Earth’s Systems

Drivers of energy and climate on Earth

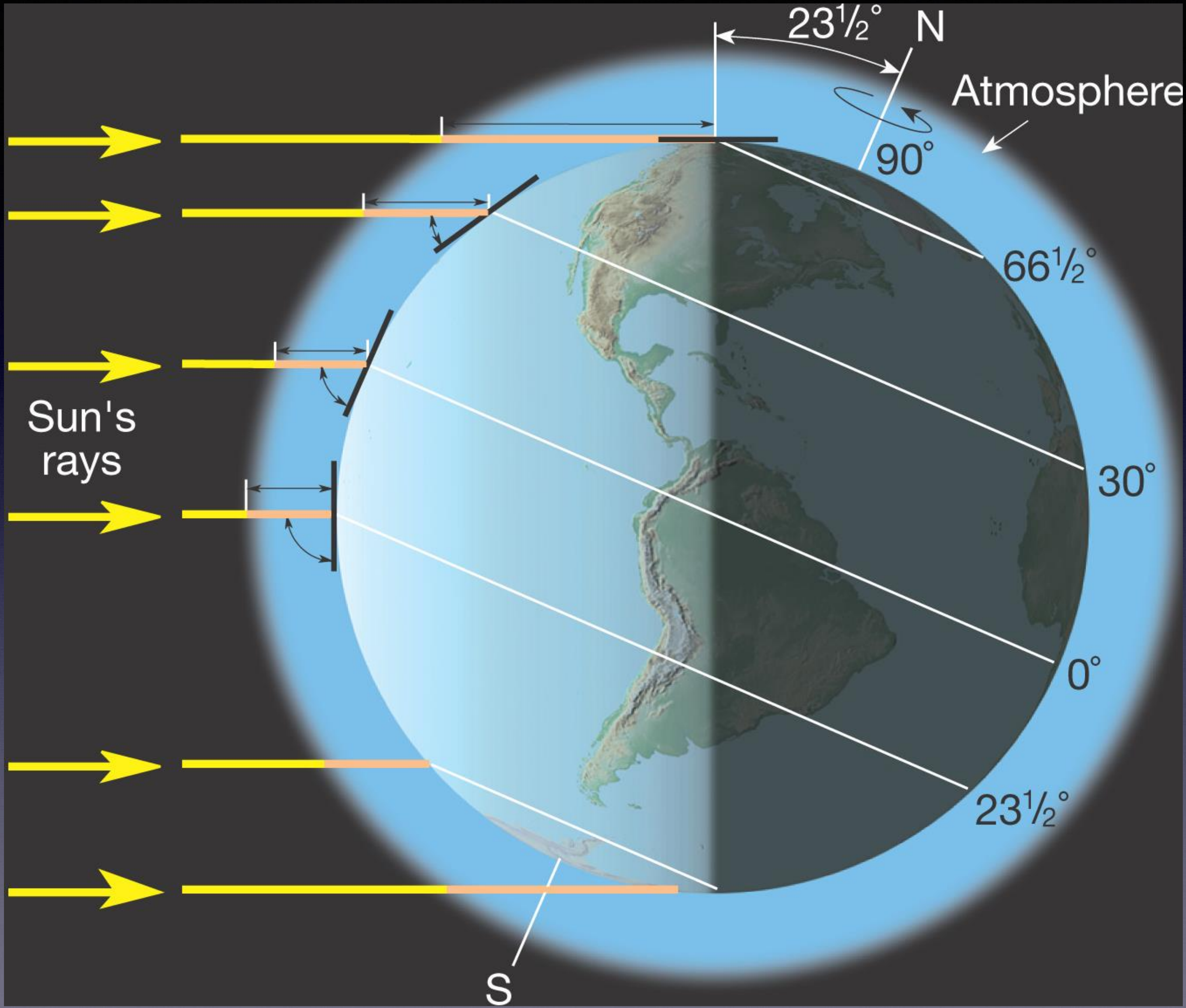
Gas Concentrations in the Atmosphere

- Air has mass: a 1cm^2 column from the earth to the top of the atmosphere weighs approx. 1.04kg.
- Air concentrations (like the ocean) are figured in ppm (parts per million)
- Temperature and water vapor content affect the density of air in the Atmosphere

