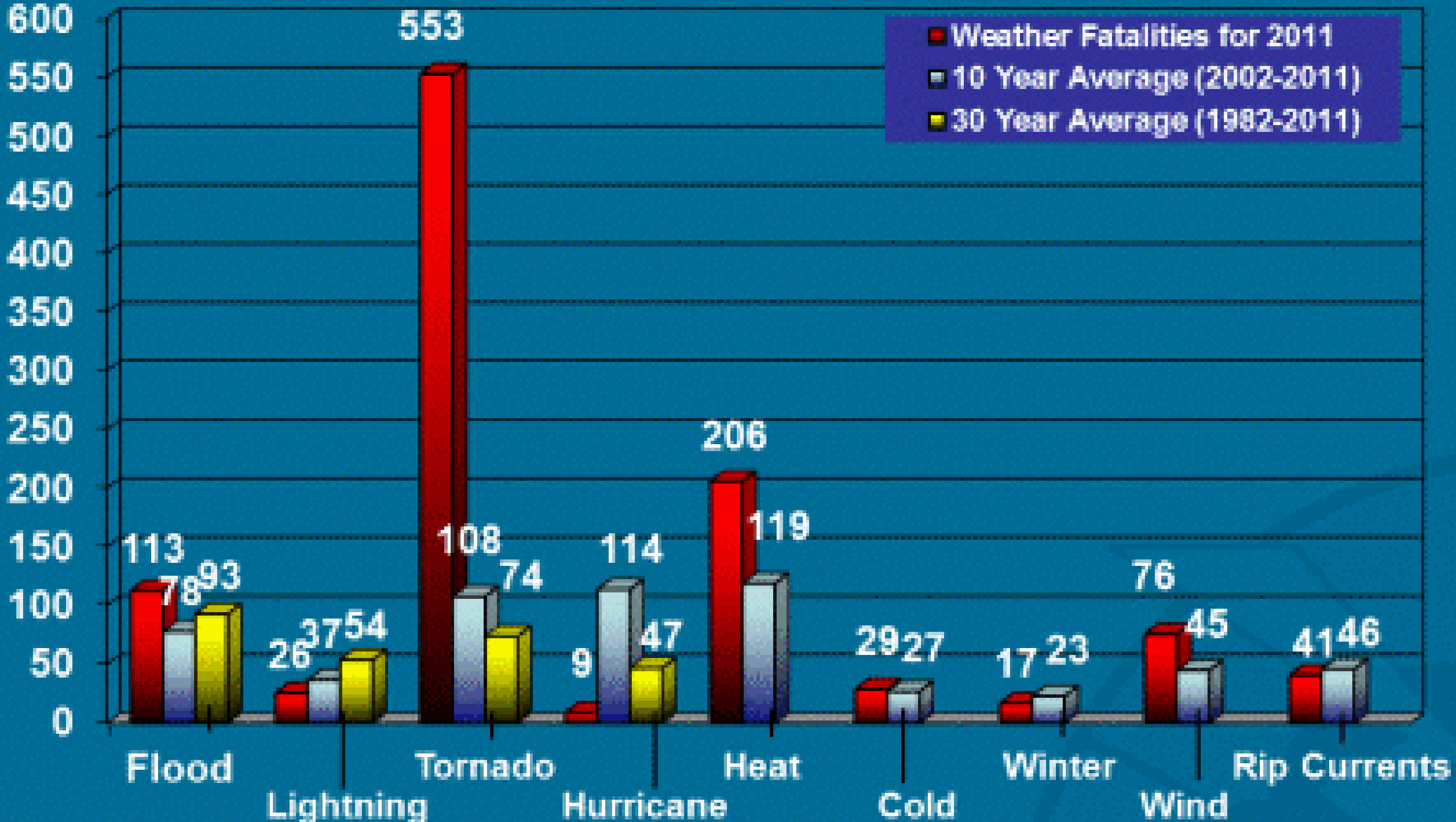
- Low Cost Fuels
- Clean Air & Water
- Economic Development, Good Jobs

Tornado approaching Tuscaloosa, April 27, 2011
(source: ABC news)

In 2011, Ohio experienced its wettest year on record.

The cost of extensive repairs to roads and bridges was estimated at almost $40 million. In requesting assistance for disastrous flooding that Occurred in April and May, Ohio's Governor John Kasich said in a letter to President Obama that the impacts in Ohio were "of such severity and magnitude that effective response is beyond the capabilities of the state and local government."

