Climate Science and Global Climate Change

- Course introduction
- History of climate science
- Planetary climates
- Earth’s paleoclimatology

Spring 2018
University of Arizona OLLI
Lockwood Carlson PhD

Raymond Pierrehumbert on climate change problem 0:57

Session Date All sessions are on Thursdays at 9 am in the Ocotillo classroom	Session Title	Topics
Session 1 **March 8**	• Introduction and initial survey • History of climate science and climate change • Paleoclimates	• Basics of planetary atmospheres, land and oceans, and climate dynamics • Historical perspective on climate science • Intro. to IPCC • Paleoclimatology techniques and brief summary
Session 2 **March 15**	• Earth's Atmosphere • Atmospheric processes • Measurements of climate • The carbon cycle	• Visible and infrared radiation, Plank's law, blackbody radiation in the atmosphere • Composition and dynamics of earth's atmosphere • Solar and IR radiation • Greenhouse processes and 'forcings'
Session 3 **March 22**	• Earth's Land masses • Oceans • Ice shelves	• Measurements of temperature across the globe • Temperature proxies for past temperature estimates • Signals for future climate
Session 4 **March 29**	• The global climate past and present: putting it all together • Climate statistics, trends, and future projections • climate computer modeling	• Global picture of interacting climate system • Applying the science: modeling and future estimates • Defining the scenarios and estimates of consequences on climate • Non-linear processes, tipping points: climate as a complex adaptive system • Possible catastrophic climate dynamics
Session 5 **April 5**	• Consequences of CO2 increases in the atmosphere • Future climate estimates: multiple scenarios • Policy options for mitigation and adaptation • Reasons for active optimism	• Estimating future climate • Policy drivers: science or prophecy? • Economic issues: remediation and/or reduction in fossil fuels • Impacts on human civilization: cities, food supply, public health, extreme weather events, etc. • IPCC process and latest summary • Paris COP 21 and the Agreement: critique and actions to date • Positive trends and opportunities

References and further reading:

Jeffrey Bennett, *A Global Warming Primer,* Big Kid Science, Boulder CO (2016) This is essentially a text for our class. Simple, clear, accurate, and credible. READ THIS BOOK. There is a free version on-line: www.globalwarmingprimer.com. A great 'gift' for friends and colleagues who have some curiosity about climate science and global warming.

Andrew Dessler, *Introduction to Modern Climate Change,* Cambridge Univ. Press (2016) A next step deeper and more comprehensive than Bennett's primer. Lot's of scientific detail and explanations. Level is advanced undergraduate non-science majors. Well written and fascinating to get more understanding of the scientific foundations.

Climate Science Special Report 2017. Latest and most complete US Government summary of climate science. Reliable and comprehensive. Dive into this to learn more about any topic: https://science2017.globalchange.gov/chapter/executive-summary/

IPCC 2013 report on climate change, https://www.ipcc.ch/report/ar5/ This is the IPCC reference for climate science, global warming, global and regional consequences, adaptation and mediation, but somewhat dated compared to the CSSR above. Extensive coverage of all issues and references to the peer reviewed literature. Summaries are accessible and very informative. Note: file size 375 MB but try the executive summary.

William deBuys, *A Great Aridness; Climate change and the future of the American Southwest*, Oxford University Press 2011. Interesting and enlightening narrative on the history, issues, learnings, and key people involved in climate understanding in our part of the country.

Raymond Pierrehumbert, *Principles of Planetary Climate,* Cambridge University Press 2010. This is a graduate level text on the fundamentals of climate physics and chemistry. An excellent resource; should be accessible for those with advanced science and math background.

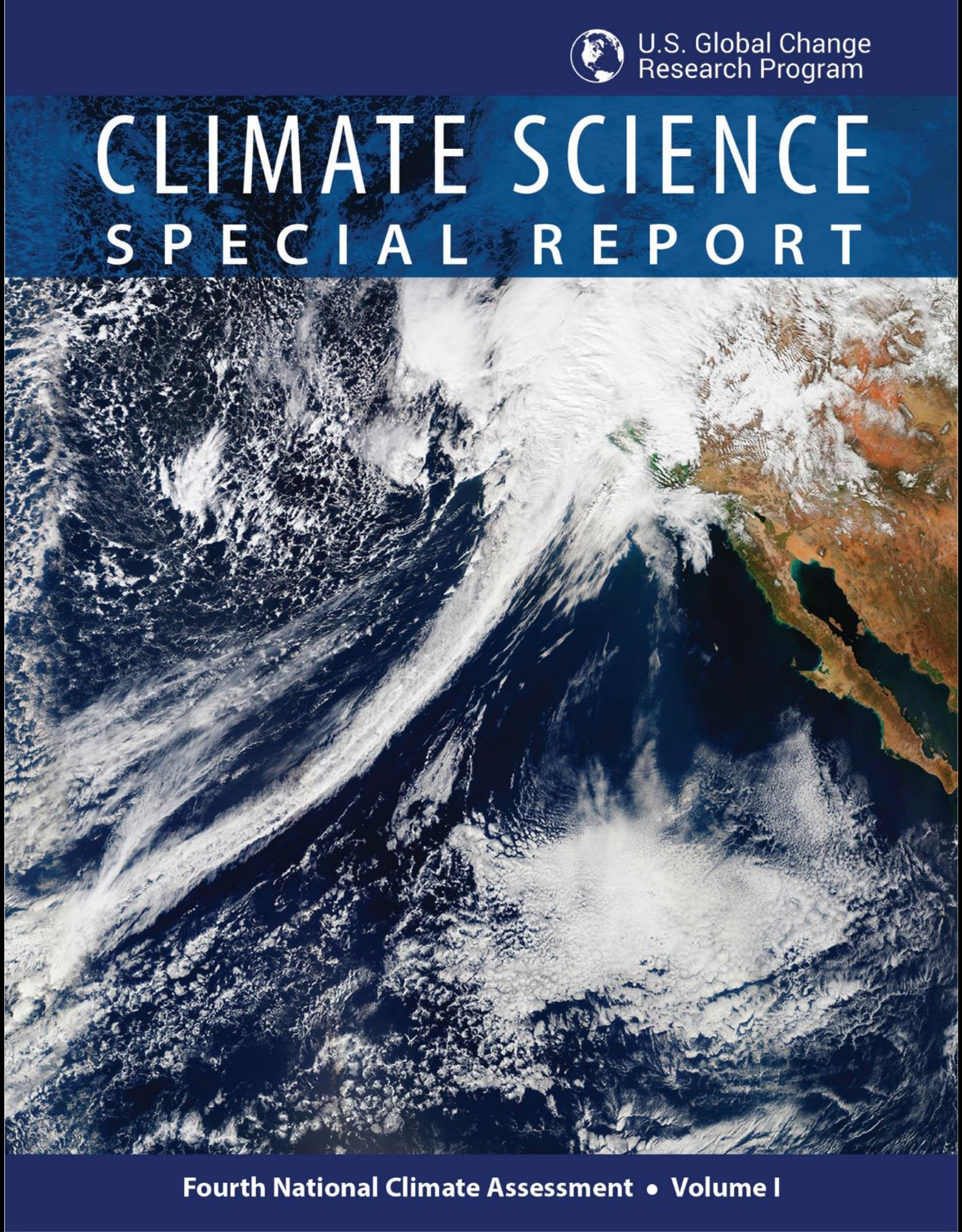
Interactive history of global warming science (fascinating): history of the science of global warming AIP

Penn State short course on climate science (excellent and accessible): course https://www.e-education.psu.edu/earth103/node/642

Yale course on climate science video (youtube) (Excellent ****): Ron Smith- Yale climate course

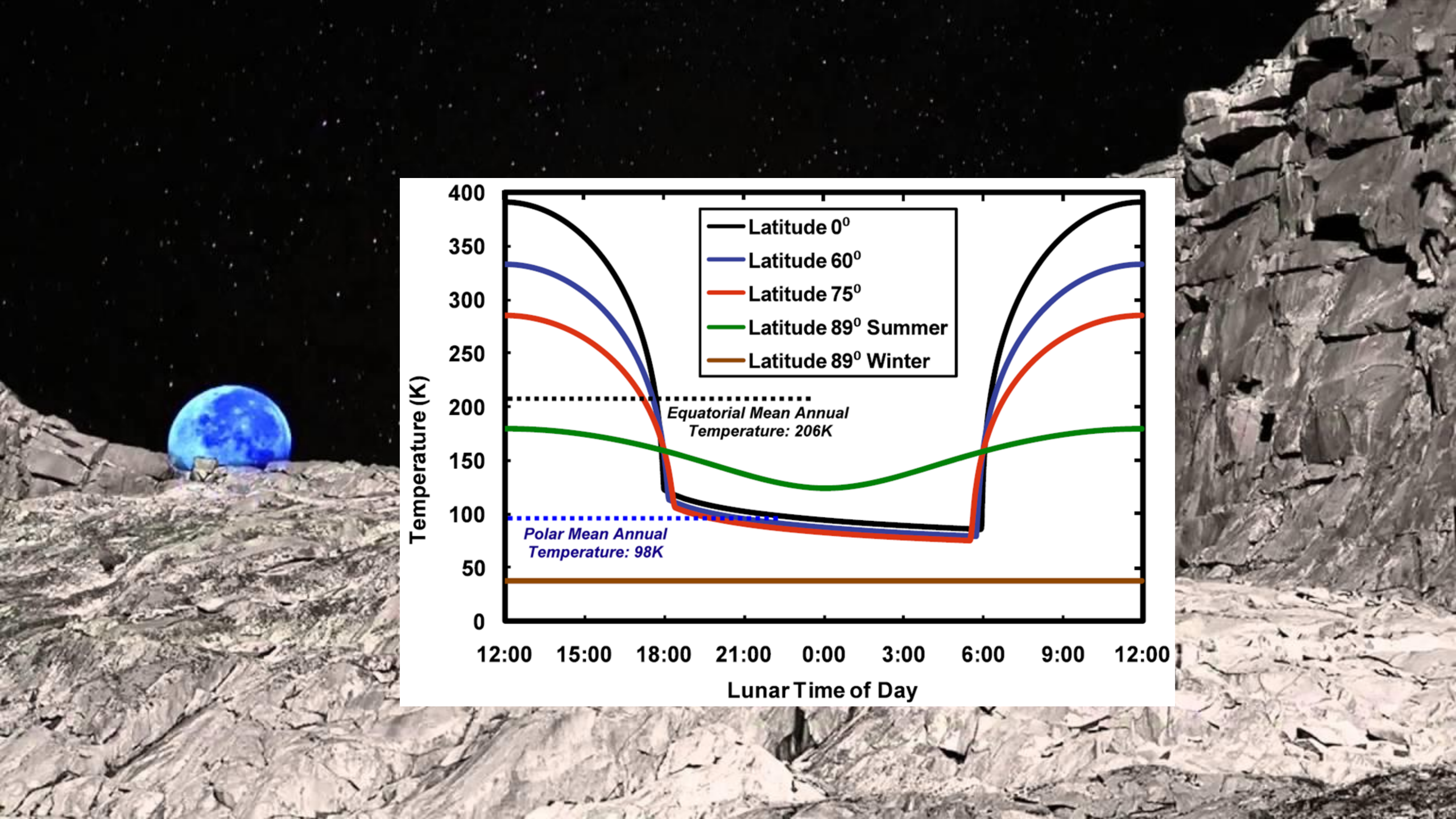
Very good **website for climate science** and issues: realclimate website- good science

2017

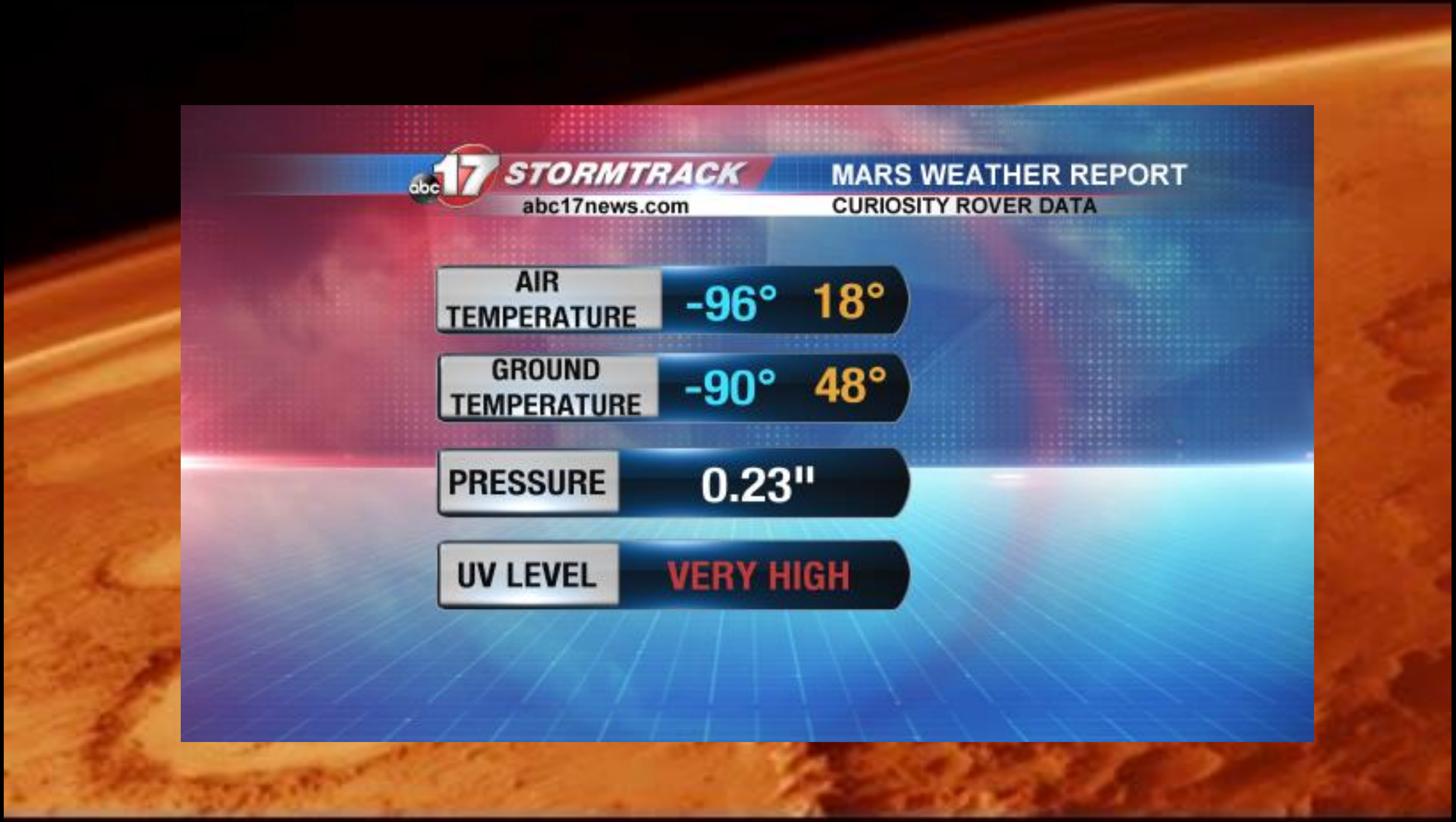

U.S. Global Change
Research Program
CLIMATE SCIENCE
SPECIAL REPORT
Fourth National Climate Assessment • Volume I

