Tuesday May 6 (last day of class):

Final homework (IPCC)
Extra credit hazards report (optional)

Wednesday May 7:

Final exam review session, 5-7pm in POST 723

Thursday May 8:

EARLY final exam (optional)
10am-12pm in POST 723

Thursday May 15:

Regular final exams (9:45-11:45am or 12-2pm)

Why should a geologist be studying climate?



10 km across ***(not to scale!)***



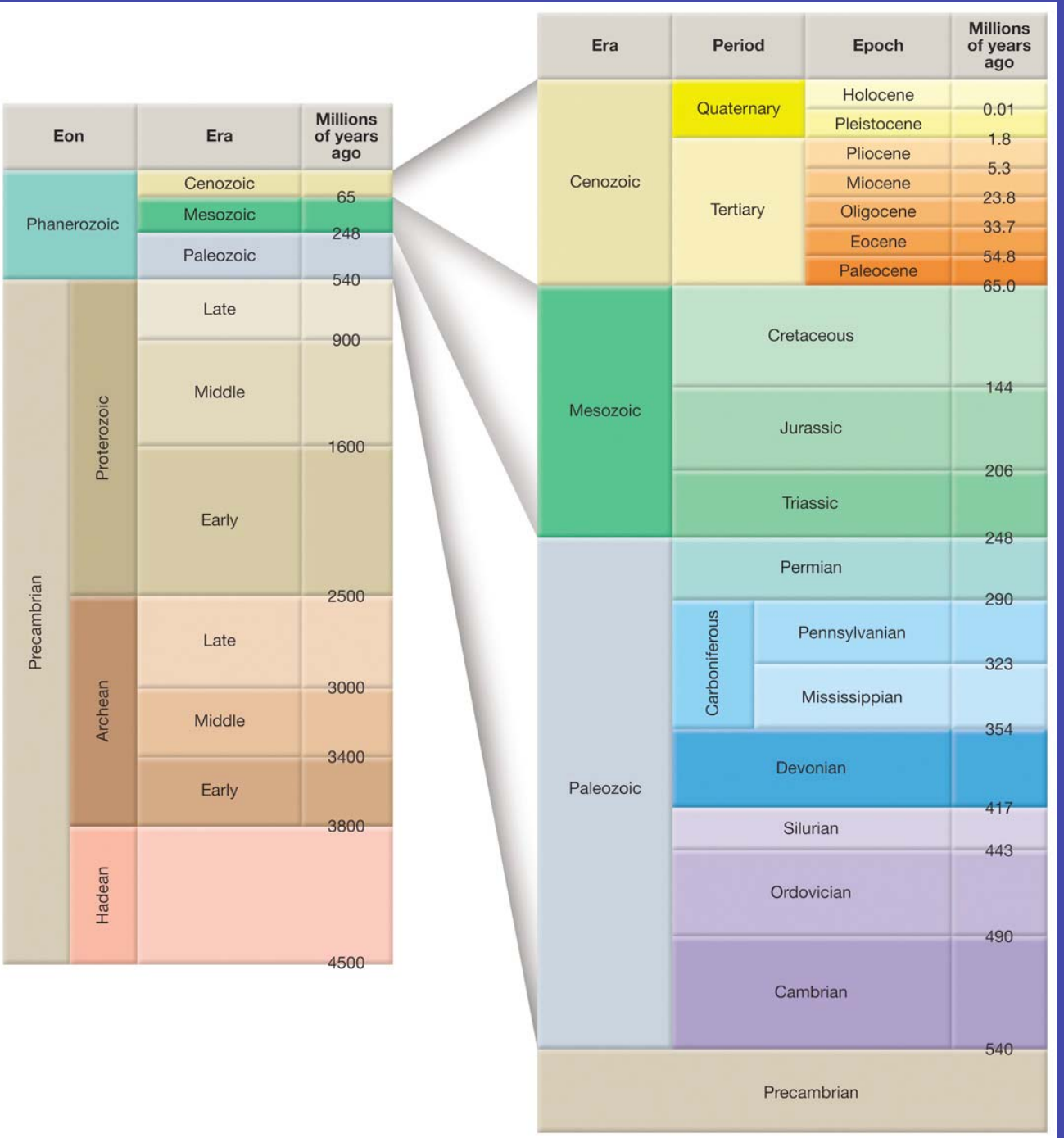
What defines

<u>BOUNDARIES</u>

on geologic timescale?



spherules



CLIMATE

change

is responsible for the organization of the

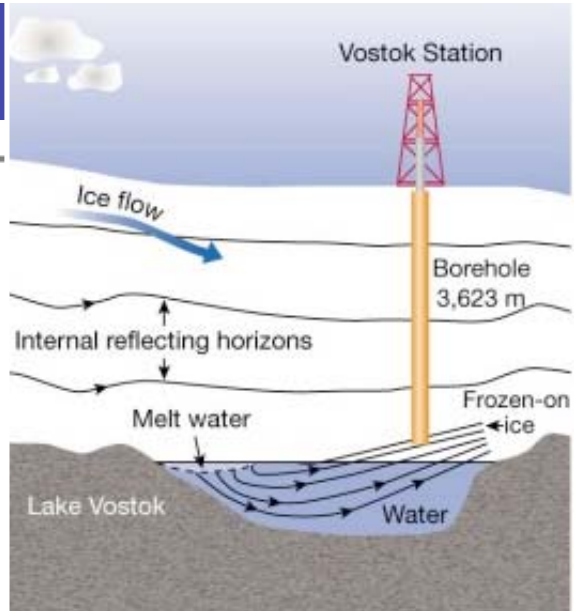
GEOLOGIC

timescale

Past climate changes may help us to predict the future



Vostok Antarctica Ice Core



Δ Temperature (°C)

4
2
0
-2
-4
-6
-8

CO_2 (ppmv)

260
240
220
200

Dust (ppm)

1.5
1.2
0.9
0.6
0.3

0 50 100 150 200 250 300 350 400

Thousands of Years Ago

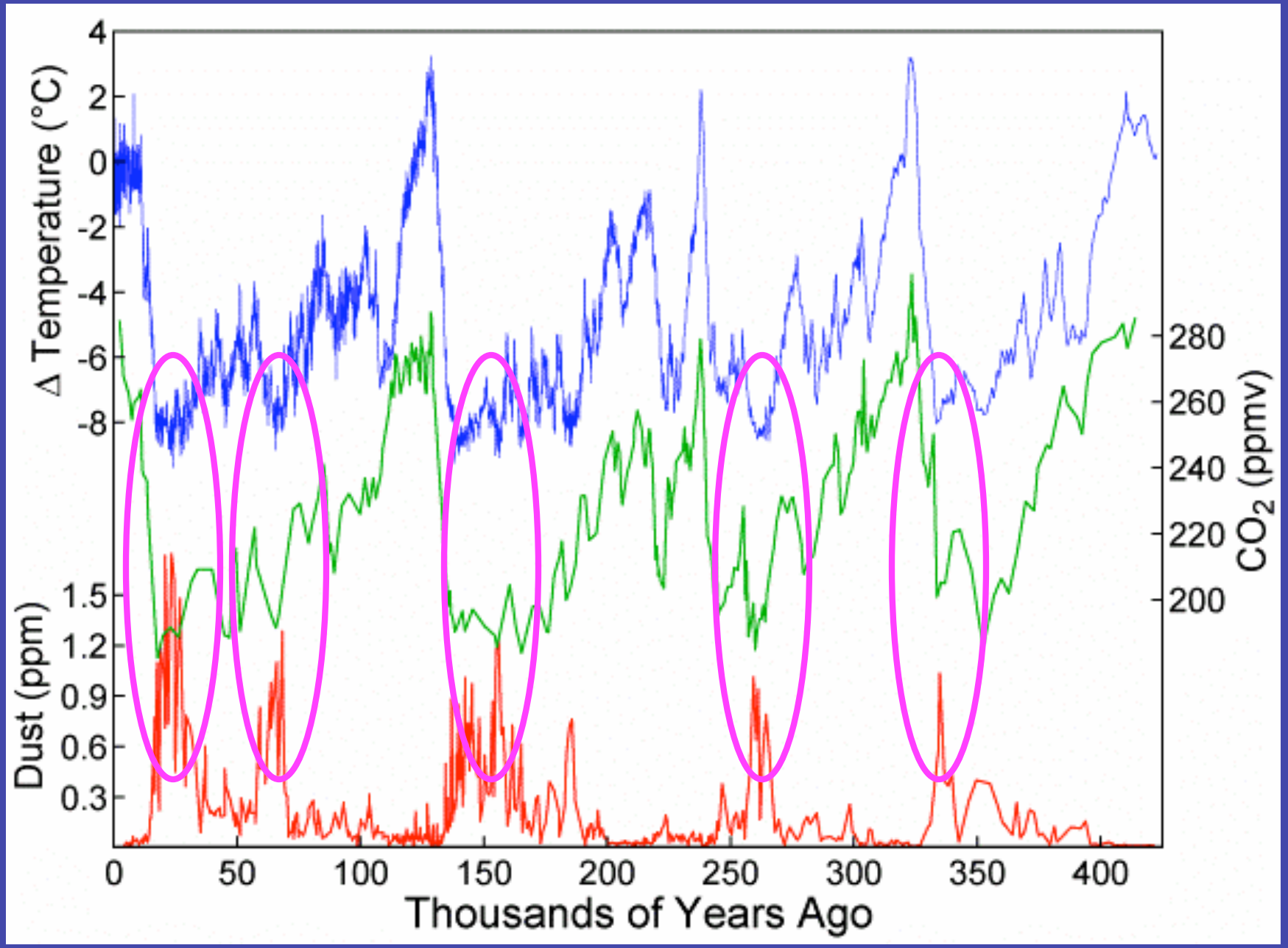
Why would atmospheric dust content be higher during periods of worldwide cooling?



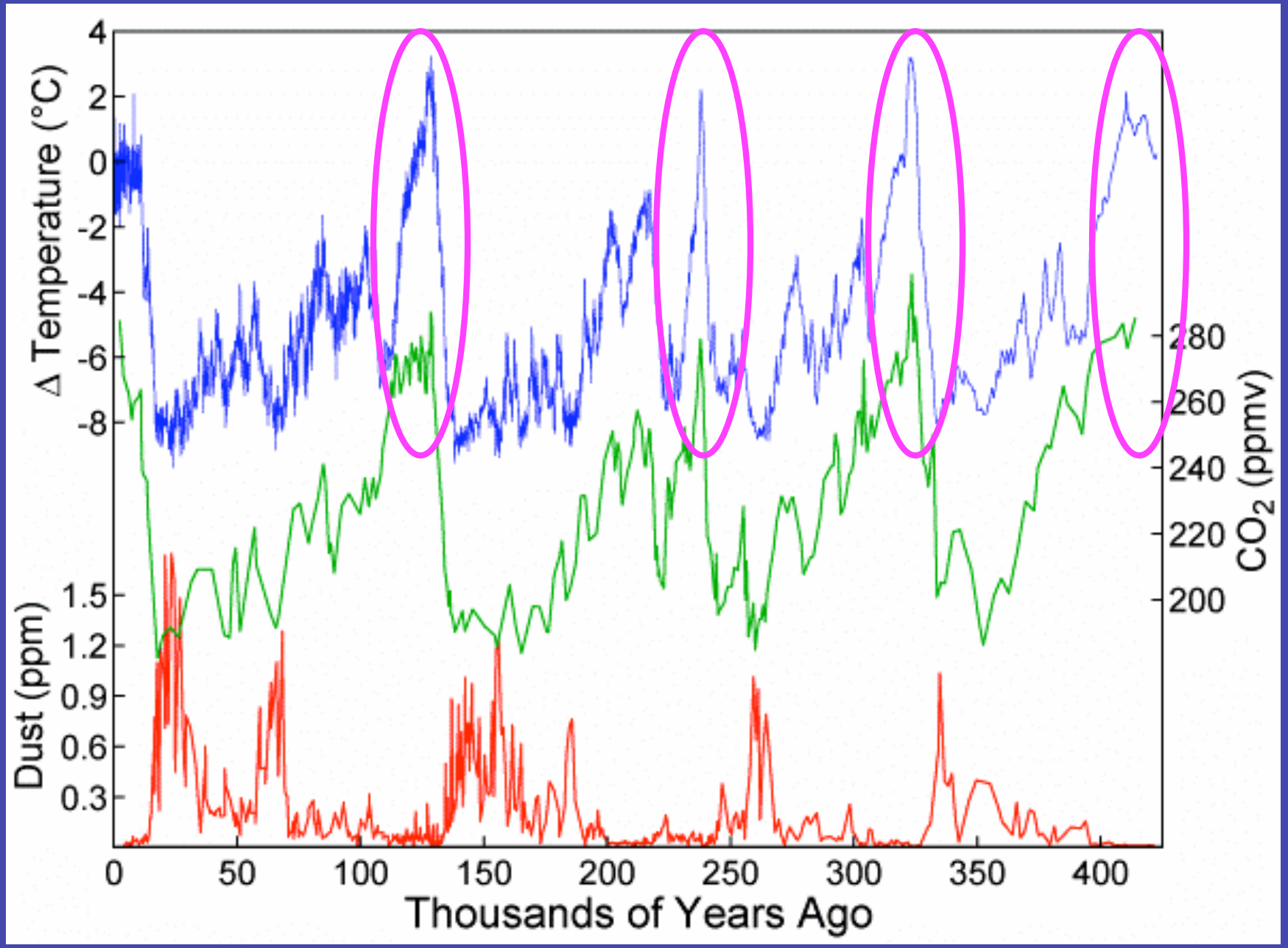


Loess – wind-transported glacial flour

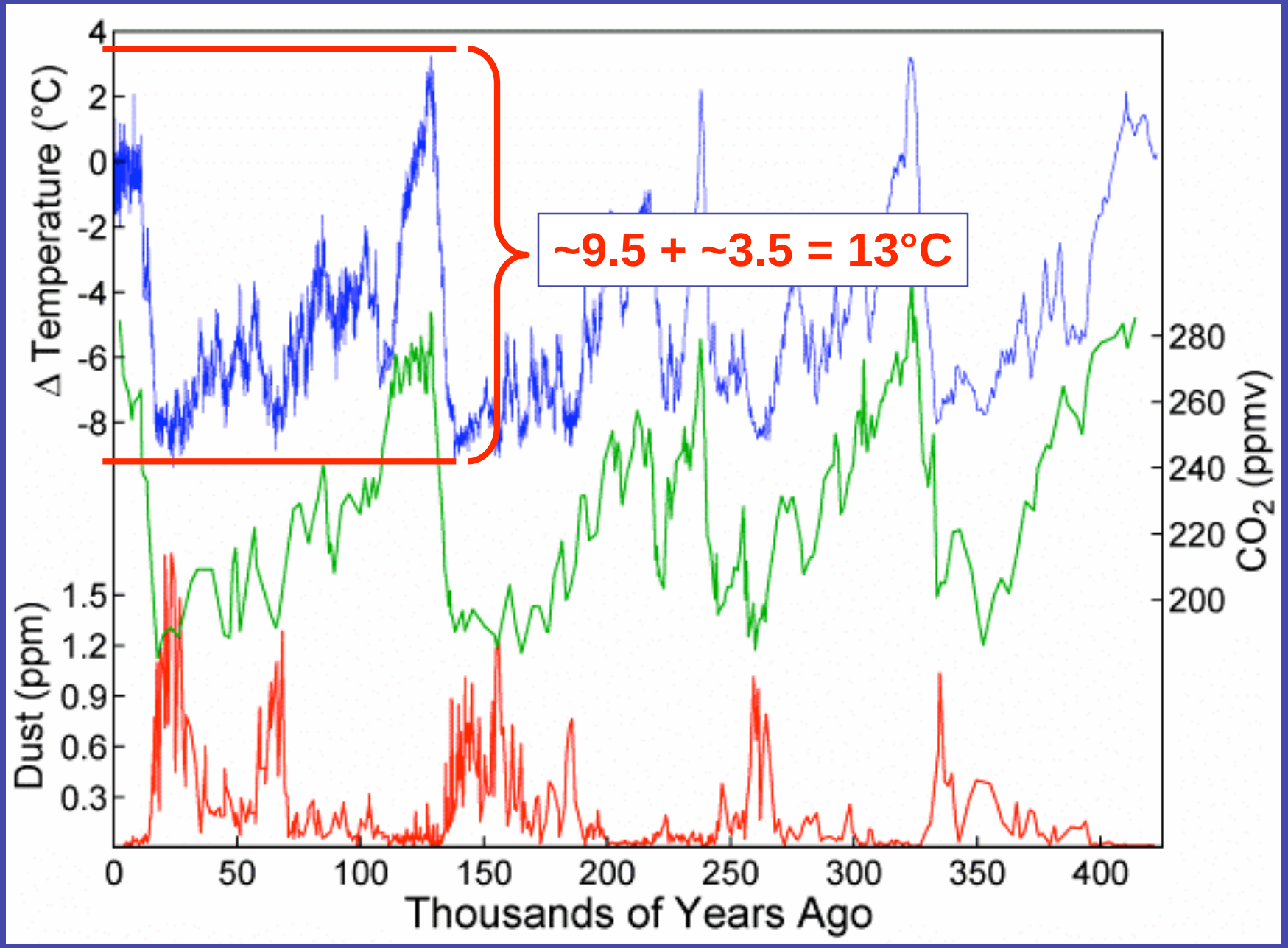
Identify the five most recent ice ages?



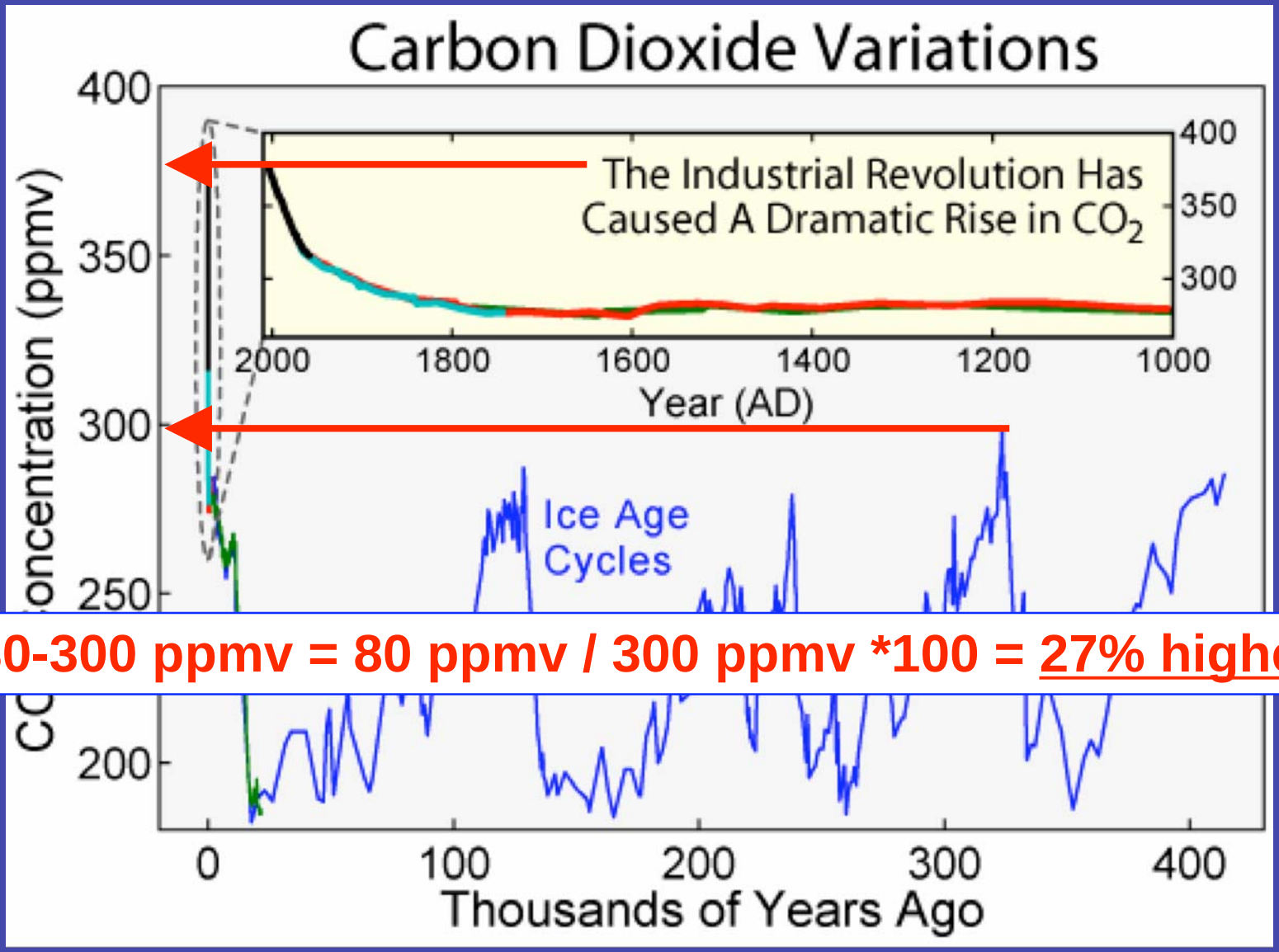
Identify the four most recent interglacials?



What was magnitude of temperature change 125 Kya?

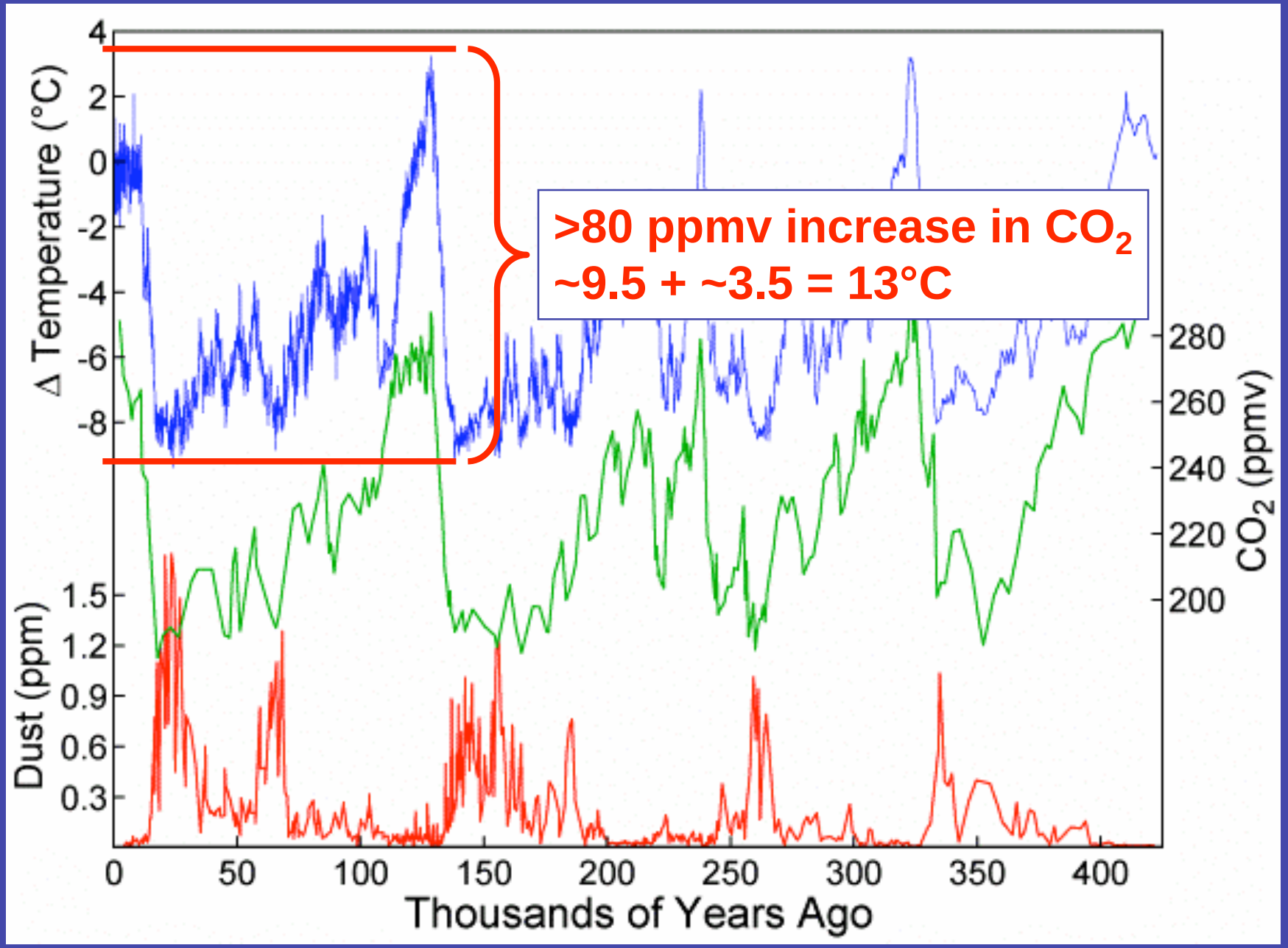


How much higher is CO_2 now than any time in 400 Kya?

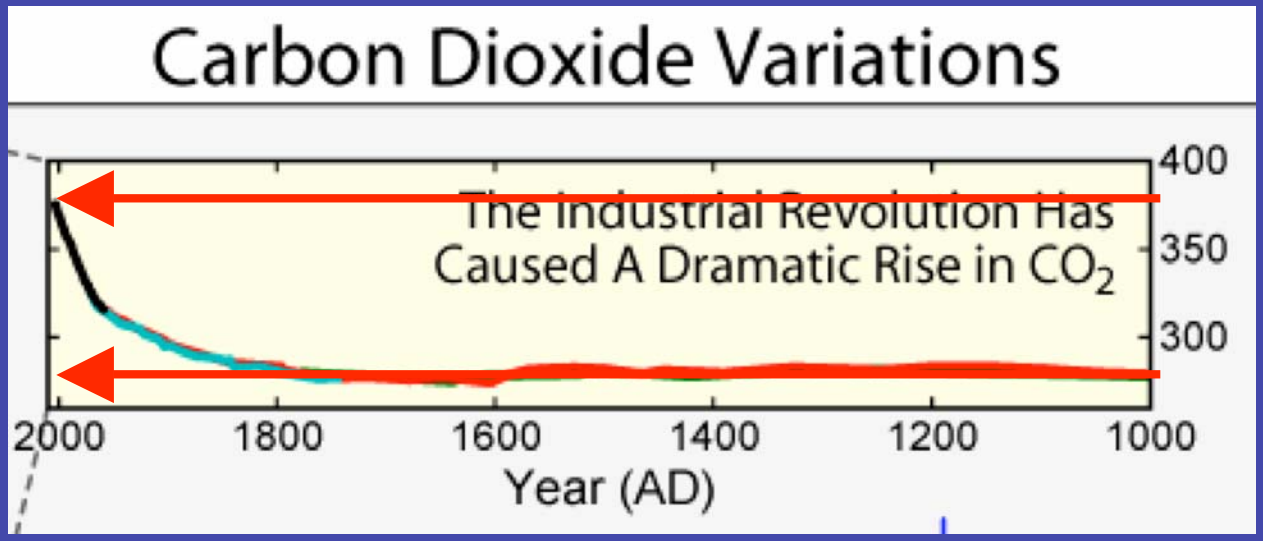


380-300 ppmv = 80 ppmv / 300 ppmv *100 = 27% higher

Modern analog at 125 Kya?