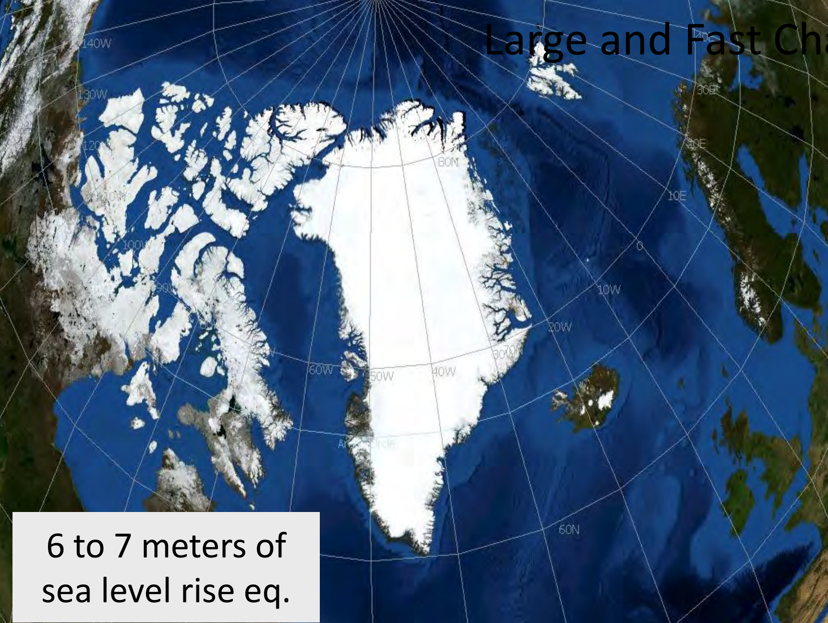
Weather Fatalities

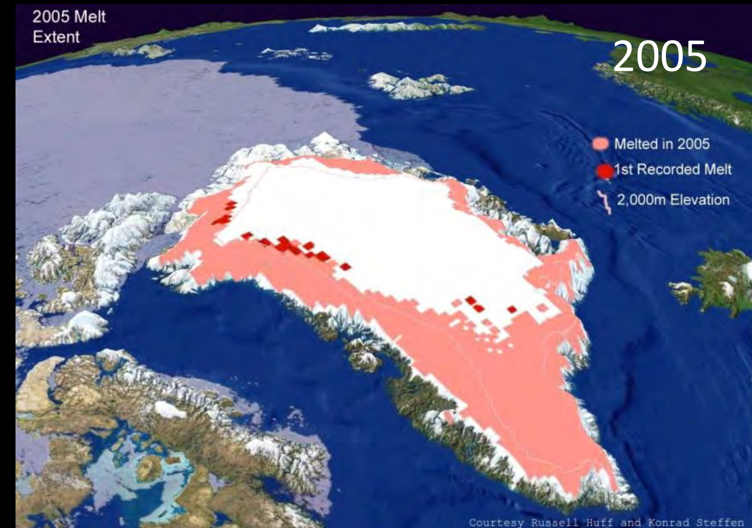


Pakistan flooding, Sept. 25, 2011, Sindh Province (source: Faisal Mahmood/Reuters))

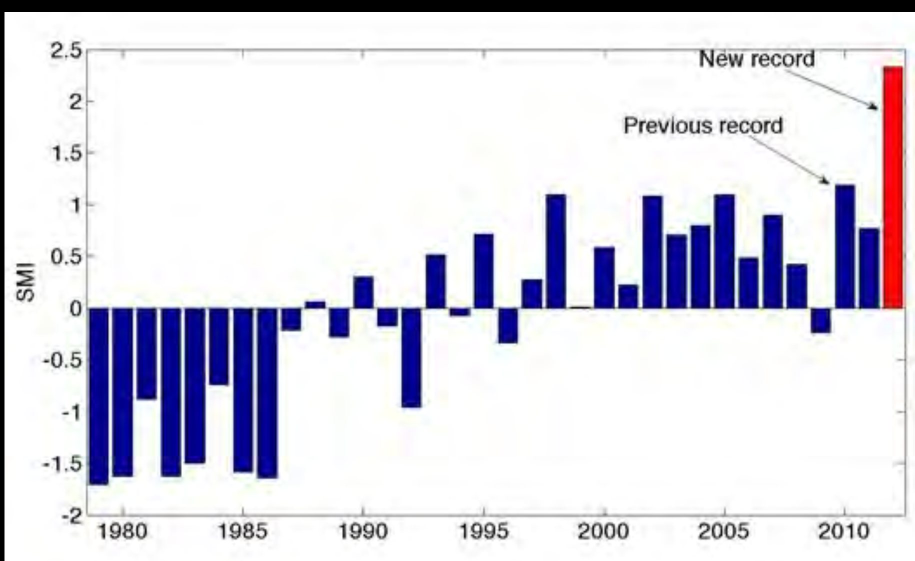
2011: Overall losses: $148 billion
Insured losses: $55 billion