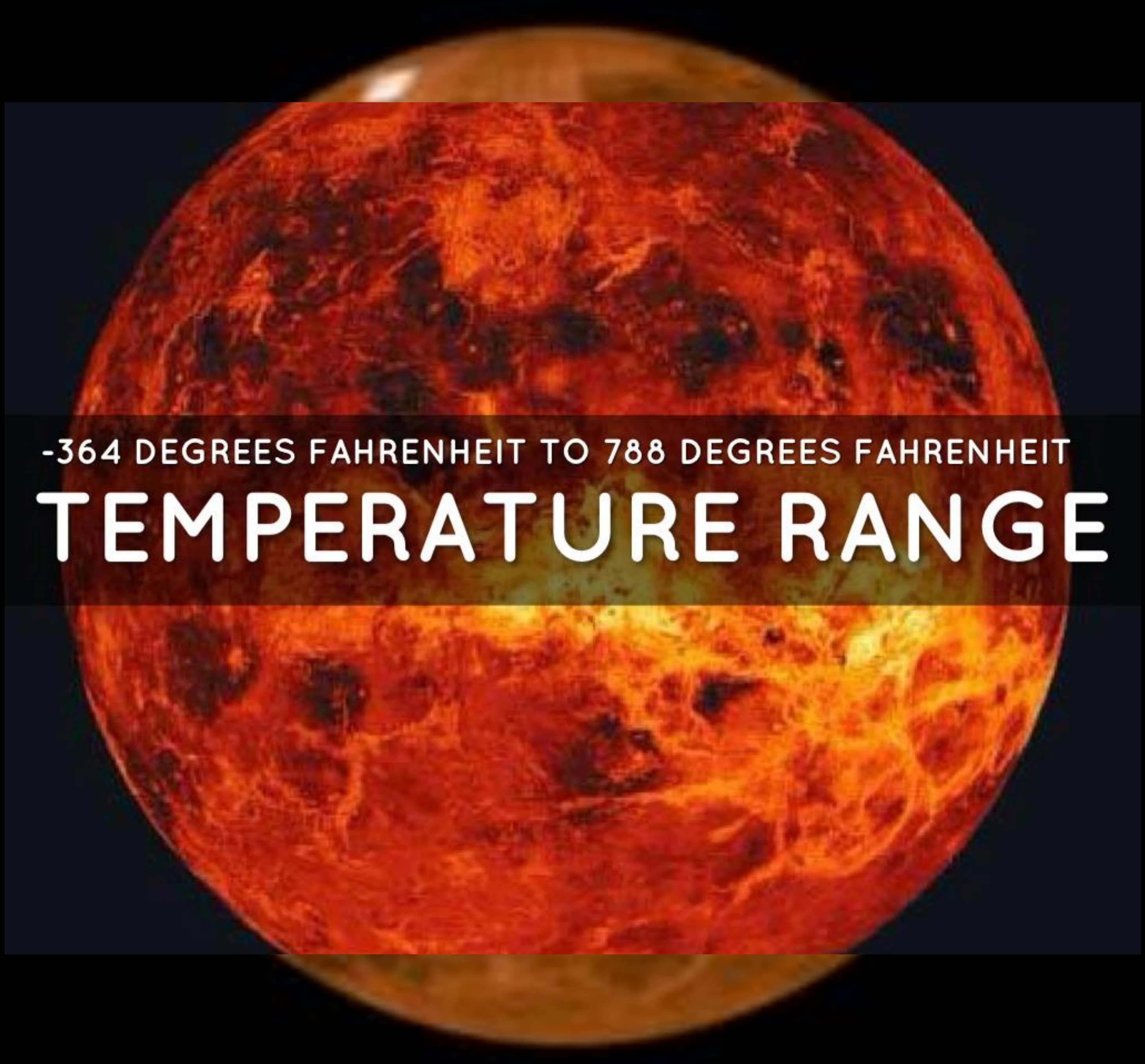
Identify issues and positions on economics, ethics, geopolitics, science, futures..
with this Rc


Climatology

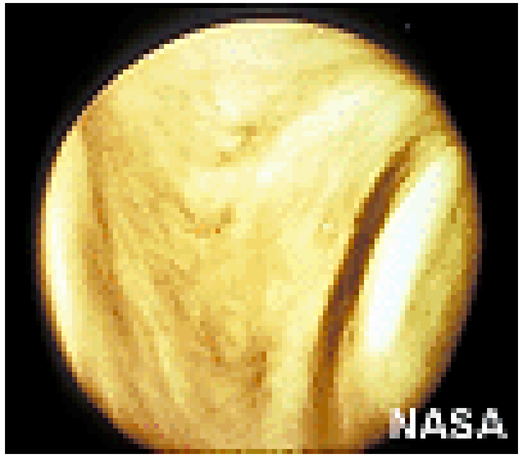


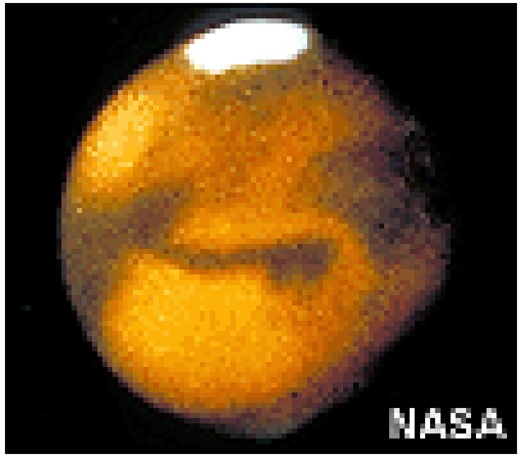
Latitude 0^0
Latitude 60^0
Latitude 75^0
Latitude 89^0 Summer
Latitude 89^0 Winter
Equatorial Mean Annual Temperature: 206K
Polar Mean Annual Temperature: 98K
Temperature (K)
0
50
100
150
200
250
300
350
400
12:00
15:00
18:00
21:00
0:00
3:00
6:00
9:00
12:00
Lunar Time of Day


abc 17 STORMTRACK
abc17news.com
MARS WEATHER REPORT
CURIOSITY ROVER DATA
AIR TEMPERATURE -96° 18°
GROUND TEMPERATURE -90° 48°
PRESSURE 0.23"
UV LEVEL VERY HIGH


-364 DEGREES FAHRENHEIT TO 788 DEGREES FAHRENHEIT
TEMPERATURE RANGE

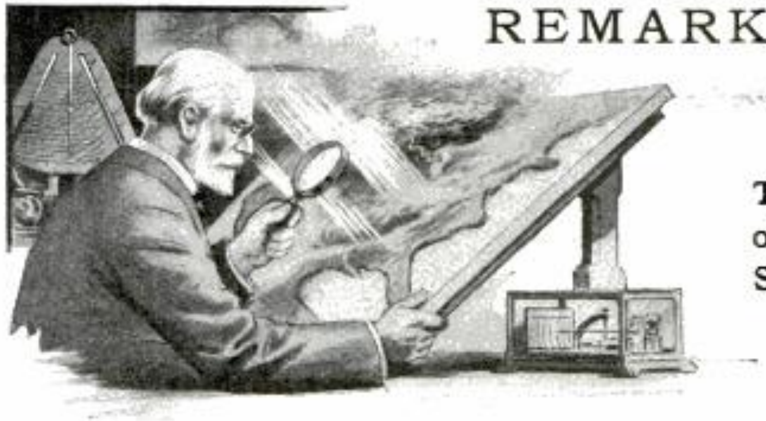
Venus





	Venus	Earth	Mars
Surface pressure relative to Earth (bars)	90	1	0.007
Major greenhouse gases (GHG)	CO_2	H_2O, CO_2	CO_2
Temperature if no GHG (°C)	-46	-18	-57
Actual temperature (°C)	477	15	-47
Temperature change due to GHG	+523	+33	+10

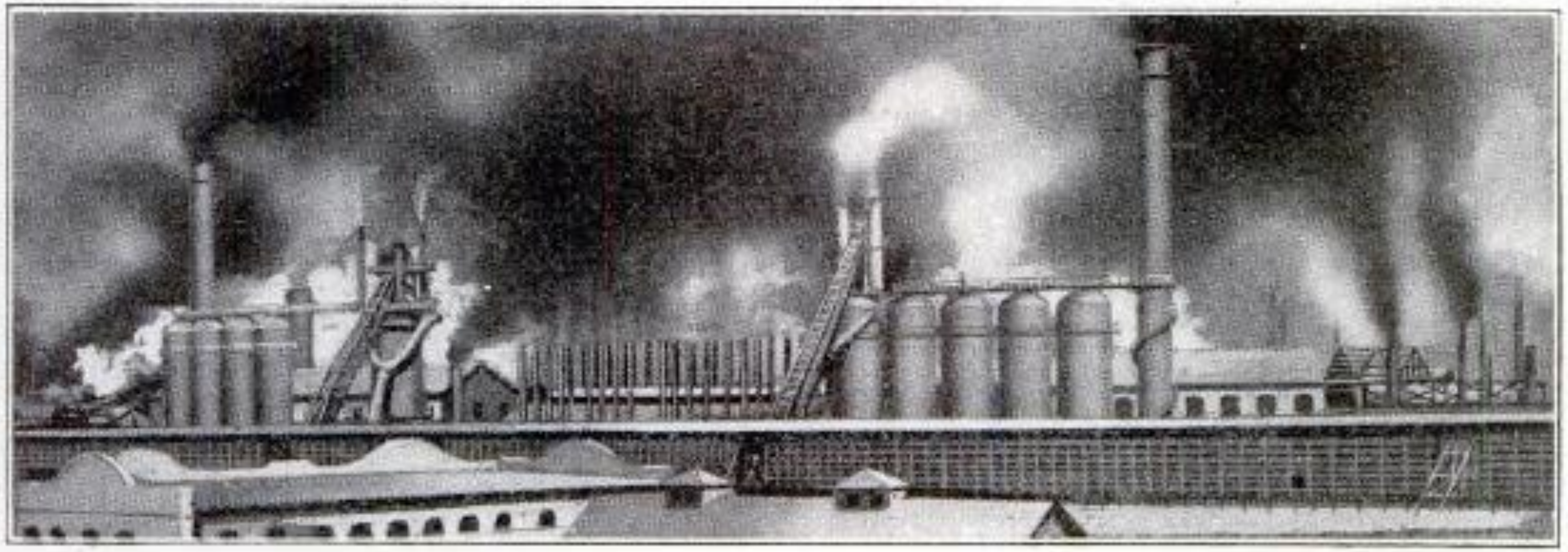
Global Waming? An Historical Perspective



REMARKABLE WEATHER OF 1911

The Effect of the Combustion of Coal on the Climate — What Scientists Predict for the Future

By FRANCIS MOLENA



The furnaces of the world are now burning about 2,000,000,000 tons of coal a year. When this is burned, uniting with oxygen, it adds about 7,000,000,000 tons of carbon dioxide to the atmosphere yearly. This tends to make the air a more effective blanket for the earth and to raise its temperature. The effect may be considerable in a few centuries.

The Short History:

1824 - Joseph Fourier discovered the greenhouse effect.

1859 - John Tyndall discovered that H_2O and CO_2 absorb infrared confirming the Fourier greenhouse effect.

1896 - Svante Arrhenius proposed human CO_2 emissions would prevent earth from entering next ice age (challenged 1906).

1950's Guy Callendar found H2O and CO2 did not overlap all spectra bands, therefore warming from CO_2 expected (countered the 1906 objections against Arrhenius).

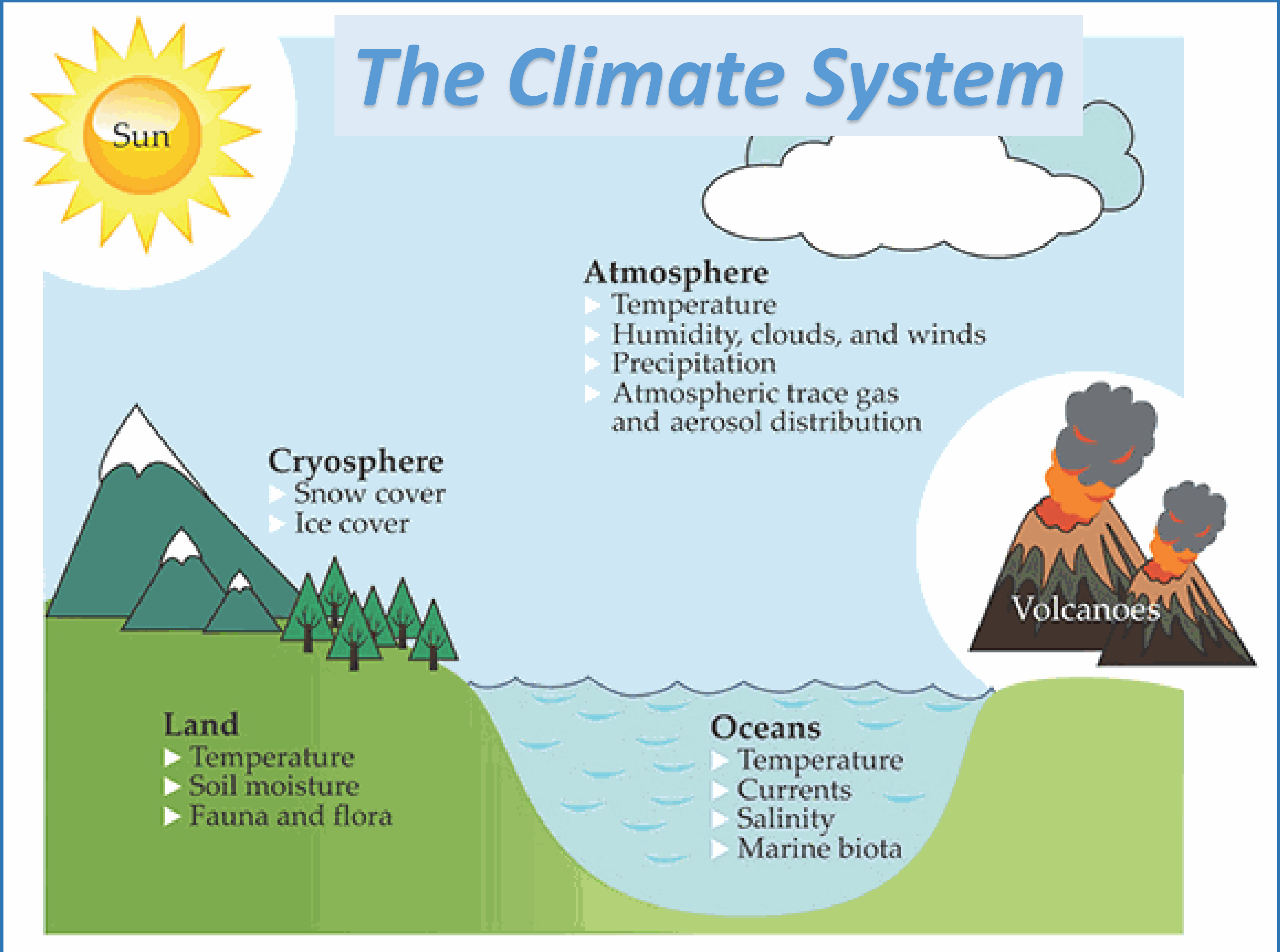
1955 - Hans Suess identified the isotopic signature of industrial based CO_2 emissions.

1956 - Gilbert Plass calculated adding CO_2 would significantly change radiation balance.

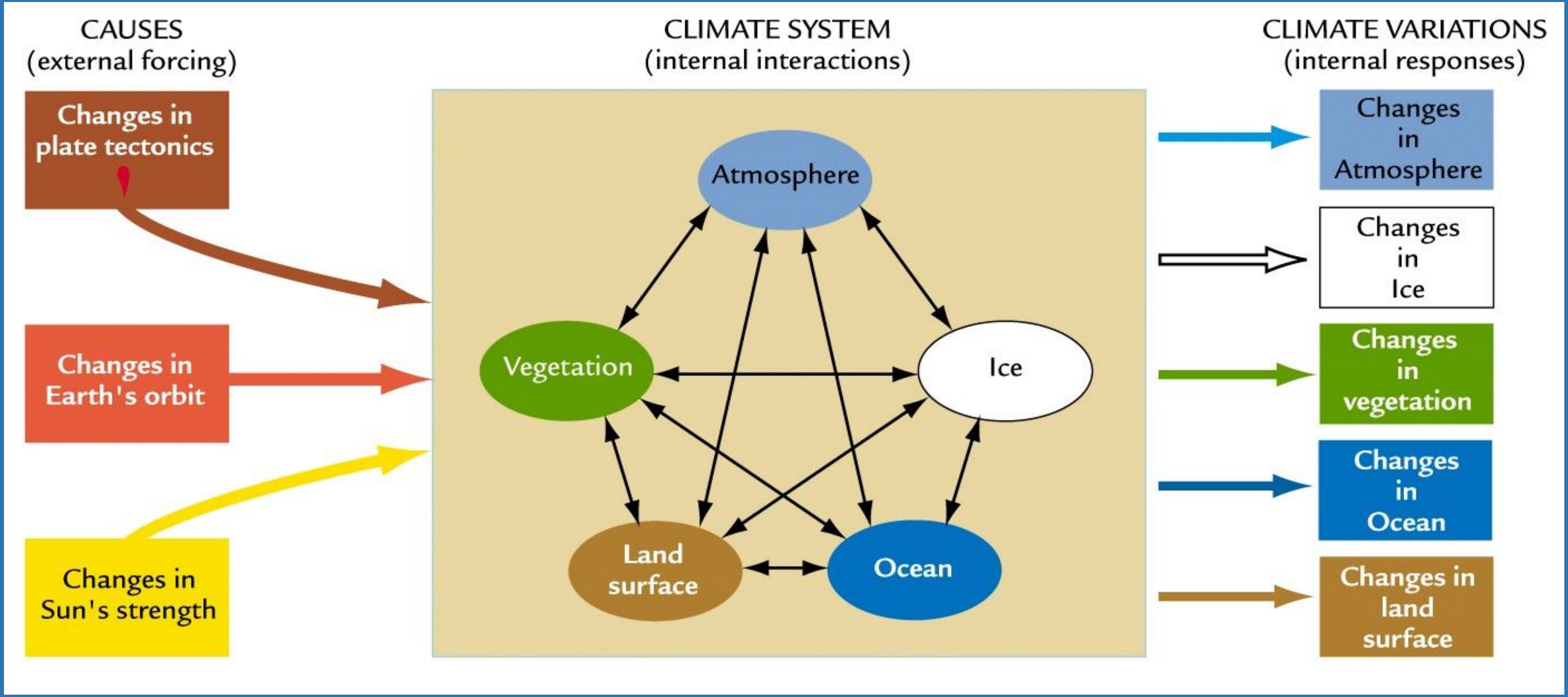
1958/60's - Charles David Keeling proved CO_2 was increasing in the atmosphere.