How much <u>will</u> temperature change?



<u>Today</u>

~380ppmv - ~275ppmv = > 100ppmv

<u>125 Kya</u>

~80ppmv change = ~13˚C change

16˚C+



What do these striations in <u>South Africa</u> result from?

A) Wind erosion
B) Continental glaciers
C) Lava flows

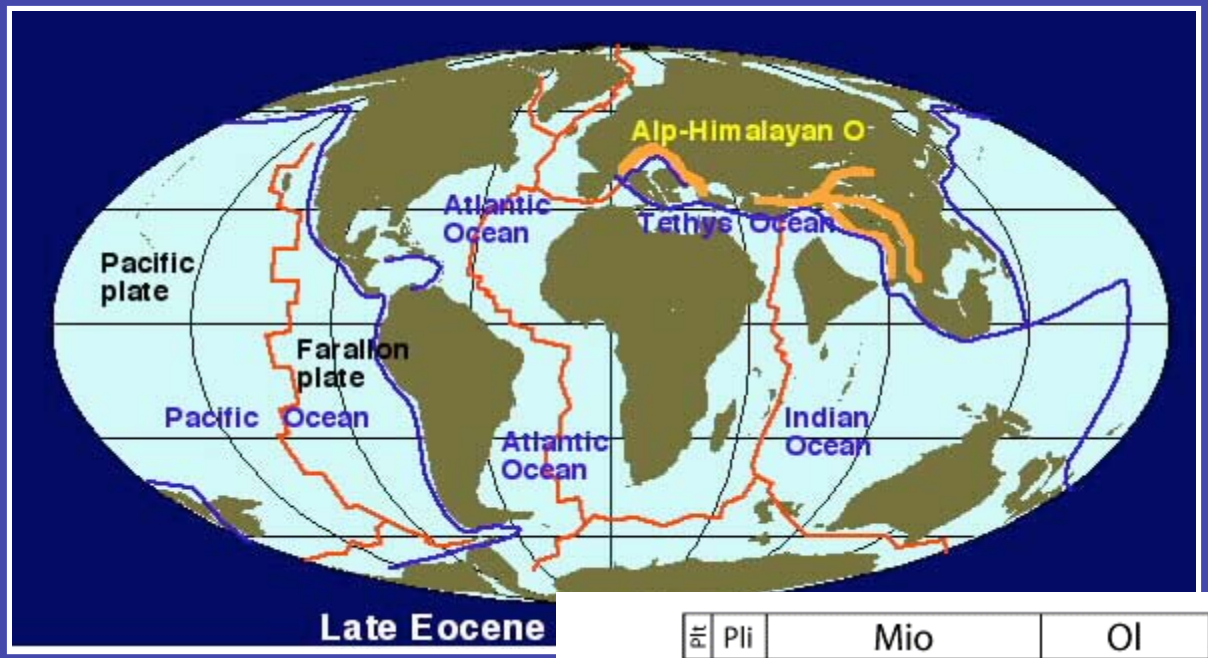




Glacial remnants in Africa are explained by:

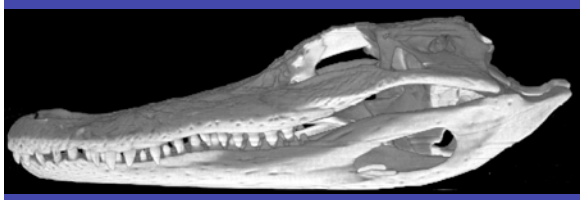
1) plate tectonics

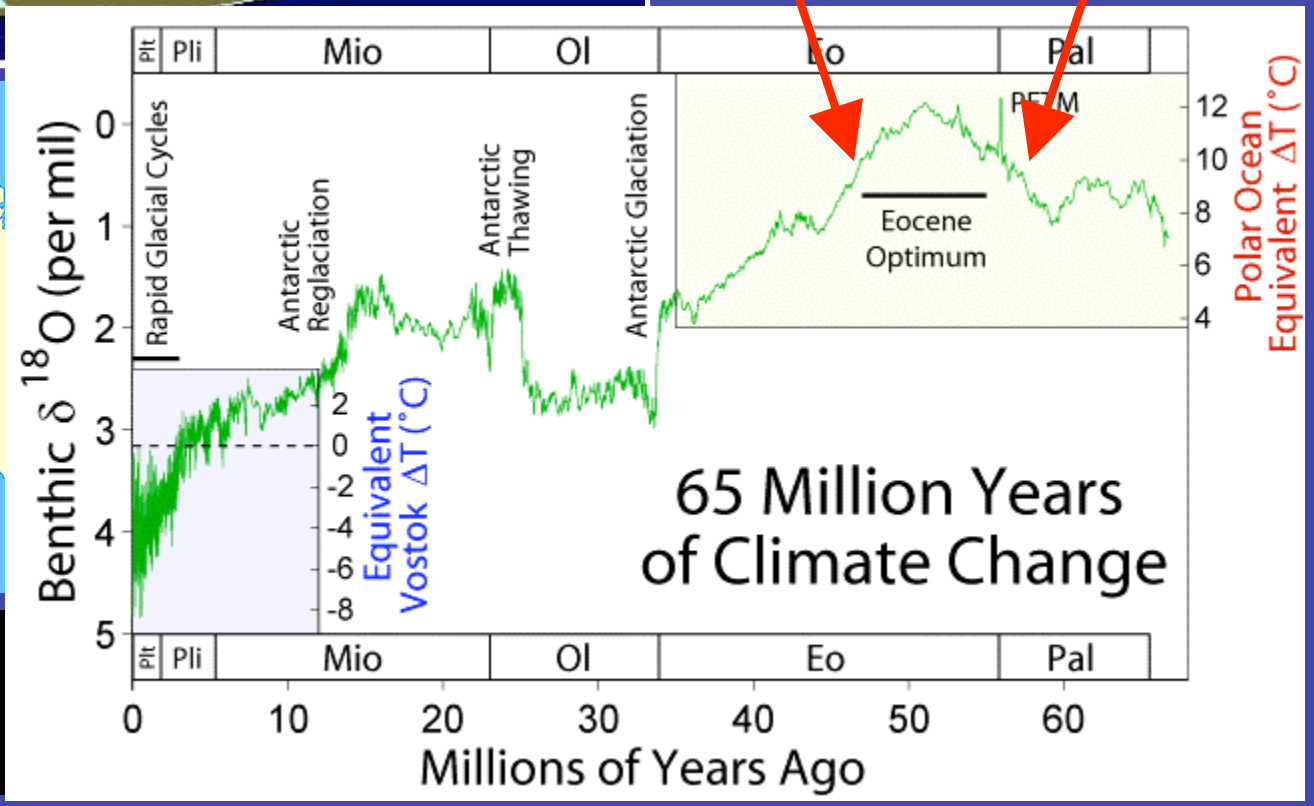


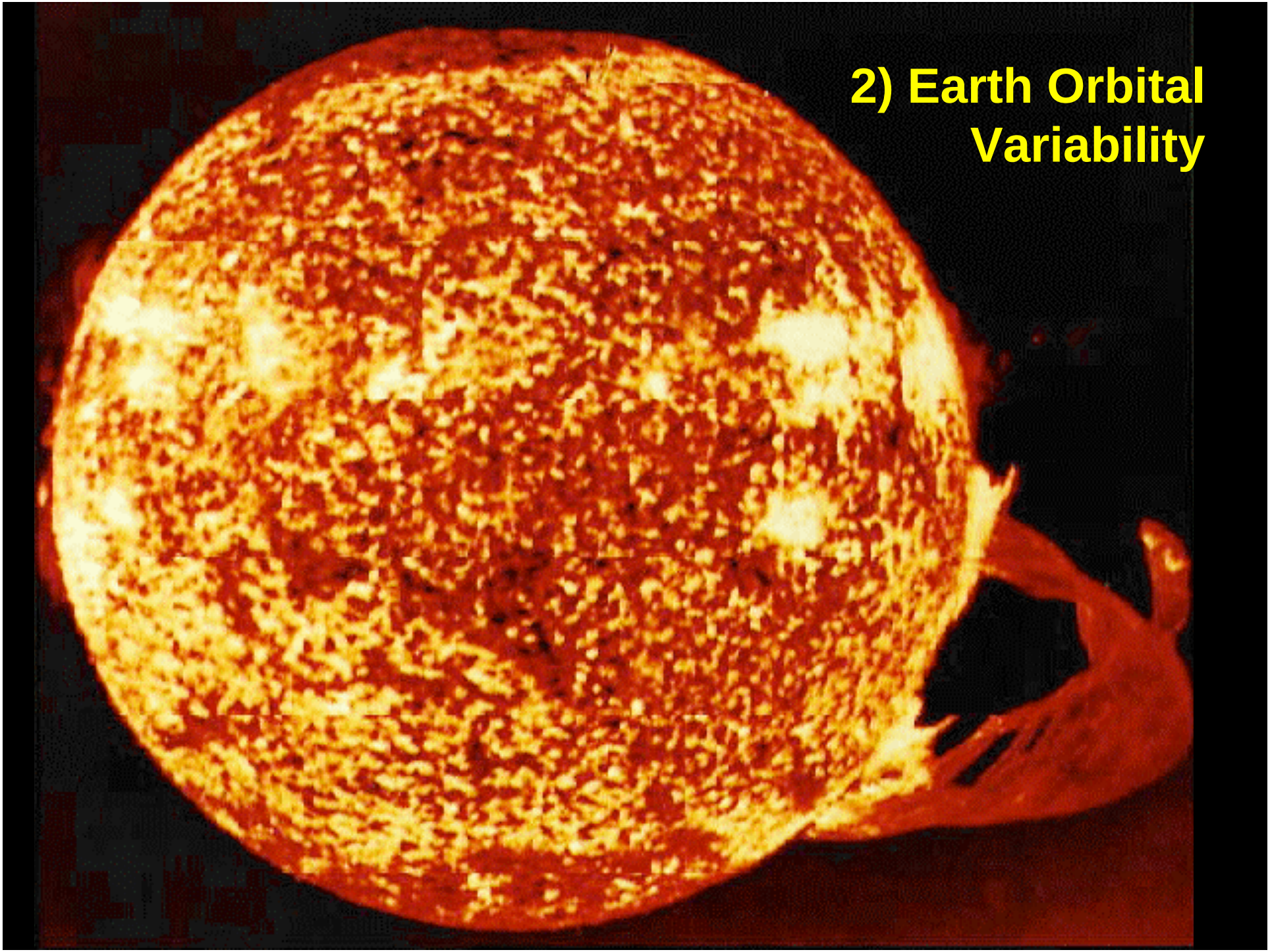


What was going on here to change global temperature?



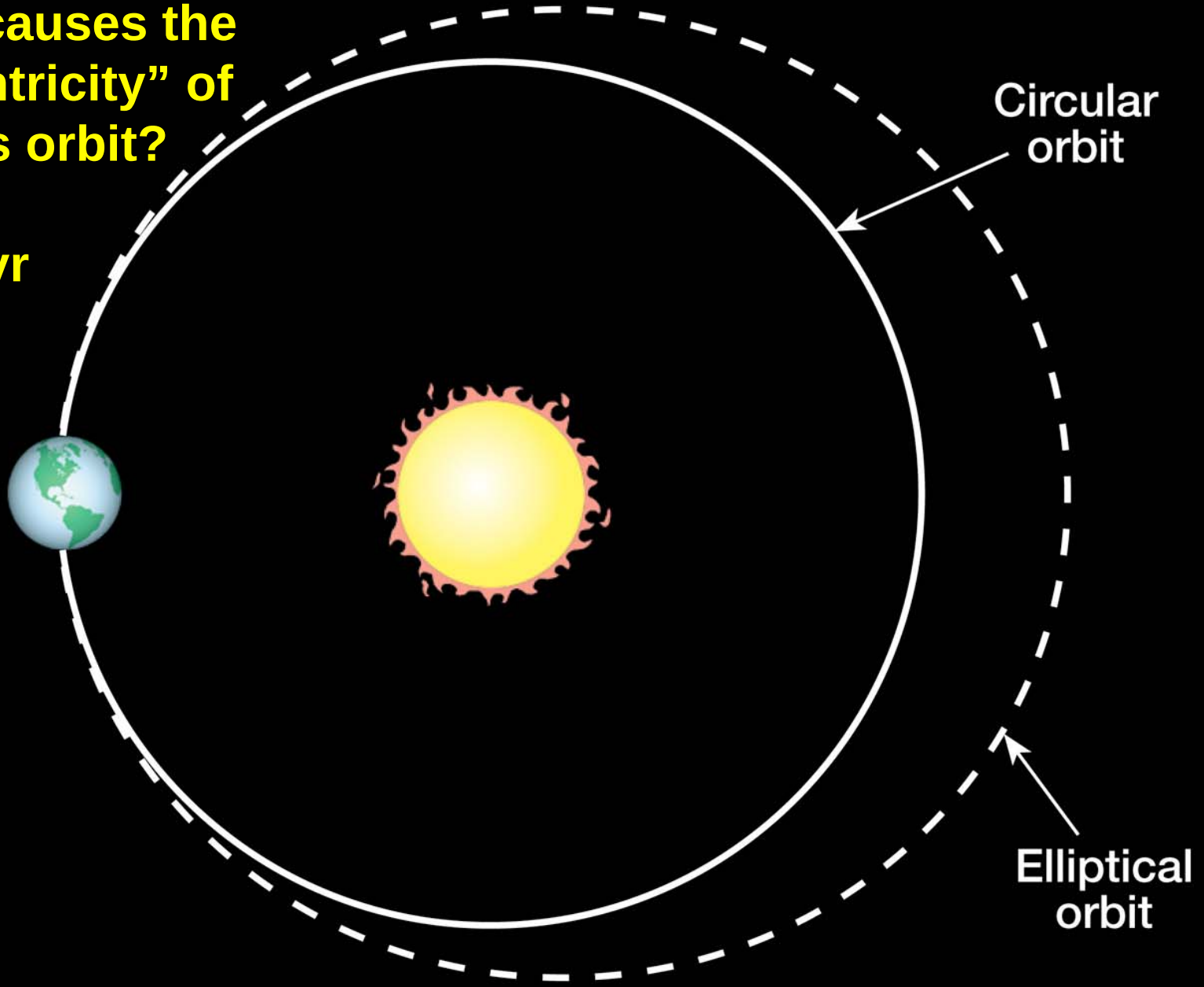




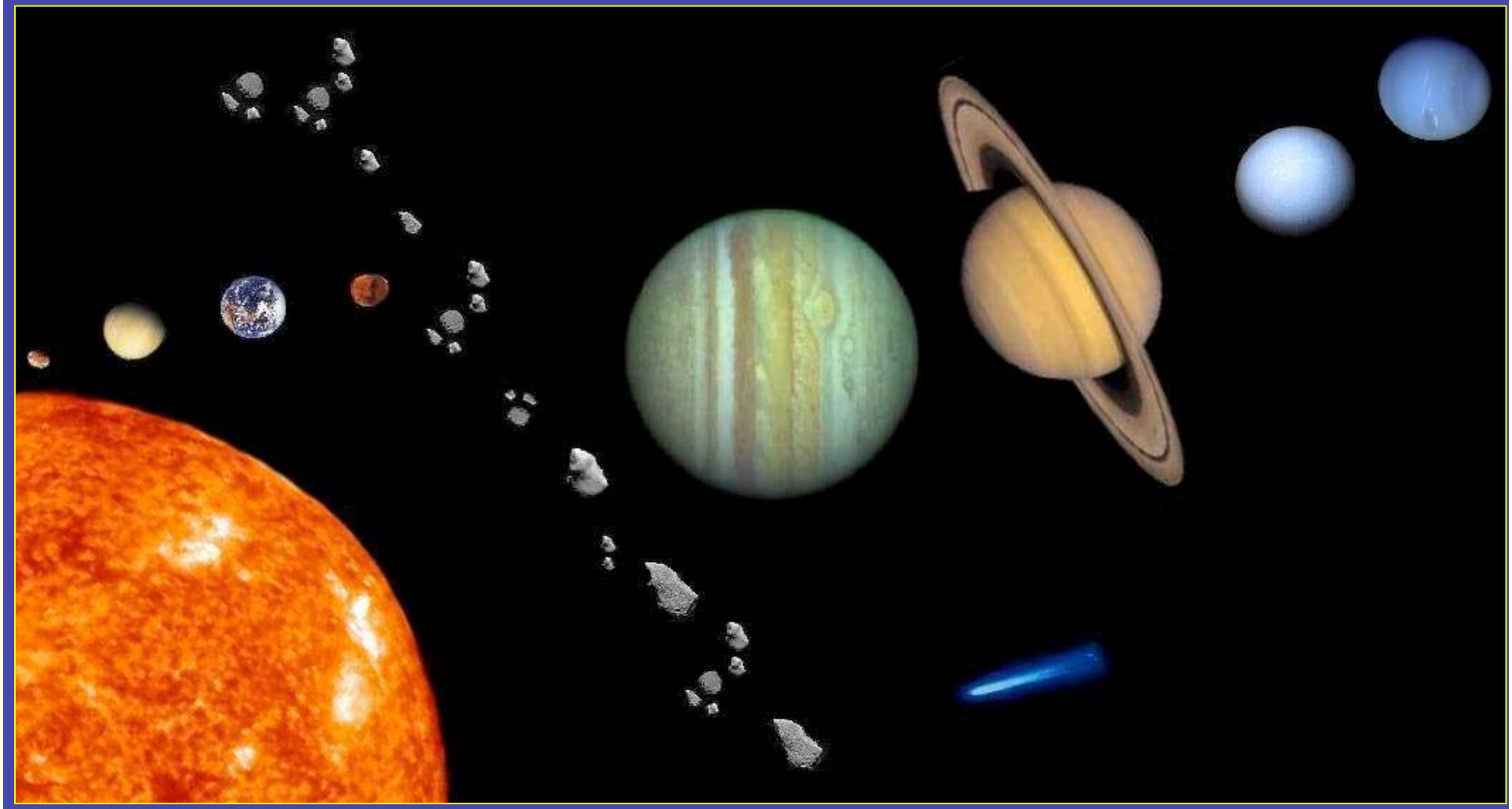

2) Earth Orbital
Variability

What causes the "eccentricity" of Earth's orbit?

~100kyr

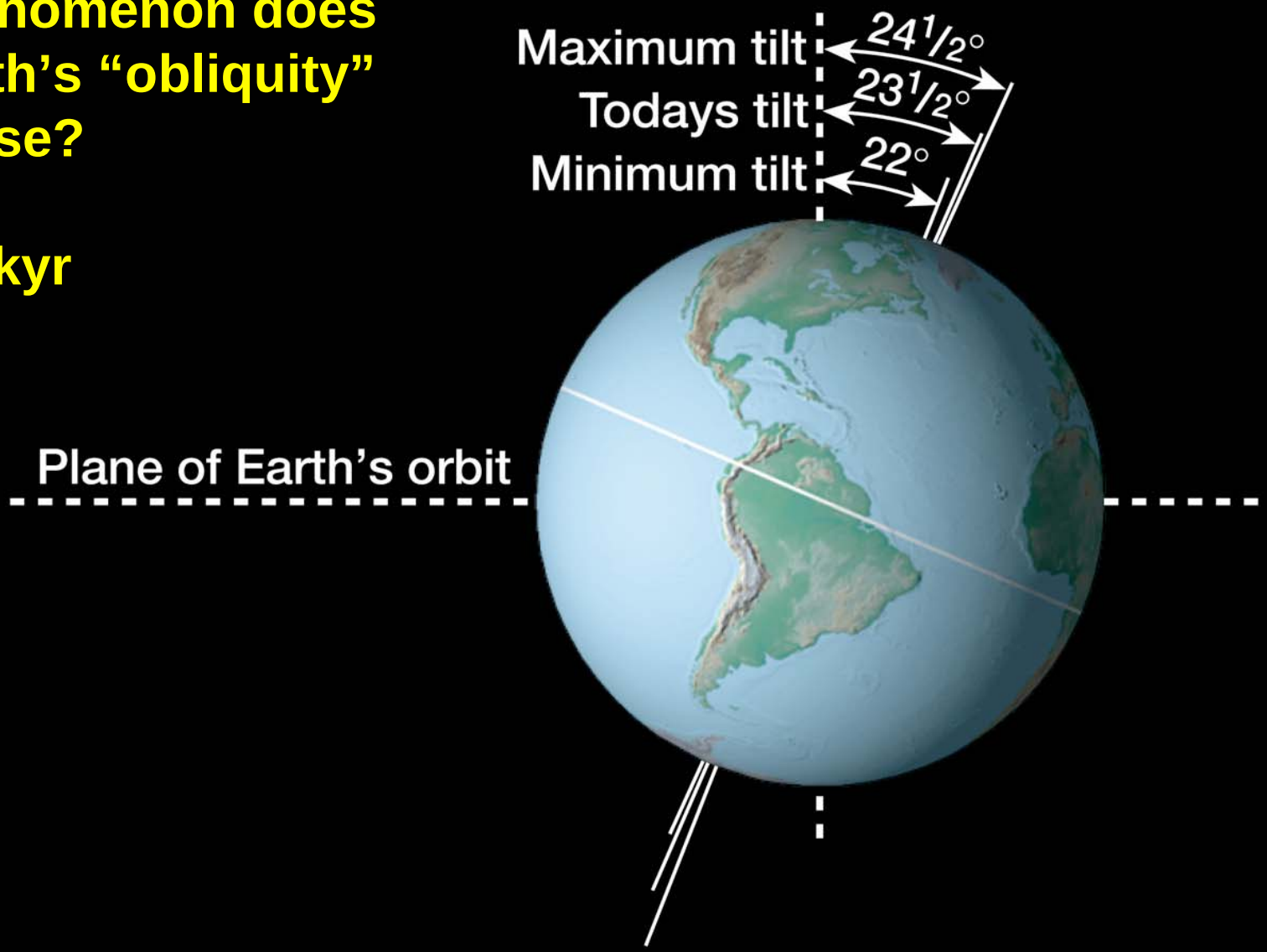


Gravitational interactions with the orbits of Jupiter and Saturn



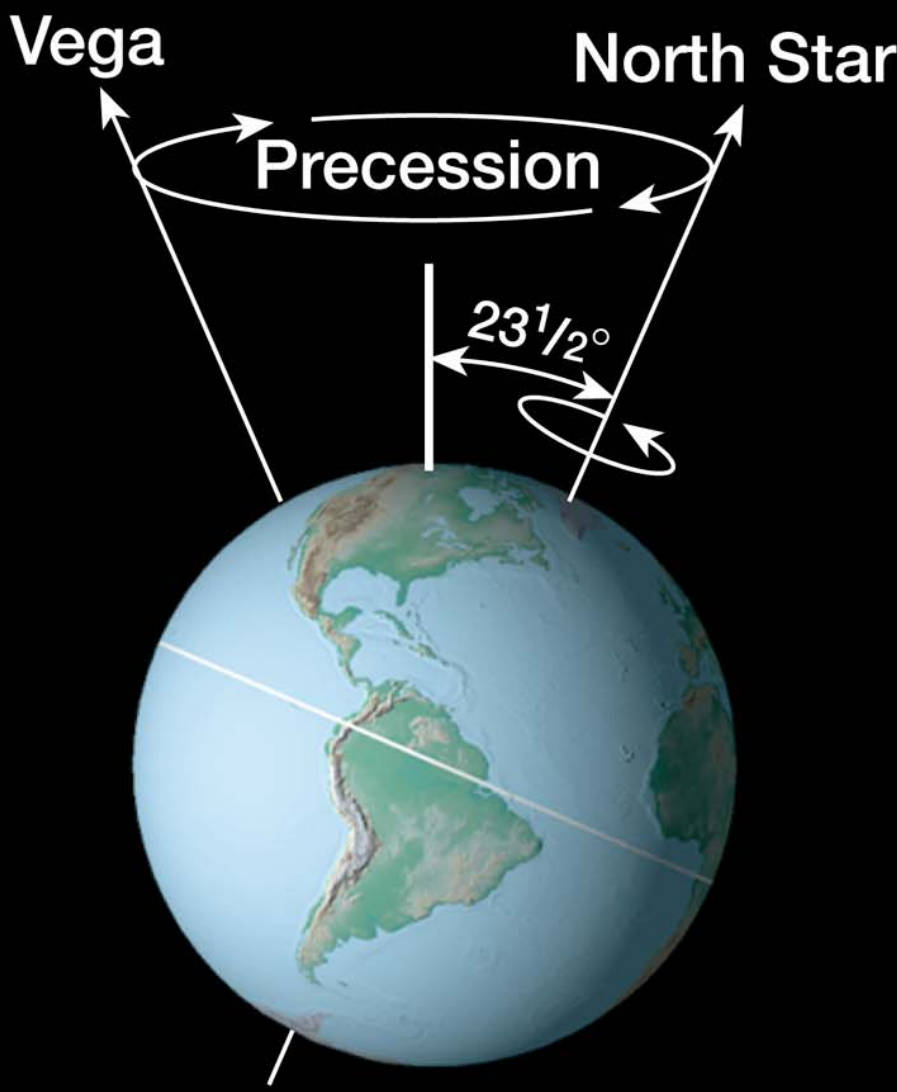
What familiar climate phenomenon does Earth's "obliquity" cause?