Large and Fast Ch…



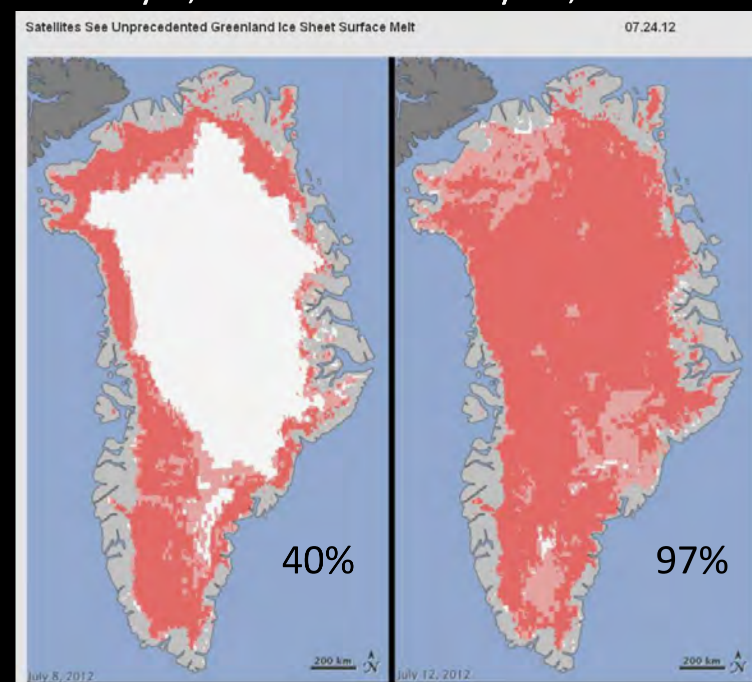


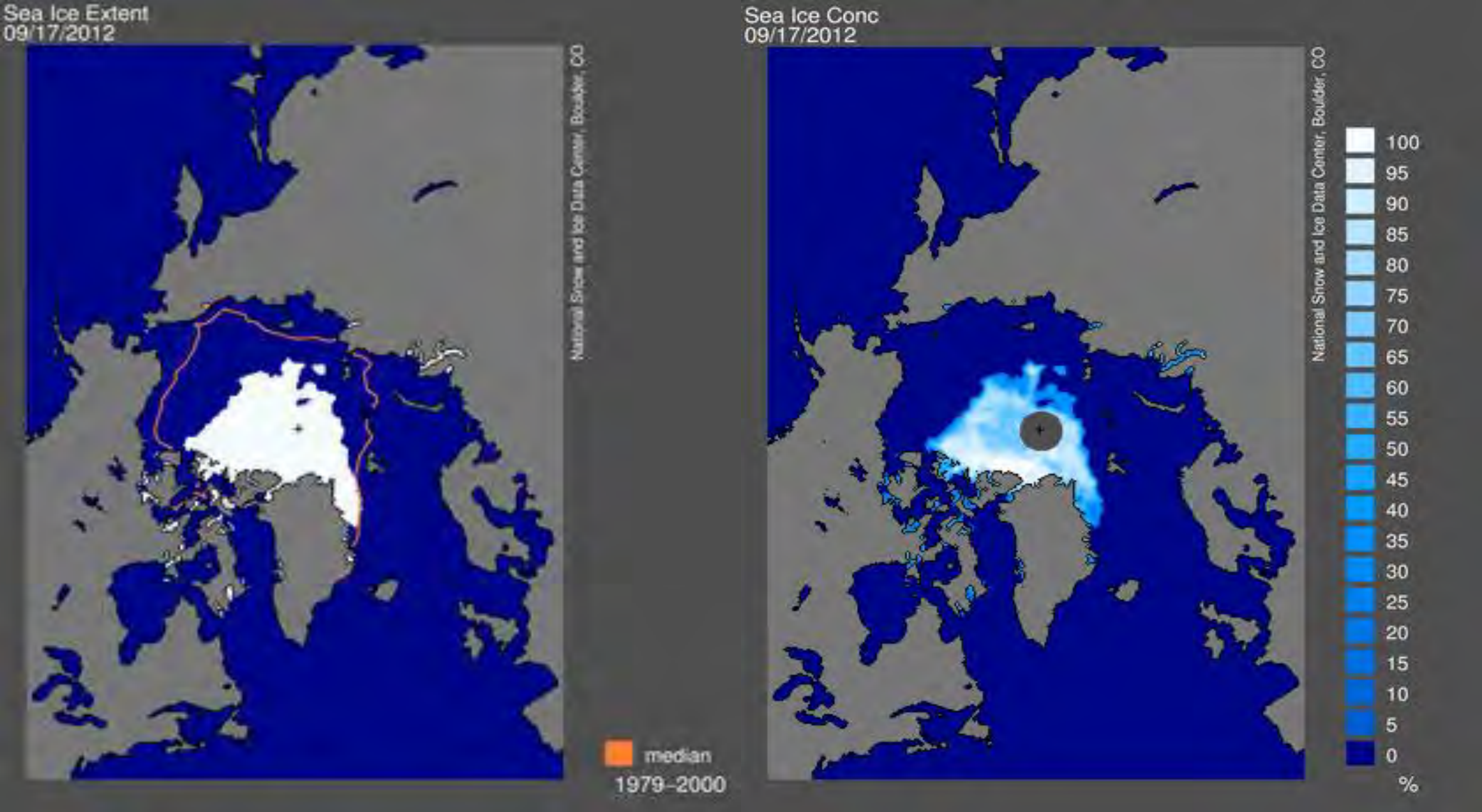
2012 record summer surface melting



July 8, 2012

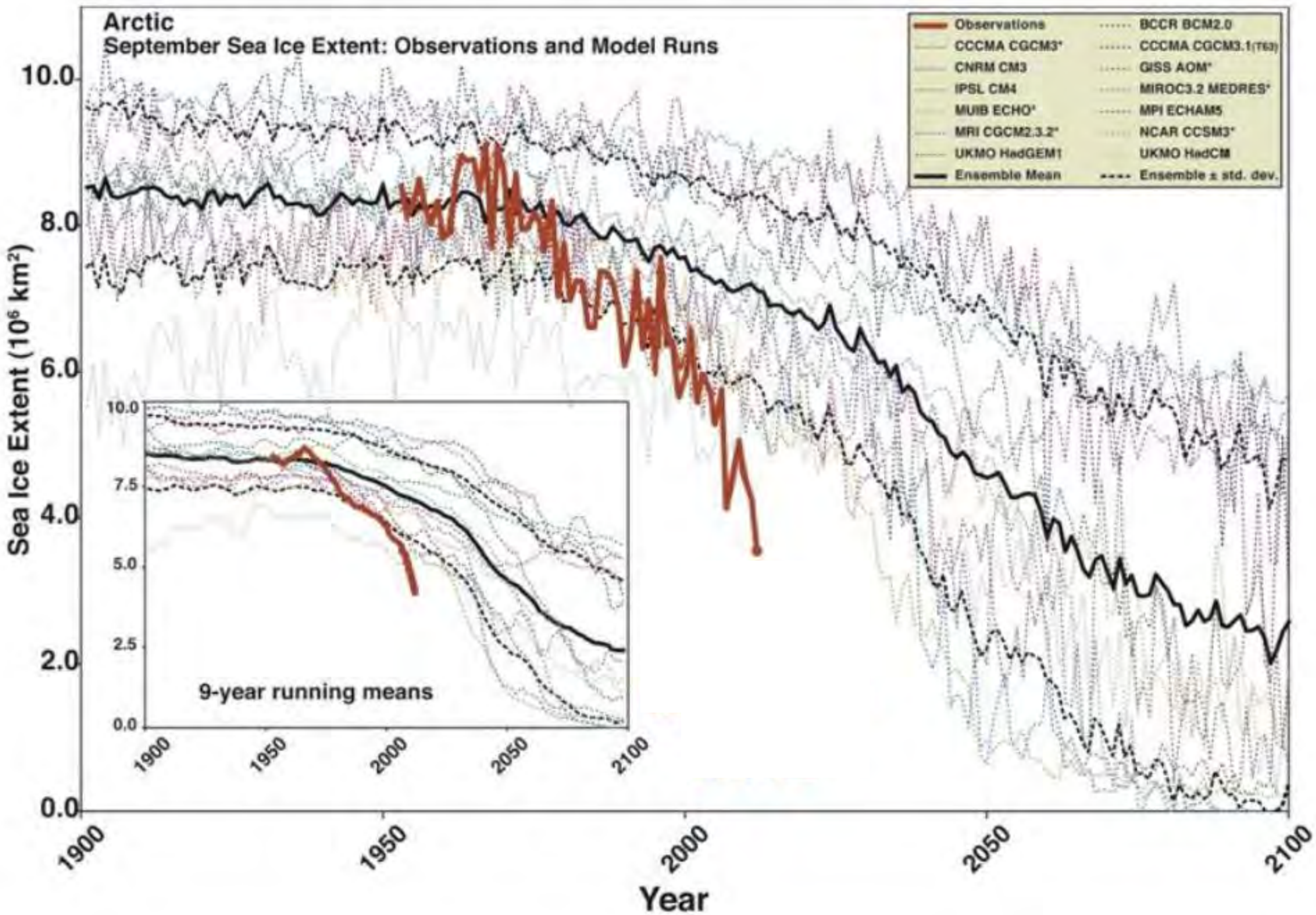
July 12, 2012



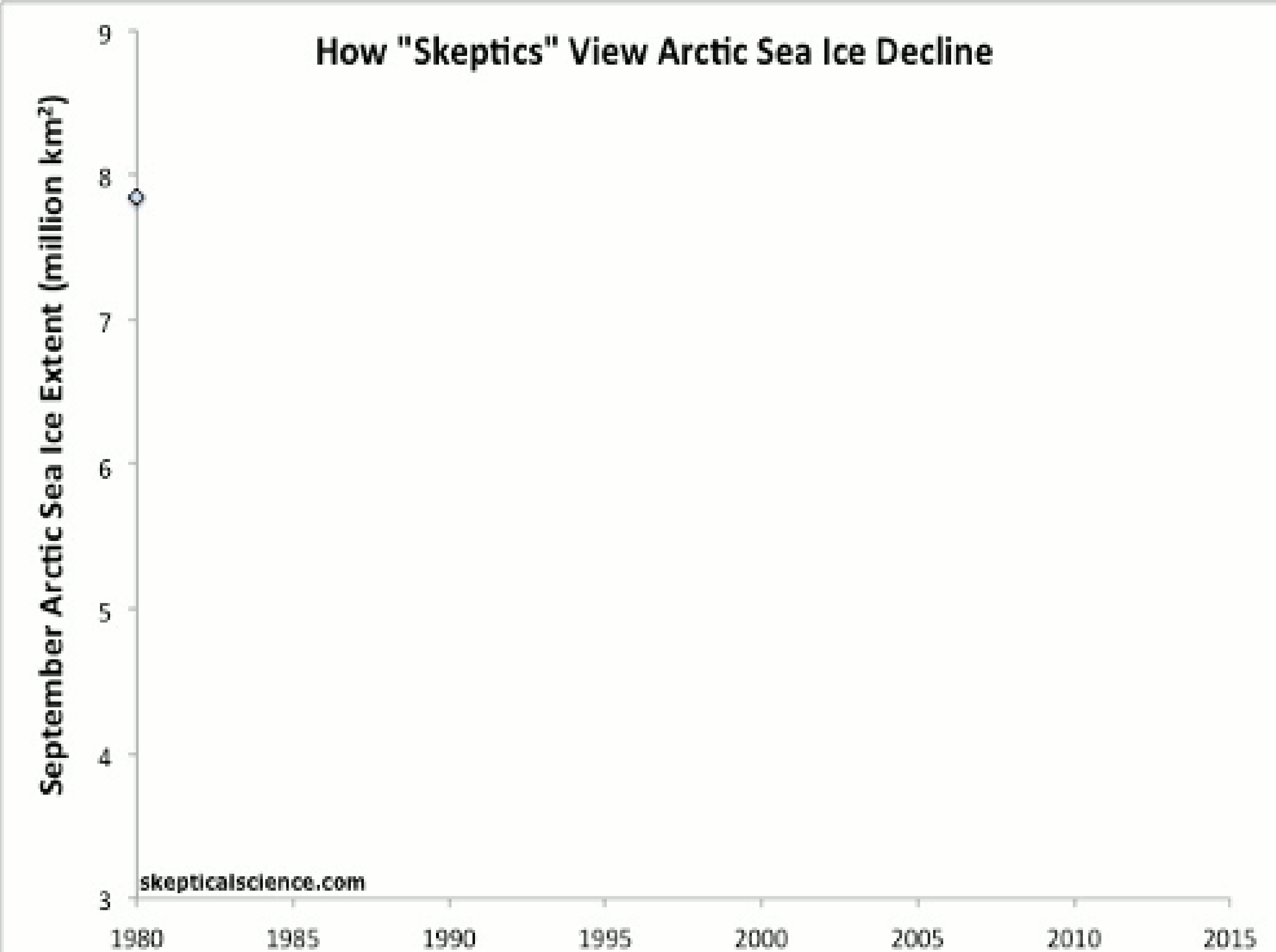


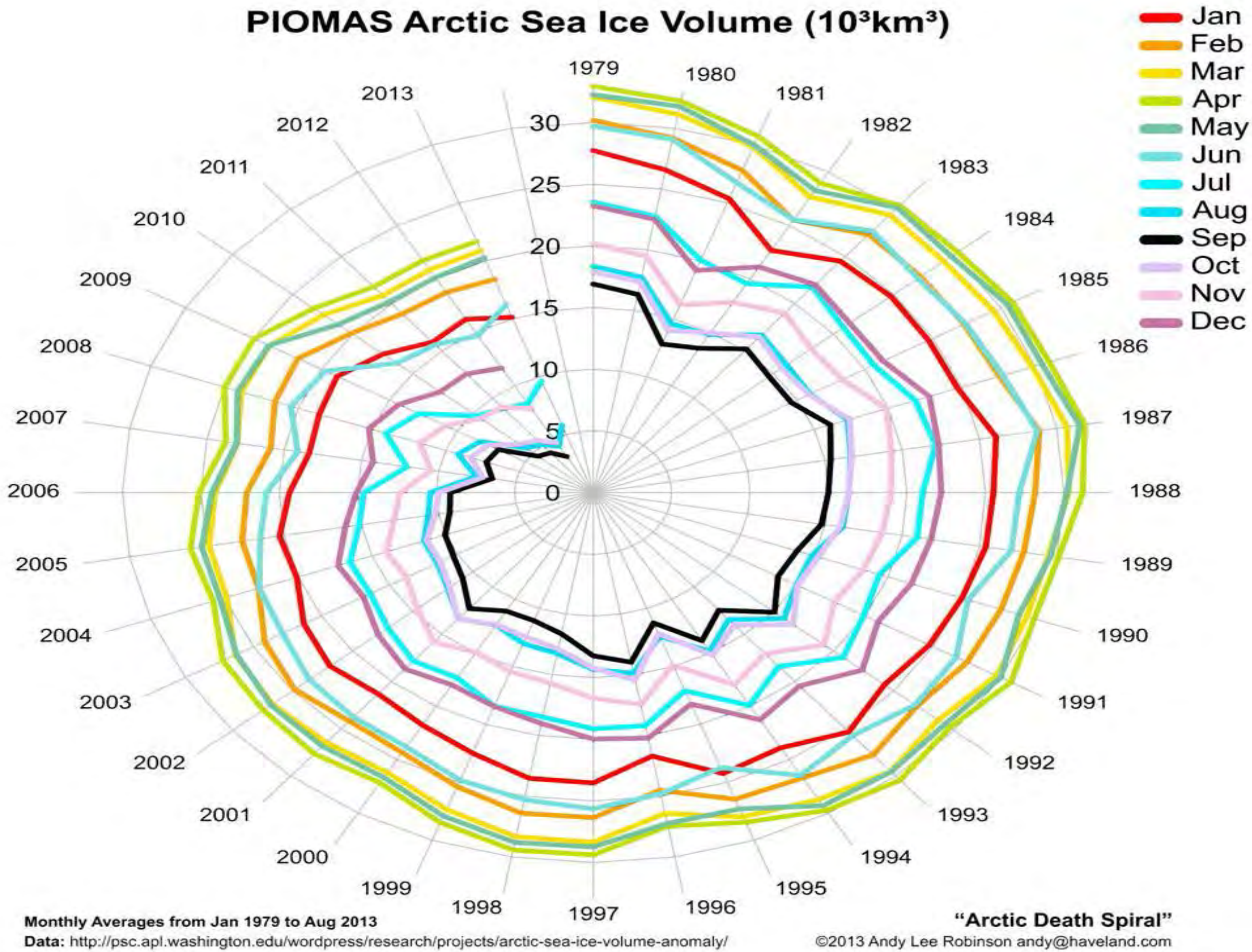
Data: September 17, 2012
Left Panel: Sea ice extent (>15% ice); Right: sea ice concentration (%).
Pink Line: Climatological extent (1979—2000).
Source: National Snow and Ice Date Center, Boulder, Colorado.
Sea ice cover in September, 2012 was 3.42 million square kilometers (1.32 M sq. mi.) which is 18% smaller than the 2007 record low of 4.17 million square kilometers (1.61 M sq. mi.).

Climate System Models Did Not Predict This!



Model runs: Stroeve *et al.*, 2007


How "Skeptics" View Arctic Sea Ice Decline
September Arctic Sea Ice Extent (million km²)
9
8
7
6
5
4
3
1980
1985
1990
1995
2000
2005
2010
2015
skepticalscience.com


PIOMAS Arctic Sea Ice Volume ($10^3 km^3$)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
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2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
0
5
10
15
20
25
30
Monthly Averages from Jan 1979 to Aug 2013
Data: http://psc.apl.washington.edu/wordpress/research/projects/arctic-sea-ice-volume-anomaly/
"Arctic Death Spiral"
©2013 Andy Lee Robinson andy@haveland.com

Hurricane / Superstorm Sandy

Death toll: 110

Estimated cost: $60 Billion

Illustrates the conditions and events and scenarios that we can expect from climate change. In New York and New Jersey there are 45 superfund toxic waste sites within half a mile of the coast.

Gov. Cuomo of New York to President Obama “we have a 100-year flood every two years now” In fact, three of the 10 biggest floods in Lower Manhatten since 1900 have occurred in the last 3 years.

Rising seas create a higher baseline for future storm surges. Current estimates are that coastal waters will rise by two feet by 2050 and four feet by the end of the century