70's/80's Suke Manabe and James Hansen began modeling climate projections.

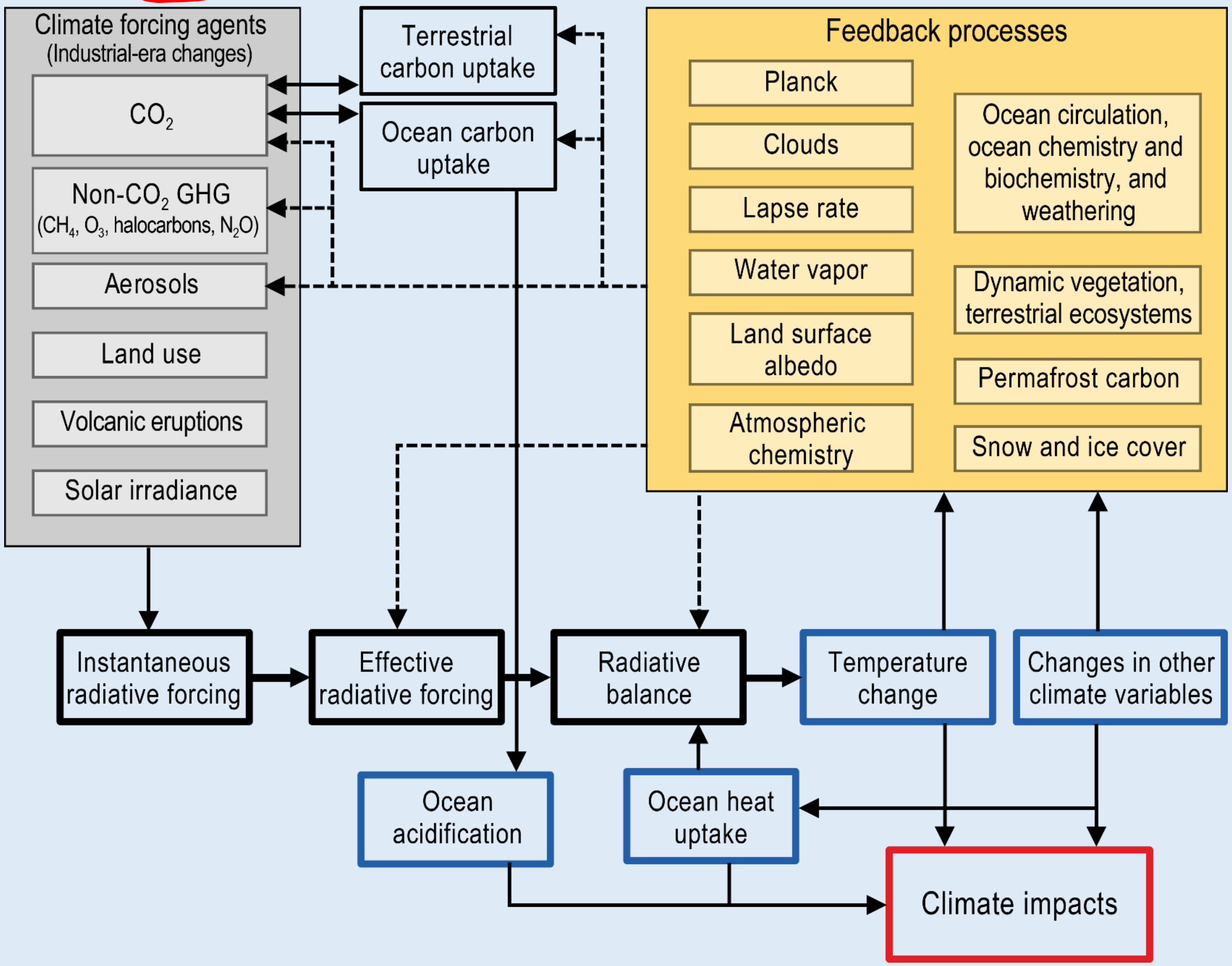
Earth’s Climate

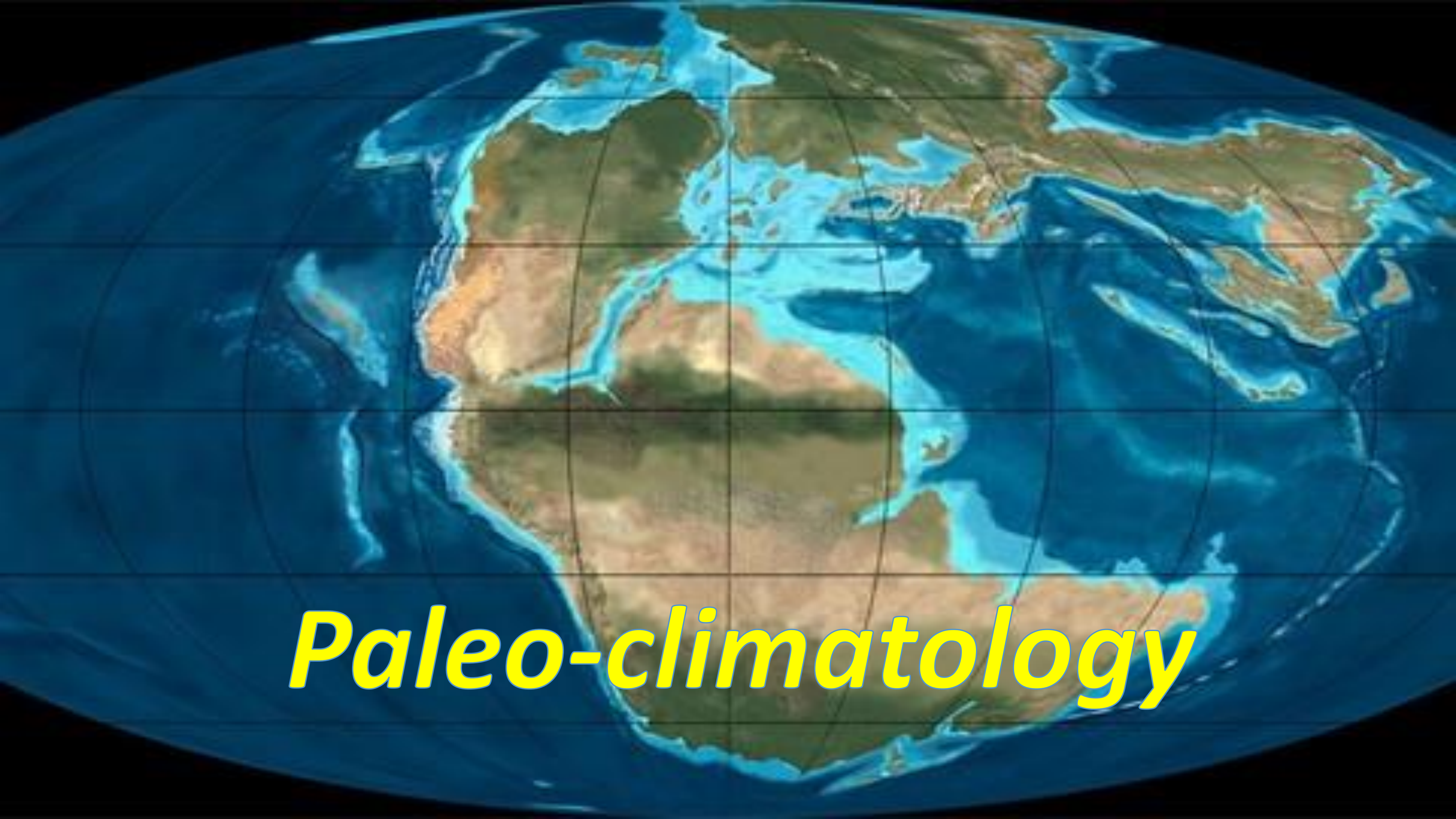


The climate system consists of the atmosphere, cryosphere, land, and oceans, each of which can be characterized by a set of state variables. Climate change is said to occur when a **forcing** generates an intercomponent flux of energy, mass, or momentum that inflicts prolonged changes to one or more state variables. The forcing may originate from within the climate system itself or from a source such as solar, volcanic, or human activity. (Adapted from ref. 4 .) ***Citation:*** Phys. Today **69**, 11, 40 (2016)

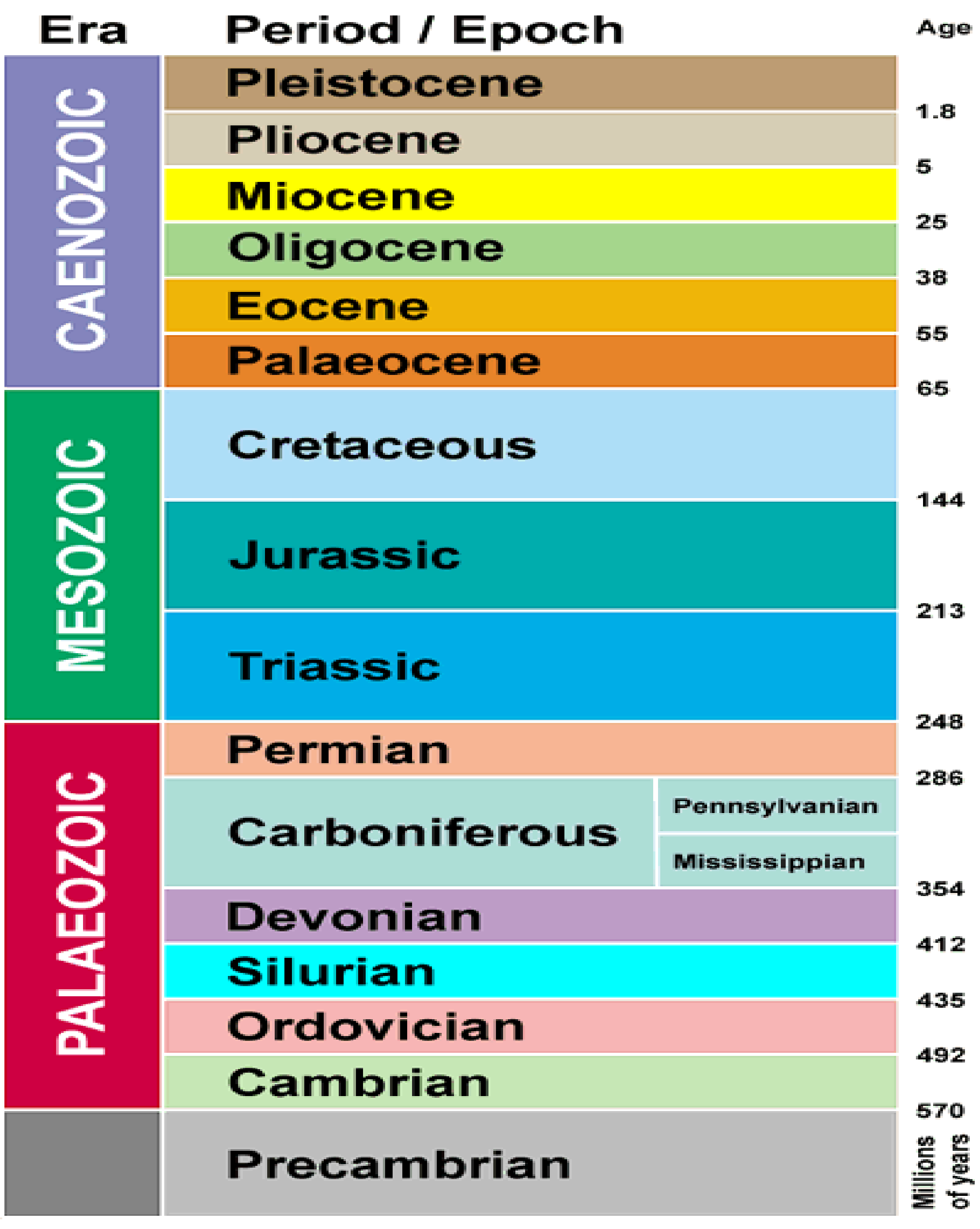

CAUSES
(external forcing)
Changes in plate tectonics
Changes in Earth's orbit
Changes in Sun's strength
CLIMATE SYSTEM
(internal interactions)
Atmosphere
Vegetation
Ice
Land surface
Ocean
CLIMATE VARIATIONS
(internal responses)
Changes in Atmosphere
Changes in Ice
Changes in vegetation
Changes in Ocean
Changes in land surface

Simplified Conceptual Framework of the Climate System





Paleo-climatology


Era
Period / Epoch
Age
CAENOZOIC
MESOZOIC
PALAEOZOIC
Pleistocene
Pliocene
Miocene
Oligocene
Eocene
Palaeocene
Cretaceous
Jurassic
Triassic
Permian
Carboniferous
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician
Cambrian
Precambrian
1.8
5
25
38
55
65
144
213
248
286
354
412
435
492
570
Millions of years

Paleoclimate measurement methods

Geomorphology- landscapes

Stratigraphy

Ocean and lake sediments

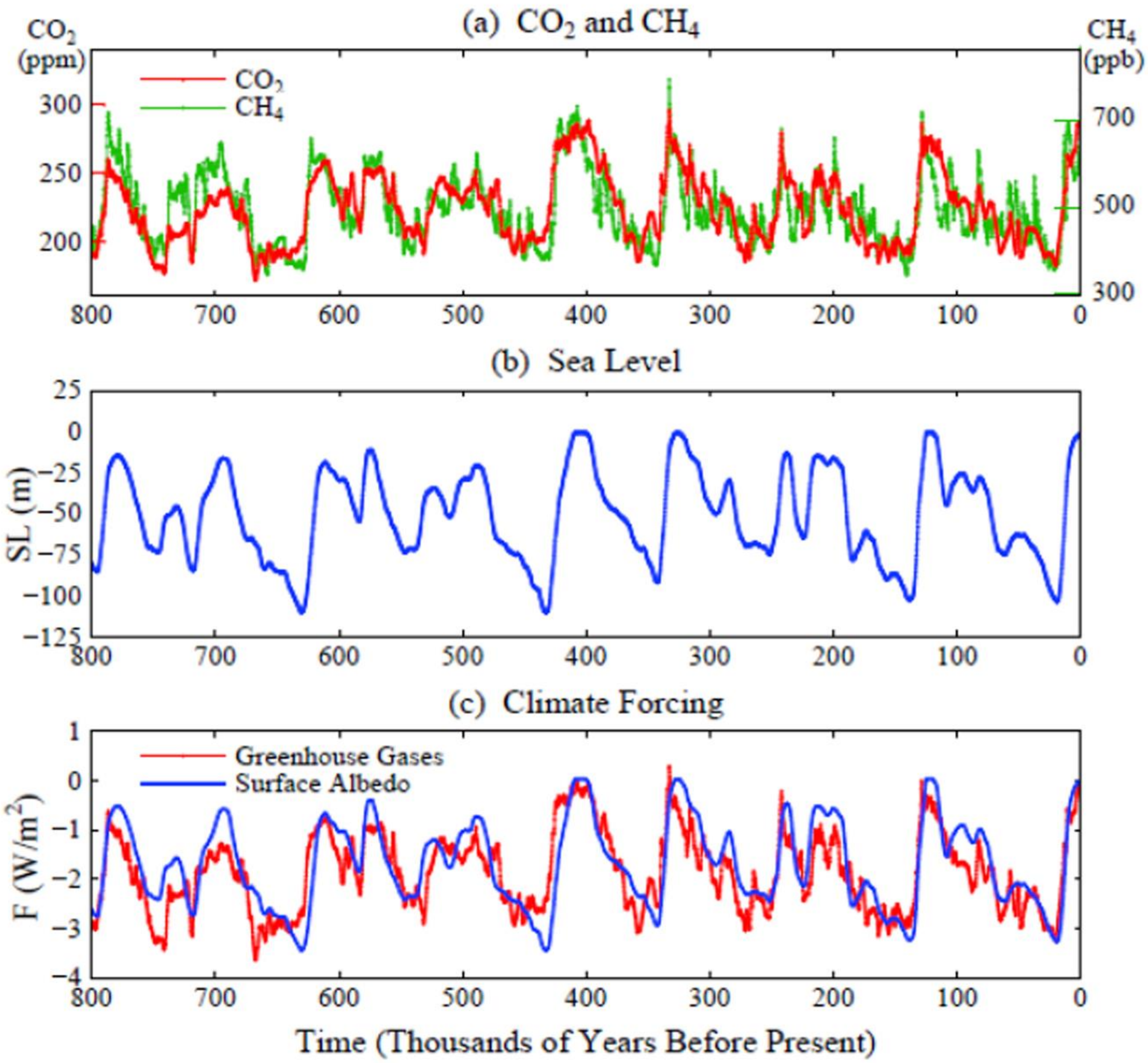
Ice cores

Tree rings

Cave deposits

Isotope dating-
stable and radioactive

How to discover past climates?