~40kyr

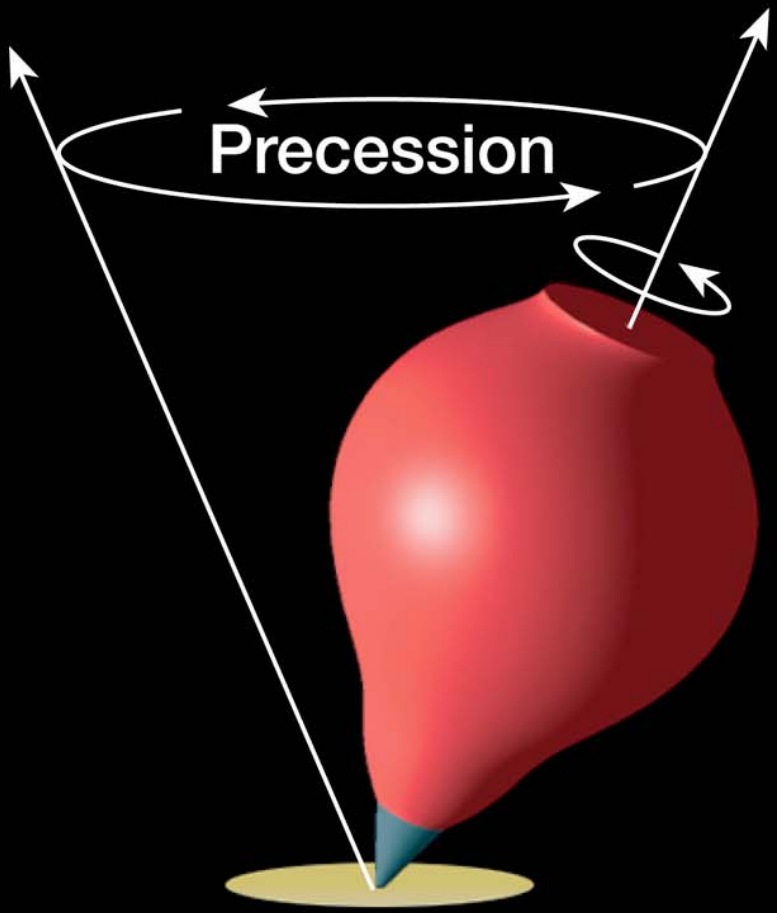



Seasonality results from Earth’s obliquity

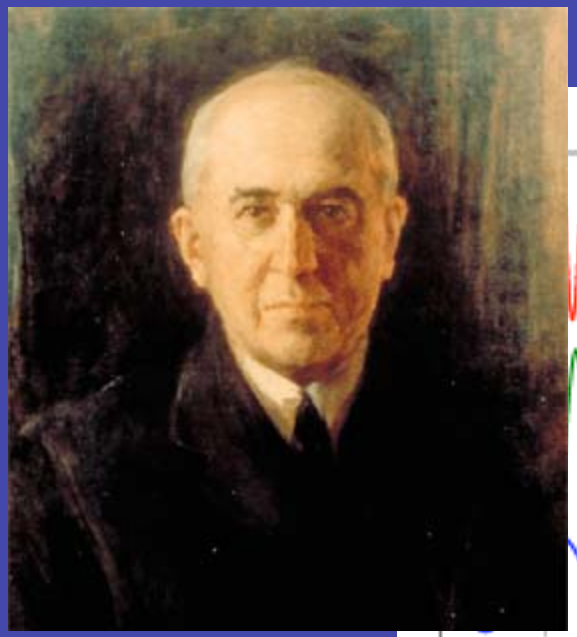
“Precession” of the equinoxes occurs due to tidal forces from Sun and Moon



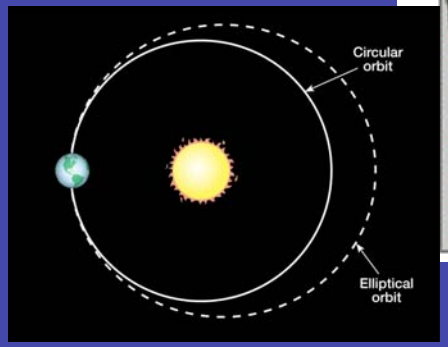
~20kyr

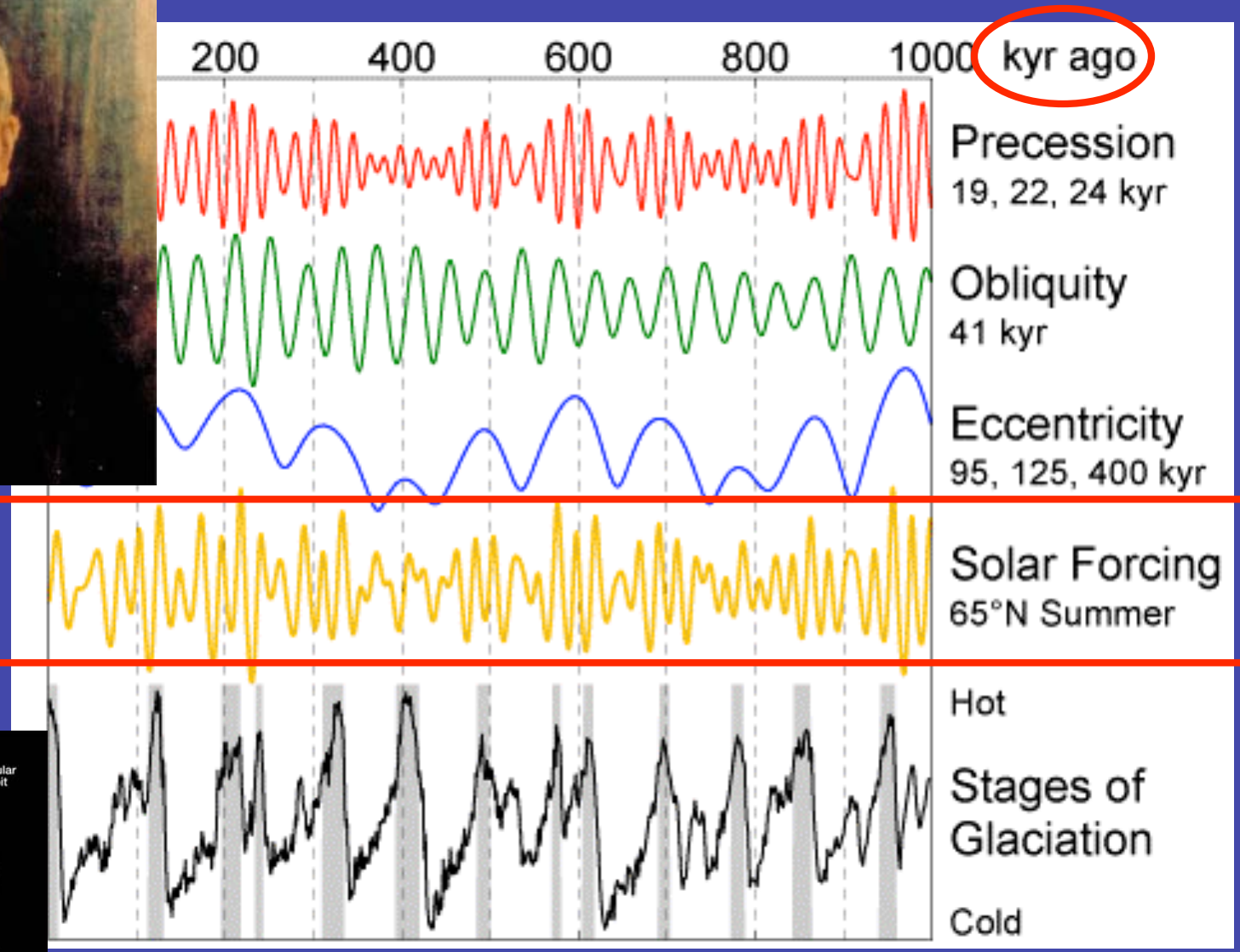


Combined solar forcing known as “Milankovitch cycles”
1920



Serbian engineer, climatologist, geophysicist

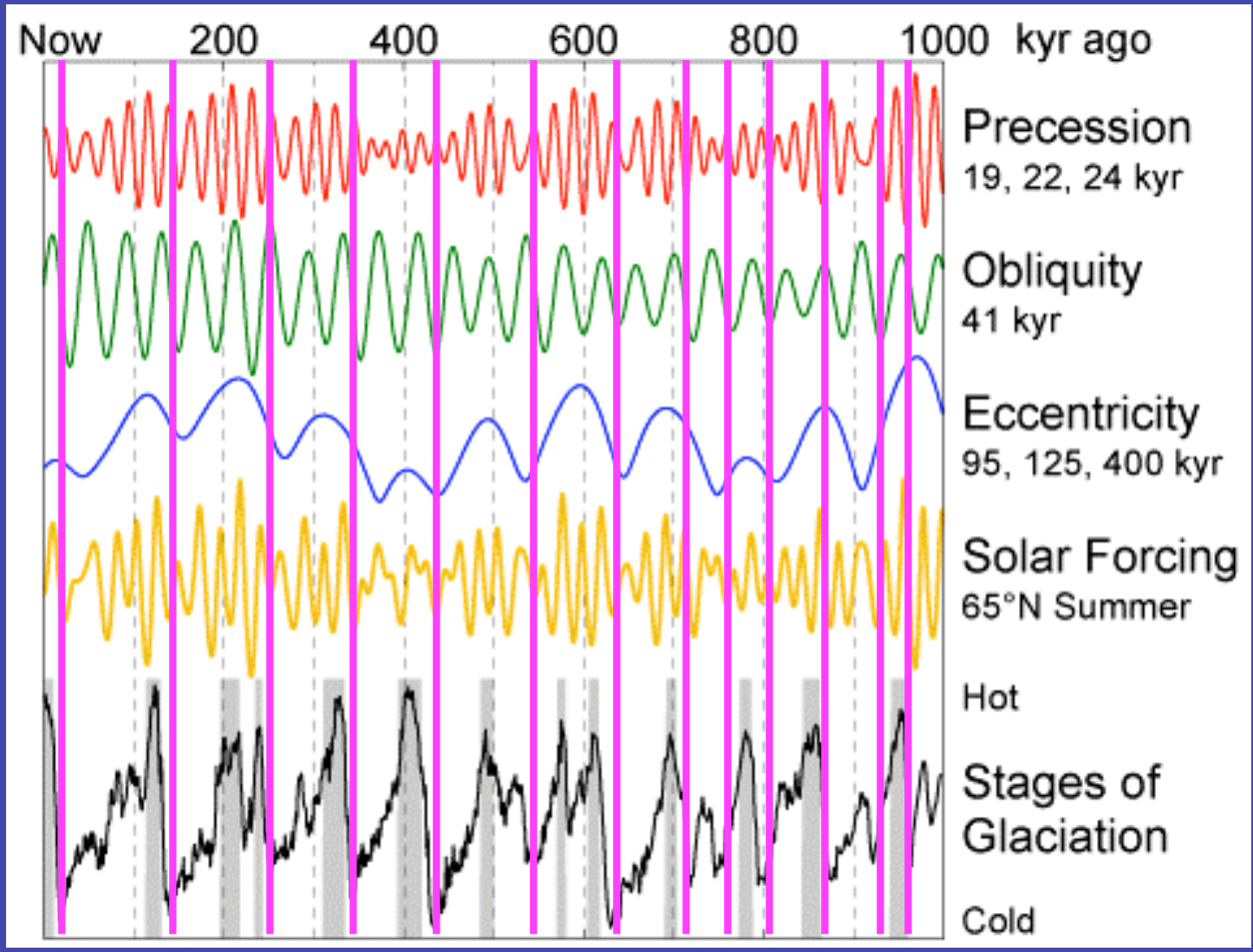


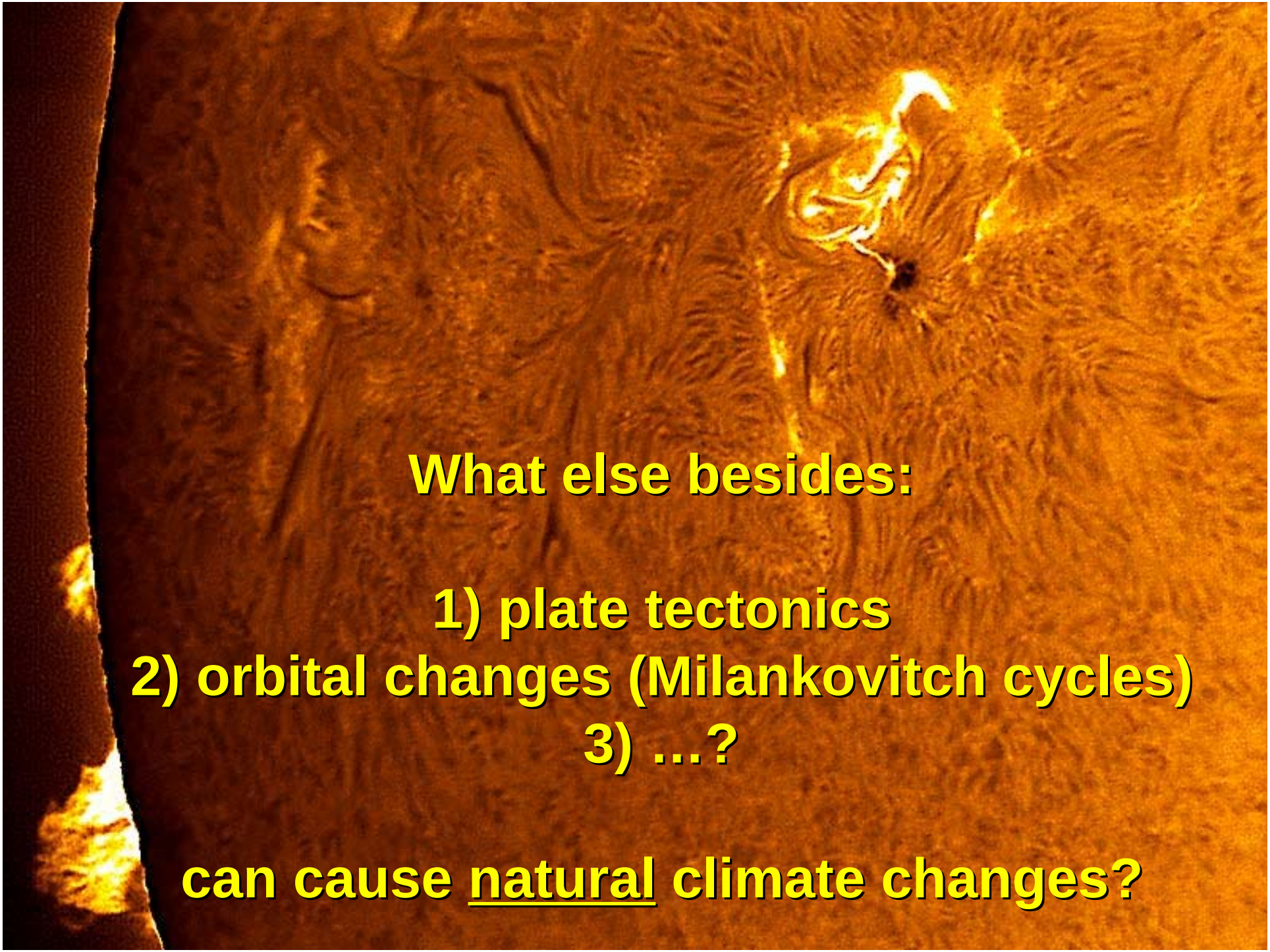


Deep sea sediments record Milankovitch cycles over 500 Kya



Milankovitch cycles influence glacial cycles

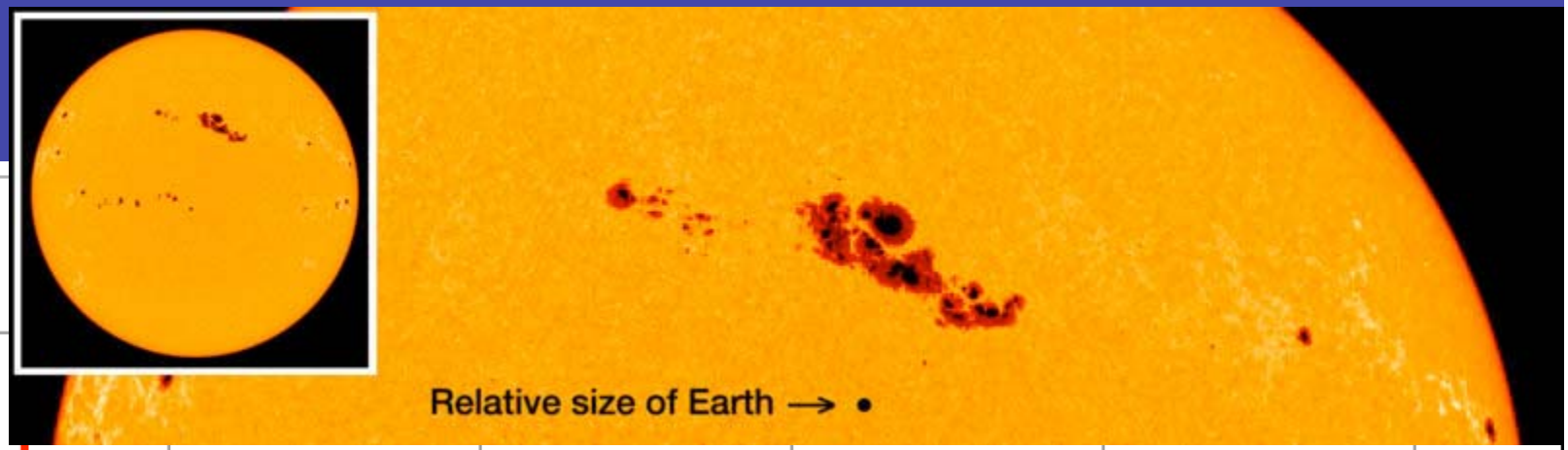


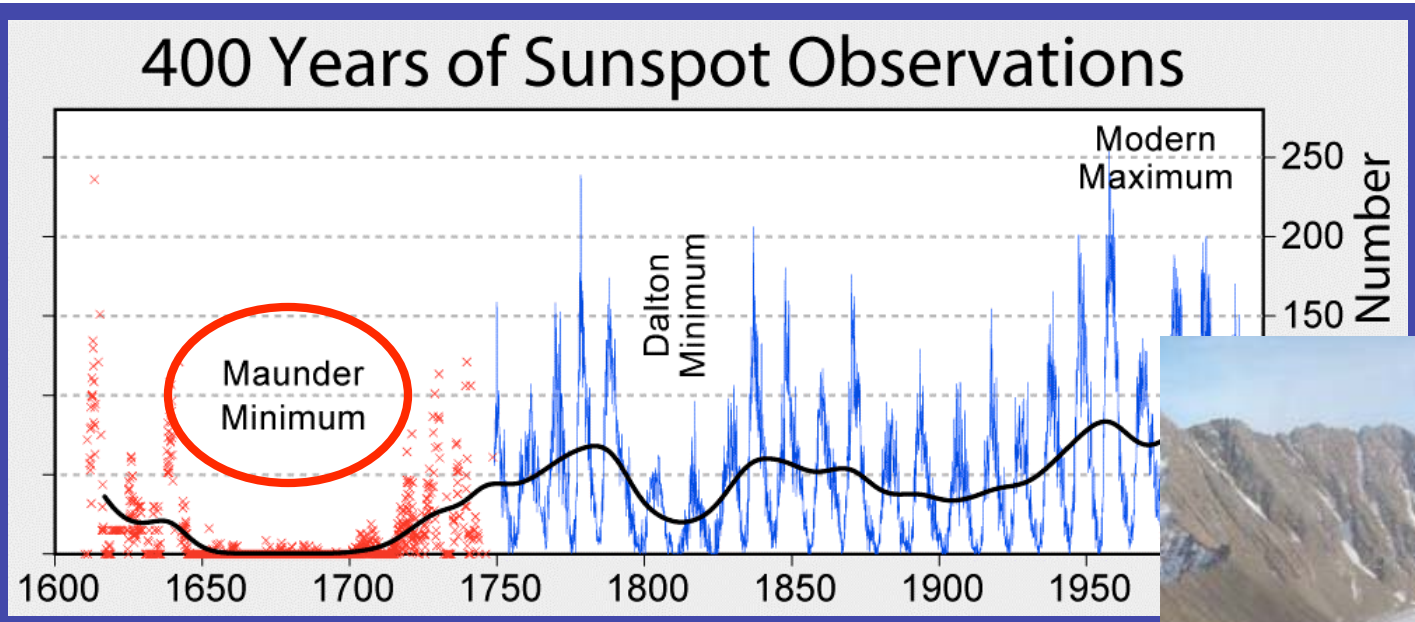

What else besides:
1) plate tectonics
2) orbital changes (Milankovitch cycles)
3) …?
can cause natural climate changes?

3) Variations in solar intensity…sunpot activity

11 yrs

10,000 yrs





Little Ice Age (~1550-1850 AD) caused by low sunspot count







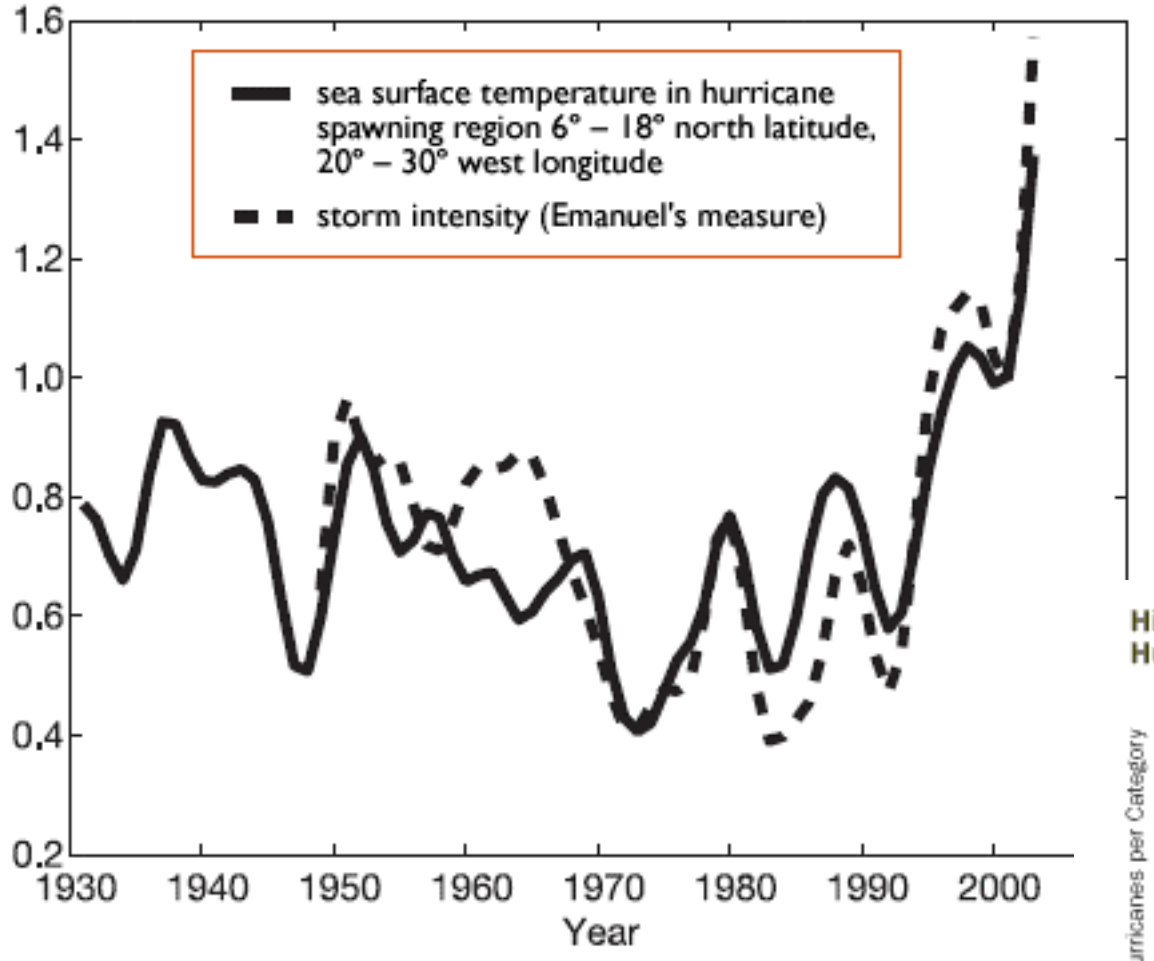
Mt. Tambora 1815

In a warming climate, cyclone intensity A) increases, B) decreases

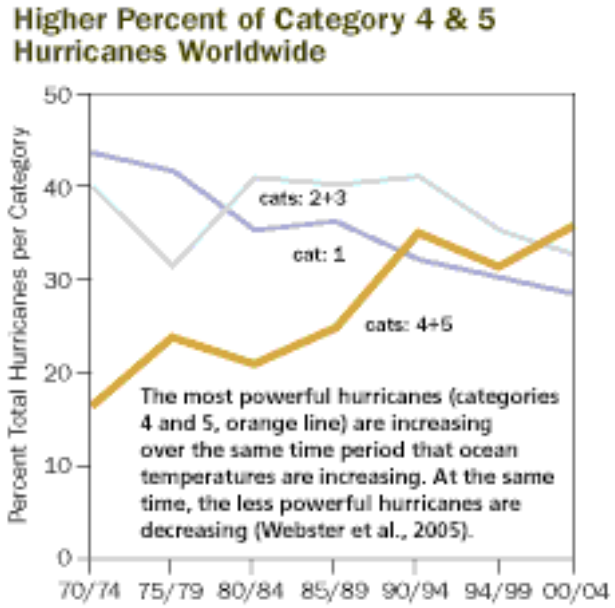


5/4/08
Cyclone Nargis
Myanmar
22,500 dead
41,000 missing

Hurricane intensity vs. ocean temperature



Storm Intensity Is Increasing

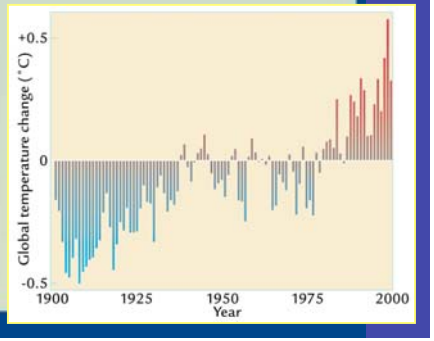


Global costs of extreme weather events (inflation-adjusted)

Storm frequency increasing?