Composition of Dry Air

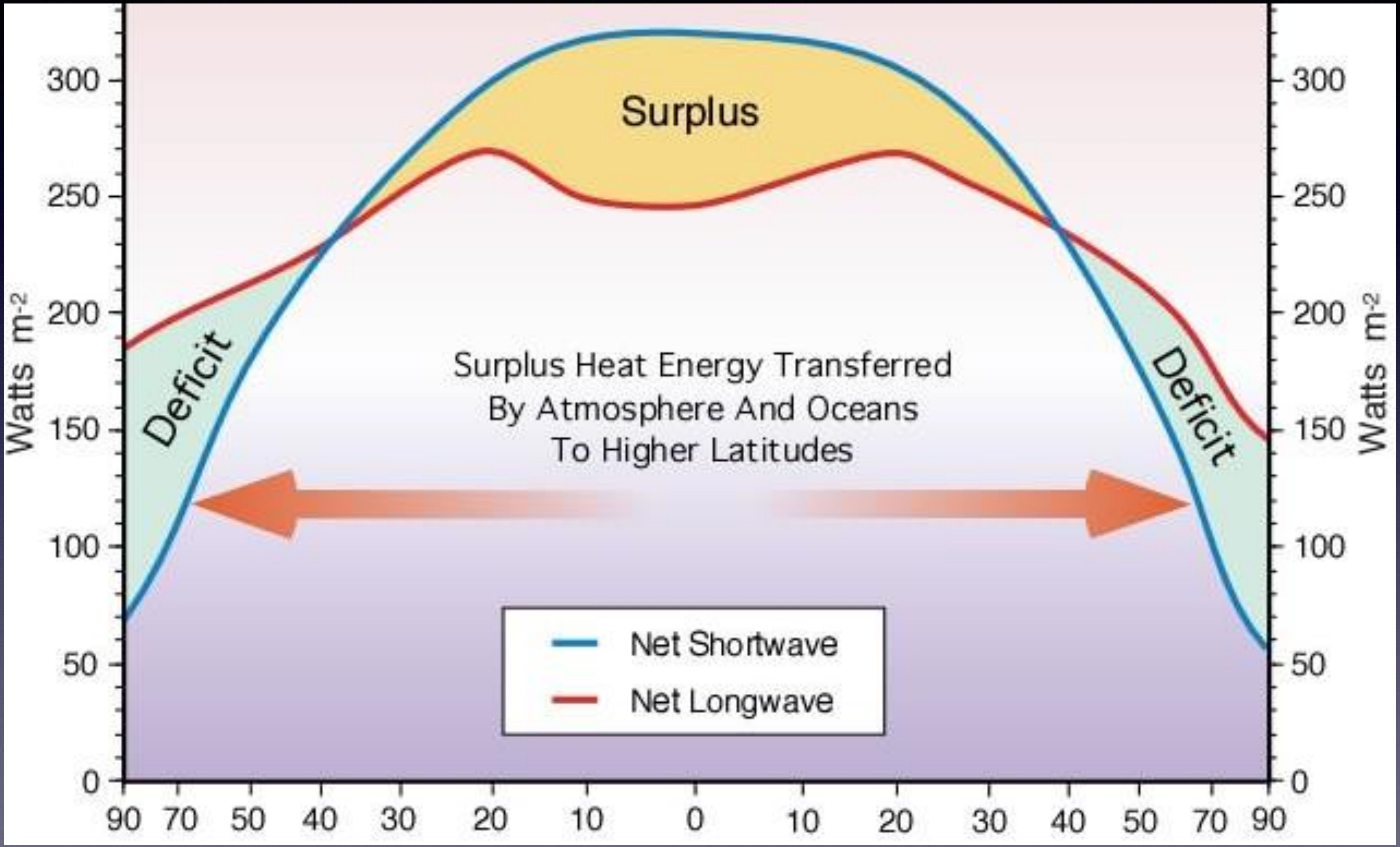
Gas		Concentration	
Name	Symbol	Volume %	ppmv
Nitrogen	N_2	78.084	780,840
Oxygen	O_2	20.947	209,470
Argon	Ar	0.934	9,340
Carbon dioxide	CO_2	0.033	330
Neon	Ne	0.001820	18.20
Helium	He	0.000520	5.20
Methane	CH_4	0.000200	2.00
Krypton	Kr	0.000110	1.10
Sulfur dioxide	SO_2	0.000100	1.00
Hydrogen	H_2	0.000050	0.50
Nitrous oxide	N_2O	0.000050	0.50
Xenon	Xe	0.000009	0.09
Ozone	O_3	0.000007	0.07
Nitrogen dioxide	NO_2	0.000002	0.02