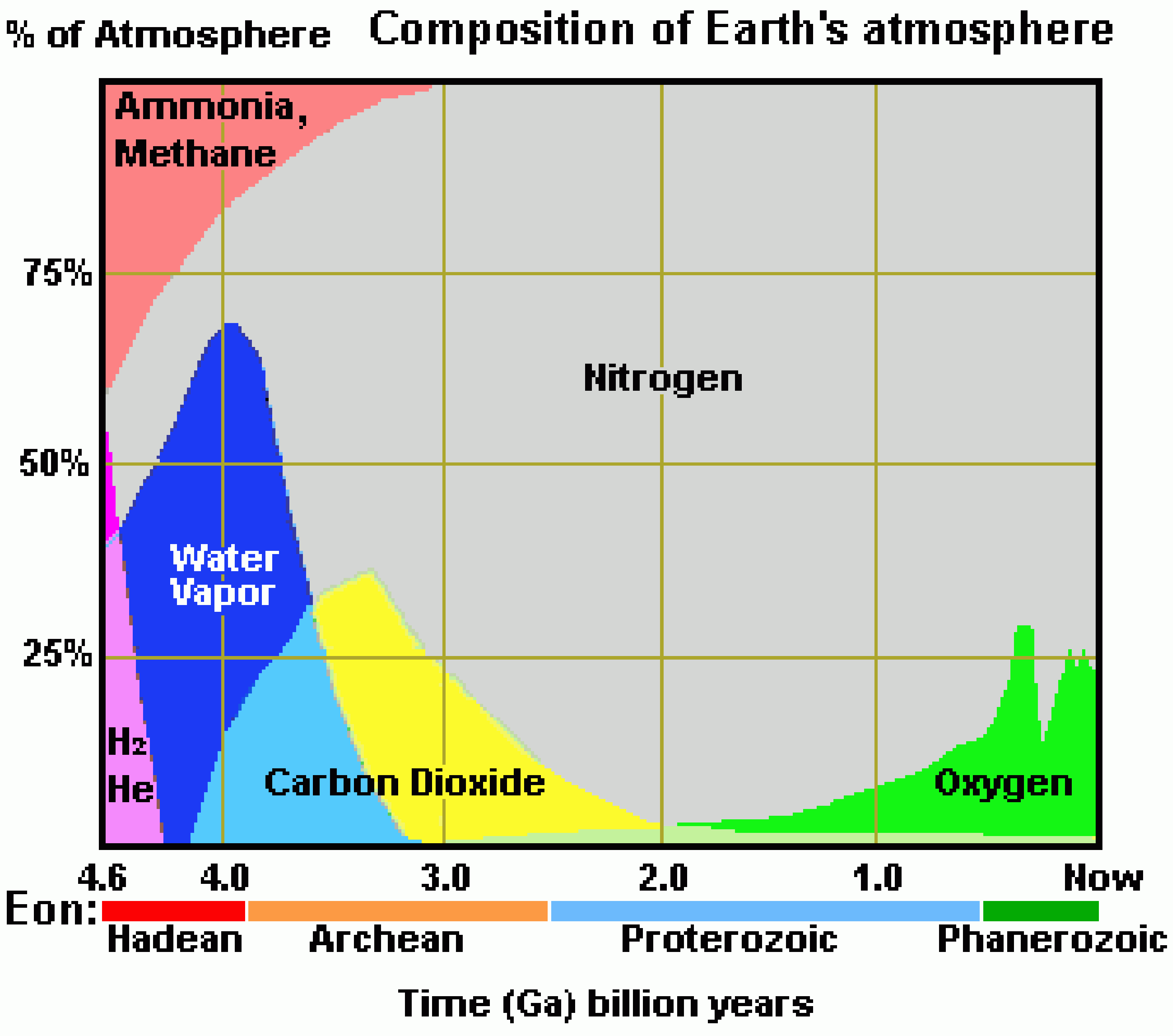


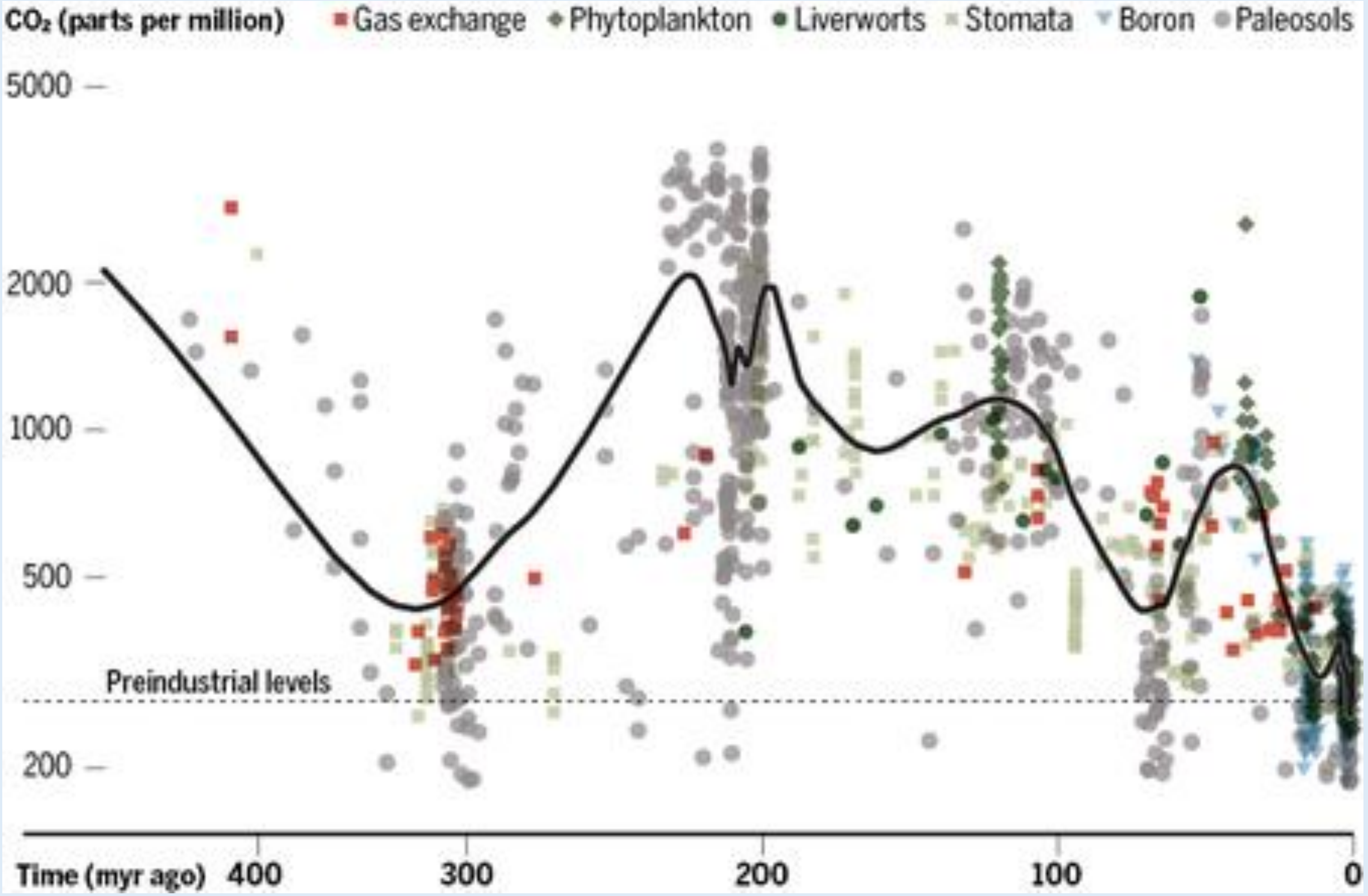
(from Hansen, J.E. and Sato, M., 2011)

Parameter	Proxy Analysis
Paleotemperatures Summer Annual cycles (Days with snowfall)	Melt Layers δD, $\delta^{18}O$
Humidity	Deuterium excess
Paleo-accumulation	Seasonal signals, ^{10}Be
Volcanic activity	Conductivity, SO_4
Tropospheric turbidity	ECM, microparticle content, trace elements
Wind speed	Particle size, concentration
Atmospheric composition: Natural Variations and man-made changes	CO_2, CH_4, N_2O content, glaciochemistry
Atmospheric circulation	Glaciochemistry (major ions)
Solar activity	^{10}Be

Ice Core Sources of Paleoclimatic Information: Modeled on a figure from Bradley, R. (1999). *Paleoclimatology: Reconstructing Climates of the Quaternary*. 2nd Ed. San Diego: Academic Press, 126

http://www.econ.yale.edu/~nordhaus/homepage/documents/icecore_review.pdf


% of Atmosphere
Composition of Earth's atmosphere
Ammonia, Methane
Nitrogen
Water Vapor
Carbon Dioxide
Oxygen
H2 He
75%
50%
25%
4.6
4.0
3.0
2.0
1.0
Now
Eon:
Hadean
Archean
Proterozoic
Phanerozoic
Time (Ga) billion years

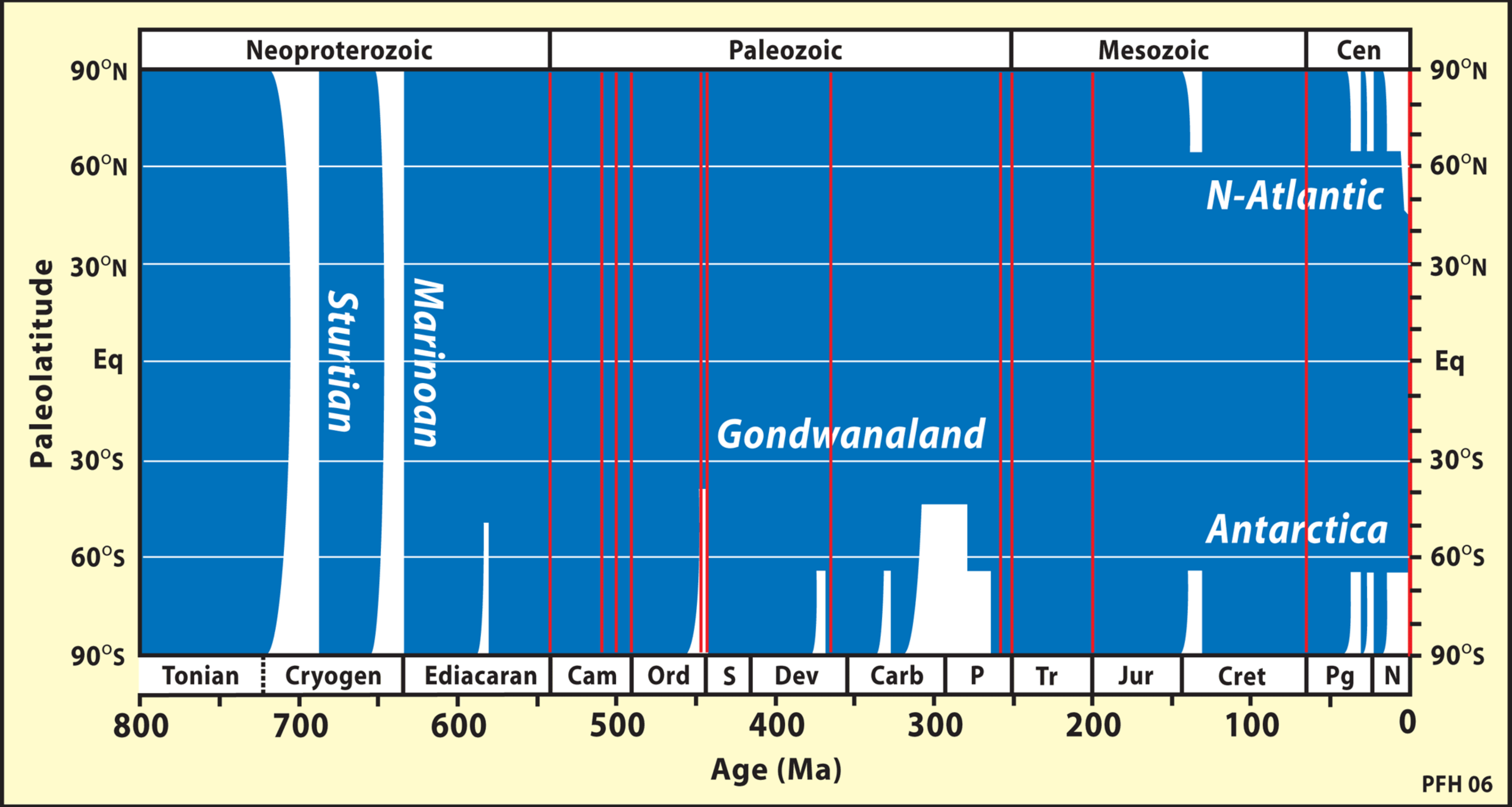


Proxies for CO2: A roller coaster ride

Atmospheric carbon dioxide (CO_2) has swung dramatically in the distant past, according to indicators based on fossils (gas exchange, phytoplankton, liverworts, and stomata) and minerals (boron, paleosols). The ancient record suggests the recent jump from preindustrial levels (far right) could have an outsized effect on climate.

(Graphic) A. Cuadra/*Science*; (Data) Dana Royer, Wesleyan Univ.