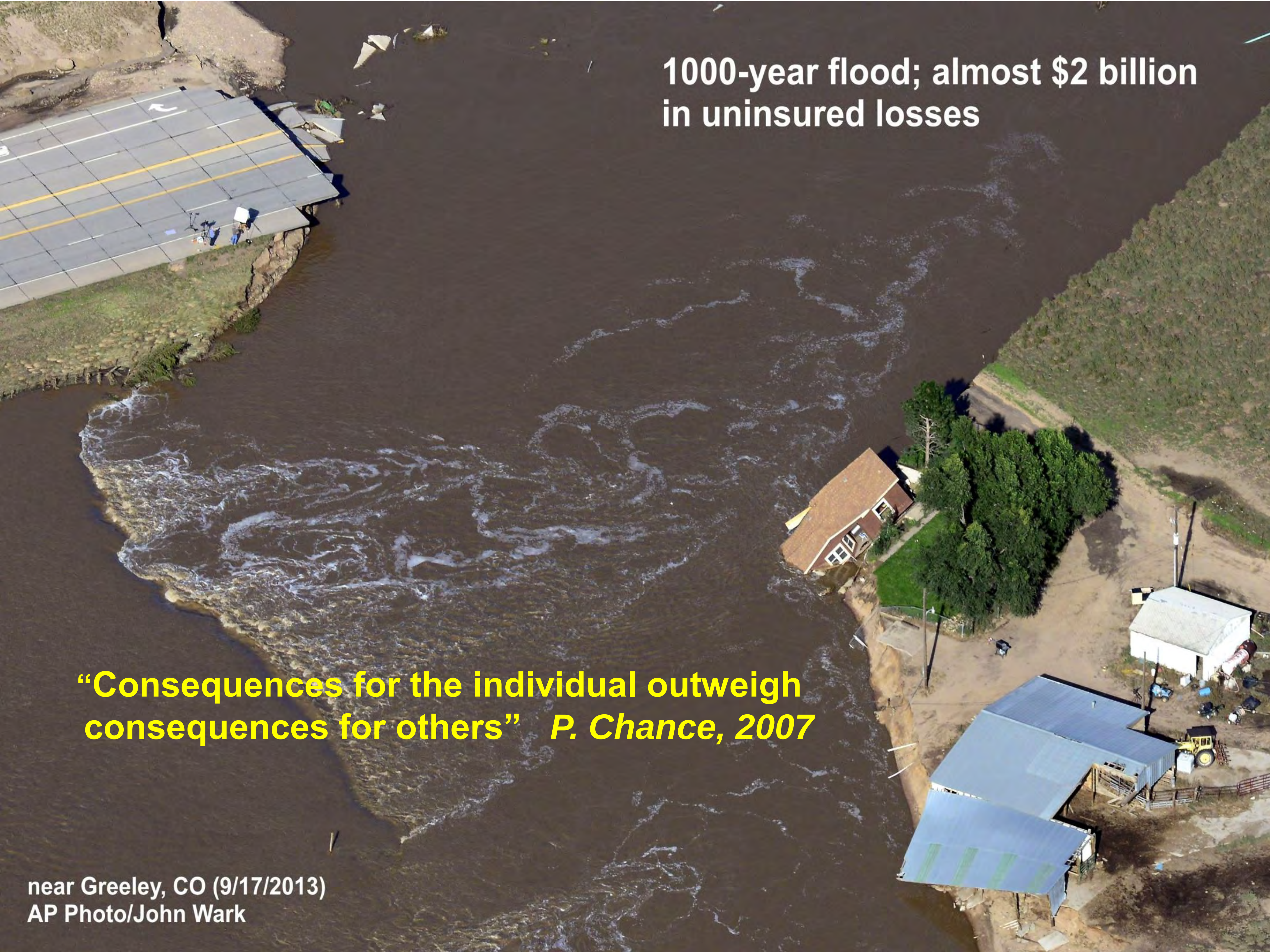
Summer 2013, Australia

Summer 2013, Smoke from Australia's Fires

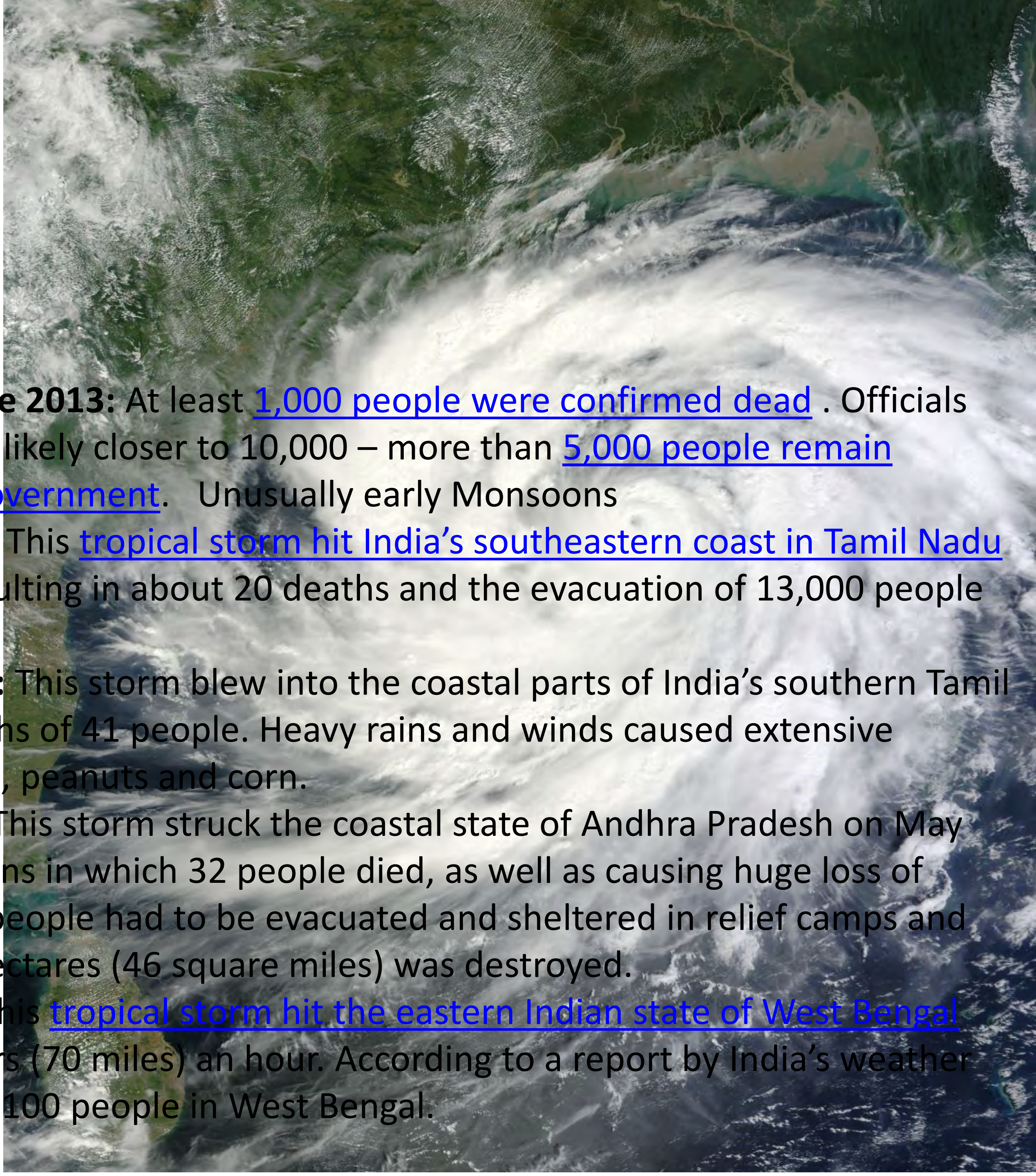
RIM Fire, August 25, 2013 Near Yosemite National Park