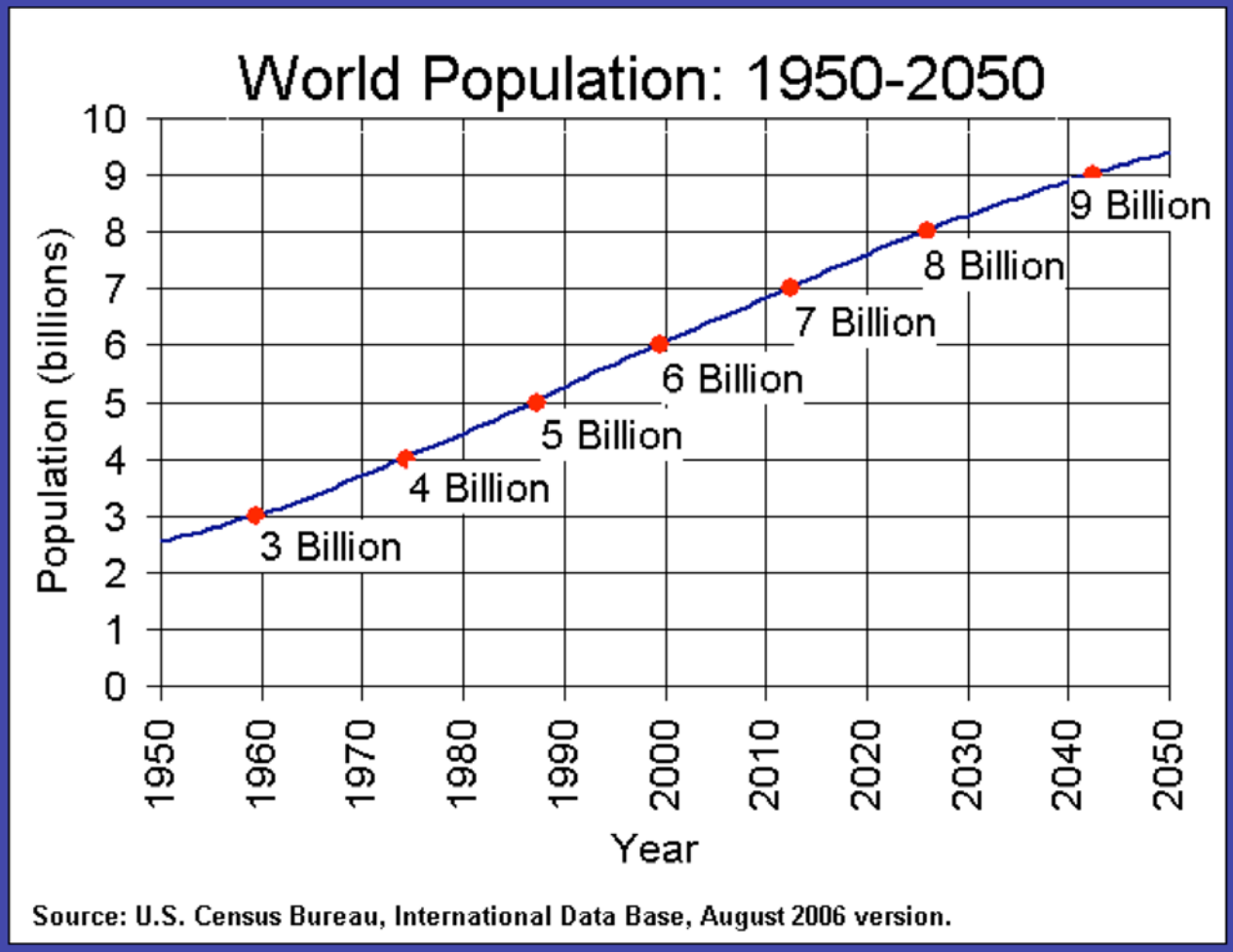
IPCC, 2001



How many humans can our planet support?
A) 6 billion, B) 9 billion, C) 12 billion, D) 18 billion

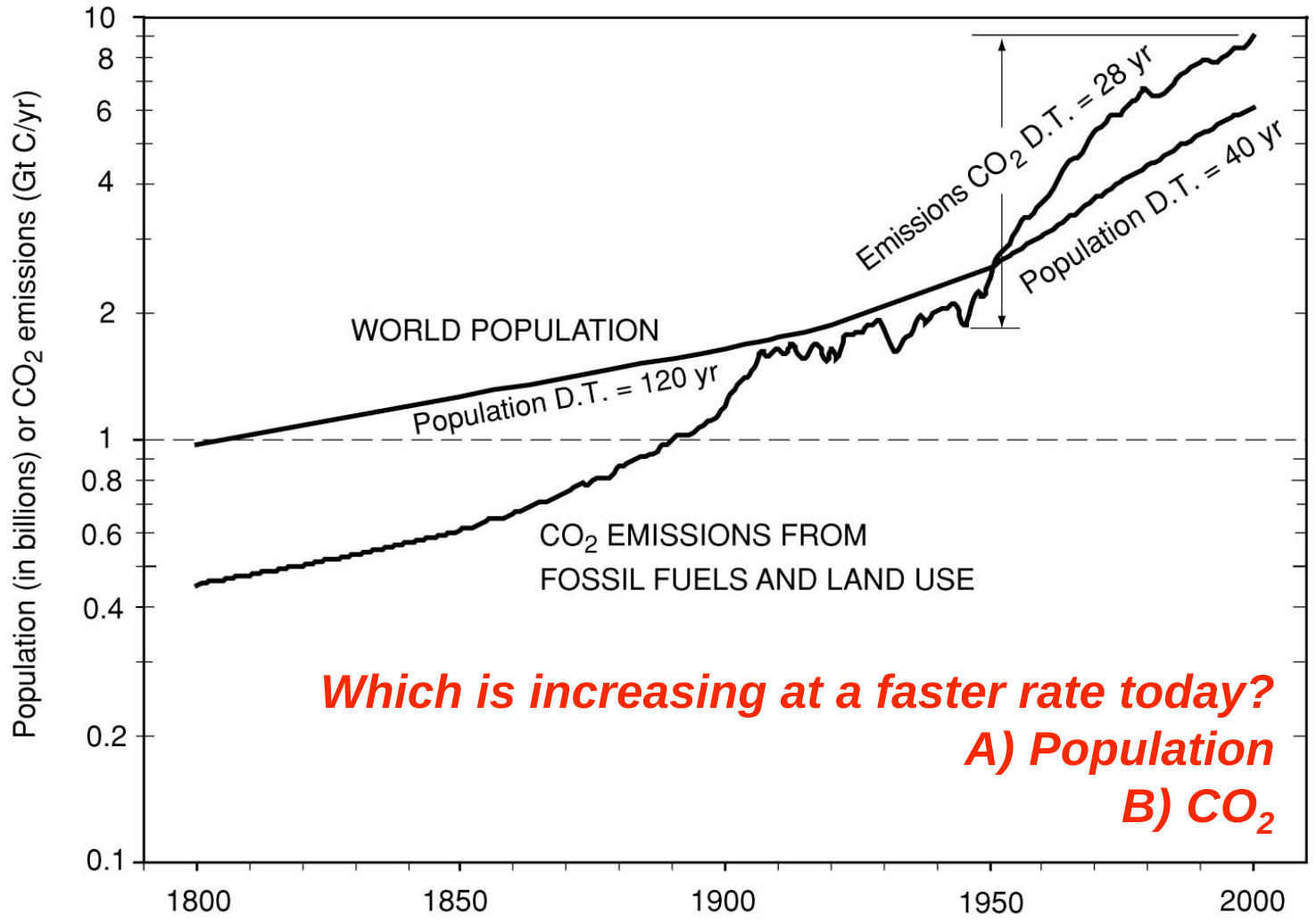


Earth's population today = 6.66 billion



How many people will Earth hold in our lifetimes?

Historic world population and CO_2 emissions



Which is increasing at a faster rate today?

A) Population

B) CO_2





What is the primary source of CO_2 today?
A) Land clearance
B) Fossil fuels

Is this going to change?

Who is burning these fossil fuels?















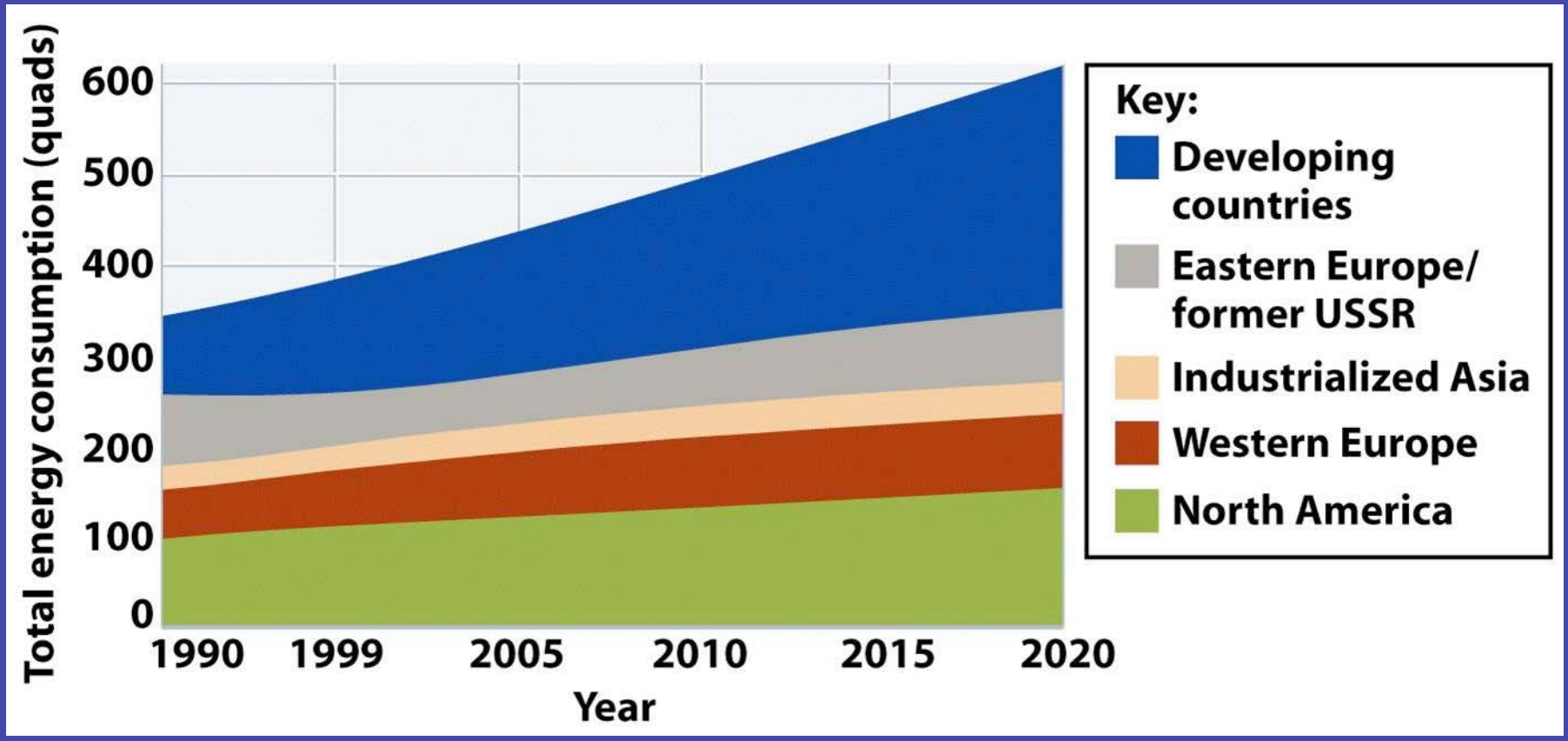
Energy Statistics > Oil consumption by country

VIEW DATA: **Totals** | Per capita | Definition | Source | Printable

Bar Graph | Pie Chart | Map | Corre

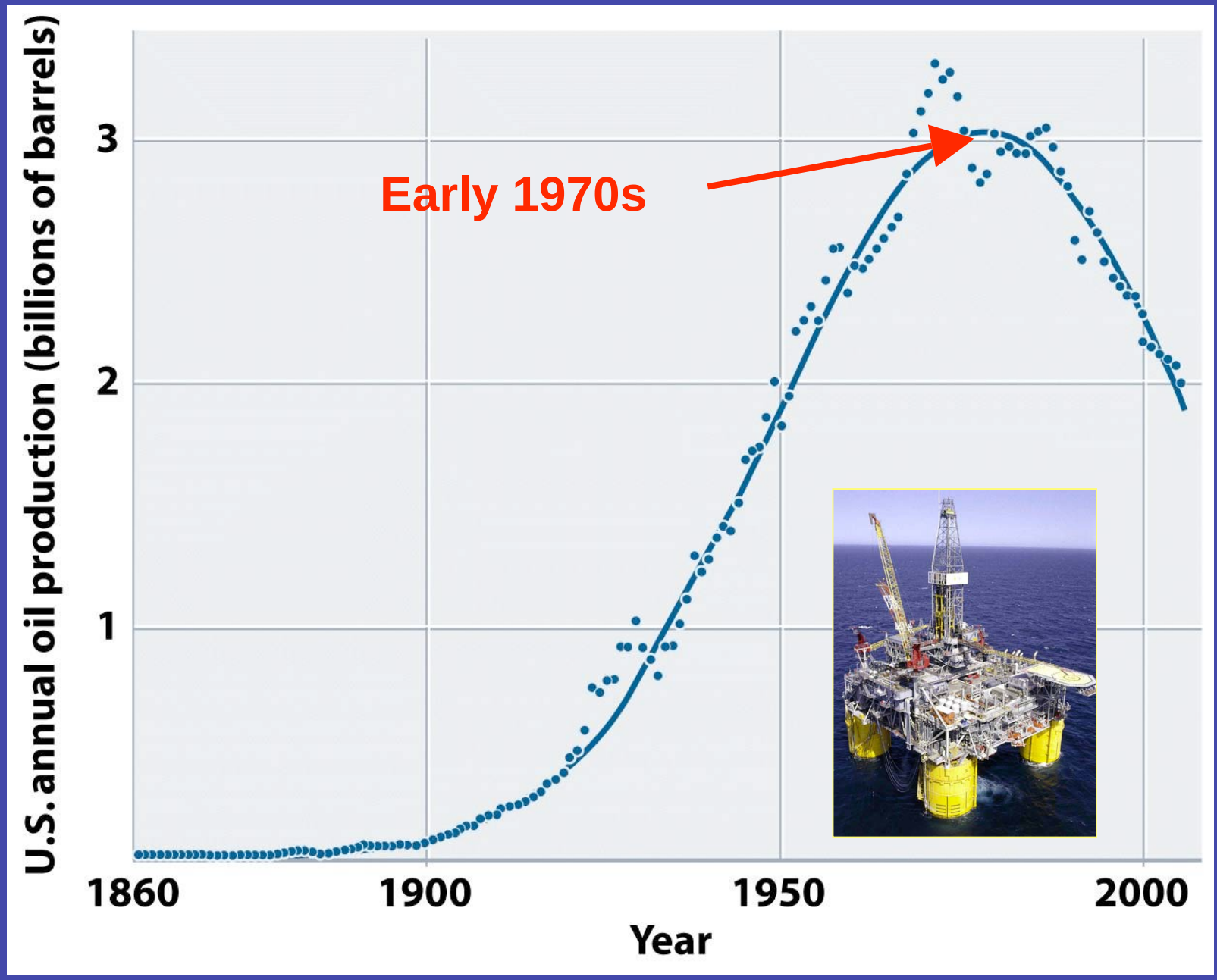
Rank	Countries	Amount (top to bottom)
#1	United States	20,030,000 barrels per day
#2	China	6,391,000 barrels per day
#3	Japan	5,578,000 barrels per day
#4	Russia	2,800,000 barrels per day
#5	Germany	2,677,000 barrels per day

3x


Total energy consumption (quads)
600
500
400
300
200
100
0
1990
1999
2005
2010
2015
2020
Year
Key:
Developing countries
Eastern Europe/ former USSR
Industrialized Asia
Western Europe
North America



In 1956, Hubbert correctly predicted the peak in US oil production



What is the effect of “Peak Oil” going to be on our planet?

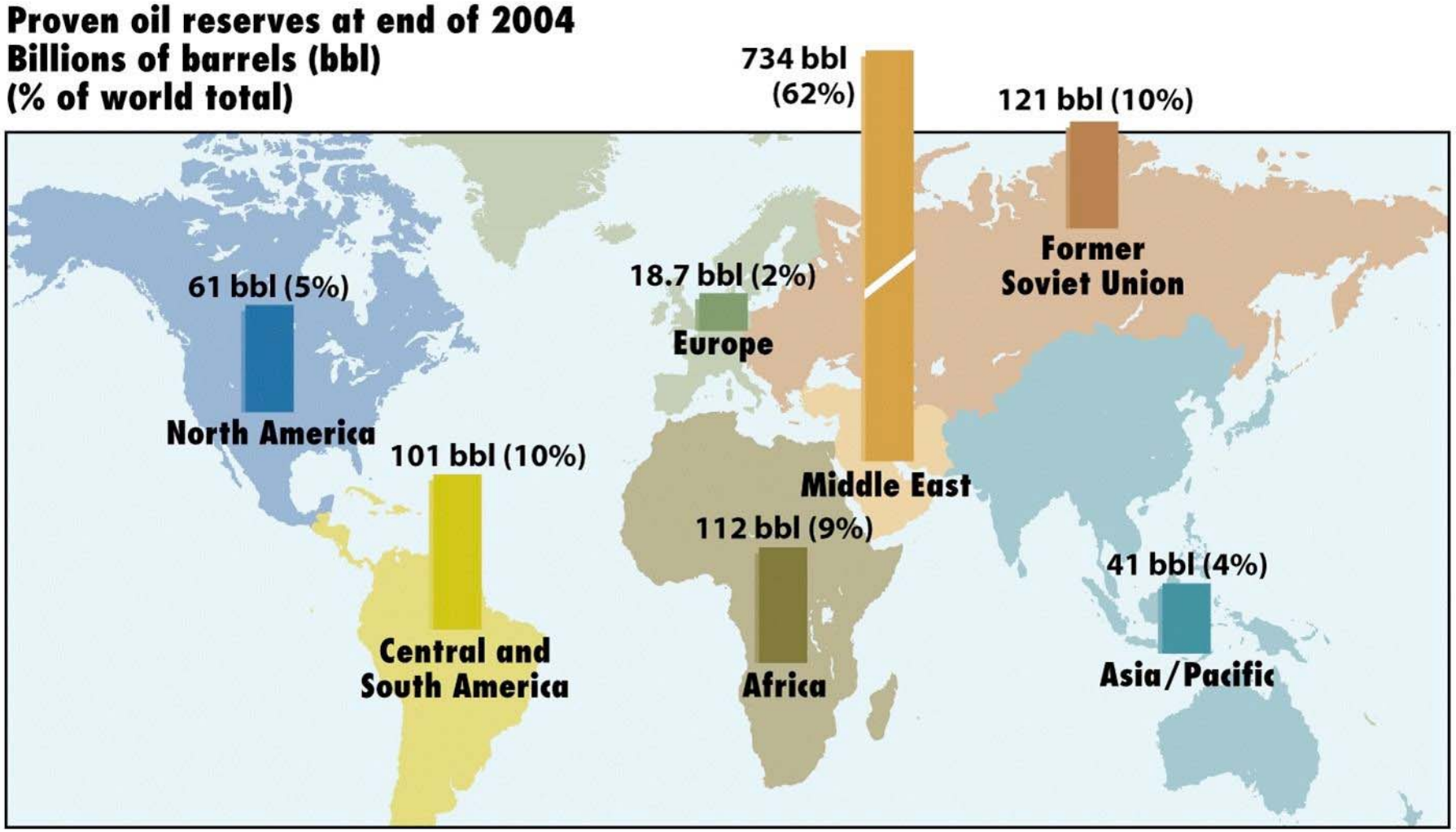






Who controls the world's oil?

A) N. America, B) C.&S. America, C) Africa, D) Middle East, E) Fmr USSR



Greatest Oil Reserves by Country, 2006

Rank	Country	Proved reserves (billion barrels)
1.	Saudi Arabia	264.3
2.	Canada	178.8
3.	Iran	132.5
4.	Iraq	115.0
5.	Kuwait	101.5
6.	United Arab Emirates	97.8
7.	Venezuela	79.7
8.	Russia	60.0
9.	Libya	39.1
10.	Nigeria	35.9
11.	United States	21.4
12.	China	18.3
13.	Qatar	15.2
14.	Mexico	12.9
15.	Algeria	11.4
16.	Brazil	11.2
17.	Kazakhstan	9.0
18.	Norway	7.7
19.	Azerbaijan	7.0
20.	India	5.8

12x

5x

3 year supply

United States has 1:3 production/consumption gap

Energy Statistics > Oil consumption by country

VIEW DATA: Totals | Per capita | Definition | Source | Printable ve

Bar Graph | Pie Chart | Map | Correlat

Rank	Countries	Amount (top to bottom)
#1	United States	20,030,000 barrels per day
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#3	Japan	5,578,000 barrels per day
#4	Russia	2,800,000 barrels per day
#5	Germany	2,677,000 barrels per day

3x

View the rest of the list (206 more countries) »

P/C gap growing 5% per year

P/C gap cost $192 billion in 2007

($240 billion per year spent in Iraq war so far)
($100 billion to provide universal health care)
($6 billion spent on cancer research)

Why is Hawaii particularly at risk in scenarios like this?







Hawaii has one of the highest rates of per capita oil consumption in the world

2x U.S. average
4x Europe average
28x China average

1. transportation and electricity-generating plants

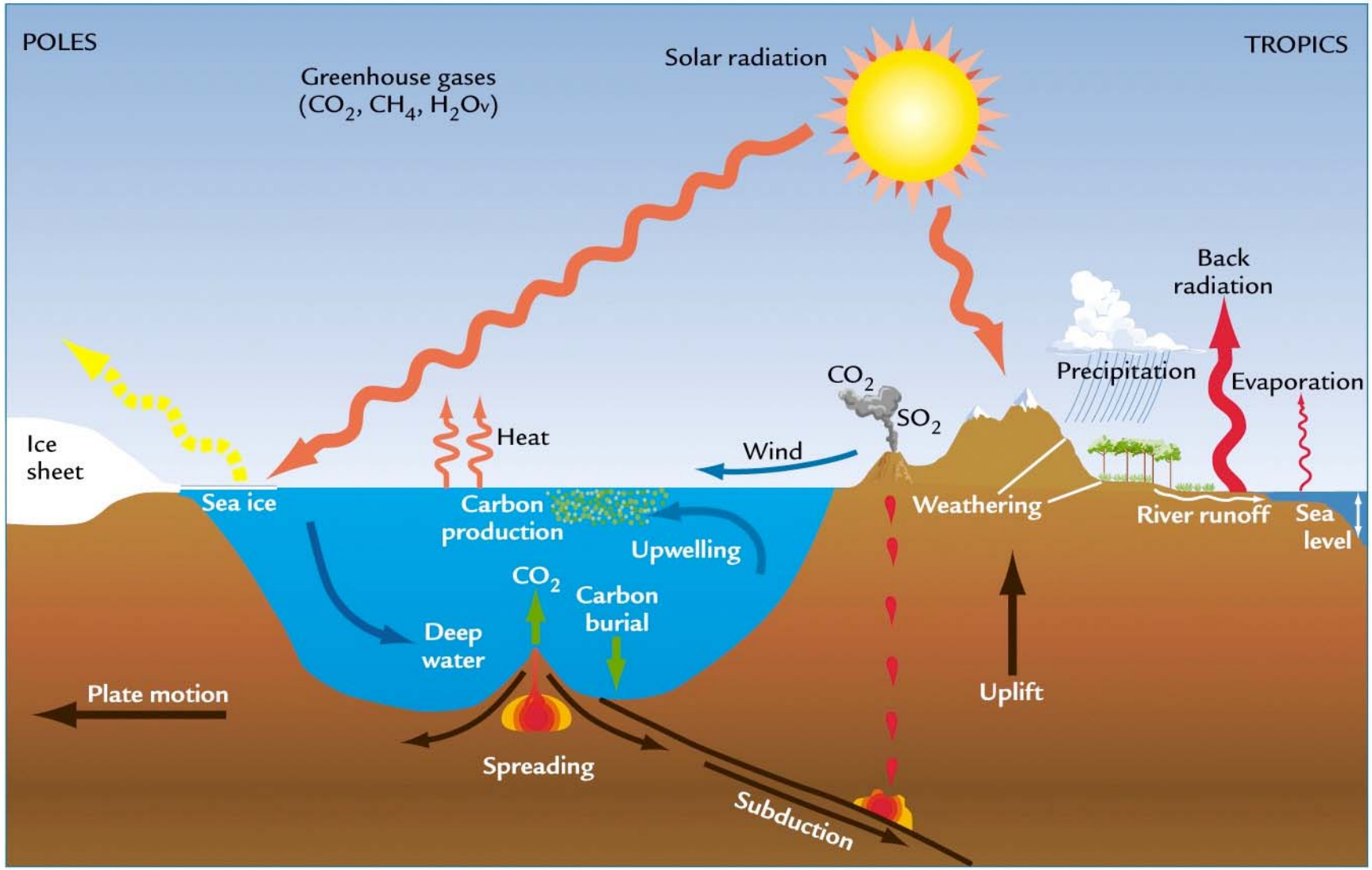
2. airplanes that fuel our tourist-based economy

3. almost all of our food and consumer goods

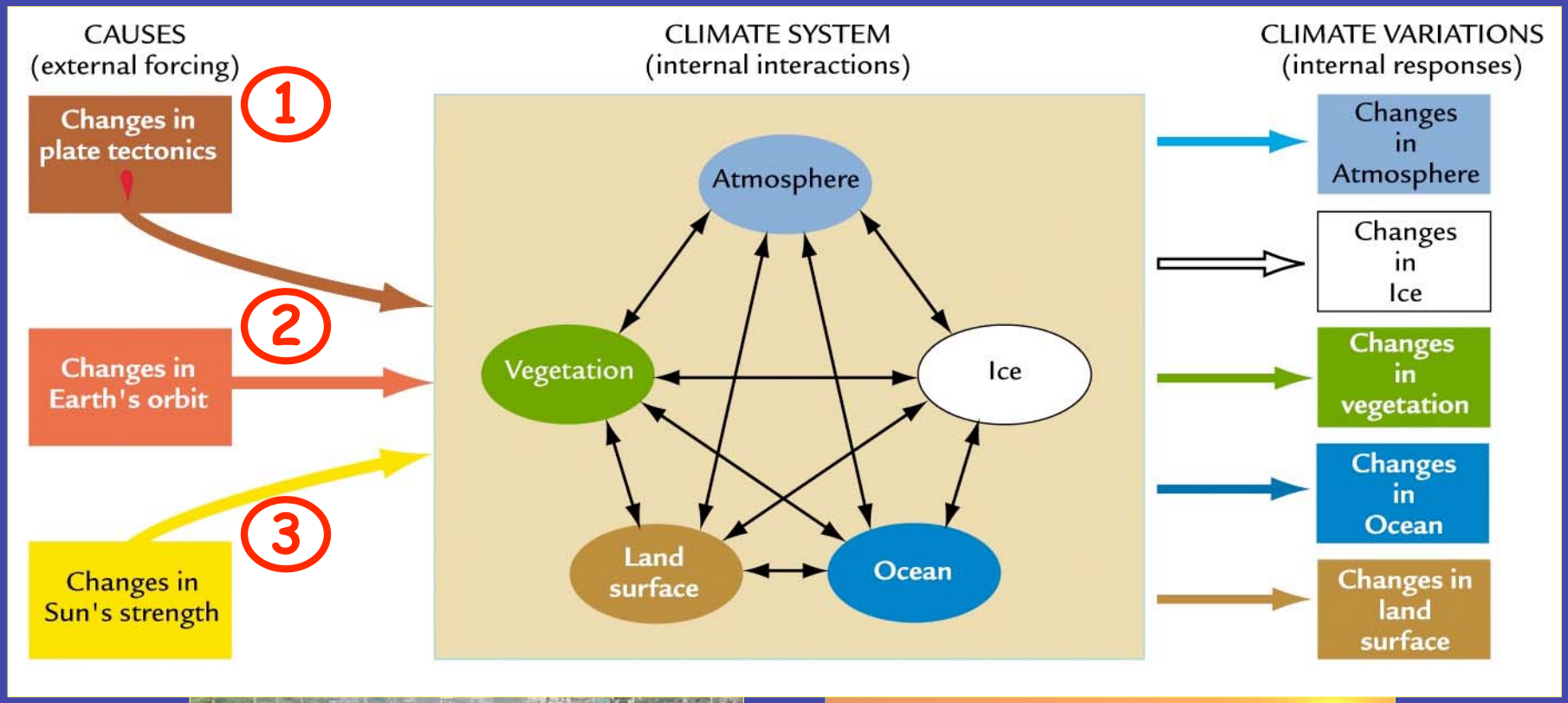
How are human actions affecting our environment?