Paleogeographic extent of continental ice sheets and permanent sea ice over the last 800 Myr (red lines indicate major mass extinctions)

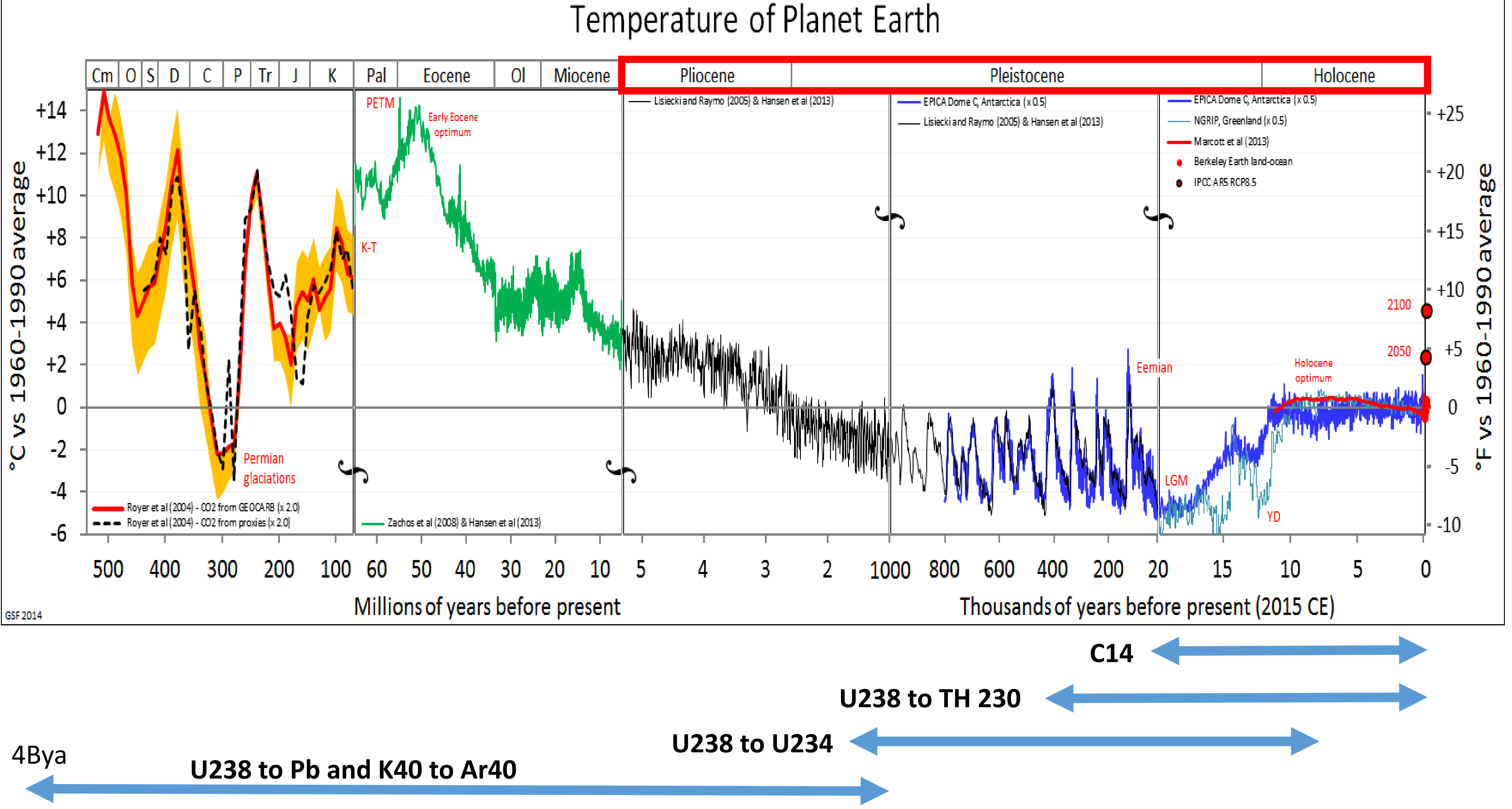


Snowball Earth

- Between 900 and 600 m.y. ago, Earth froze completely (or almost) about four times
- Global freezing alternated with extremely rapid sea-level rise and global warming
- Evidence:
  - Glacial deposits on all continents, even at low latitudes
  - Glacial deposits immediately succeeded by thick deposits of carbonate rocks

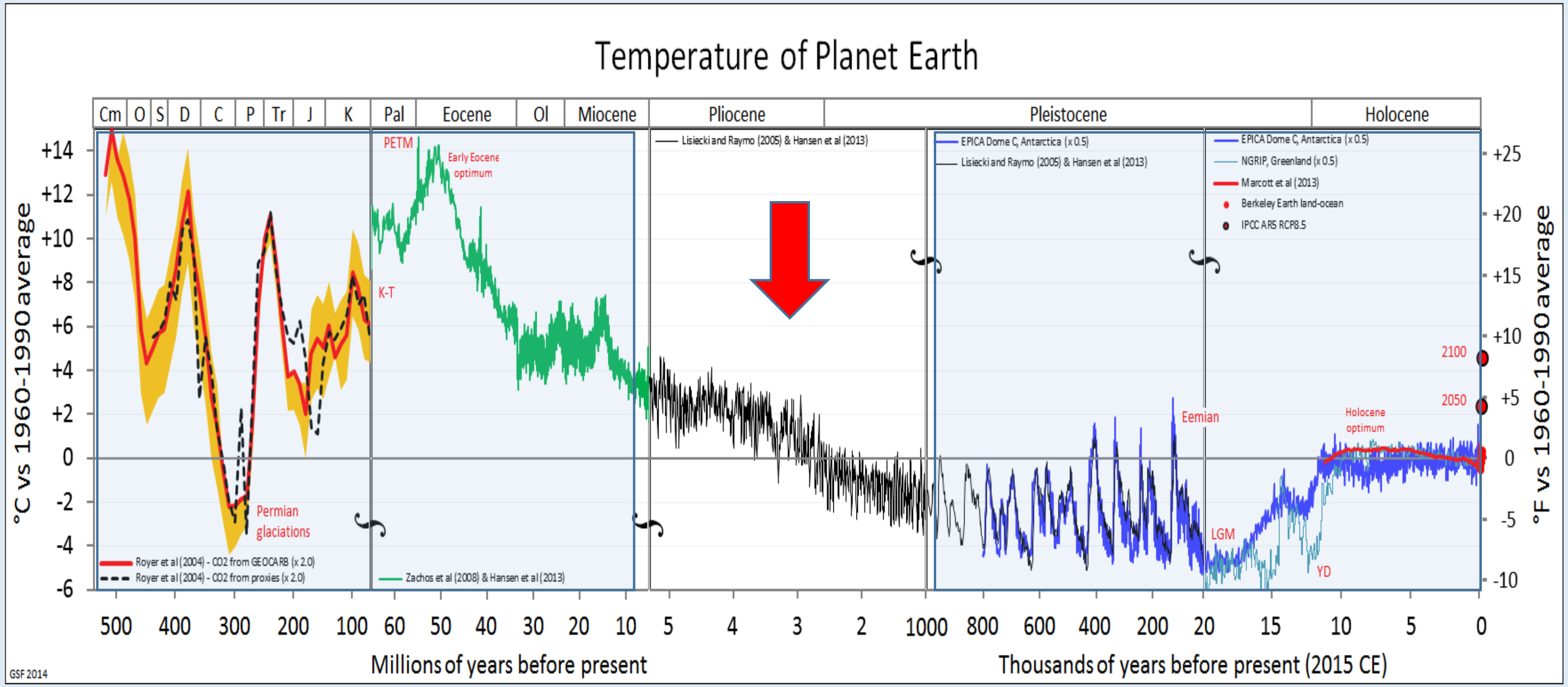
Elatina Fm diamictite below Ediacaran GSSP site in the Flinders Ranges NP, South Australia. A$1 coin for scale.

Volcanoes may have had a role in replenishing CO_2, possibly ending the global ice age that was the snowball Earth during the Cryogenian Period.



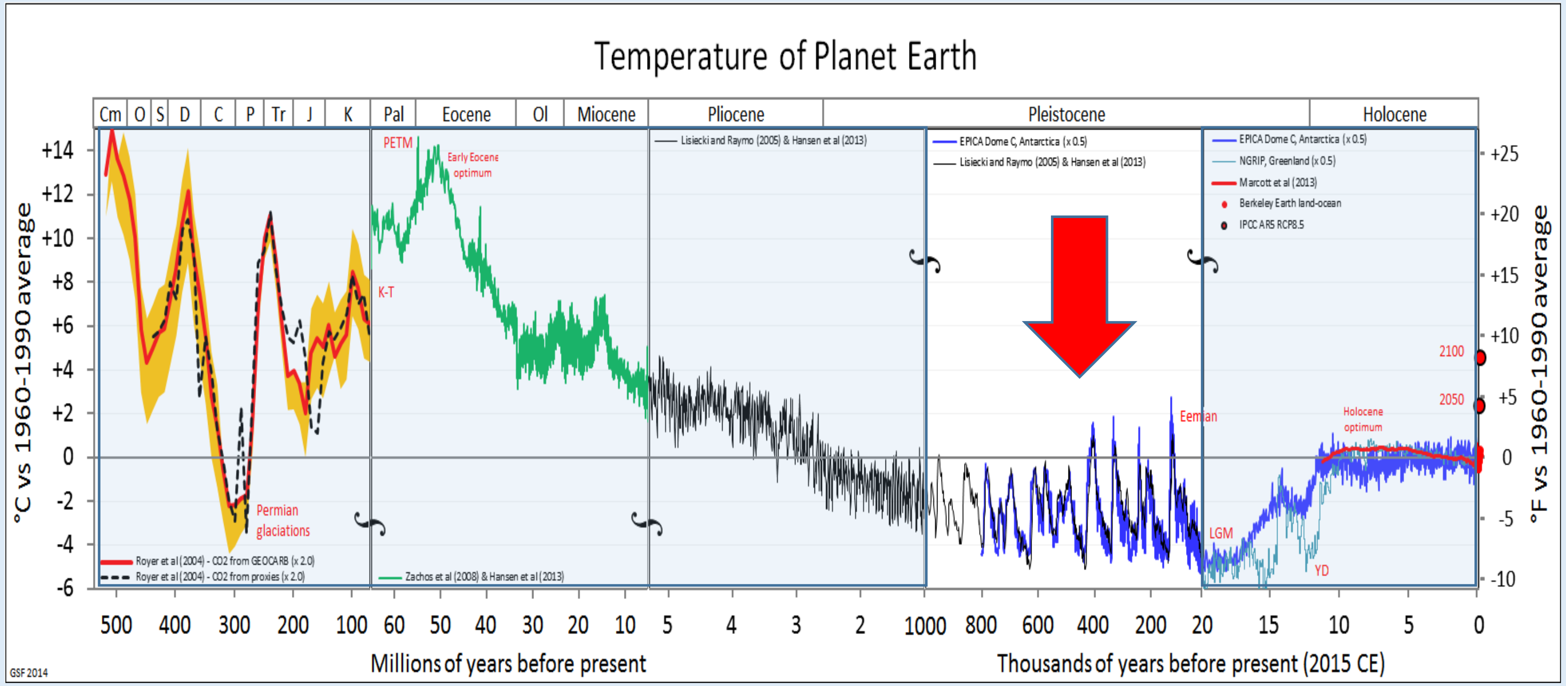
Temperature of Planet Earth
Cm O S D C P Tr J K Pal Eocene Ol Miocene Pliocene Pleistocene Holocene
°C vs 1960-1990 average
°F vs 1960-1990 average
PETM
Early Eocene optimum
K-T
Permian glaciations
Eemian
LGM
YD
Holocene optimum
2100
2050
Royer et al (2004) - CO2 from GEOCARB (x 2.0)
Royer et al (2004) - CO2 from proxies (x 2.0)
Zachos et al (2008) & Hansen et al (2013)
Lisiecki and Raymo (2005) & Hansen et al (2013)
EPICA Dome C, Antarctica (x 0.5)
NGRIP, Greenland (x 0.5)
Marcott et al (2013)
Berkeley Earth land-ocean
IPCC AR5 RCP8.5
Millions of years before present
Thousands of years before present (2015 CE)
GSF 2014
C14
U238 to TH 230
U238 to U234
4Bya
U238 to Pb and K40 to Ar40

Pliocene climate- 5.3 to 2.6 Mya

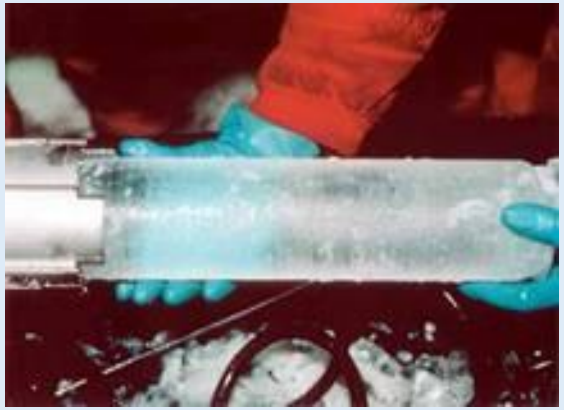


- Continents close to present locations
- Average temperatures 2-3 C higher
- Mid-latitude temps 10-20 C higher
- No Greenland ice sheet
- Sea level +25 m
- <u>Somewhat analogous to next 200 yrs</u>
- Tundra today was forest then

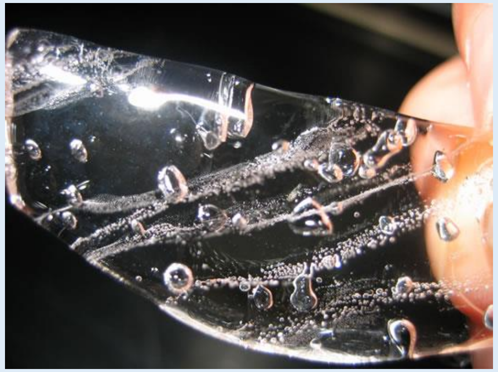
Pleistocene climate- 2.6 Mya to 12 kya

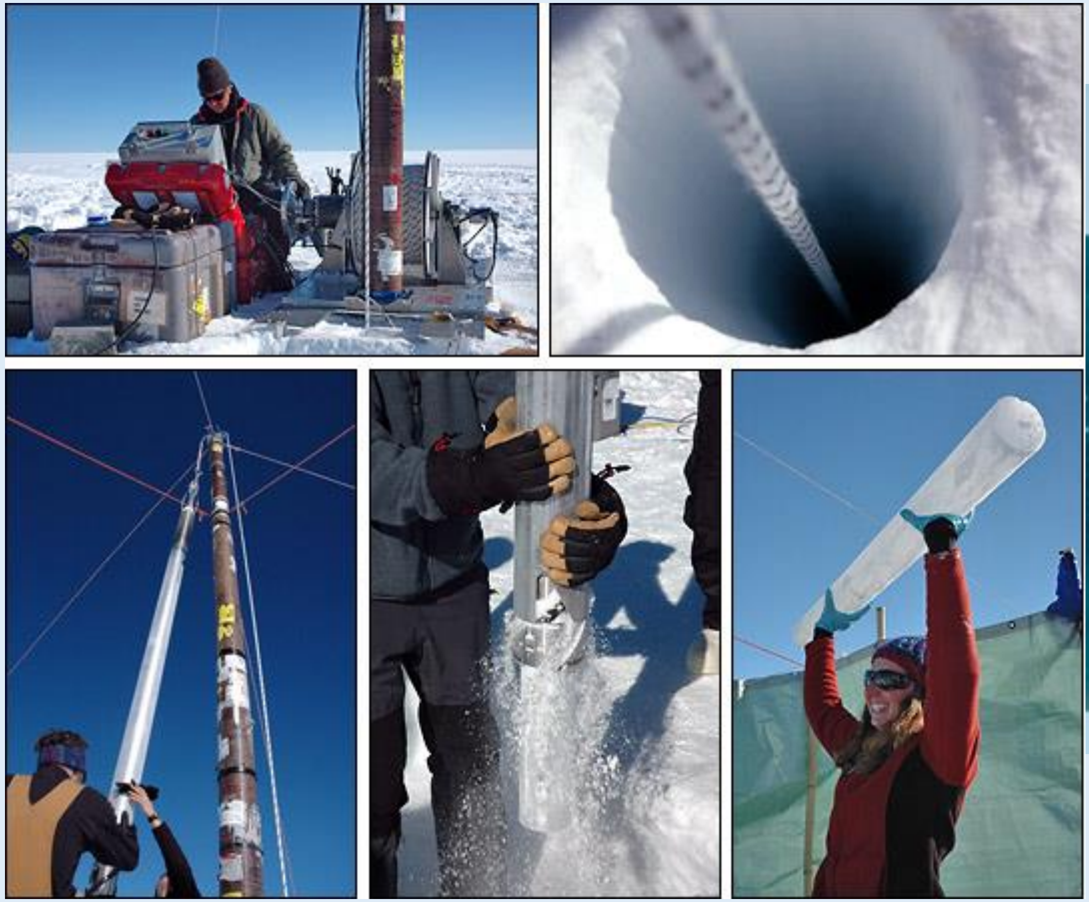


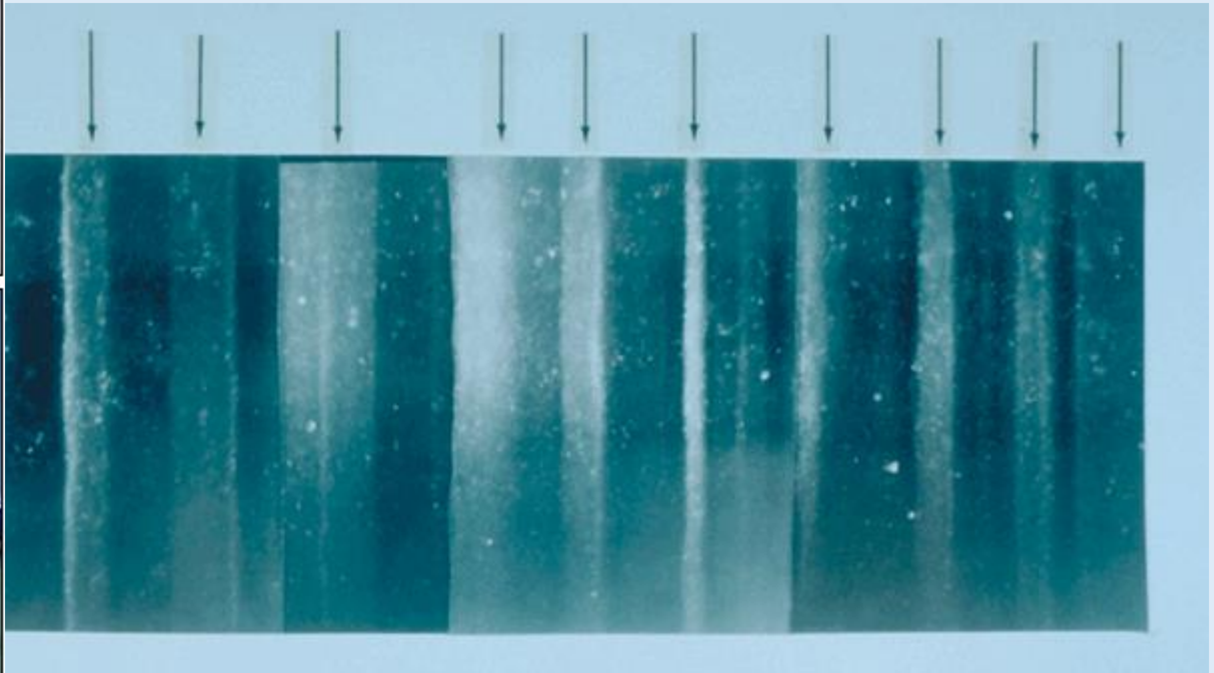
- Coldest in last 2 B yrs
- Much lower CO2
- Glaciation cycles
- Milankovitch pacing
- Last Glacial Maximum (LGM) 26.5 kya