The U.S has endured a near-record 2012 wildfire season with the total acres burned roughly the same size as Massachusetts and Connecticut combined:

2006-- 9.8 million acres
2007-- 9.3 million acres
2012-- 9.1 million acres


1000-year flood; almost $2 billion
in uninsured losses
"Consequences for the individual outweigh
consequences for others" P. Chance, 2007
near Greeley, CO (9/17/2013)
AP Photo/John Wark

October, 2013
Cyclone Phailin, India
Over 1 Million people evacuated



1. Uttarakhand flash floods, June 2013: At least 1,000 people were confirmed dead . Officials have said the actual death toll is likely closer to 10,000 – more than 5,000 people remain missing according to the state government.   Unusually early Monsoons

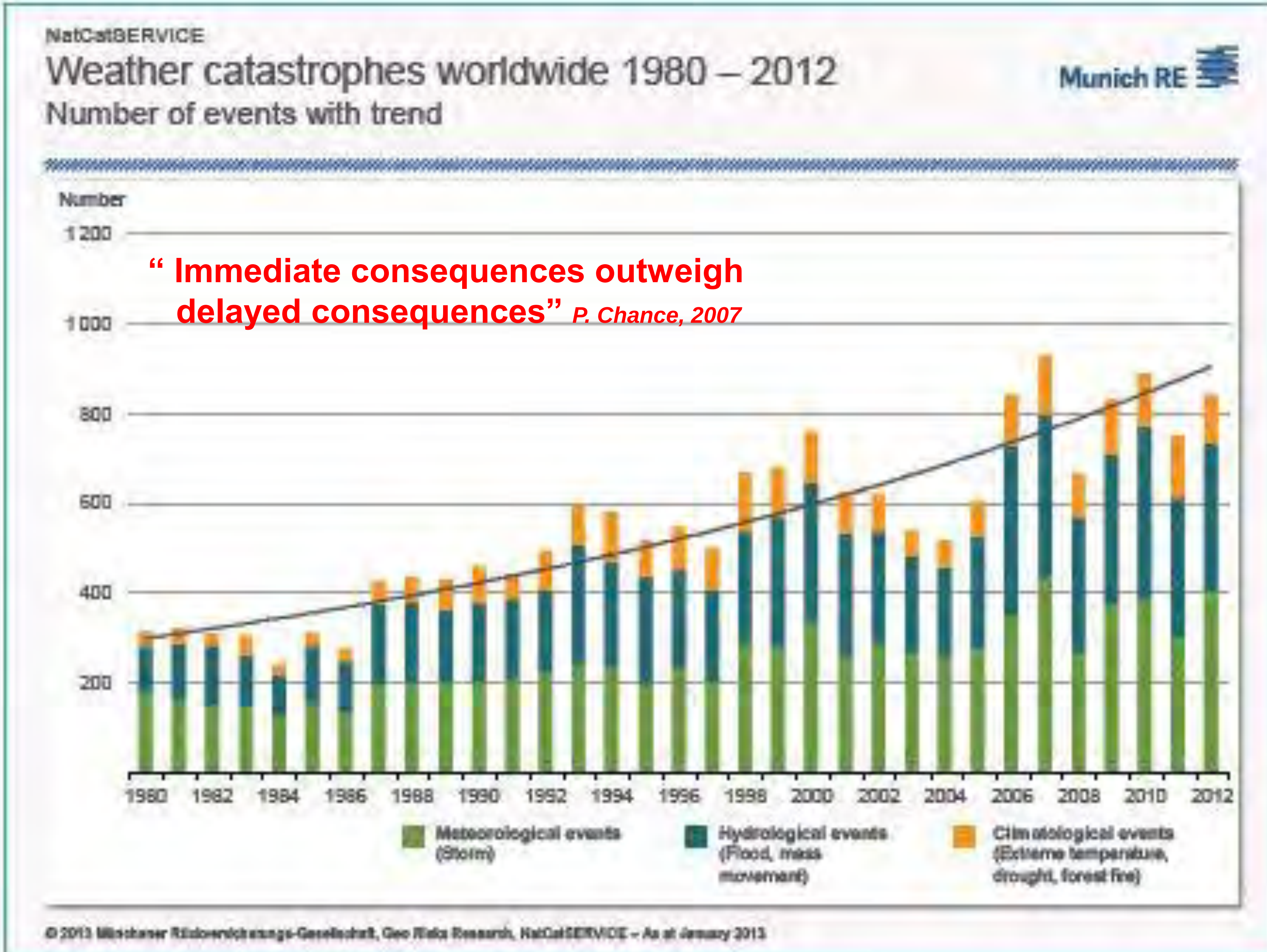
2. Cyclone Nilam, Oct. 31, 2012: This tropical storm hit India's southeastern coast in Tamil Nadu state's Mahabalipuram area, resulting in about 20 deaths and the evacuation of 13,000 people from their homes.

3. Cyclone Thane, Dec. 30, 2011: This storm blew into the coastal parts of India's southern Tamil Nadu state, resulting in the deaths of 41 people. Heavy rains and winds caused extensive damage to standing crops of rice, peanuts and corn.

4. Cyclone Laila, May 20, 2010: This storm struck the coastal state of Andhra Pradesh on May 20, 2010, bringing very heavy rains in which 32 people died, as well as causing huge loss of property. Tens of thousands of people had to be evacuated and sheltered in relief camps and agricultural crops over 12,000 hectares (46 square miles) was destroyed.

5. Cyclone Aila, May 25, 2009: This tropical storm hit the eastern Indian state of West Bengal and Bangladesh at 112 kilometers (70 miles) an hour. According to a report by India's weather office, the cyclone killed at least 100 people in West Bengal.