Climate system is complicated - how can we simplify?



Forcings (causes) Responses (effects)



4



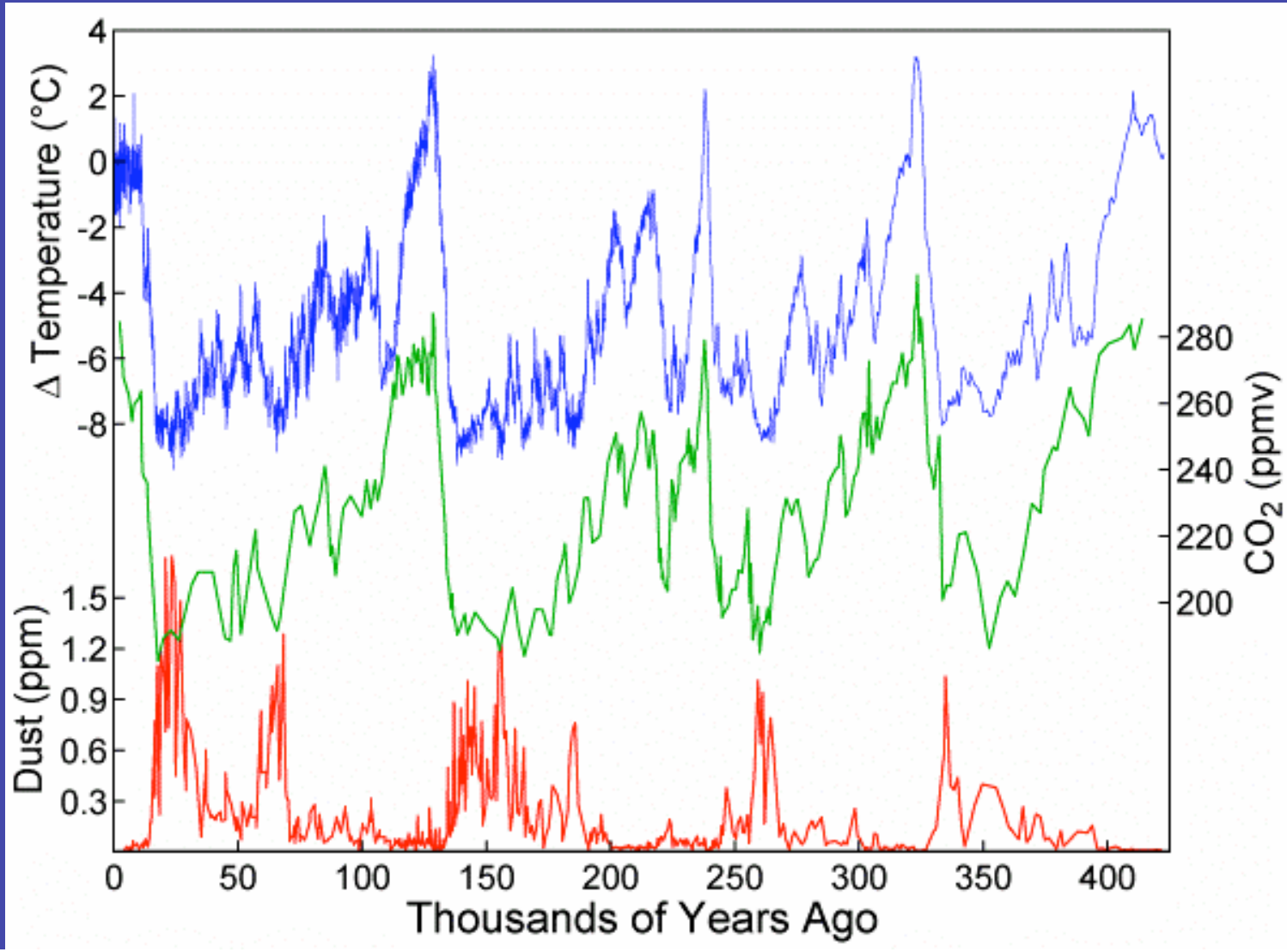


NATURAL causes of global climate change:

1) plate tectonics (100s of millions of years)

2) orbital changes (100s of thousands of years)

3) solar intensity (10s of thousands of years)



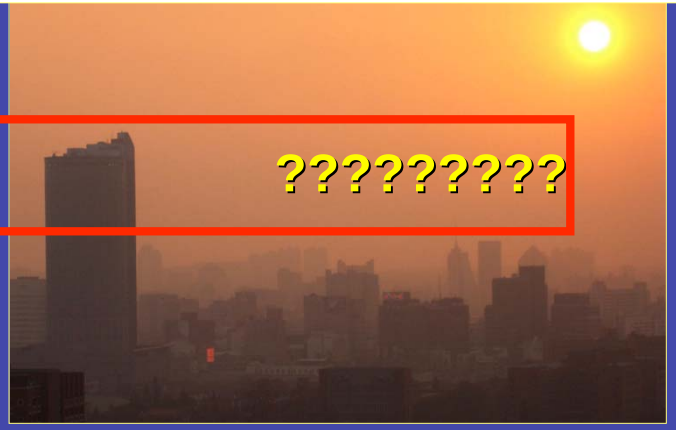
Speed of Forcing

Speed of Response

CAUSES (external forcing)		CLIMATE VARIATIONS (internal responses)	
Changes in plate tectonics	100's of millions of yrs	Hours to Weeks	Changes in Atmosphere
		Hours to 10,000 yrs	Changes in Ice
Changes in Earth's orbit	100,000s of yrs	Hours to Centuries	Changes in vegetation
		Days to 1,500 yrs	Changes in Ocean
Changes in Sun's strength	10,000s of yrs	Hours to Months	Changes in land surface

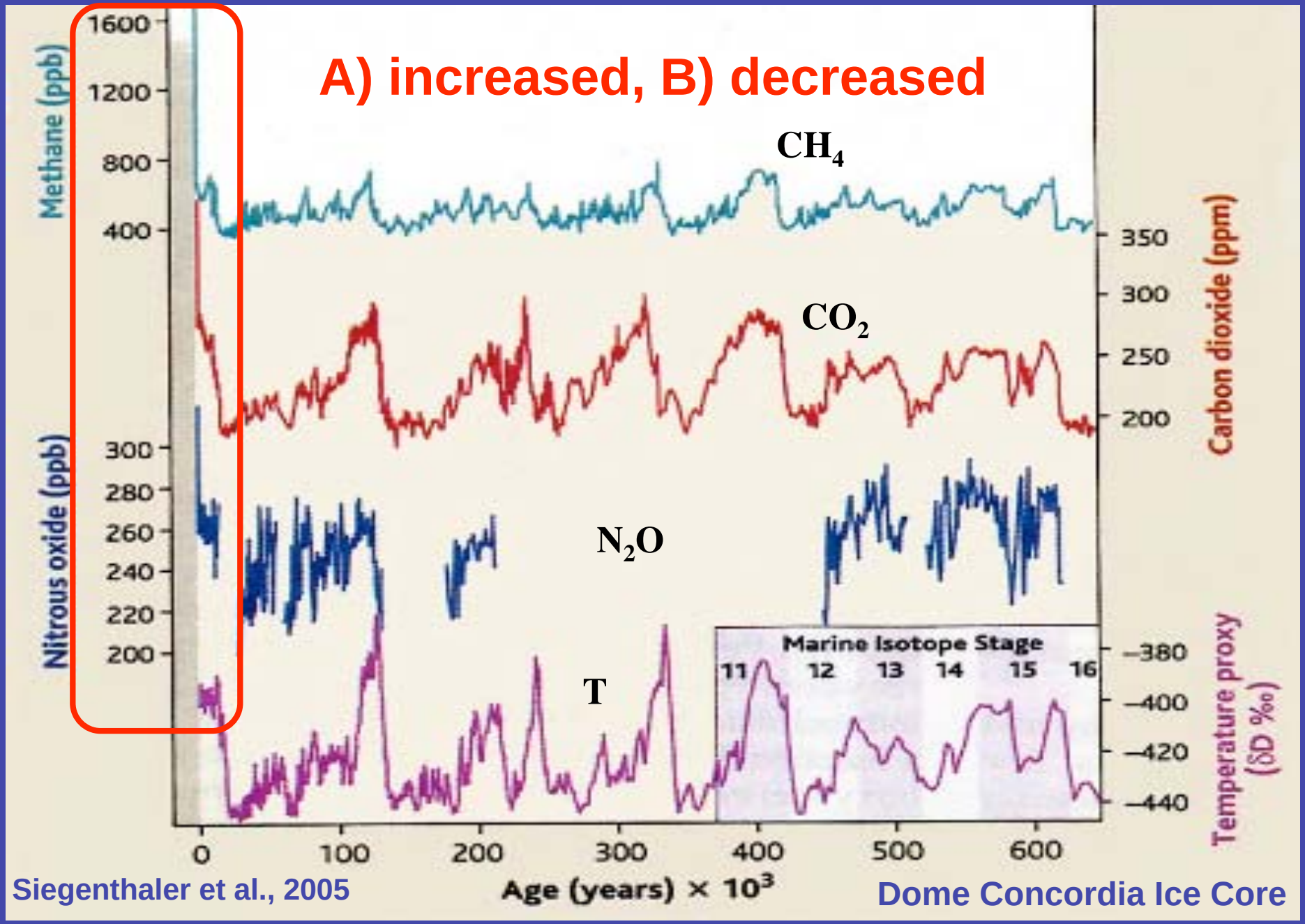


Decades to Centuries



?????????

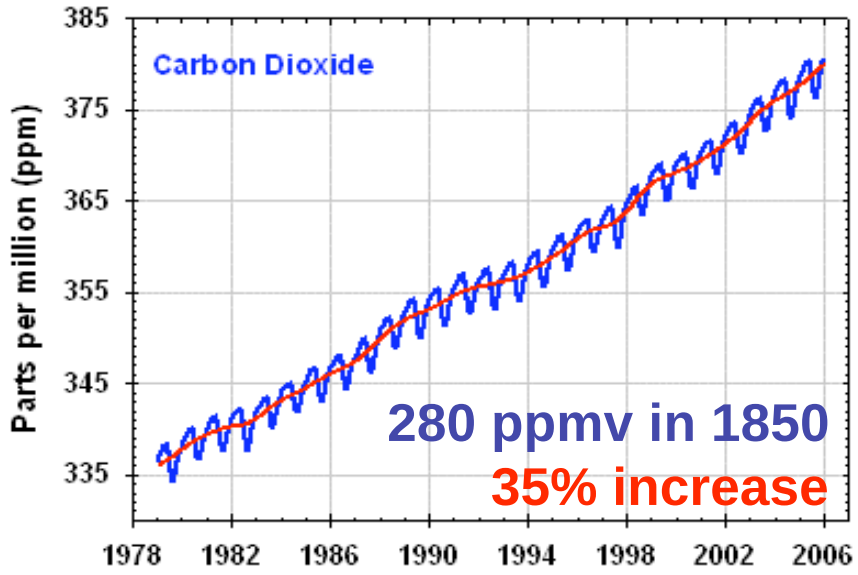
Greenhouse gas concentrations in atmosphere have recently:

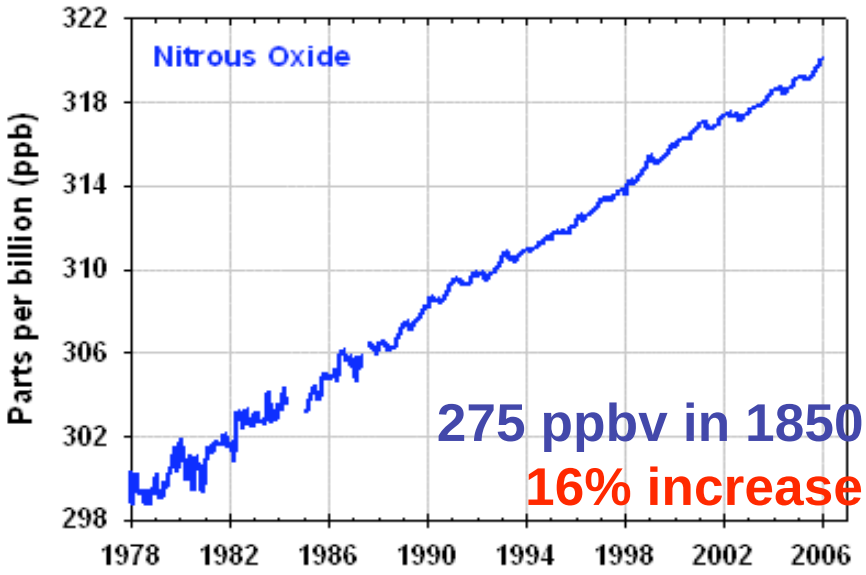


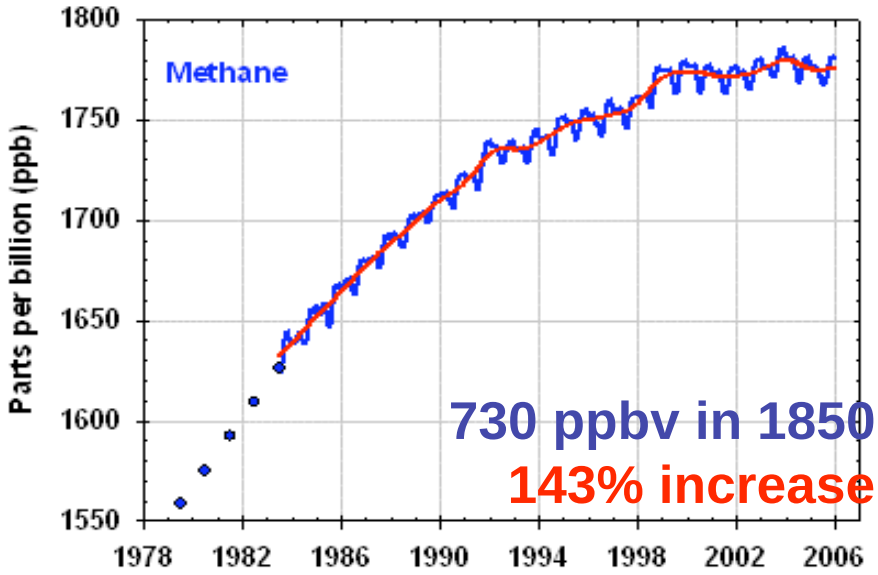
Siegenthaler et al., 2005

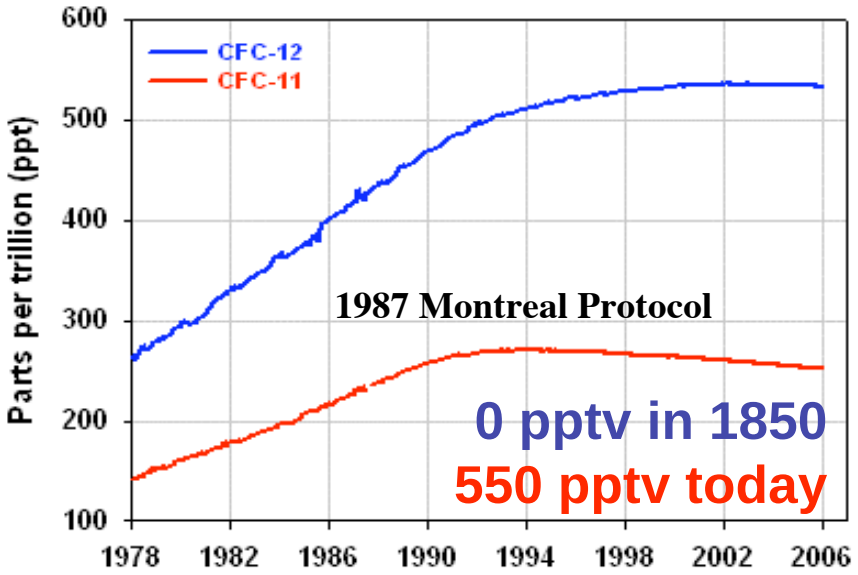
Dome Concordia Ice Core

Without doubt human activities have changed atmospheric chemistry







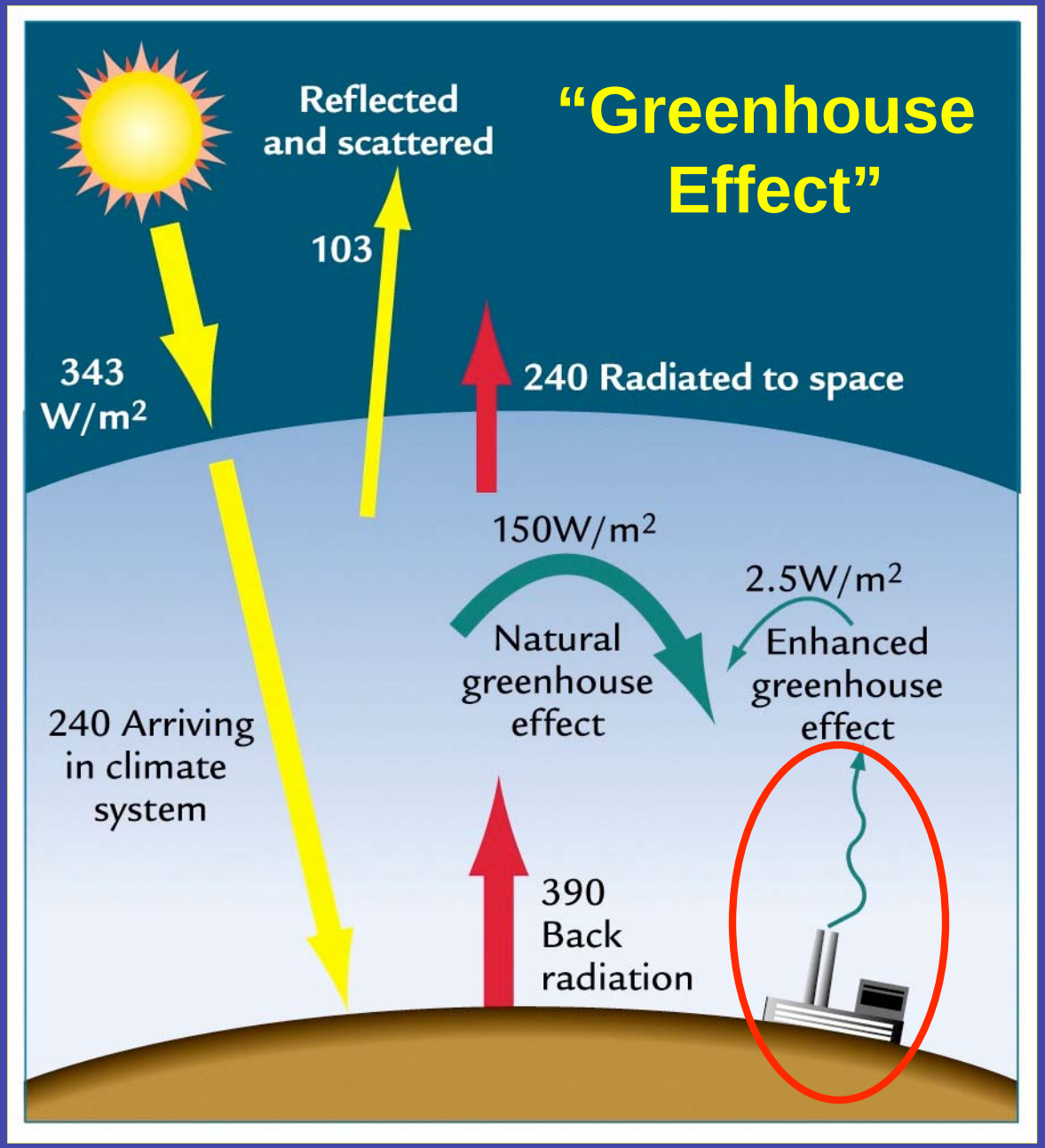


CDIAC, 2006

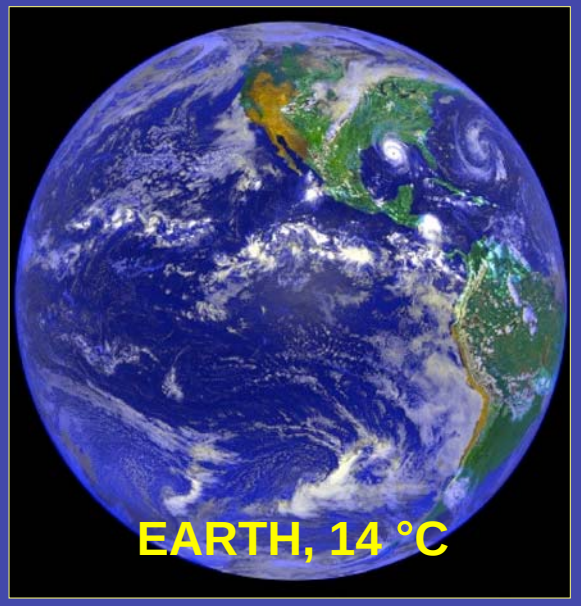
What allows Earth to support life?