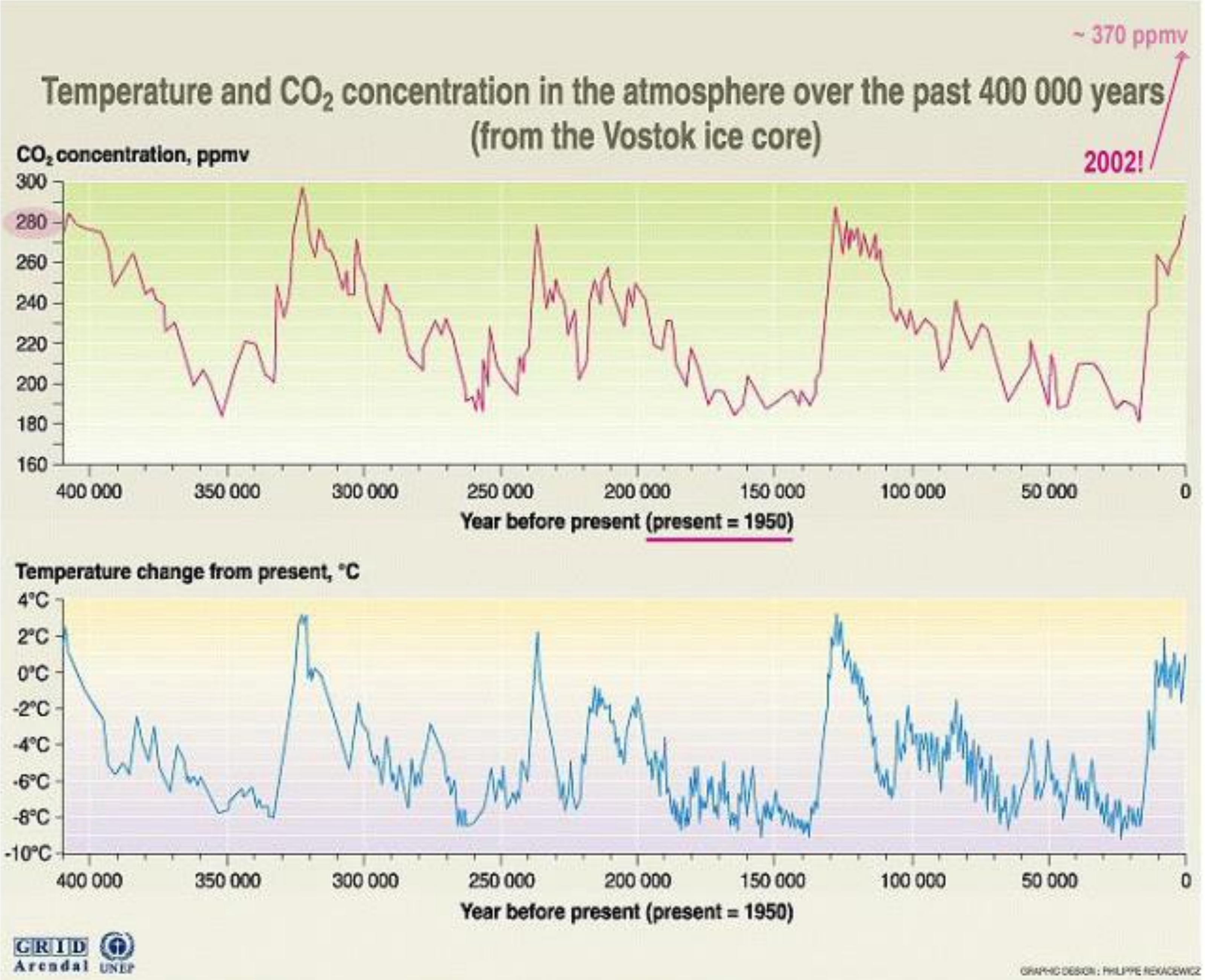


Vostok Antarctic Ice Cores





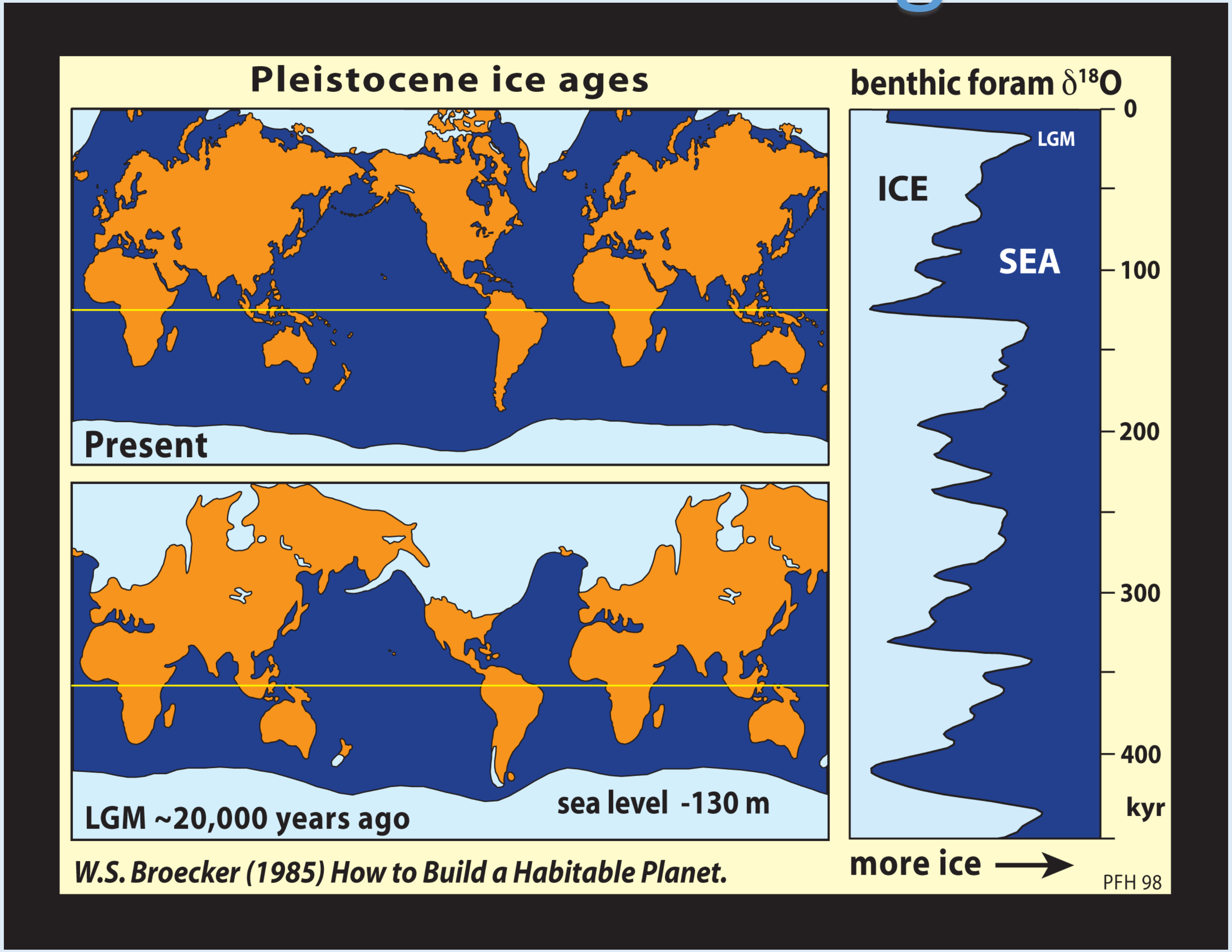




Source: J.R. Petit, J. Jouzel, et al. Climate and atmospheric history of the past 420 000 years from the Vostok ice core in Antarctica, Nature 399 (3JUne), pp 429-436, 1999.

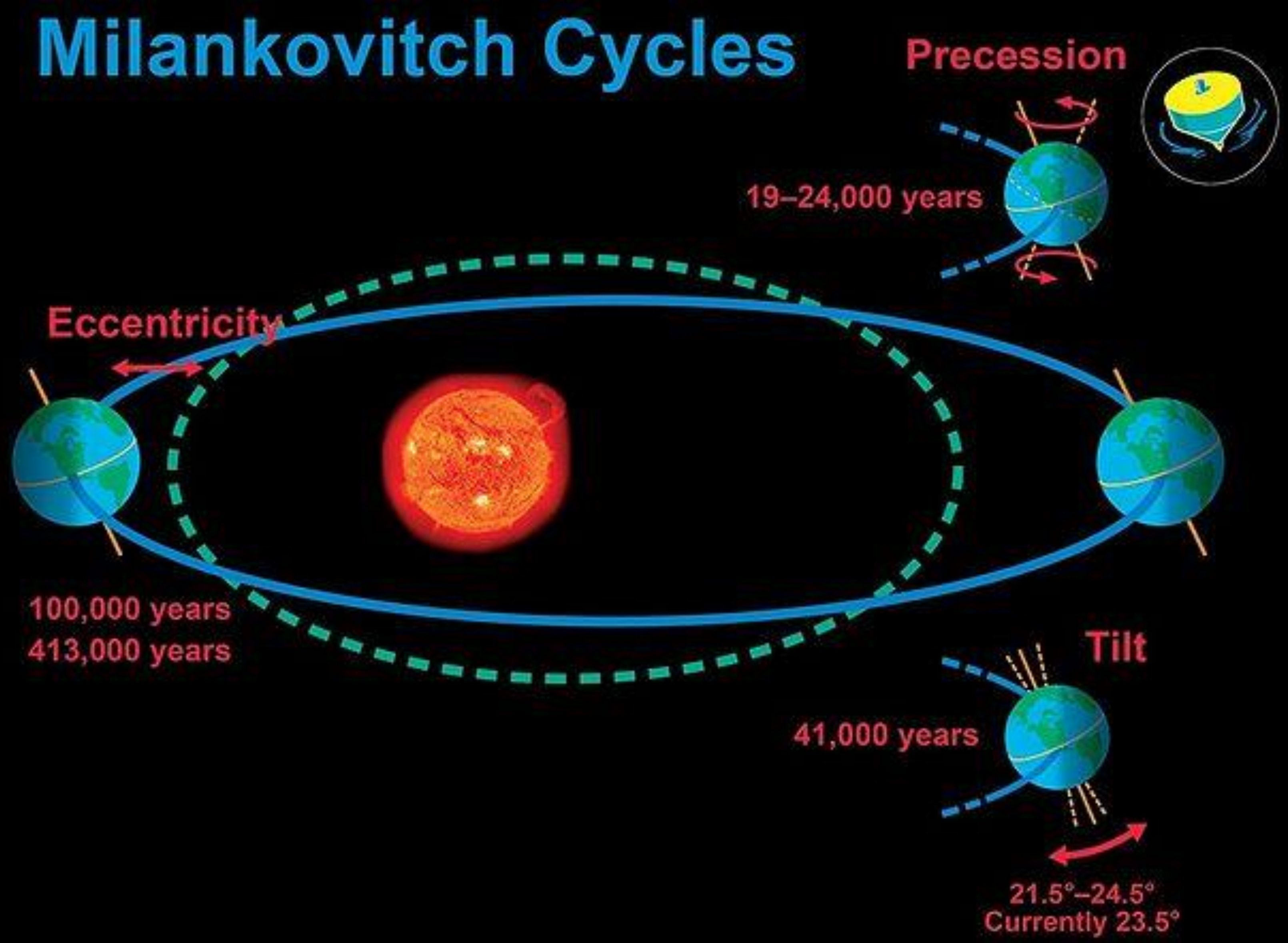
(Note: 2002 information added to diagram)

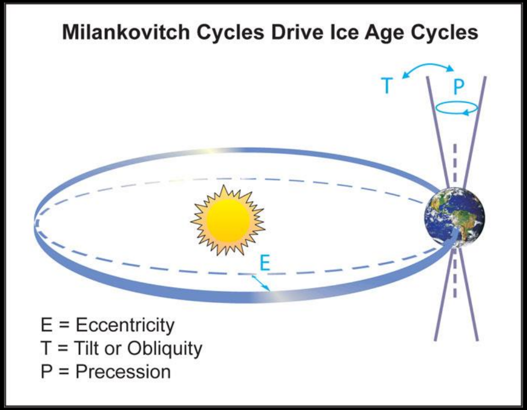
Pleistocene Ice Ages

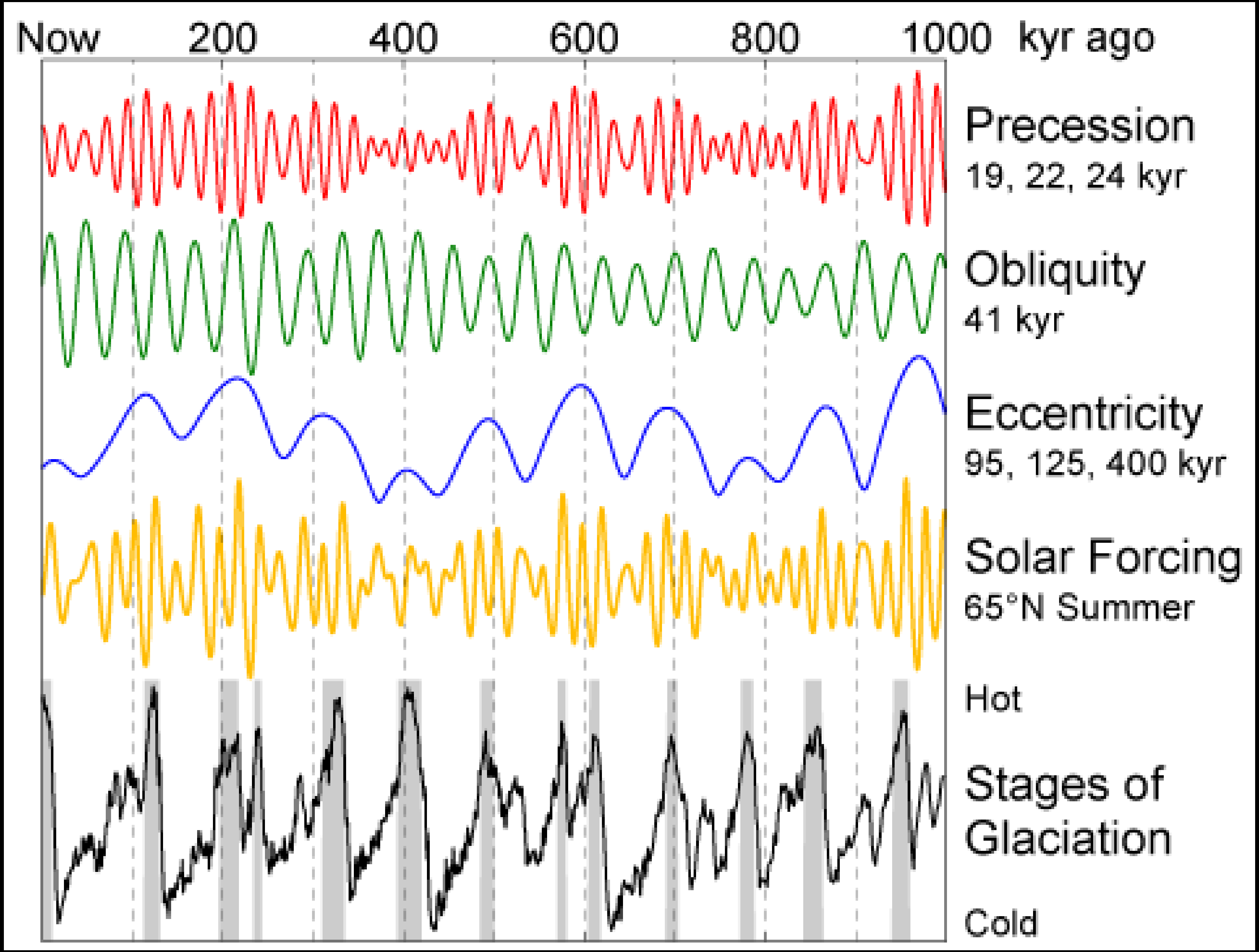


W.S. Broecker (1985) How to Build a Habitable Planet.