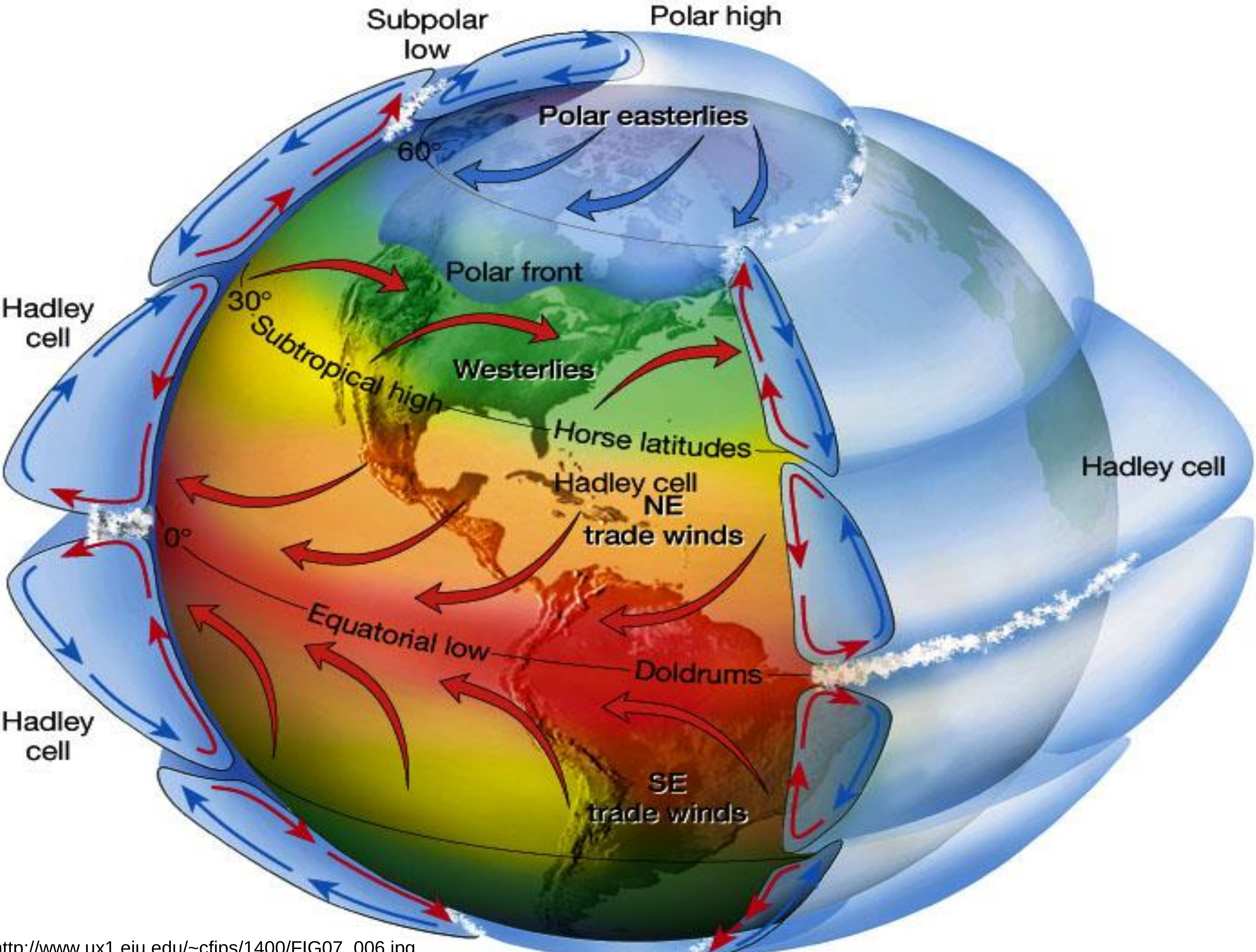
Notes:
-- ppmv = Parts per million parts by volume
-- Water vapor varies up to maximum of 4 volume percent
-- The total volume percent of the listed gases does not equal exactly 100 percent due to rounding numbers



23½°
N
Atmosphere
90°
66½°
Sun's rays
30°
0°
23½°
S

Distribution of Energy





http://www.ux1.eiu.edu/~cfjps/1400/FIG07_006.jpg


Global Climate Change:
Global Warming

Lets first dispel of some misinformation
Intergovernmental Panel of Climate Change

But who is the IPCC?

IPCC (1995): "The balance of evidence suggests a discernible human influence on global climate."