EARTH, 14 °C



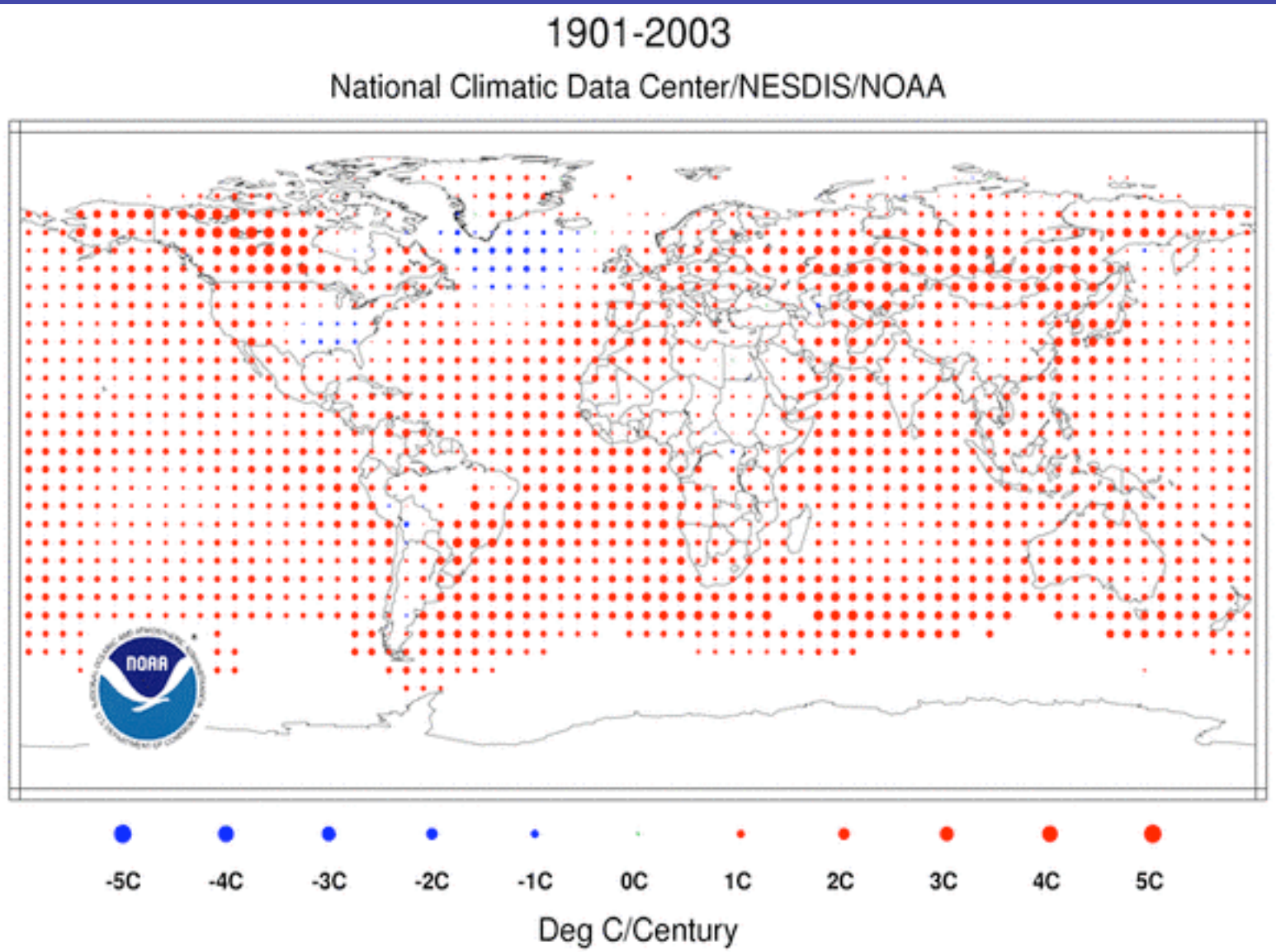
"Greenhouse Effect"



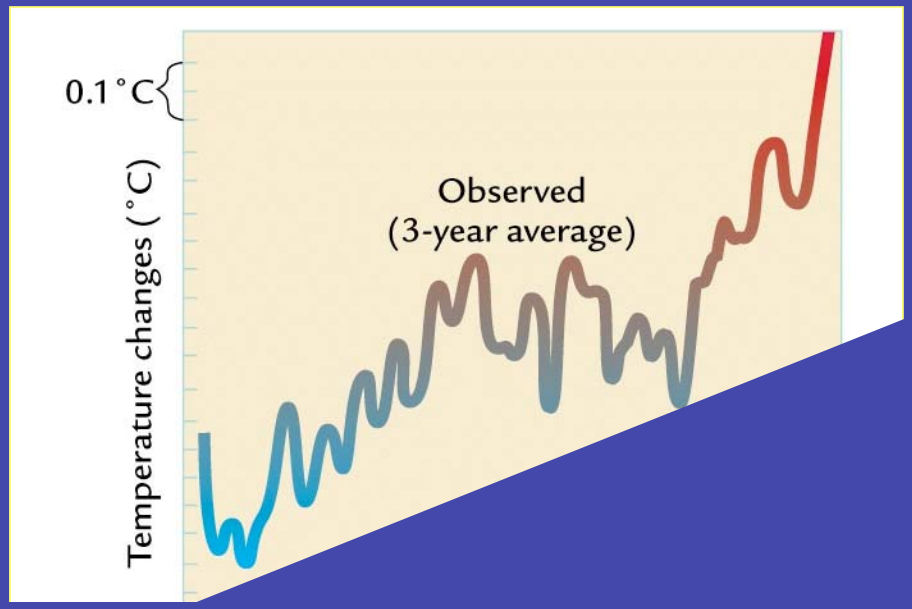
Earth's own Greenhouse Effect is

NATURAL and NECESSARY

What is 100-year trend in annual temperature?
A) increase, B) decrease

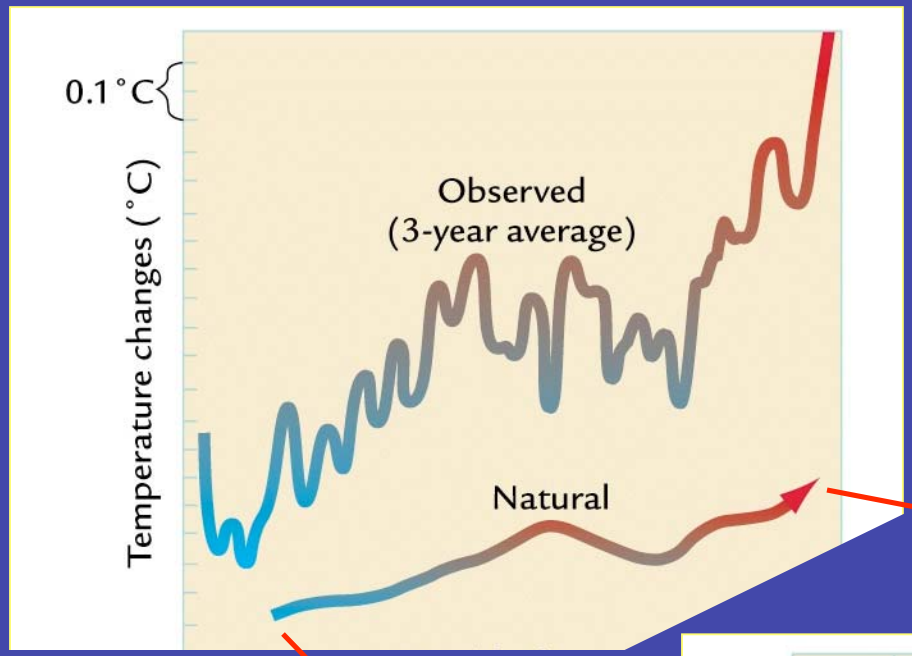


GREENHOUSE MATH PROBLEM



Observed Temperature (1900-2000)

GREENHOUSE MATH PROBLEM

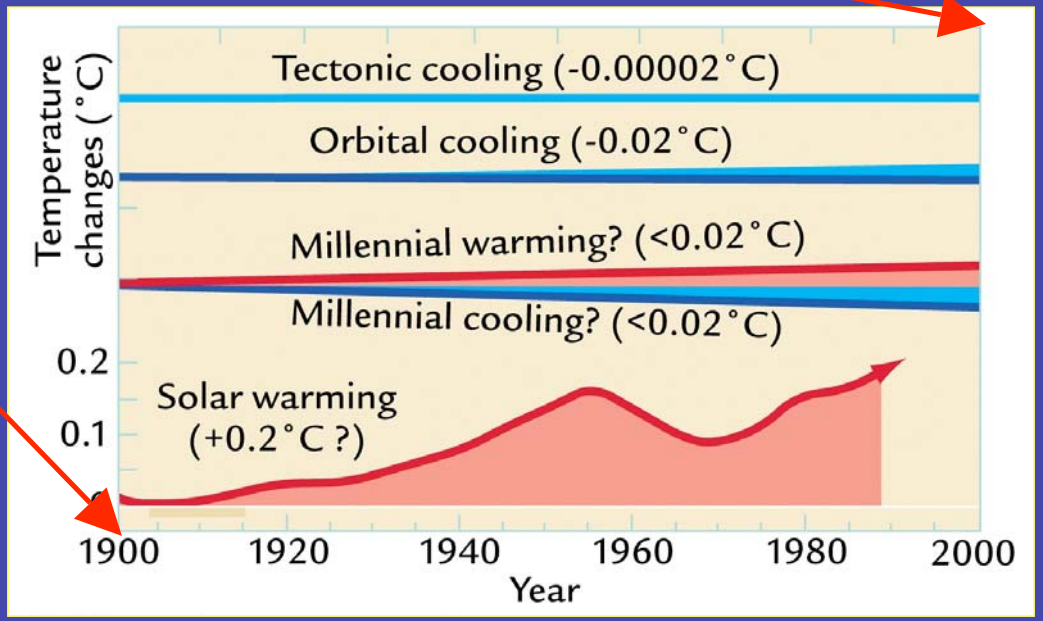


Observed Temperature

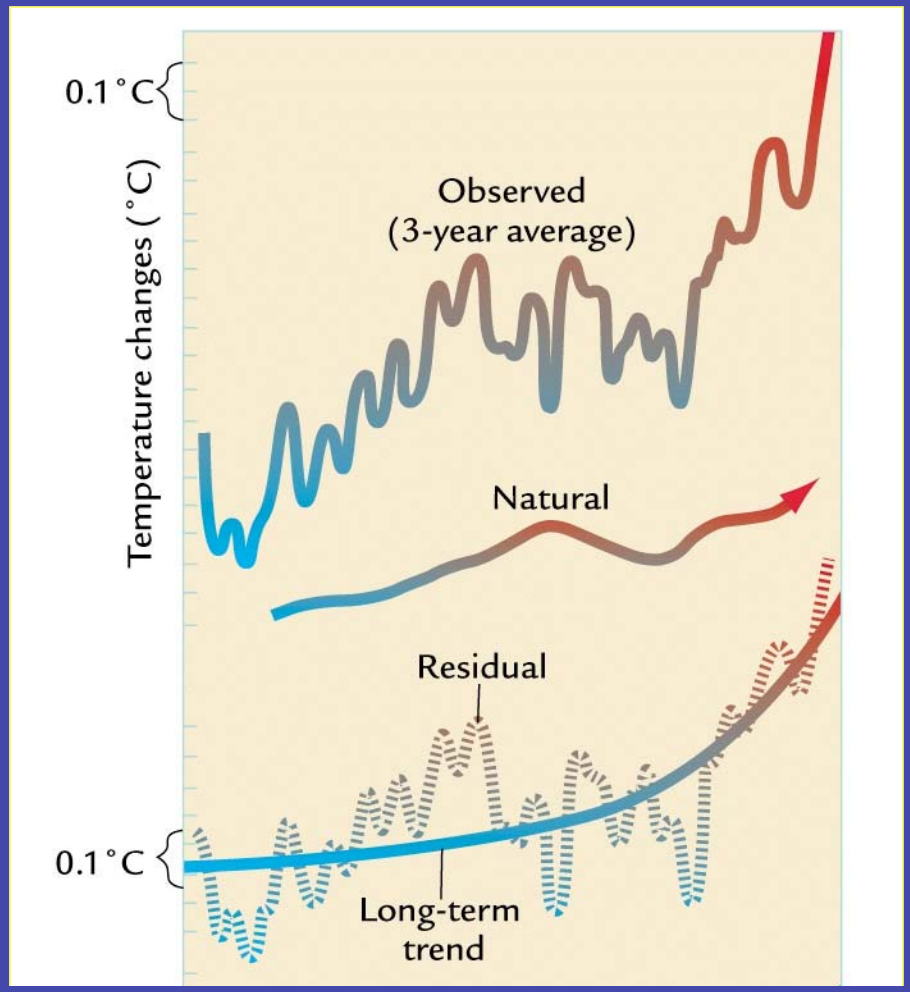
...minus...

Natural Warming

tectonic
orbital
millenial
solar



GREENHOUSE MATH PROBLEM



Observed Temperature

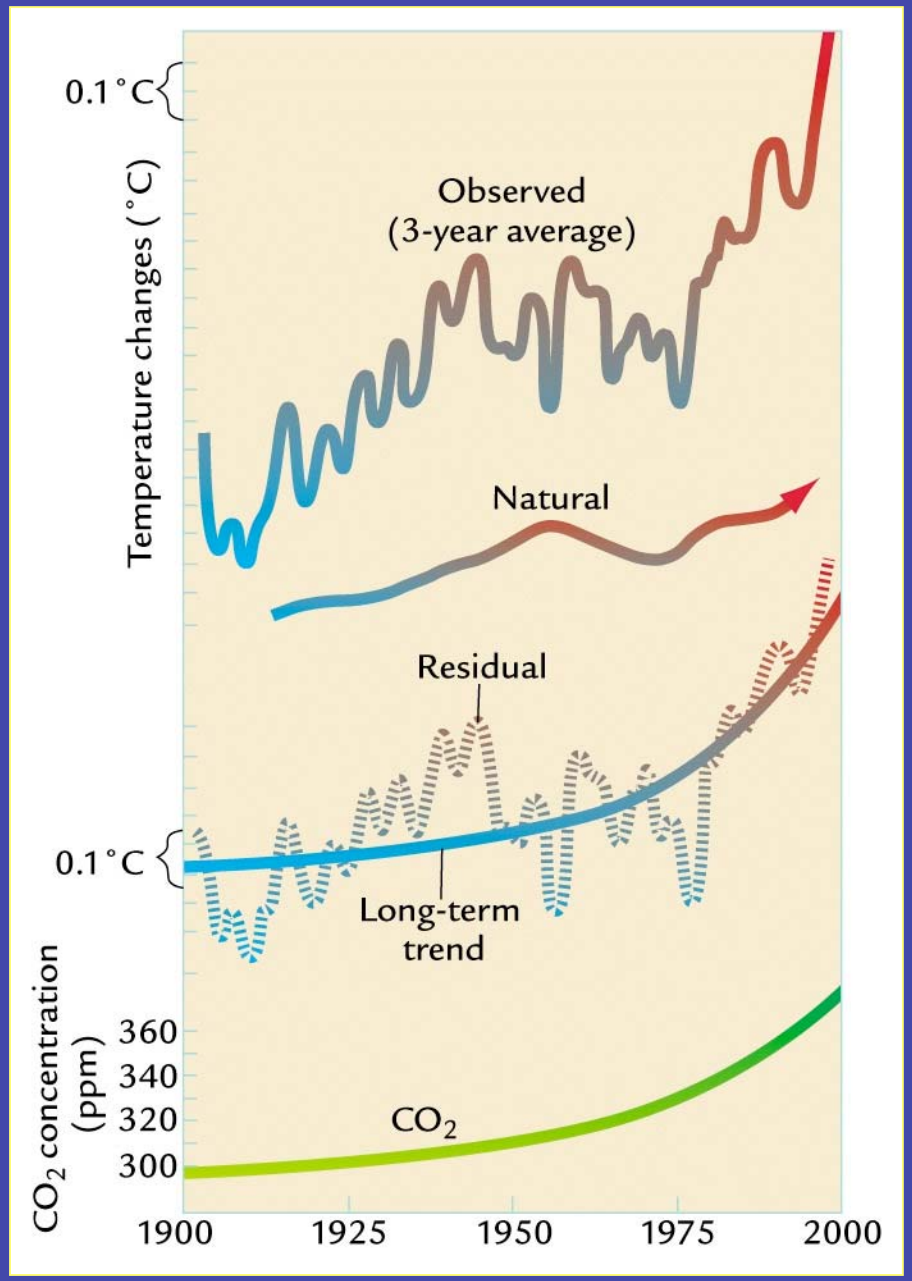
...minus...

Natural Warming

...equals...

Residual (Human Effects)

GREENHOUSE MATH PROBLEM



Observed Temperature

...minus...

Natural Warming

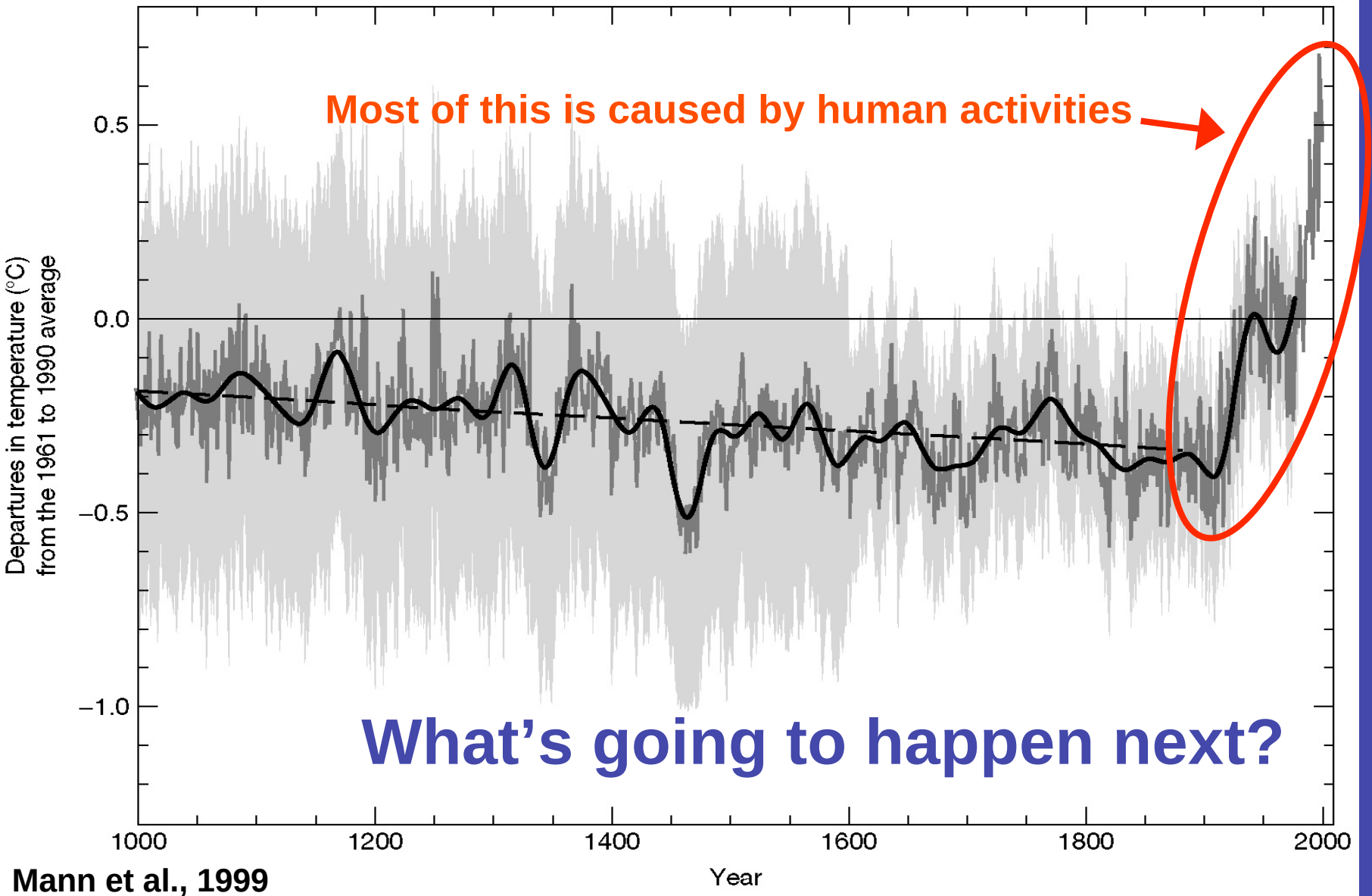
...equals...

Residual (Human Effects)

...looks a lot like...

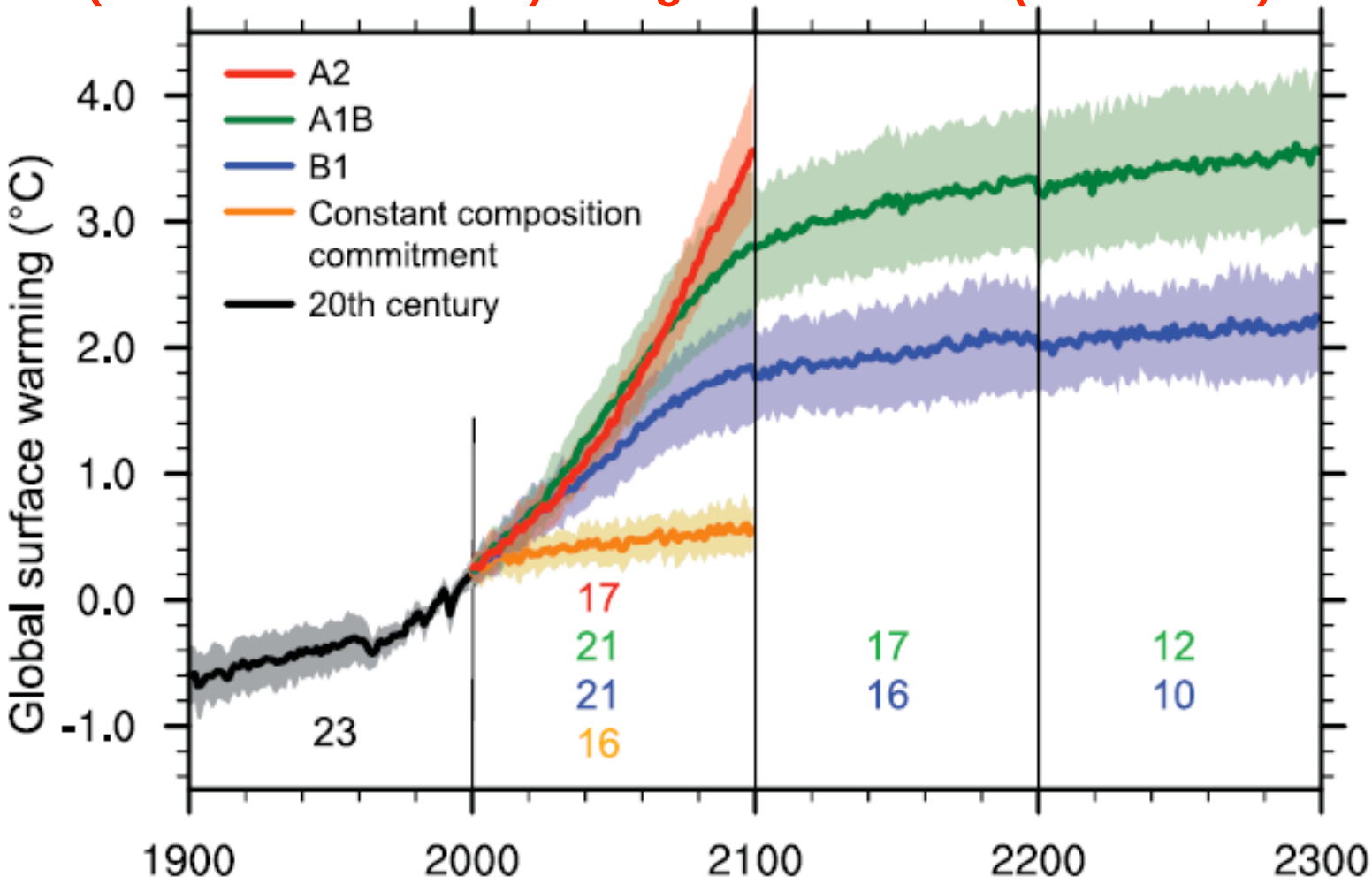
Carbon Dioxide Increase

Northern Hemisphere temperature record



Mann et al., 1999

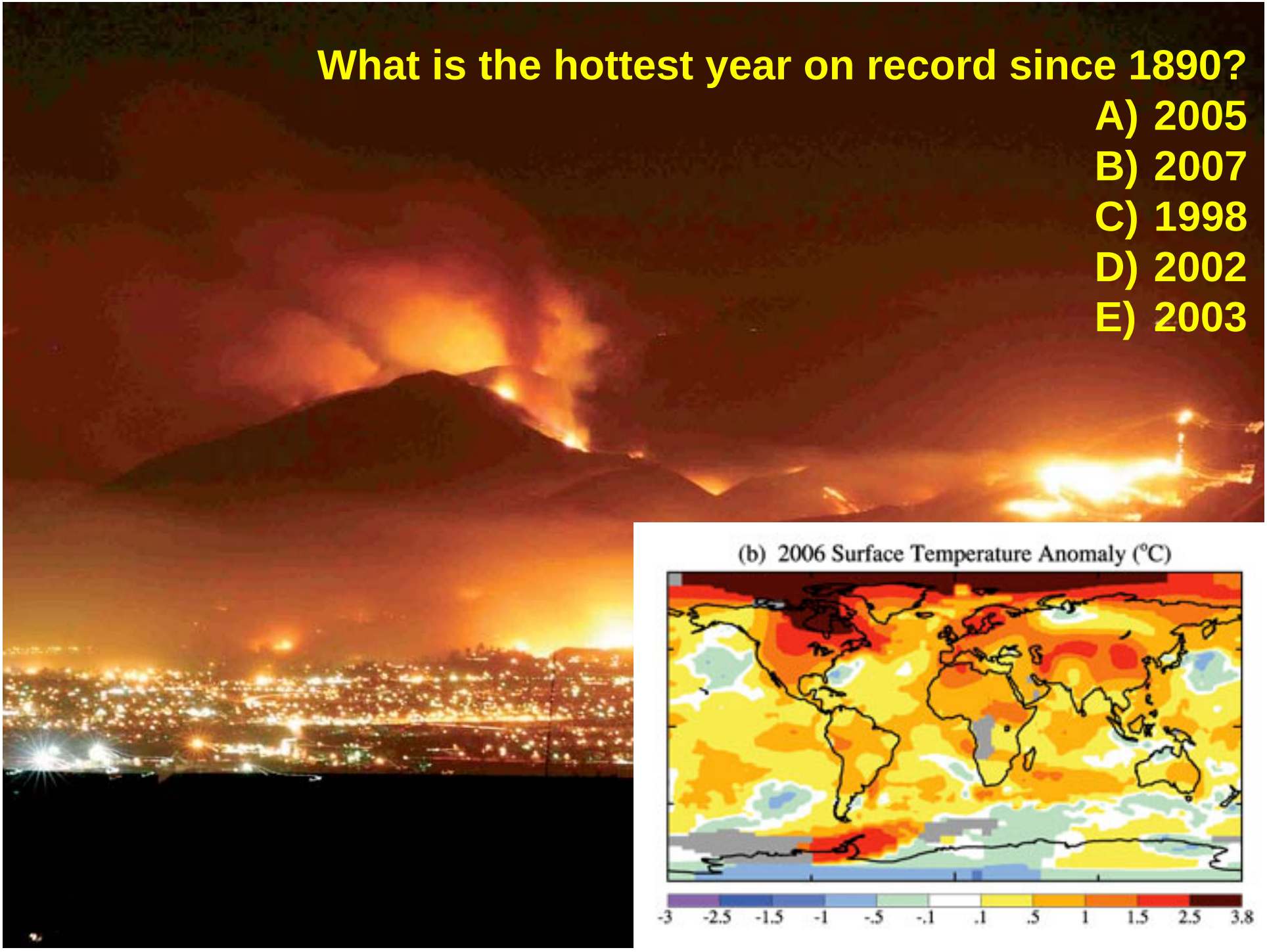
How much is temperature projected to change in our lifetimes (between 2000-2060) using A1B scenario (IPCC 2007)?



A) 0.0°C, B) 0.5°C, C) 1.5°C, D) 2.0°C, E) 3.0°C

What is the hottest year on record since 1890?

A) 2005
B) 2007
C) 1998
D) 2002
E) 2003



What are the impacts of human-induced temperature rise?