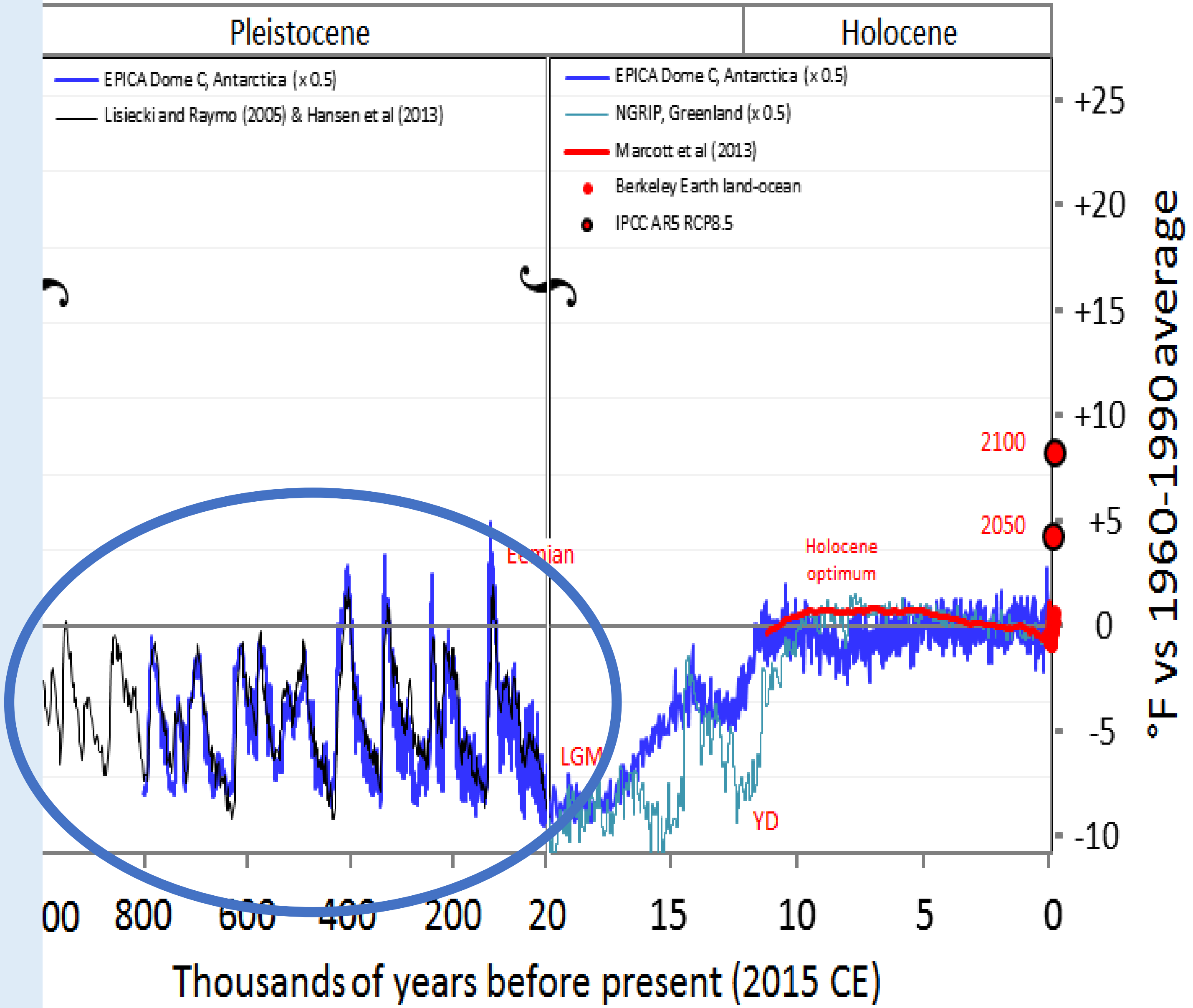
http://www.snowballearth.org/week1.html


Milankovitch Cycles
Precession
19–24,000 years
Eccentricity
100,000 years
413,000 years
Tilt
41,000 years
21.5°–24.5°
Currently 23.5°

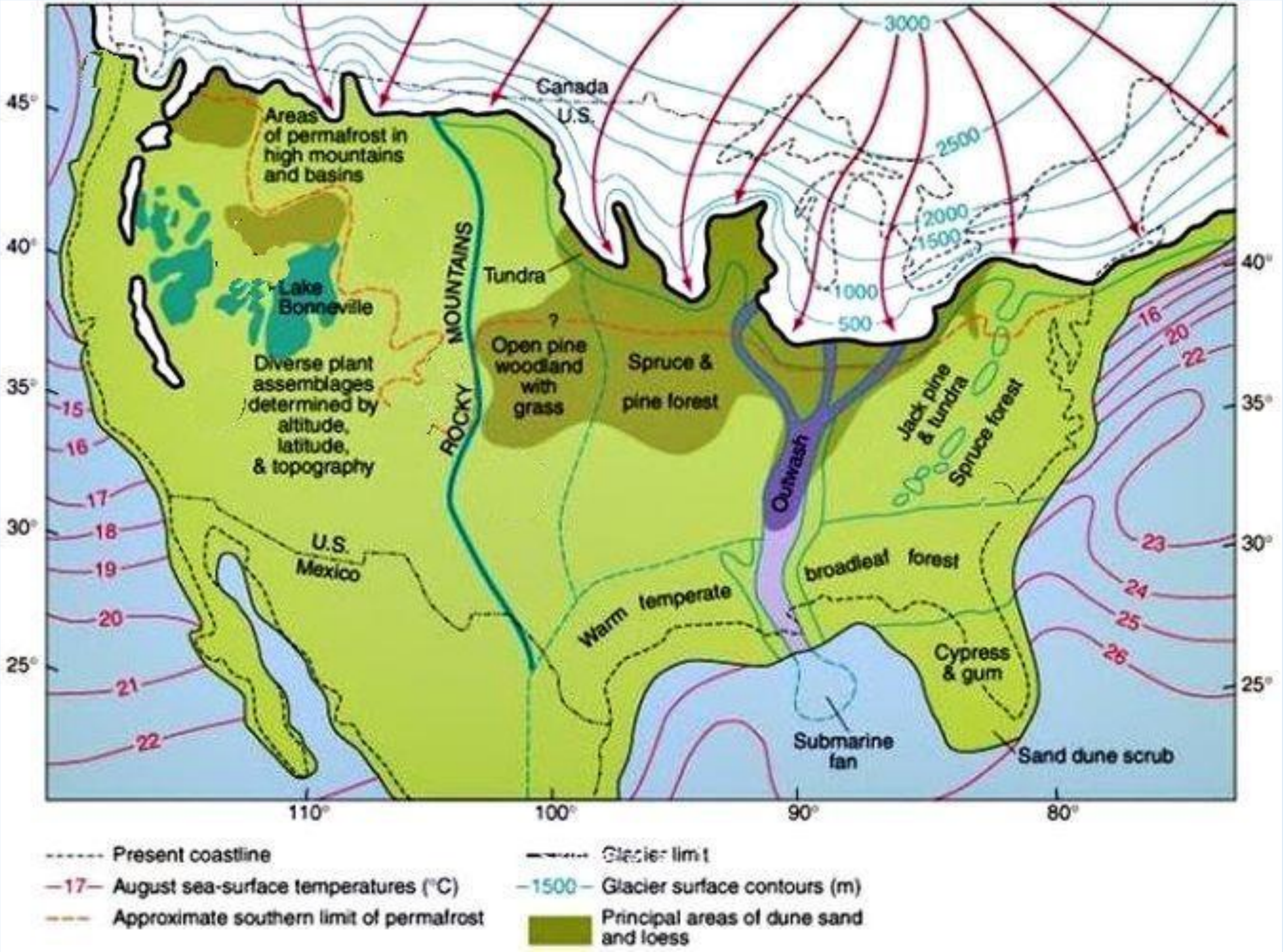

Milankovitch Cycles Drive Ice Age Cycles
T
P
E
E = Eccentricity
T = Tilt or Obliquity
P = Precession


Now
200
400
600
800
1000
kyr ago
Precession
19, 22, 24 kyr
Obliquity
41 kyr
Eccentricity
95, 125, 400 kyr
Solar Forcing
65°N Summer
Hot
Stages of Glaciation
Cold

arth

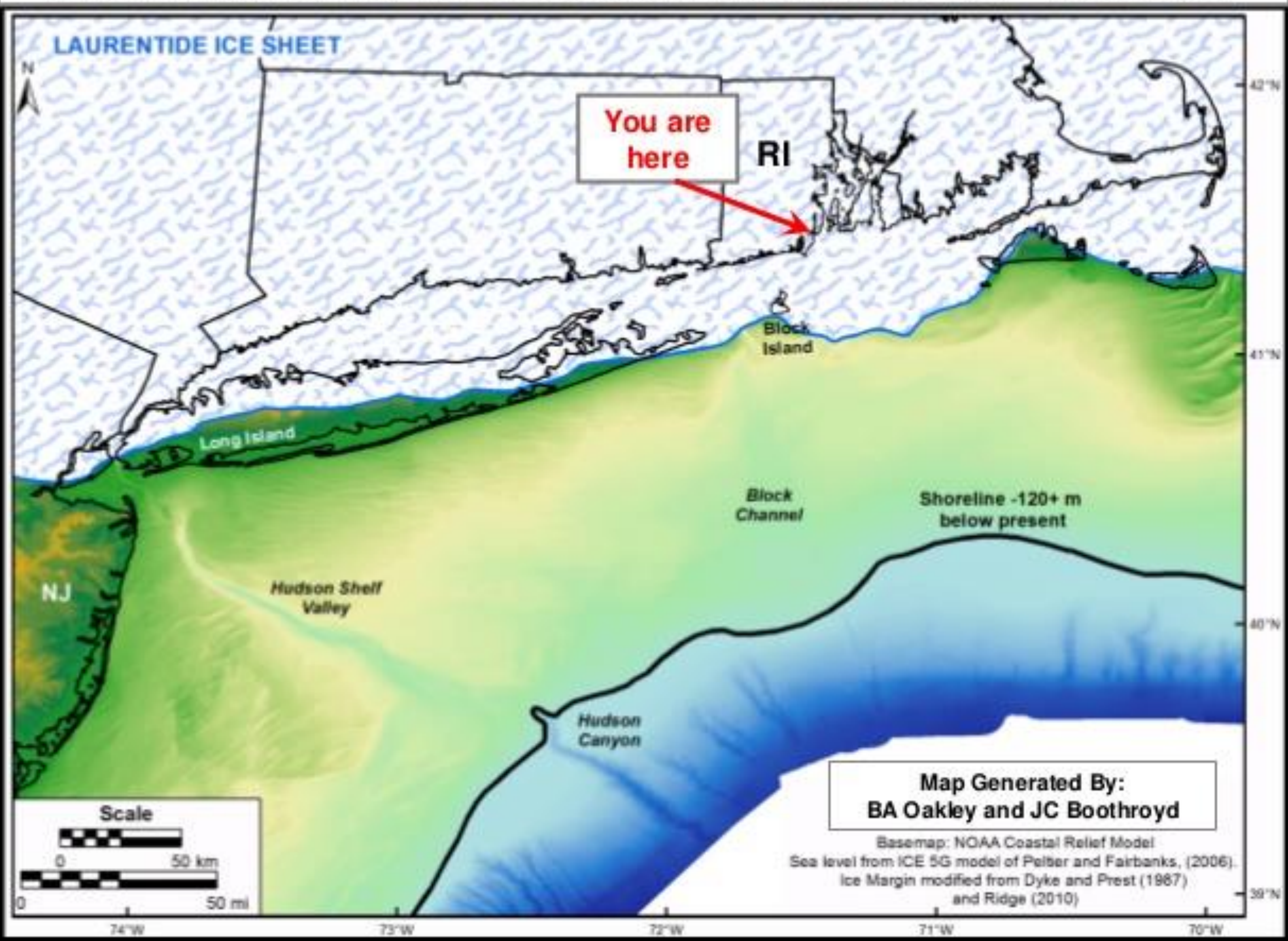


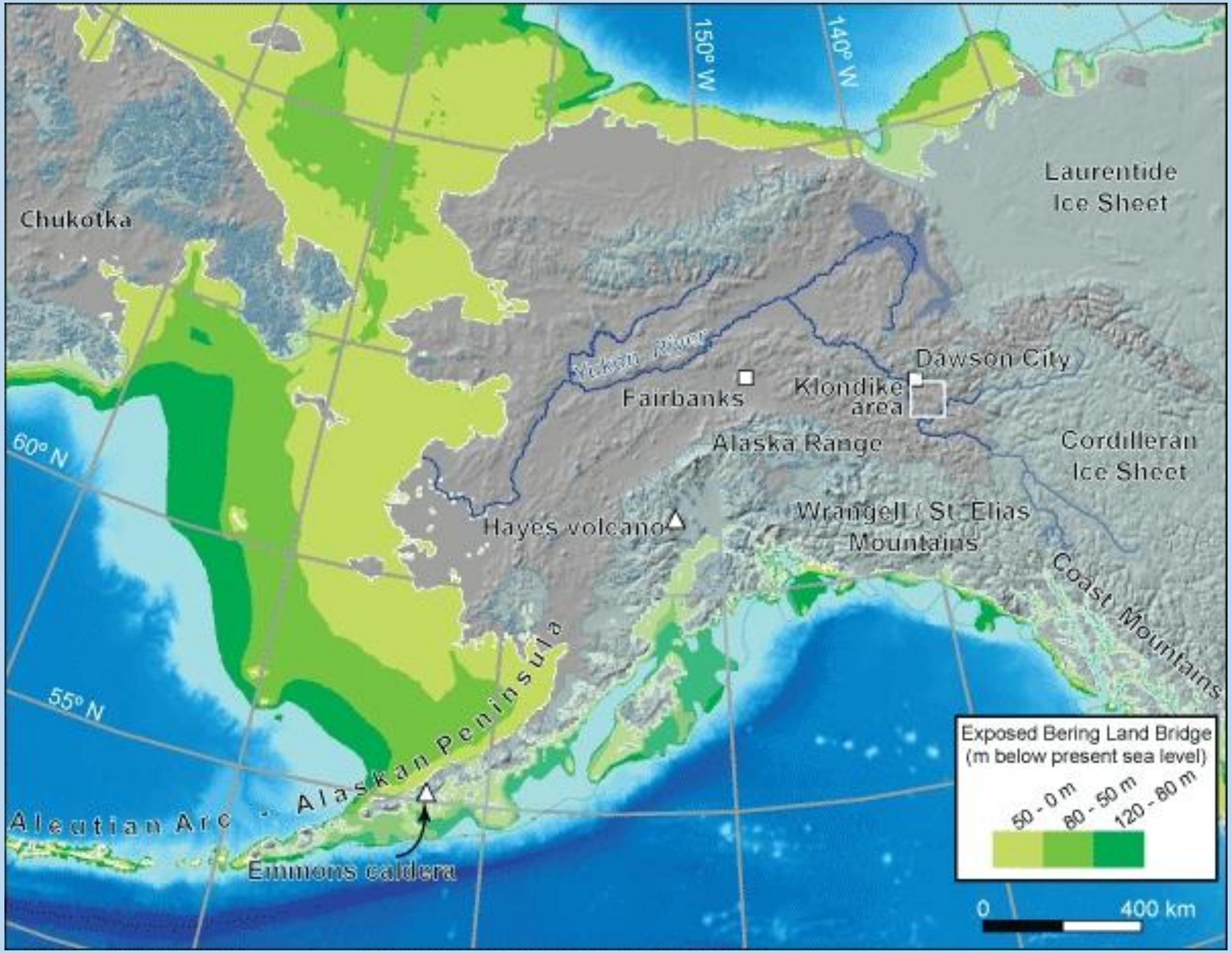
Pleistocene
Holocene
EPICA Dome C, Antarctica (x 0.5)
Lisiecki and Raymo (2005) & Hansen et al (2013)
EPICA Dome C, Antarctica (x 0.5)
NGRIP, Greenland (x 0.5)
Marcott et al (2013)
Berkeley Earth land-ocean
IPCC AR5 RCP8.5
2100
2050
Holocene
optimum
LGM
YD
+25
+20
+15
+10
+5
0
-5
-10
°F vs 1960-1990 average
800
200
20
15
10
5
0
Thousands of years before present (2015 CE)