IPCC (2001): "Most of the warming of the past 50 years is likely (>66%) to be attributable to human activities."

IPCC (2007): "Warming is unequivocal, and most of the warming of the past 50 years is very likely (90%) due to increases in greenhouse gases."

IPCC (2013): "Warming of the atmosphere and ocean is unequivocal. Many of the associated impacts such as sea level change (among other metrics) have occurred since 1950 at rates unprecedented in the historical record.

There is a clear human impact on the climate. It is extremely likely that human influence has been the dominant cause of observed warming since 1950, with the level of confidence having increased since the fourth report."

The IPCC (Intergovernmental Panel on Climate Change) Sequence of Key Findings……

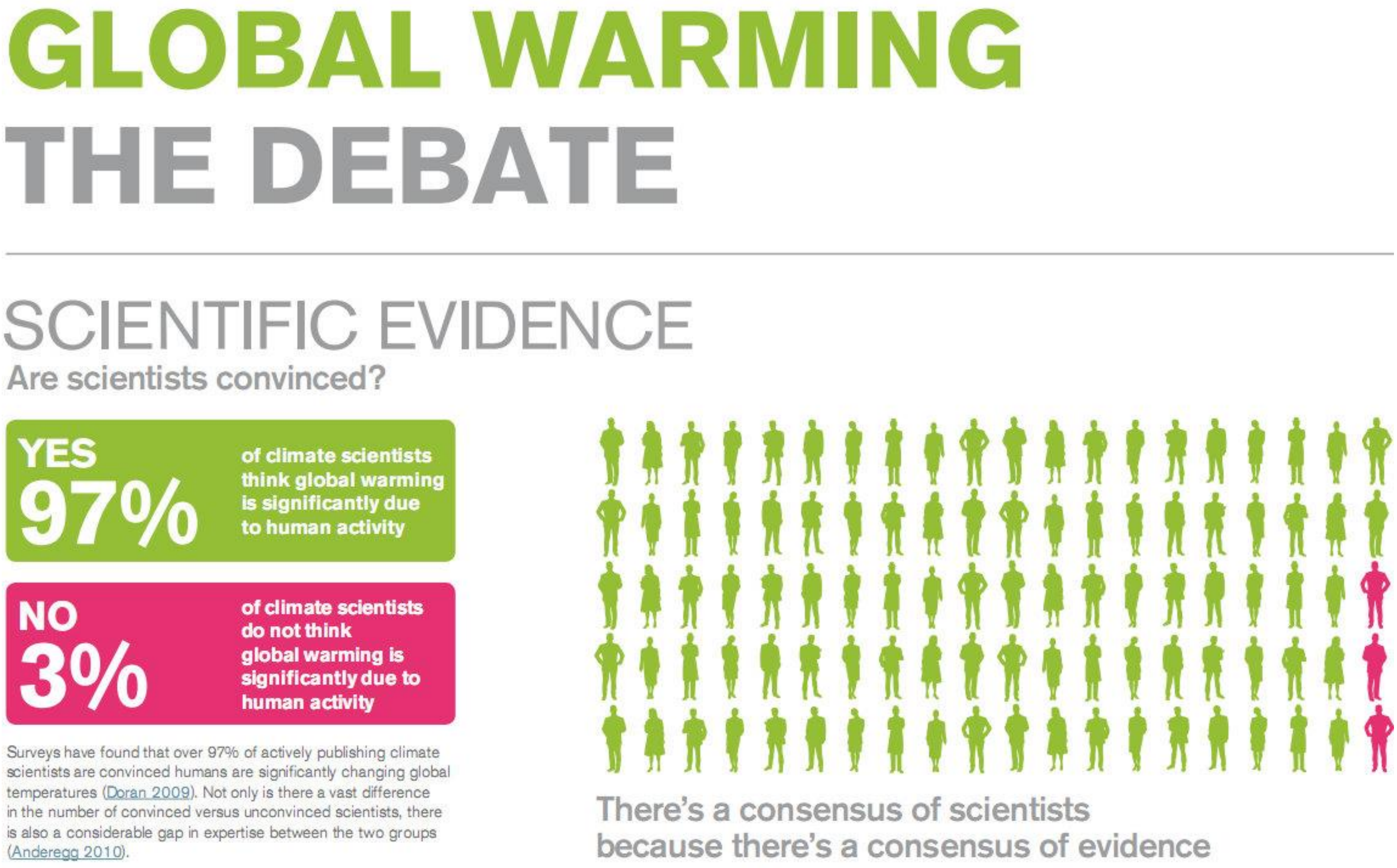
IPPC 2018 Report

A.1 Human activities are estimated to have caused approximately 1.0°C of global warming[5] above pre-industrial levels, with a *likely* range of 0.8°C to 1.2°C. Global warming is *likely* to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. (*high confidence*)

A.2 Warming from anthropogenic emissions from the pre-industrial period to the present will persist for centuries to millennia and will continue to cause further long-term changes in the climate system, such as sea level rise, with associated impacts (*high confidence*).