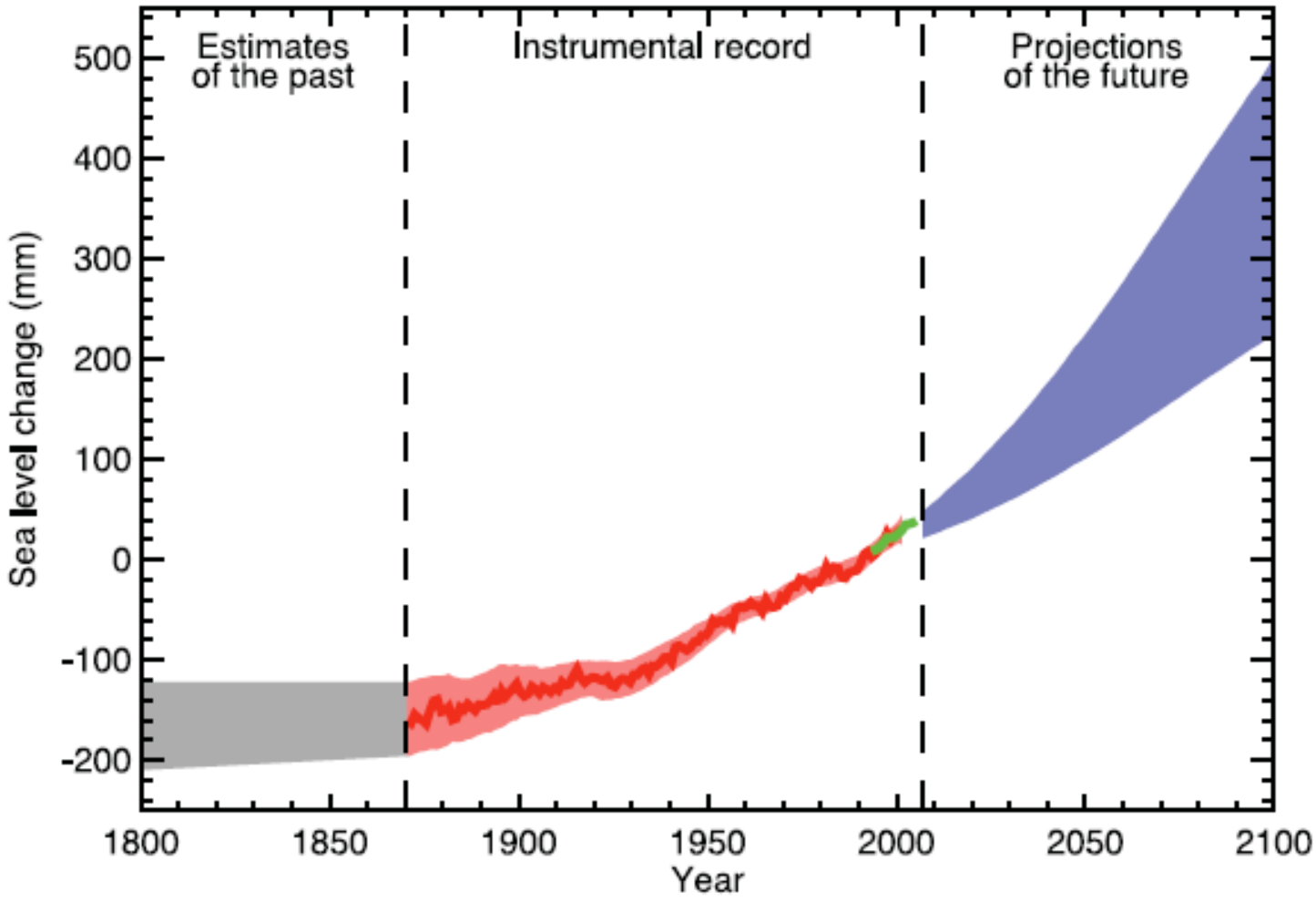








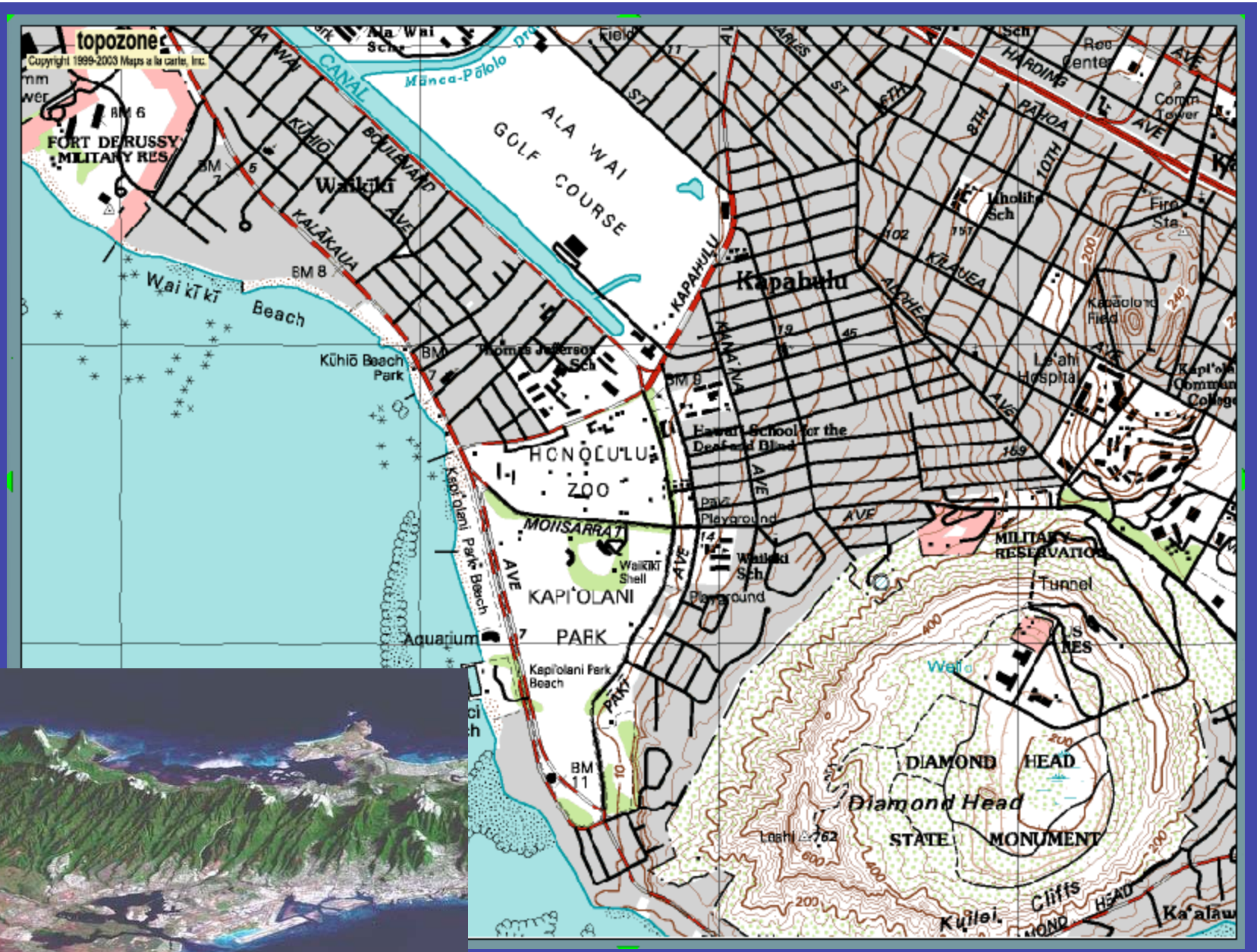
How is sea level projected to change in our lifetimes?



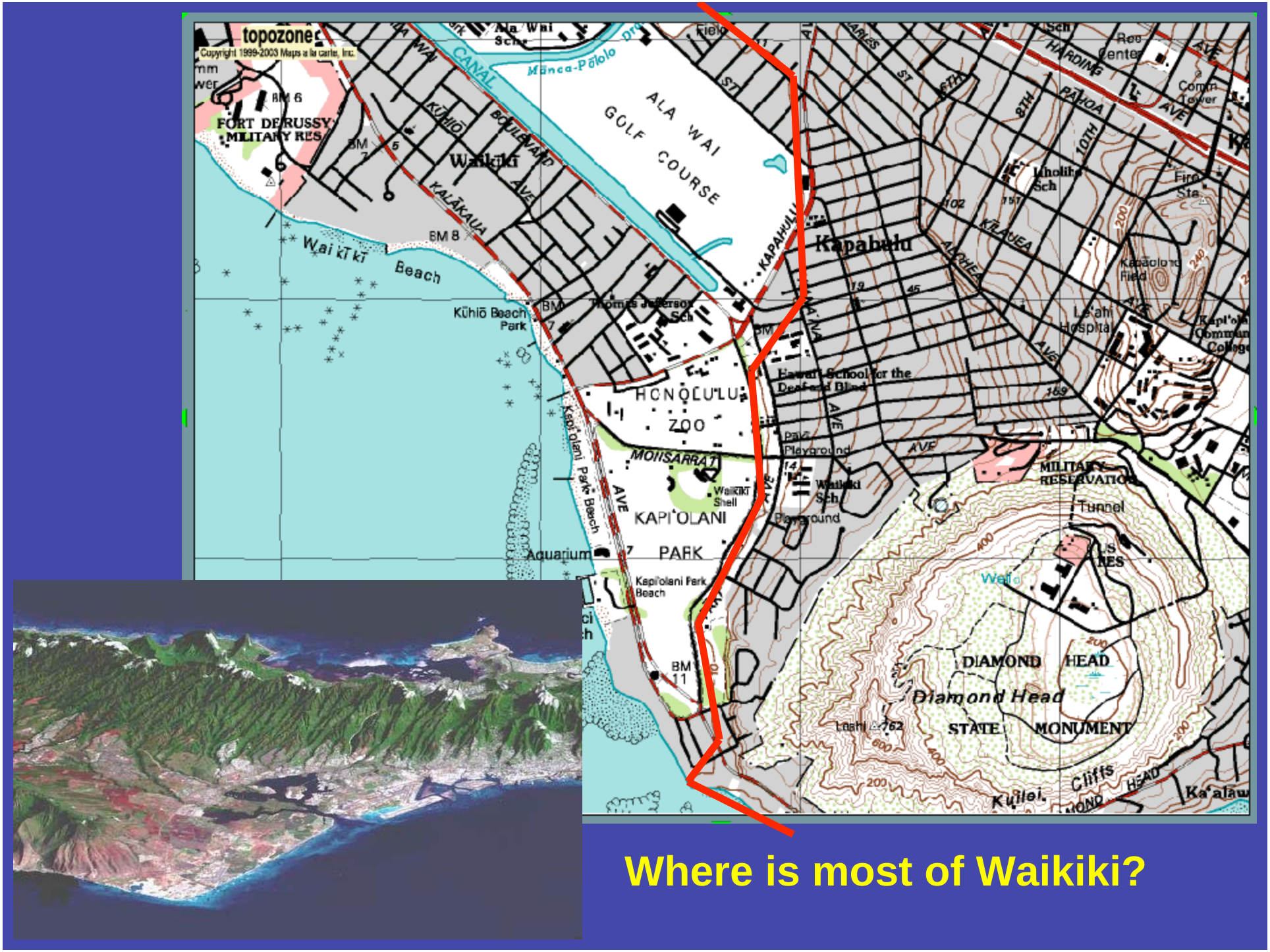
IPCC projection includes only thermal expansion of seawater

What's missing?



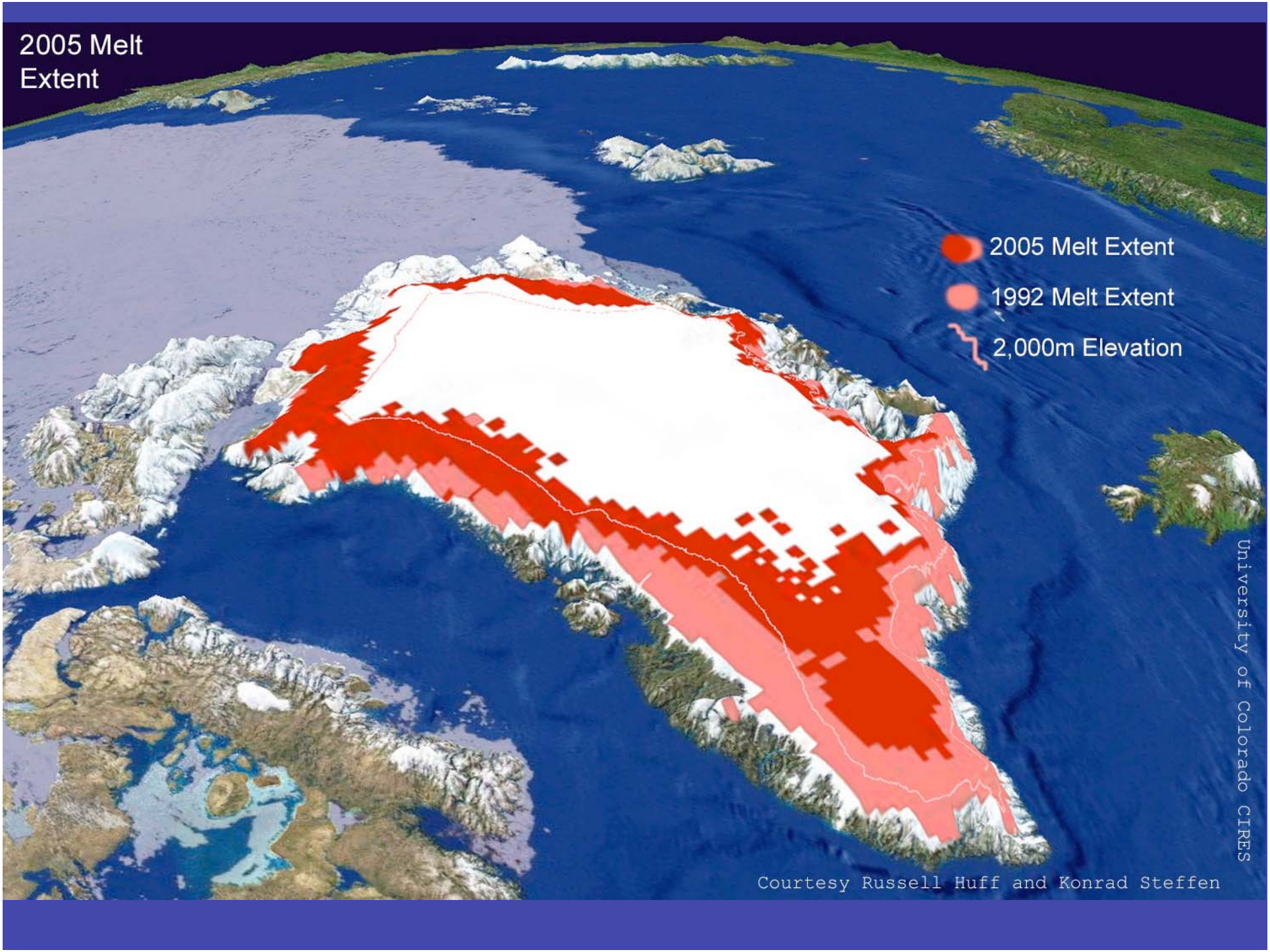


Where is 1m of sea level rise?

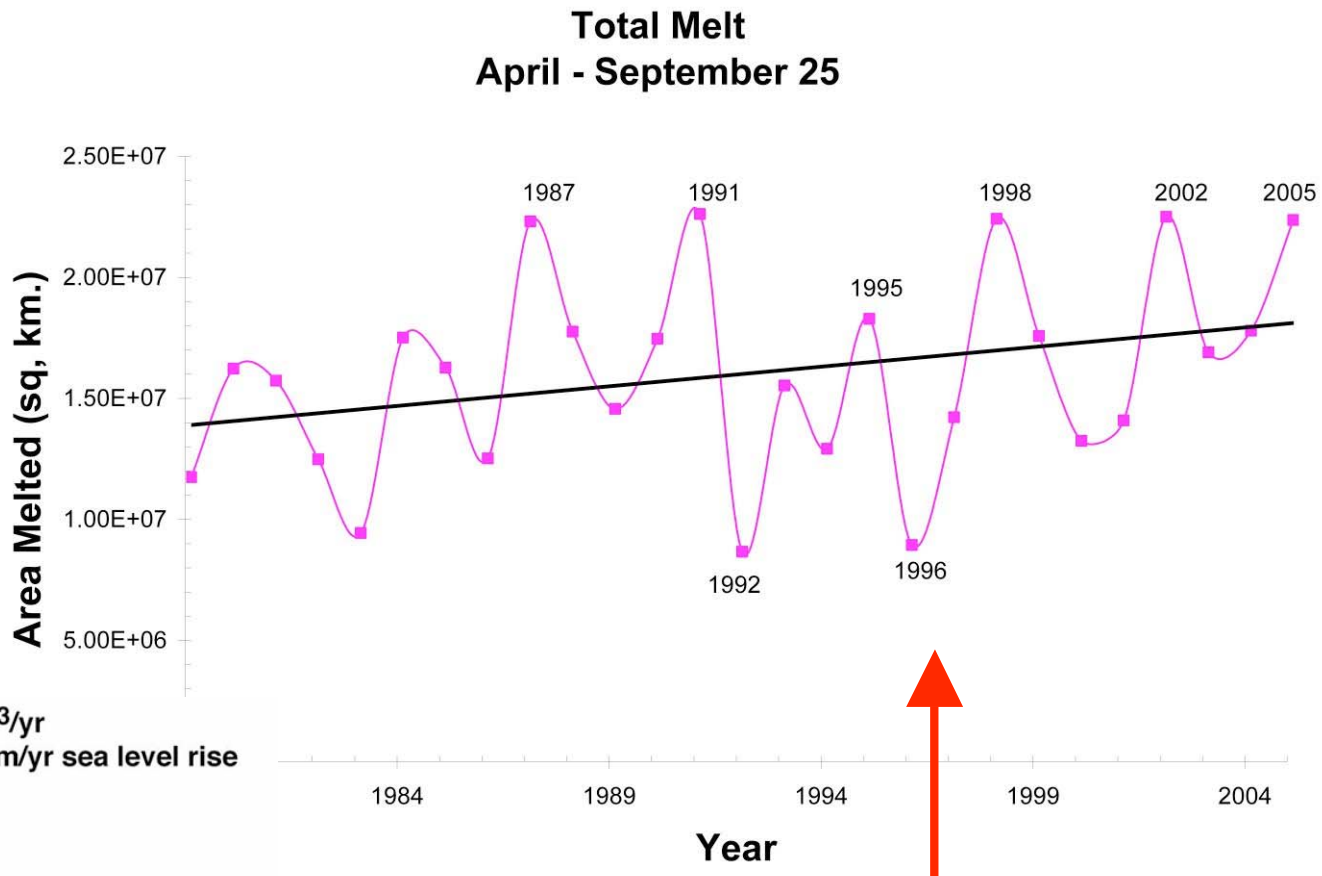

topozone
Copyright 1999-2003 Maps a la carte, Inc.
FORT DERUSSY MILITARY RES
Waikīkī
Wai kī kī Beach
Kūhiō Beach Park
ALA WAI GOLF COURSE
Mānoa-Pālolo Drainage Canal
Kapahulu
HONOLULU ZOO
KAPI'OLANI PARK
Kapi'olani Park Beach
Aquarium
MILITARY RESERVATION
Tunnel
DIAMOND HEAD
Diamond Head
STATE MONUMENT
Kuilei Cliffs
Ka'alawa
Where is most of Waikiki?

Possible sea level rise in our lifetimes - where is your house?

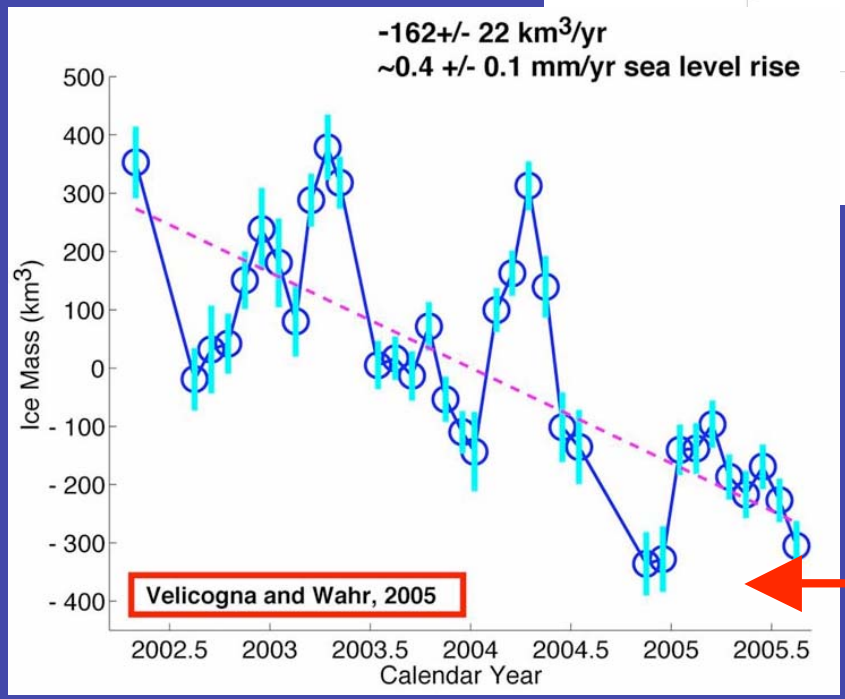



2005 Melt Extent
2005 Melt Extent
1992 Melt Extent
2,000m Elevation
Courtesy Russell Huff and Konrad Steffen
University of Colorado CIRES

Greenland ice is melting



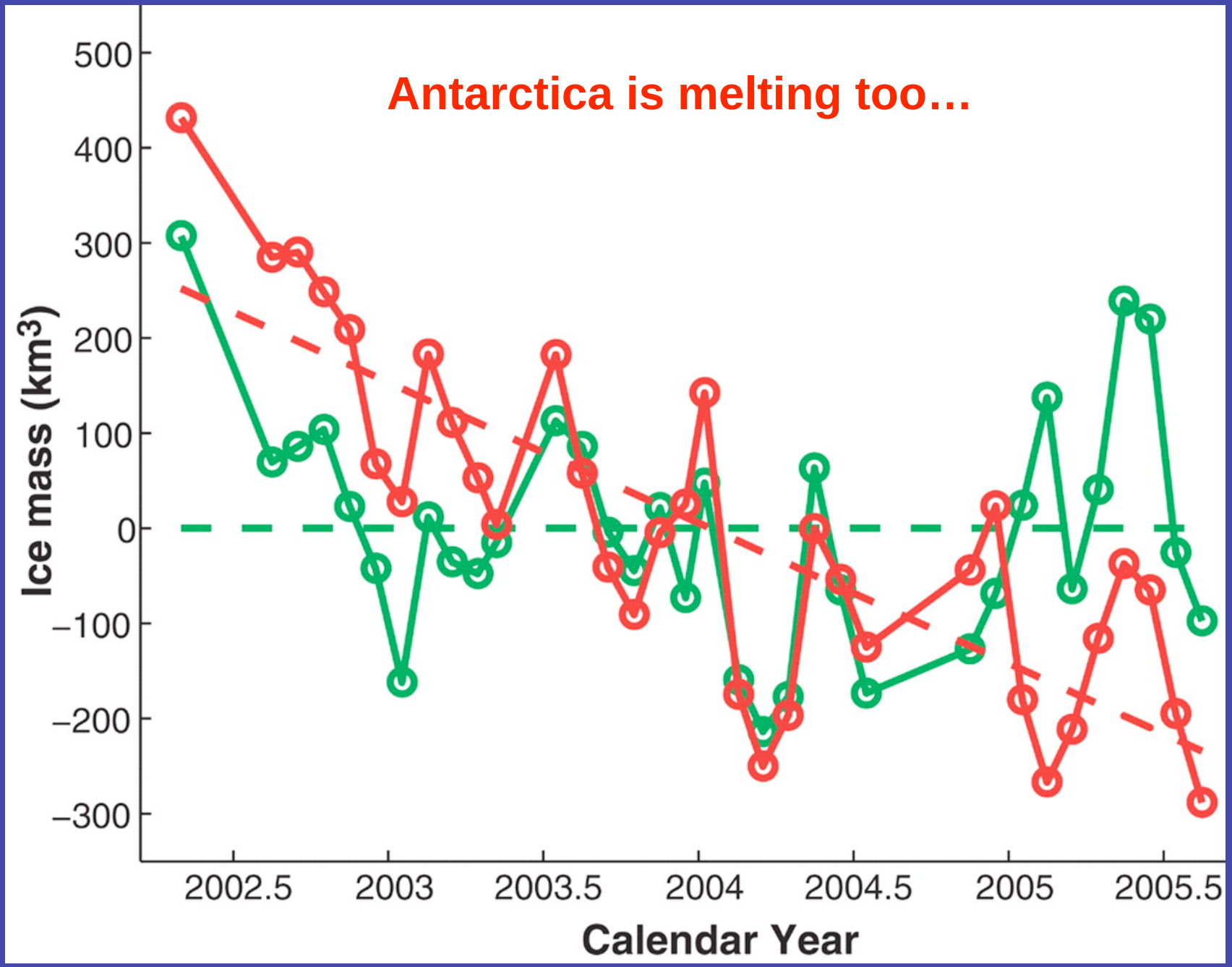
Total melt area



Ice volume

How about Antarctica?