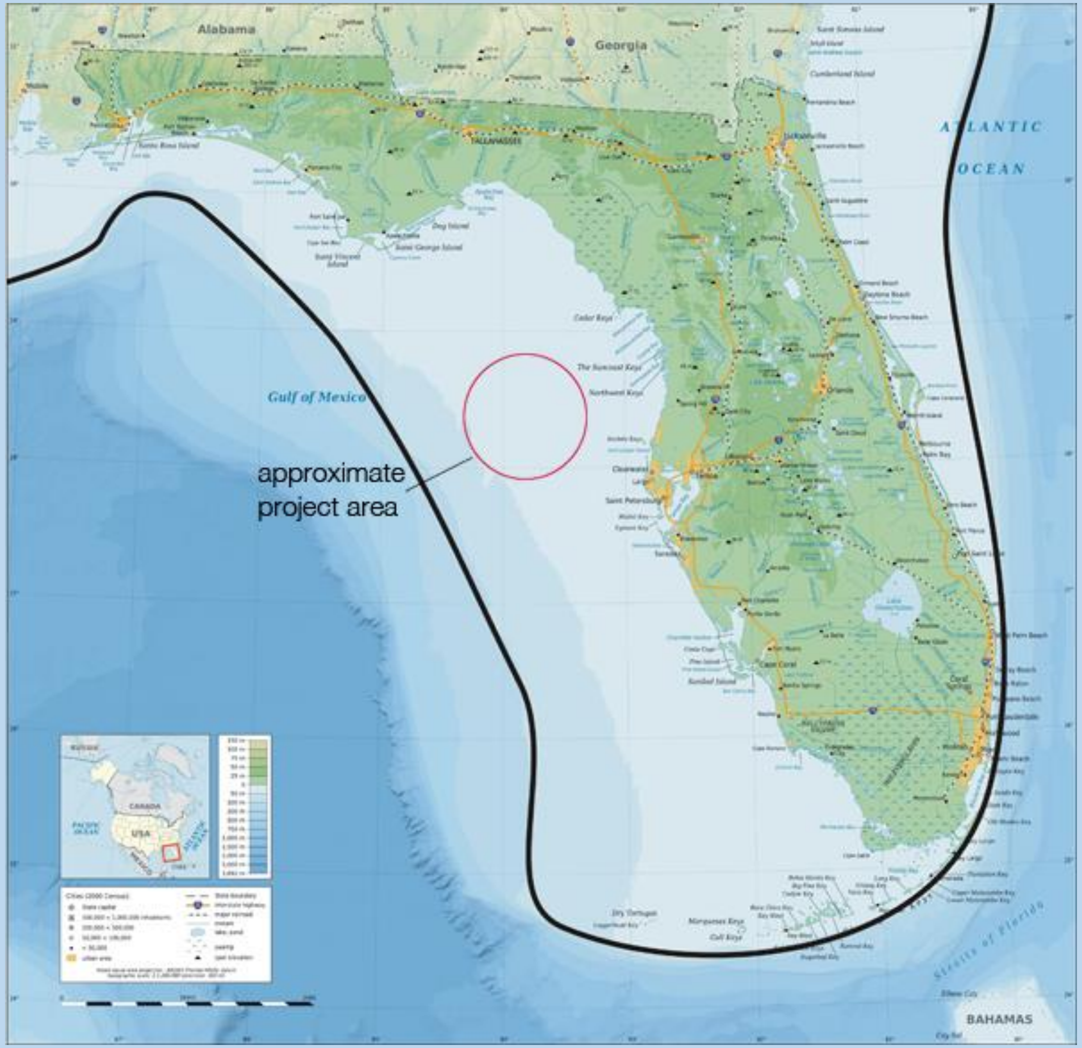


US at
Last Glacial
Maximum
(LGM)
26,500 ya

S New England, E New York, Continental Shelf at LGM ~ 26,000 yBP




150° W
140° W
Laurentide
Ice Sheet
Chukotka
Yukon River
Dawson City
Fairbanks
Klondike
area
Alaska Range
Cordilleran
Ice Sheet
60° N
Hayes volcano
Wrangell / St. Elias
Mountains
Coast Mountains
55° N
Alaskan Peninsula
Aleutian Arc
Emmons caldera
Exposed Bering Land Bridge
(m below present sea level)
50 - 0 m
80 - 50 m
120 - 80 m
0
400 km

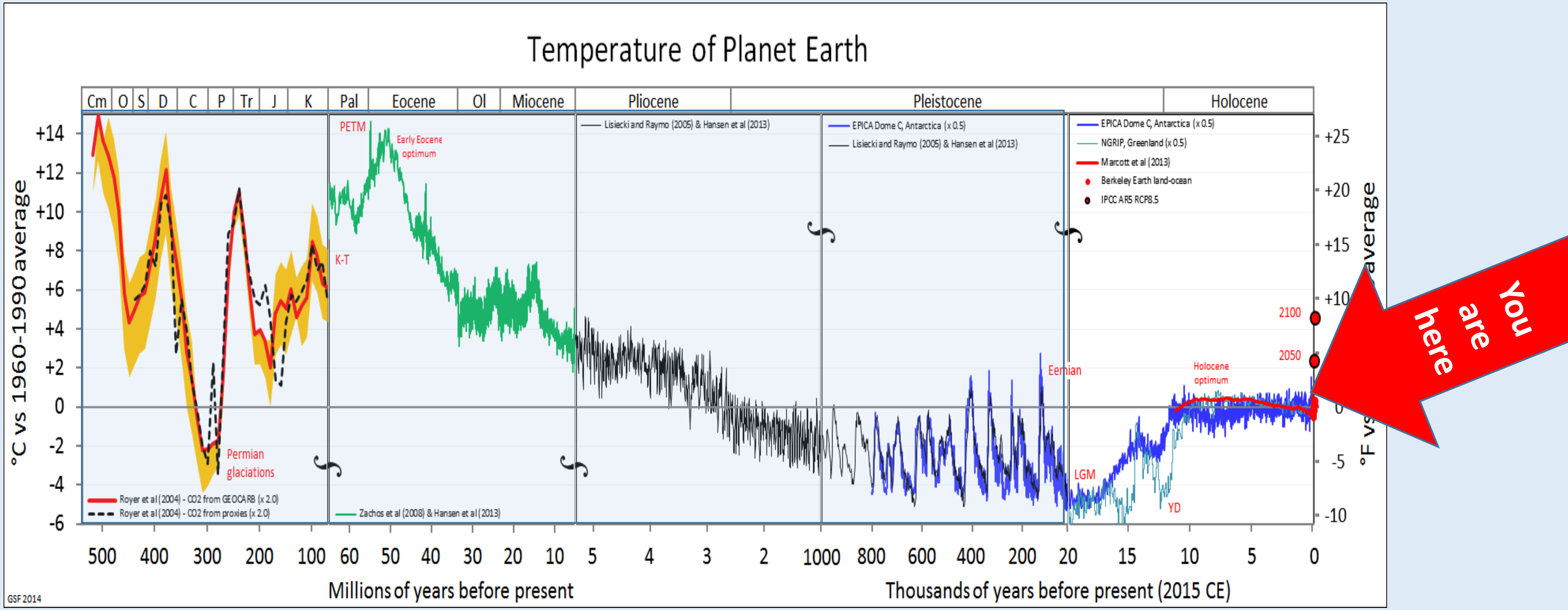

Alabama
Georgia
ATLANTIC
OCEAN
Gulf of Mexico
approximate
project area
BAHAMAS

Ice Ages - cause

- Atmospheric composition, especially greenhouse gases and dust;
- Changes in the Earth’s orbit and inclination;
- The motion of tectonic plates resulting in changes in the landmass distribution;
- Variations in the solar output;
- The impact of large meteorites;
- Eruptions of supervolcanoes

Are We Headed For Another Ice Age?

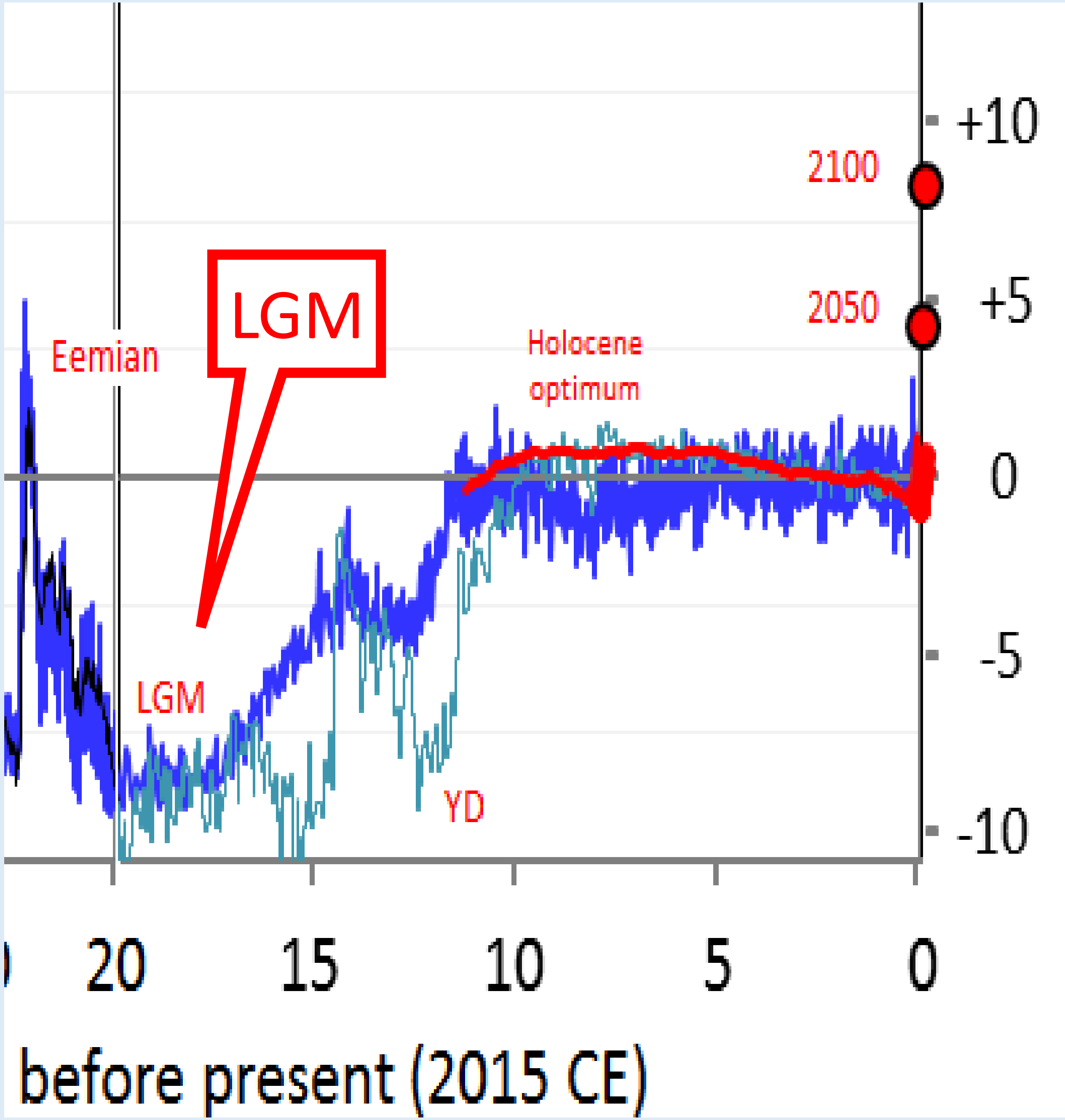
- Heating & Cooling in Historic Times
- Smoke, Haze, CO_2 May Alter Climate
- **Don't Really Know**
- Global warming due to fossil fuels may be catastrophic in many ways, but will probably not much affect these longer-term cycles. We will have run out of fossil fuels long before the duration of a typical interglacial.



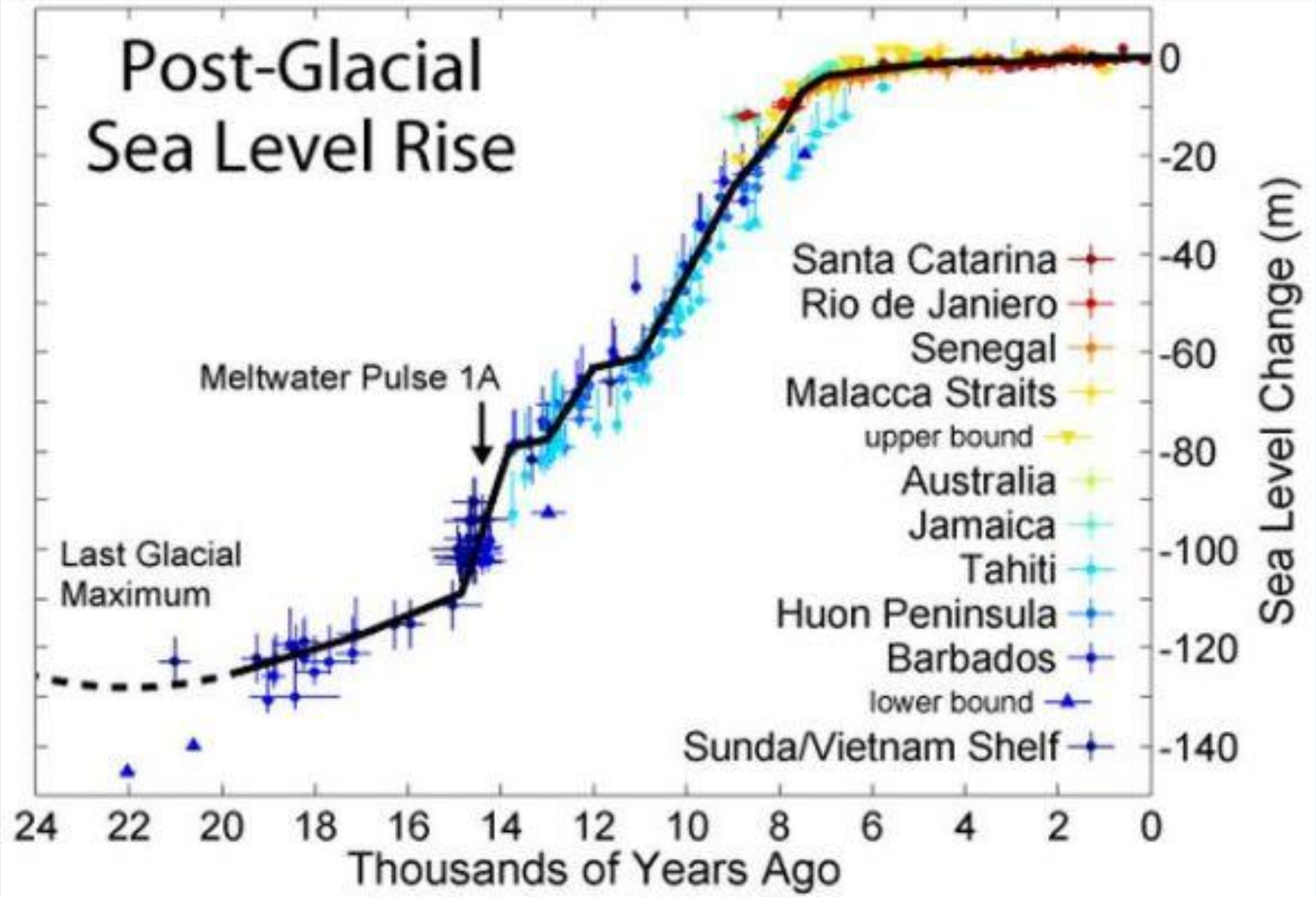
Holocene climate- 20 kya to present(?)

- Glaciers receding
- Warming from last ice age approx. 5 C
- Climate almost constant for 12,000 y
- Reference point for climate change today

Zoom in:



LGM
Eemian
Holocene
optimum
2100
2050
LGM
YD
+10
+5
0
-5
-10
20
15
10
5
0
before present (2015 CE)


Post-Glacial
Sea Level Rise
Meltwater Pulse 1A
Last Glacial
Maximum
Santa Catarina
Rio de Janiero
Senegal
Malacca Straits
upper bound
Australia
Jamaica
Tahiti
Huon Peninsula
Barbados
lower bound
Sunda/Vietnam Shelf
0
-20
-40
-60
-80
-100
-120
-140
Sea Level Change (m)
24
22
20
18
16
14
12
10
8
6
4
2
0
Thousands of Years Ago