A.3 Climate-related risks for natural and human systems are higher for global warming of 1.5°C than at present, but lower than at 2°C (*high confidence*). These risks depend on the magnitude and rate of warming, geographic location, levels of development and vulnerability, and on the choices and implementation of adaptation and mitigation options (*high confidence*).

Scientific consensus: Earth's climate is warming



U.S. Agencies

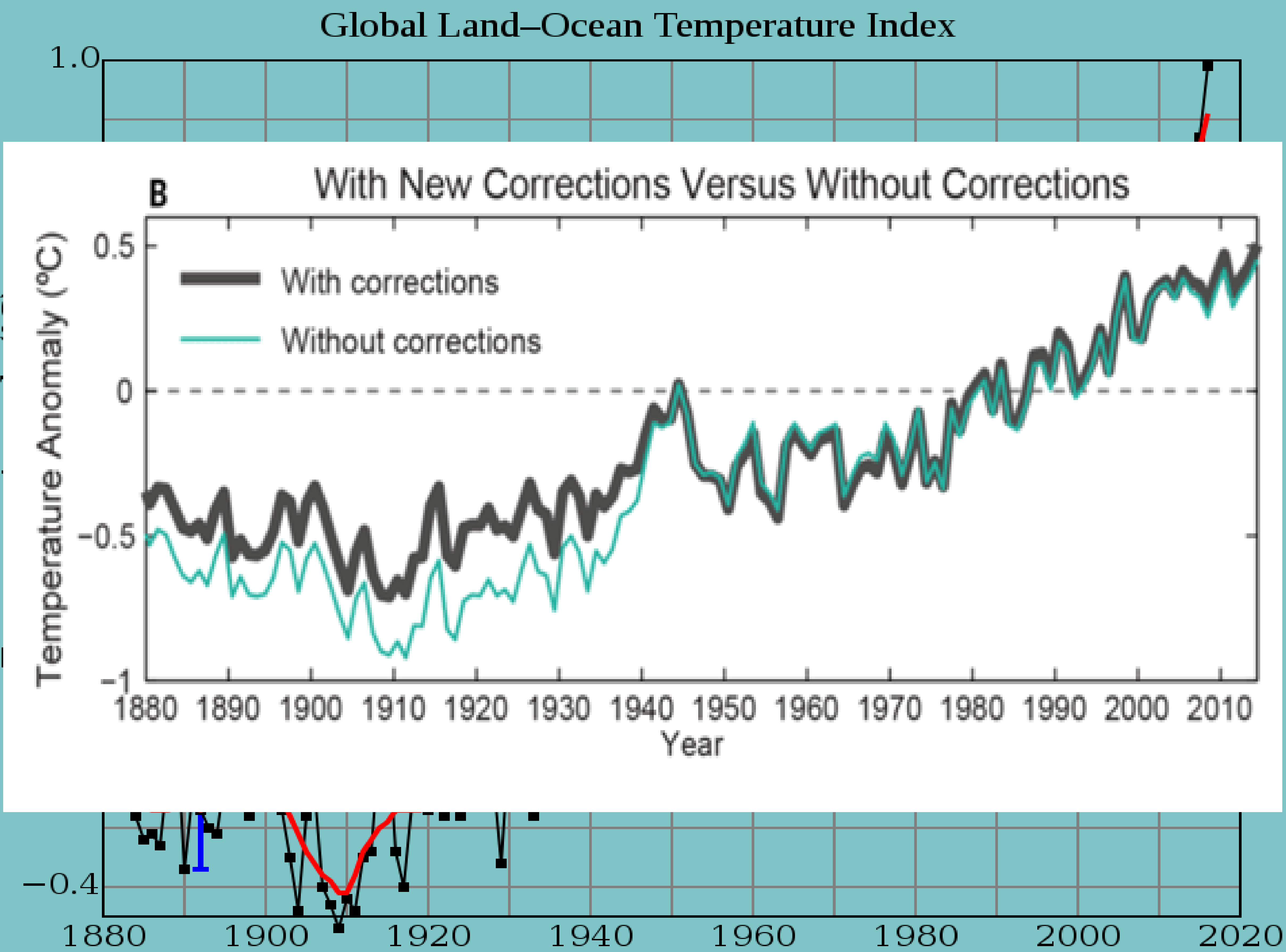
Worldwide Agencies

Now . . . It is true that scientific consensus does not equal "truth".