Antarctica is melting too…
500
400
300
200
100
0
−100
−200
−300
Ice mass (km3)
2002.5
2003
2003.5
2004
2004.5
2005
2005.5
Calendar Year

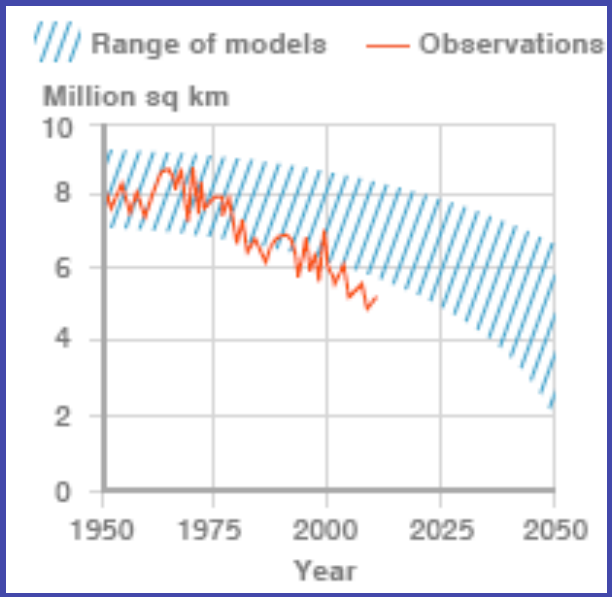
Greenland or West Antarctica - 21 feet (7 meters)



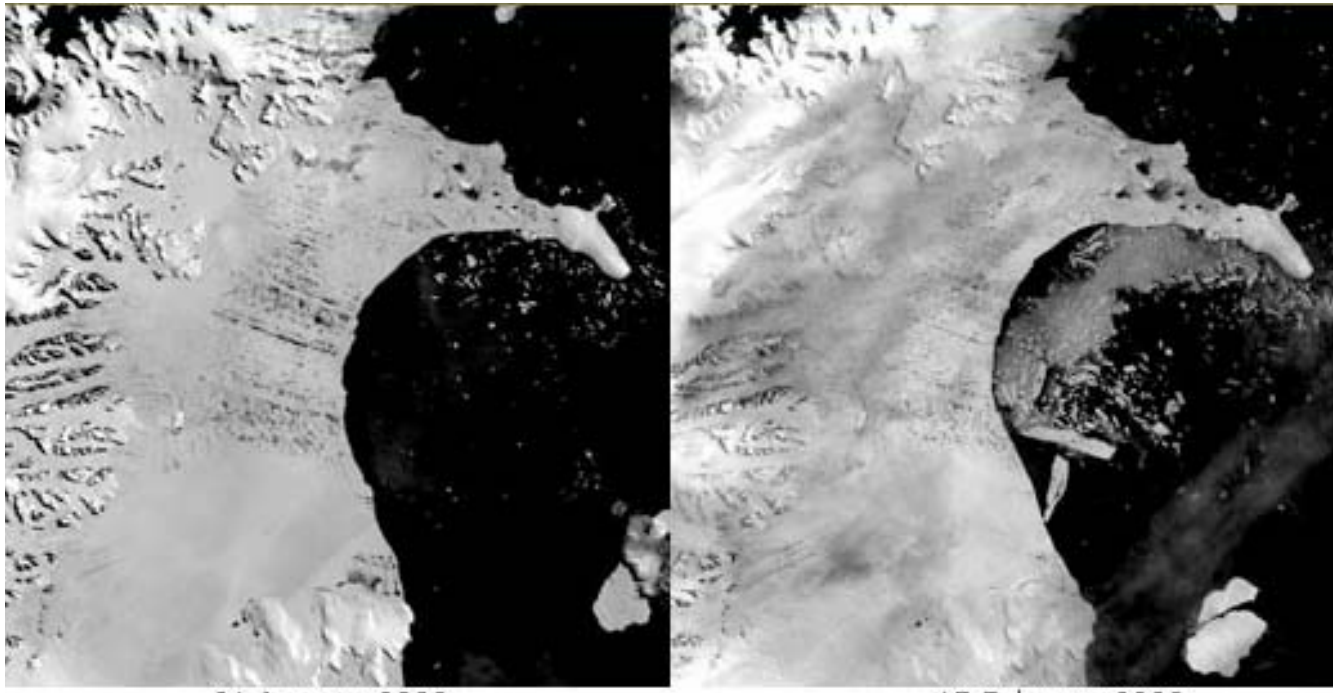


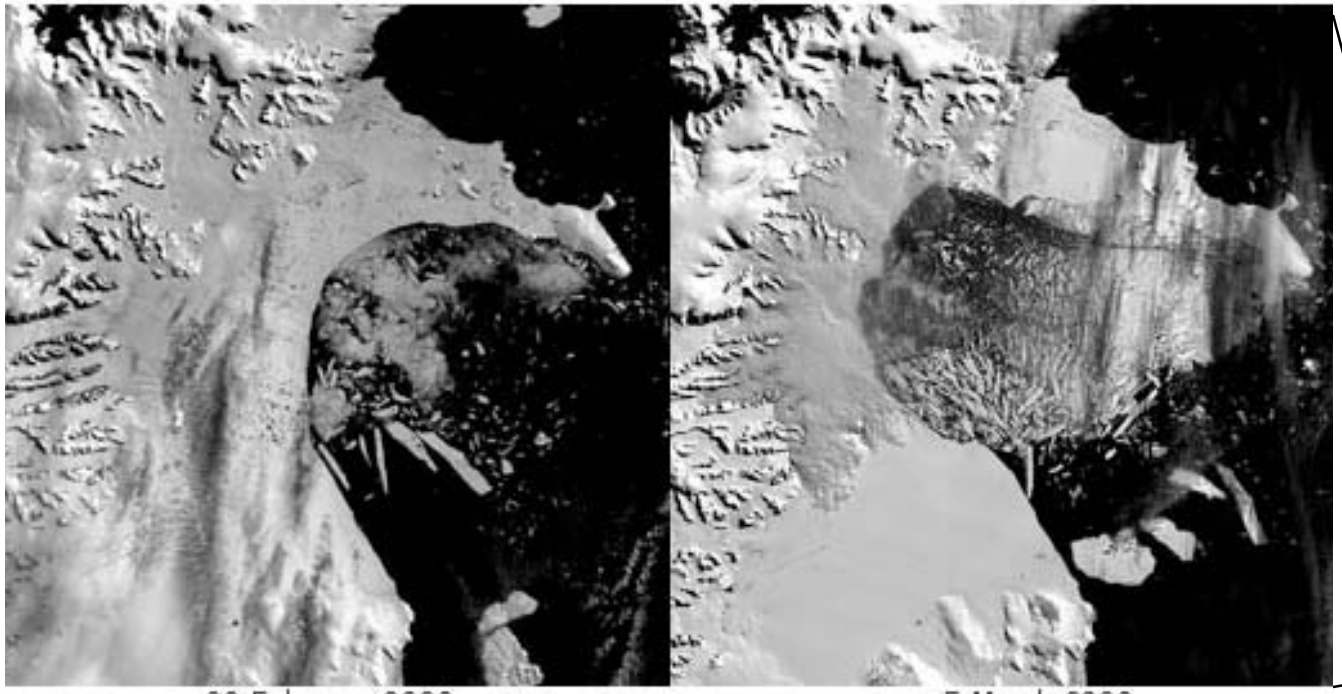
Don’t fall in this!

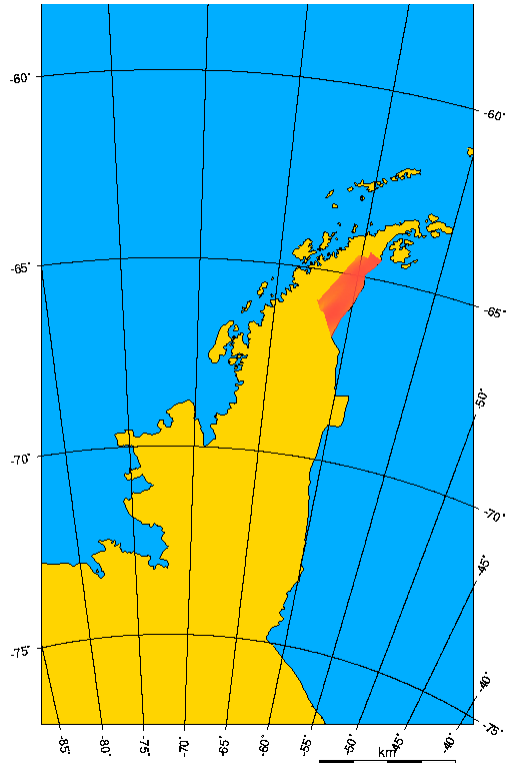
What does all this water do to ice flow speeds?



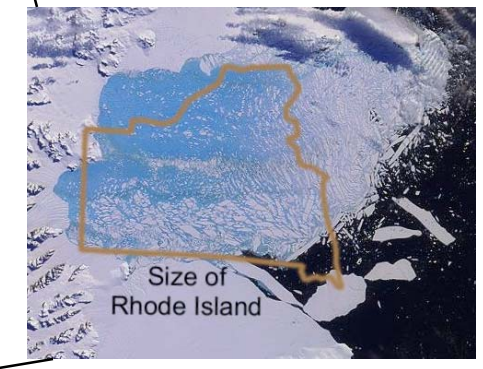
Larsen Ice Shelf







35-day collapse



Cyclone Kills Thousands in Myanmar

May 4, 2008





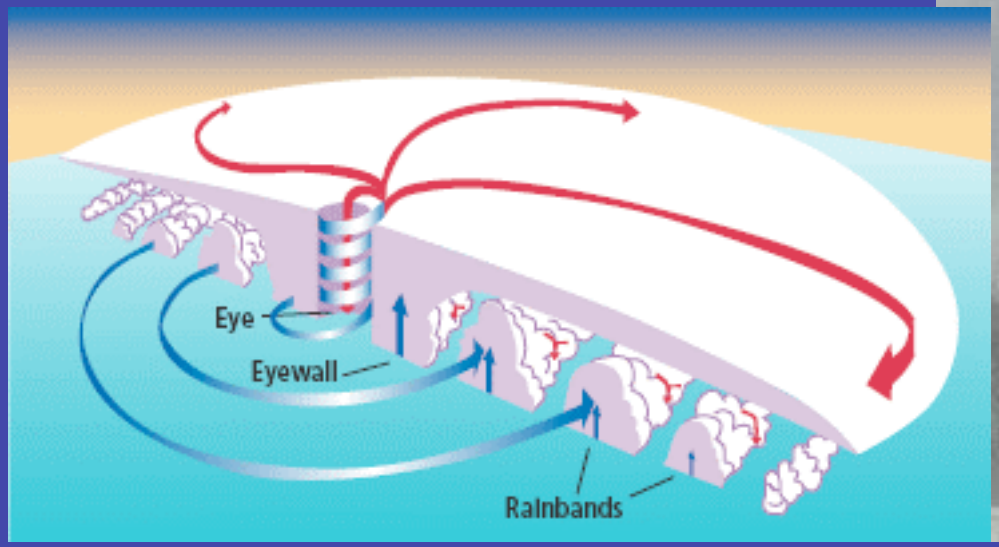
Hurricane
Cyclone
Typhoon

1) warm ocean temperatures

2) low vertical wind shear

(i.e., no strong change in wind speed or direction between two different altitudes)

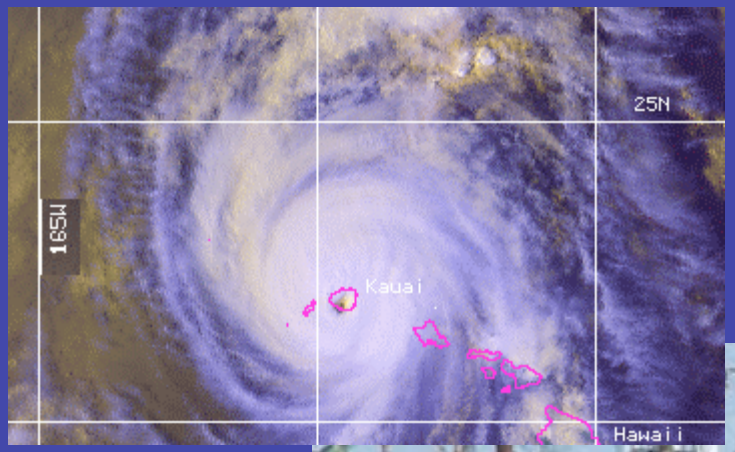
3) high humidity





Category Five Hurricane

- Winds greater than 155 mph (135 kt or 249 km/hr).
- Storm surge generally greater than 18 ft above normal.
- Complete roof failure on many residences and industrial buildings.
- Some complete building failures with small utility buildings blown over or away.
- All shrubs, trees, and signs blown down.
- Severe and extensive window and door damage.
- Low-lying escape routes are cut by rising water 3-5 hours before arrival of the center of the hurricane.
- Major damage to lower floors of all structures located less than 15 ft above sea level and within 500 yards of the shoreline.
- Massive evacuation of residential areas on low ground within 5-10 miles (8-16 km) of the shoreline may be required.



How many Inikis (C4) can our islands handle?

Sept. 11 1992

$2.6 billion



Category 4-5 projected storm surge heights 6m



Lanikai





Bellows

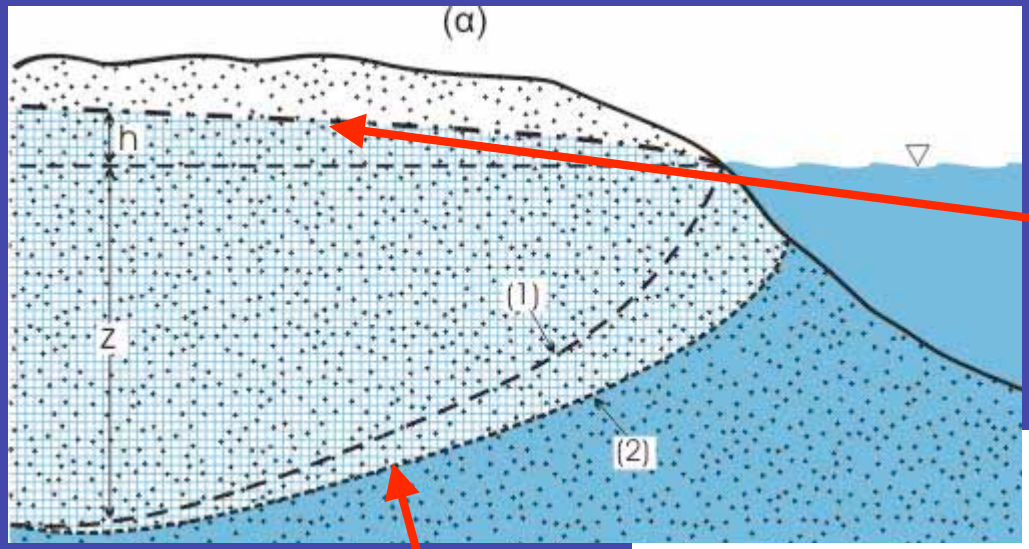
Coral bleaching





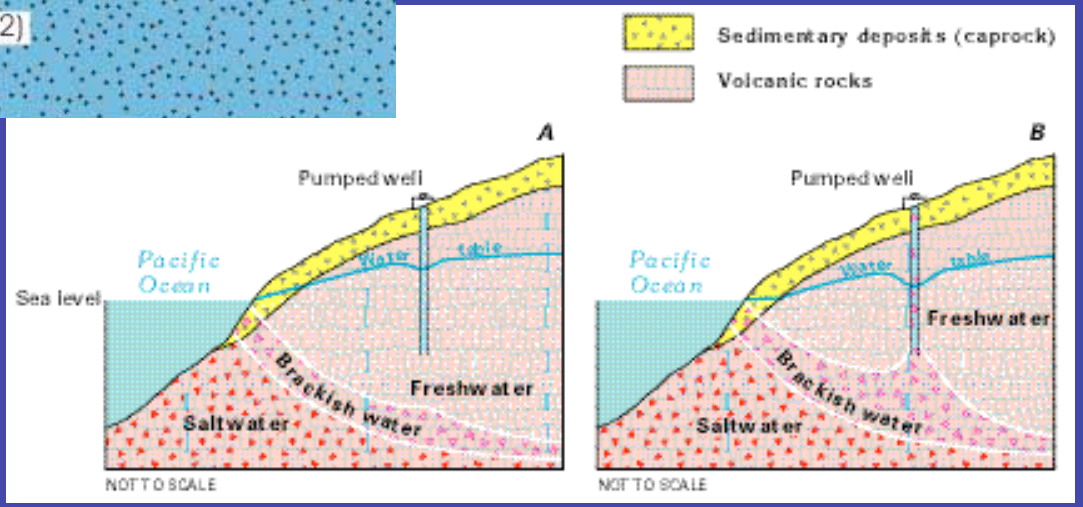


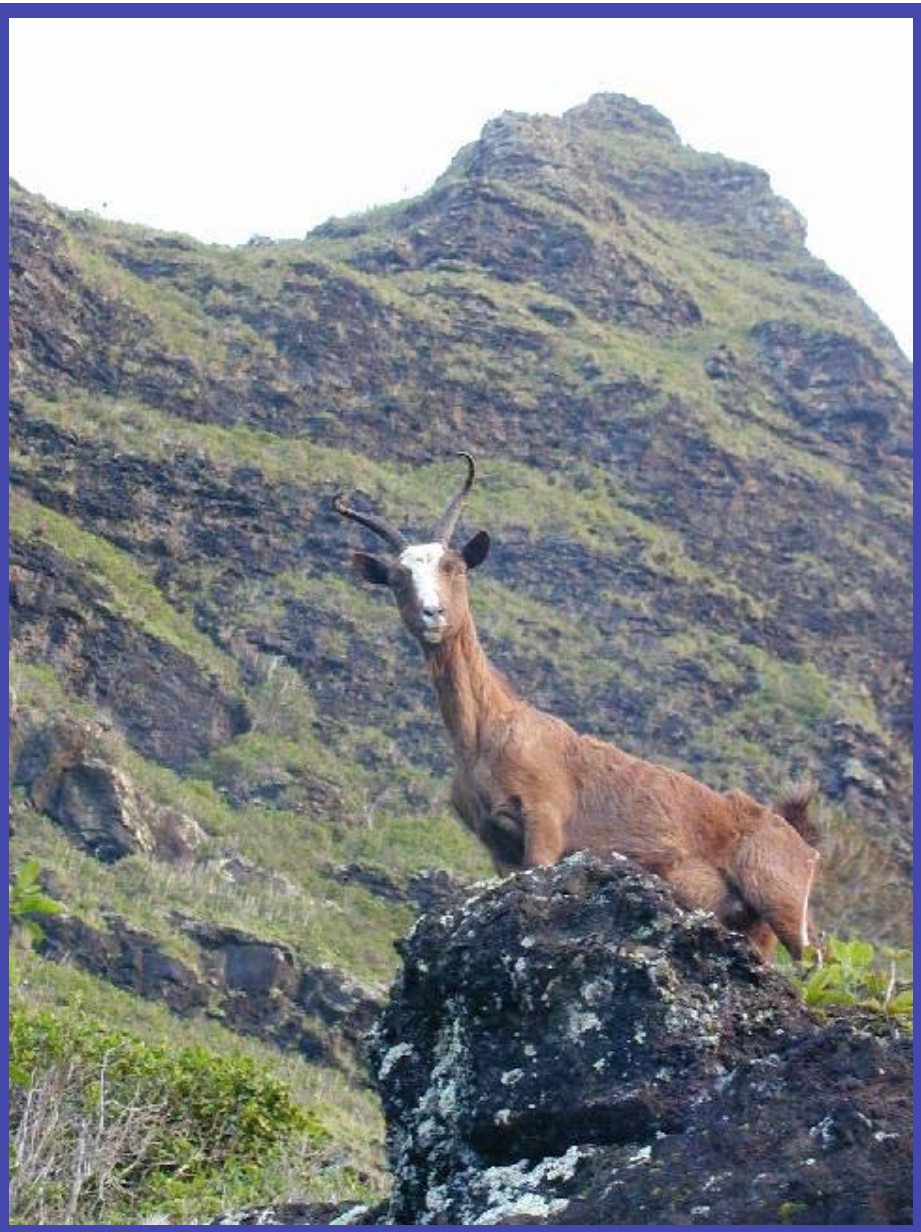
What happens when you decrease rainfall and increase sea level?



Depth to water table increasing

Depth to salt water decreasing





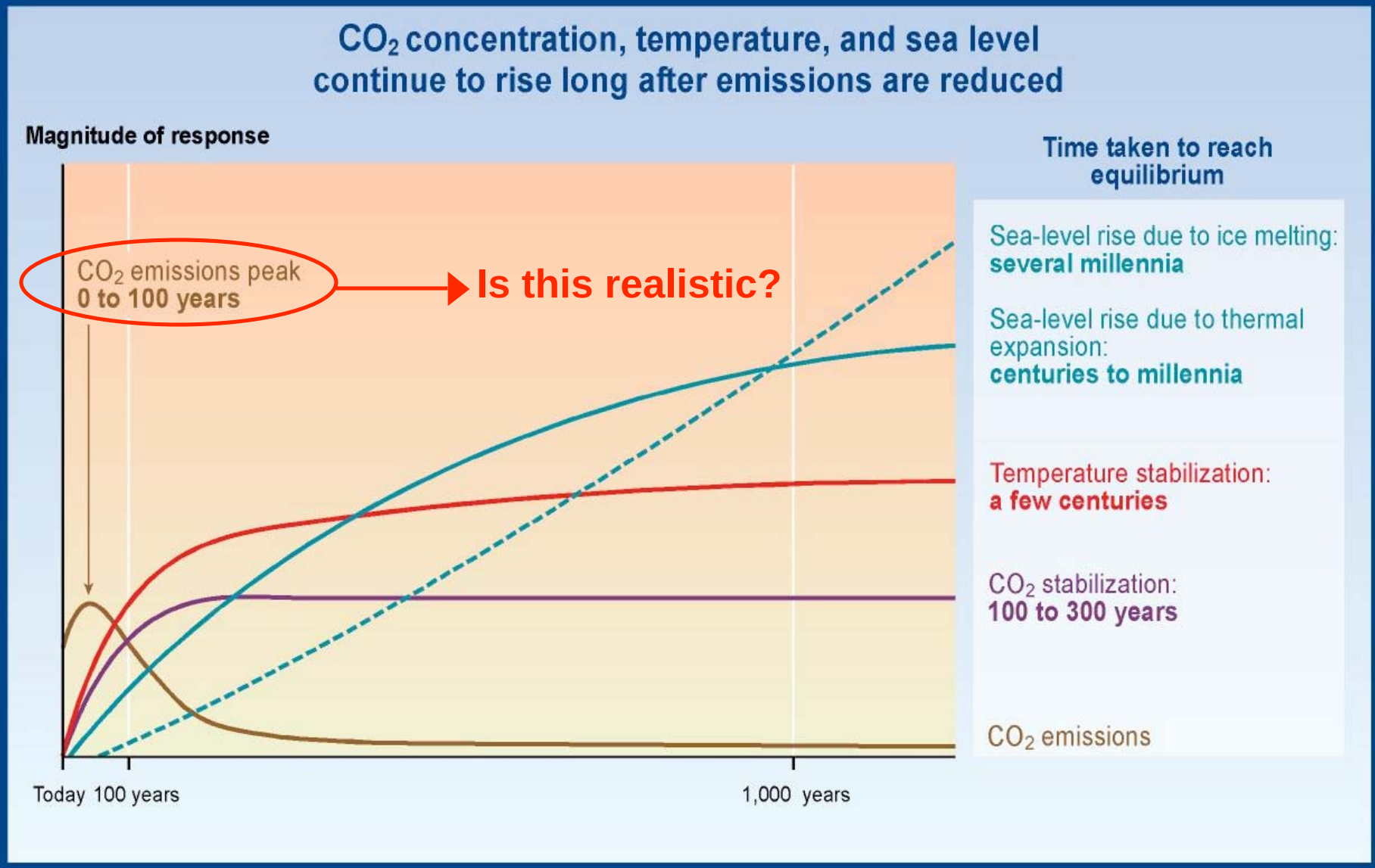
Invasive species encroachment







Lag time of climate components



IPCC, 2001

Human/Climate Analogy

What happens when you put a frog in a pot of boiling water?

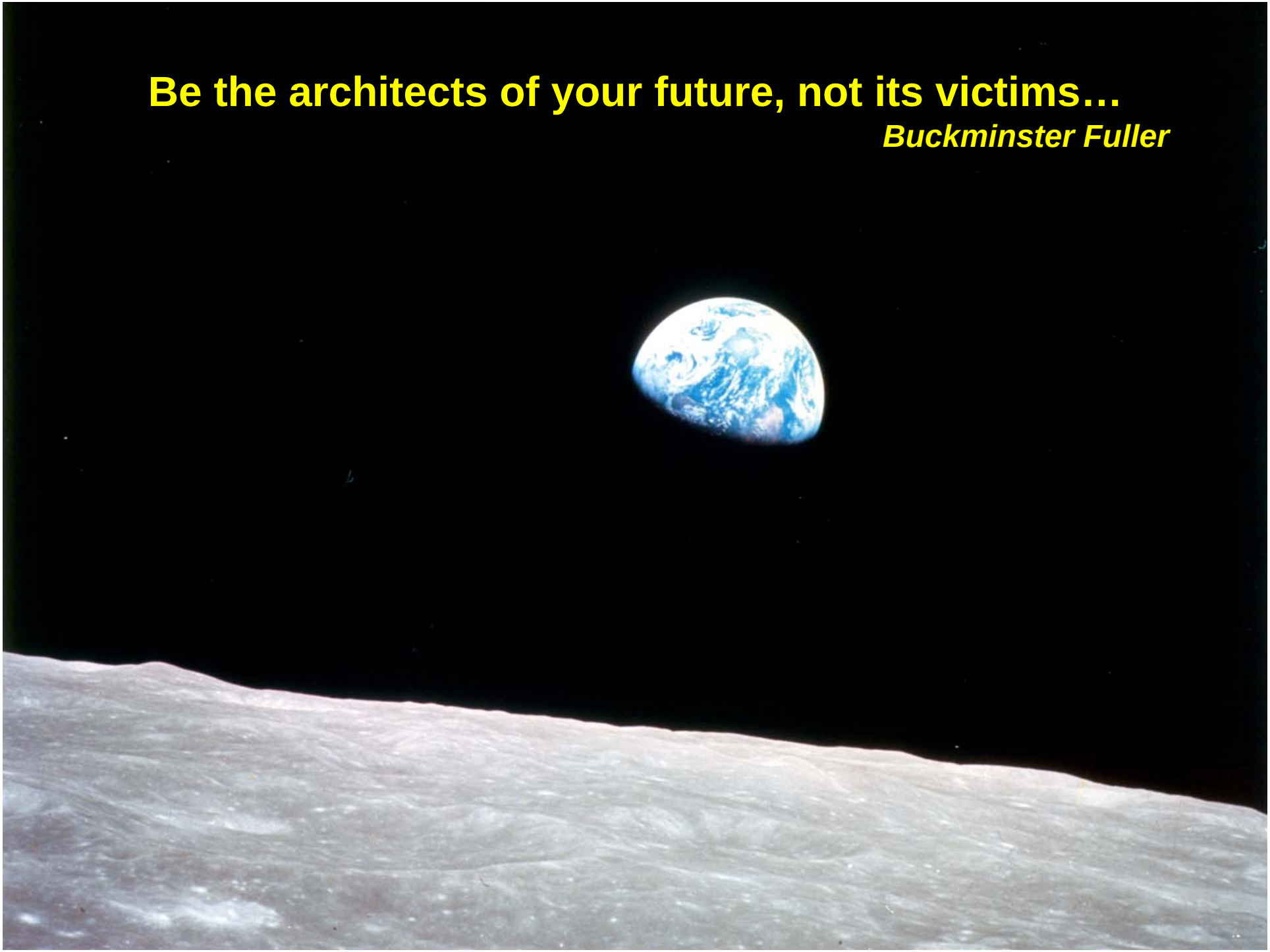




What happens when you put a frog in cold water then bring it to a boil?

What percentage are we of the geologic record?




Be the architects of your future, not its victims…
Buckminster Fuller