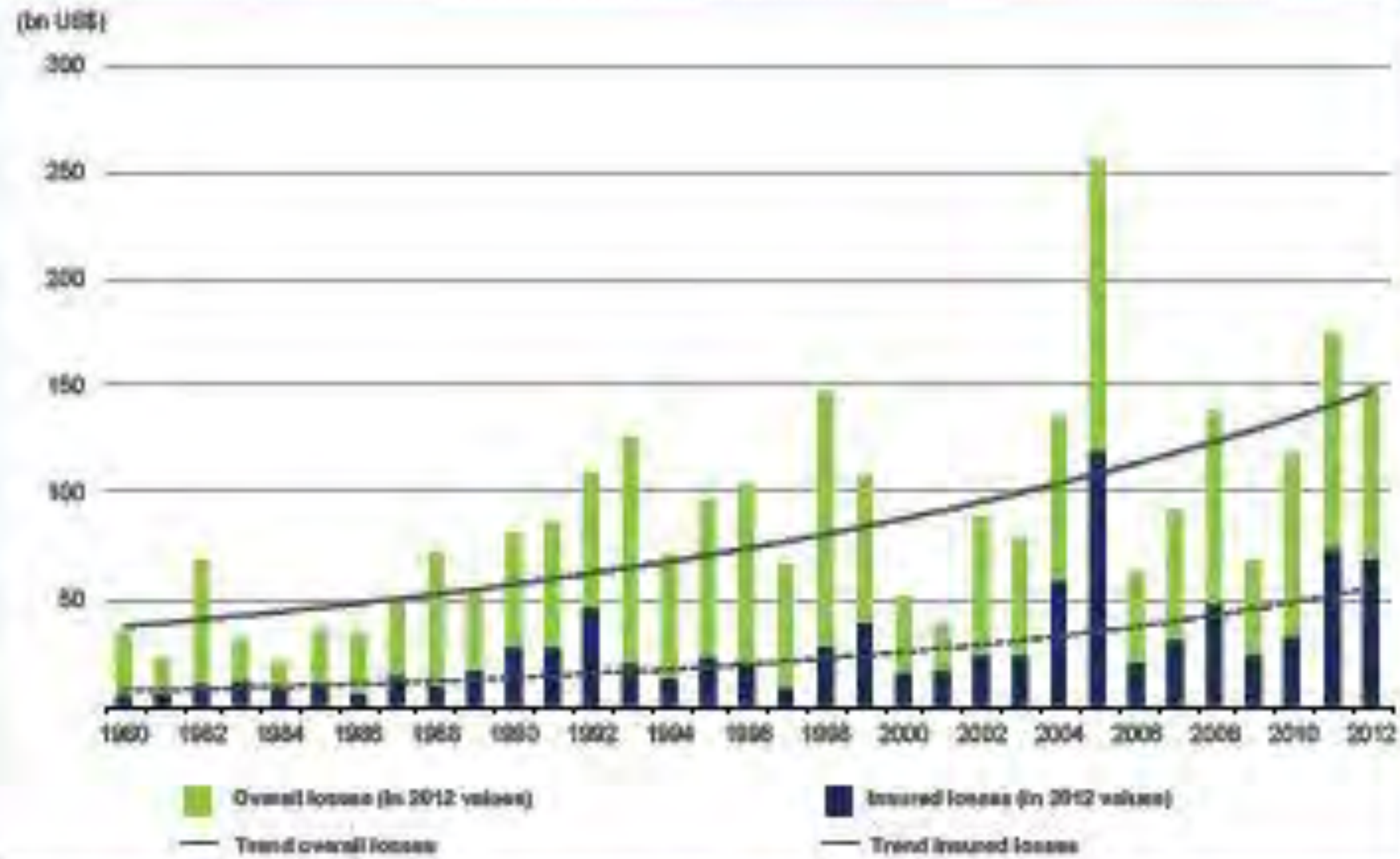
“ Immediate consequences outweigh delayed consequences” ***P. Chance, 2007***



NatCatSERVICE

Weather catastrophes worldwide 1980 – 2012

Overall and insured losses with trend



So Society has Three Options!

- ***Mitigation,*** means taking measures to reduce the pace & magnitude of the changes in global climate that are caused by human activities.

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

- ***Adaptation***, means taking measures to reduce the adverse impacts on human well-being that result from the climate changes 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!

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

It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is the most adaptable to change. *Evolutionary Theory*

Individuals, groups and nations, in contrast to evolution, can understand their circumstances and deliberately make the appropriate changes in polices in order to improve their outcome.

Investments for Global Climate Change (winners and losers / greed and fear)

Some changes are underway:

- Conservation
- Increased efficiency
- Four cylinders and hybrids soar in popularity
- Electric cars

Renewable energy such as:

- Fuel cells
- Zero emission coal-burning power plants
- IGCC (Integrated gasification combined cycle)
- Solar (photovoltaic cells, passive solar, etc.)
- Geothermal and recovered energy power plants
- Ethanol
- Wind power

Mass transit / light rail, buses, etc.

Housing design - toward more compact cities

Nanotechnology & LED technology ***EPA ENERGY STAR program**

No "silver bullet" but lot's of "silver buckshot" Cost-effective energy-saving homes is one!

Responding to the risks of climate change is one of the most important challenges facing the United States today. Unfortunately, there is no "magic bullet" for dealing with this issue; No single solution or set of actions that can eliminate the risks we face. America's climate choices will involve political and value judgments by decision makers at all levels. These choices, however, must be informed by sound scientific analyses. National Research Council, 2011

Health: Impacts of heat waves; Extreme Weather events (storms); reduced air quality (increases in tropospheric ozone; aerosols); Climate-sensitive diseases (e.g., food-borne and vector borne diseases tend to increase with temperature). 2010, National Institute of Environmental Health Sciences

Advanced energy efficiency technologies and practices conserve energy resources

Impacts in the U.S. Midwest: We can expect hotter summers, longer dry periods, warmer, wetter winters; difficulties maintaining current summer air quality in urban areas; stress on infrastructure and economy (Great Lakes shipping).EPA

Our greatest challenges of the 21st Century will be:
(1) learning how to get along with each other and
(2) learning how to get along with our Planet.

These two challenges deal with human behavior and are closely related!

For Global Climate Change --- Nature is the Time Keeper!

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http://bprc.osu.edu/

Lonnie G. Thompson

thompson.3@osu.edu

bprc.osu.edu