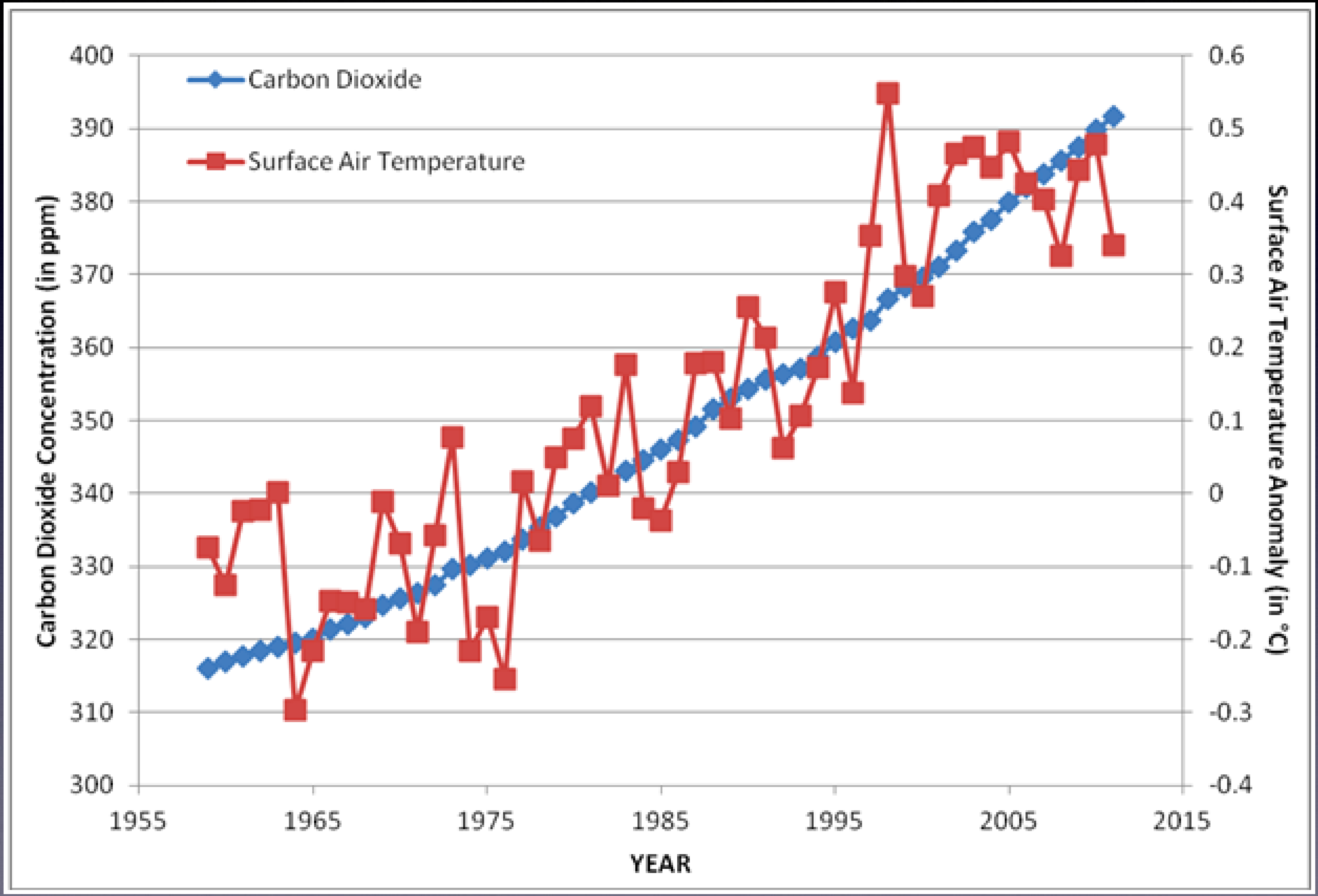
However, in science, a consensus is reached when the **preponderance of evidence** supports a particular position over others.

If you are not an expert in a particular field on what basis are you denying the consensus?

Is the planet warming?



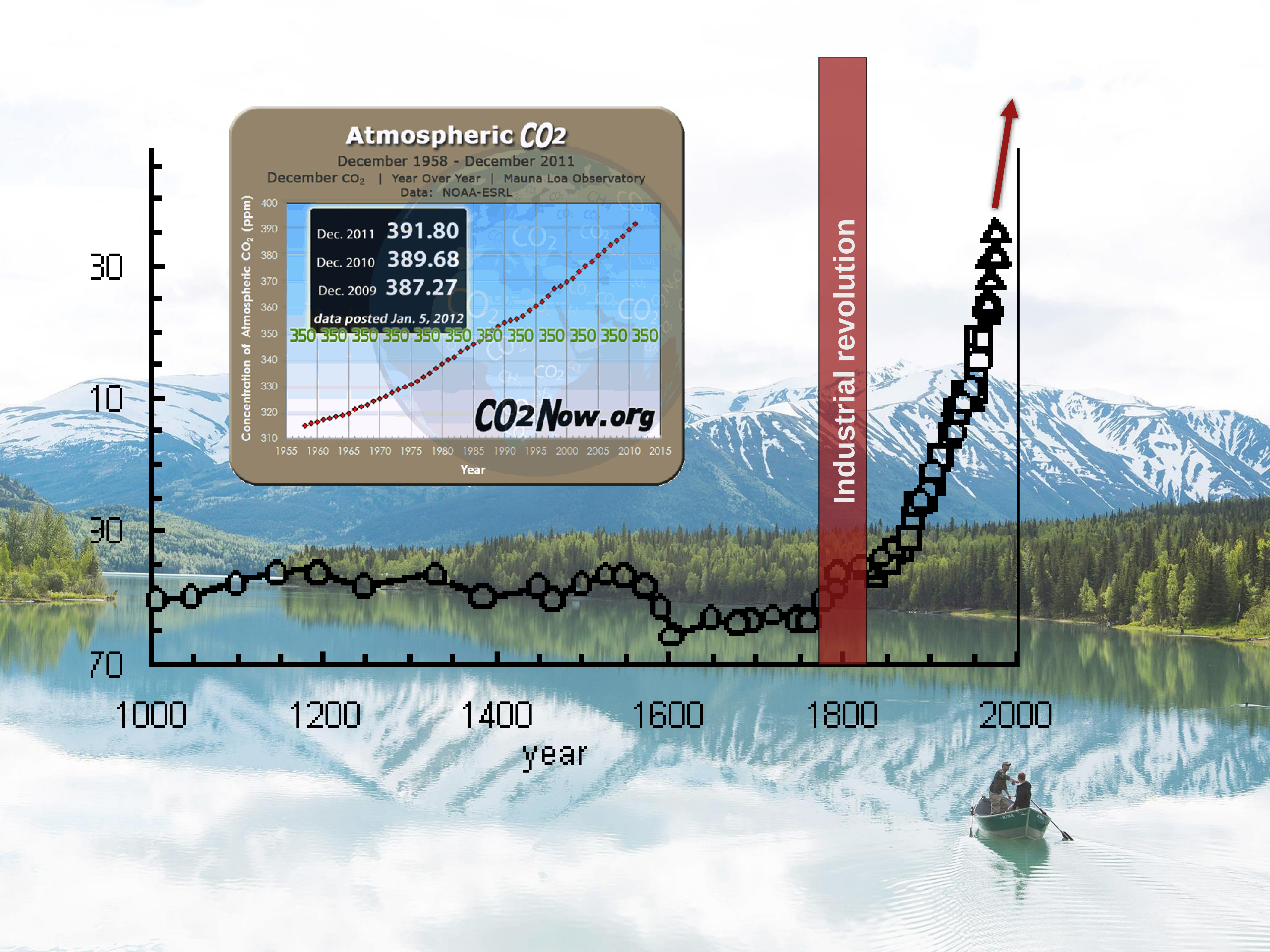
Beyond the Natural Cycle



Why do we always hear about CO_2 when discussing Global Warming?

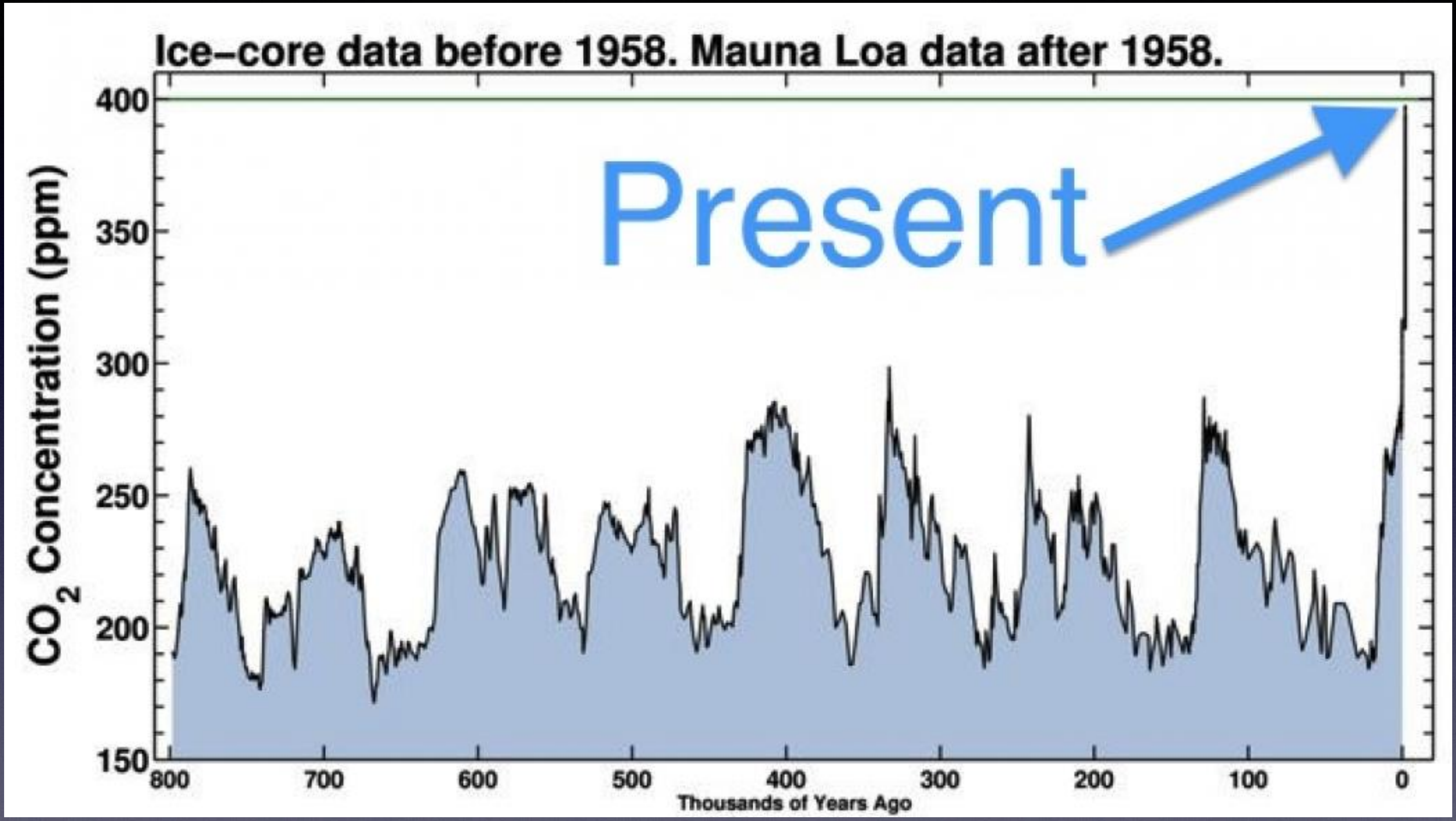
Temperature and Carbon Dioxide (CO_2) levels are very closely linked

When CO_2 levels are high - temperatures are high.
When CO_2 levels are low temperatures are low.



Atmospheric CO2
December 1958 - December 2011
December CO₂ | Year Over Year | Mauna Loa Observatory
Data: NOAA-ESRL
Concentration of Atmospheric CO₂ (ppm)
Dec. 2011 391.80
Dec. 2010 389.68
Dec. 2009 387.27
data posted Jan. 5, 2012
350 350 350 350 350 350 350 350 350 350 350 350
CO2Now.org
Year
Industrial revolution
30
10
30
70
1000
1200
1400
1600
1800
2000
year

Beyond the Natural Cycle



Nothing this high over the last 1 million years (ice core records). Need to go back 15-20 million years to find equivalent levels (estimated at ca. 400 ppm — and the world was very different!)

So, the question is not whether or not climate change/global warming is happening because it is a **SCIENTIFIC FACT** that it is . . .

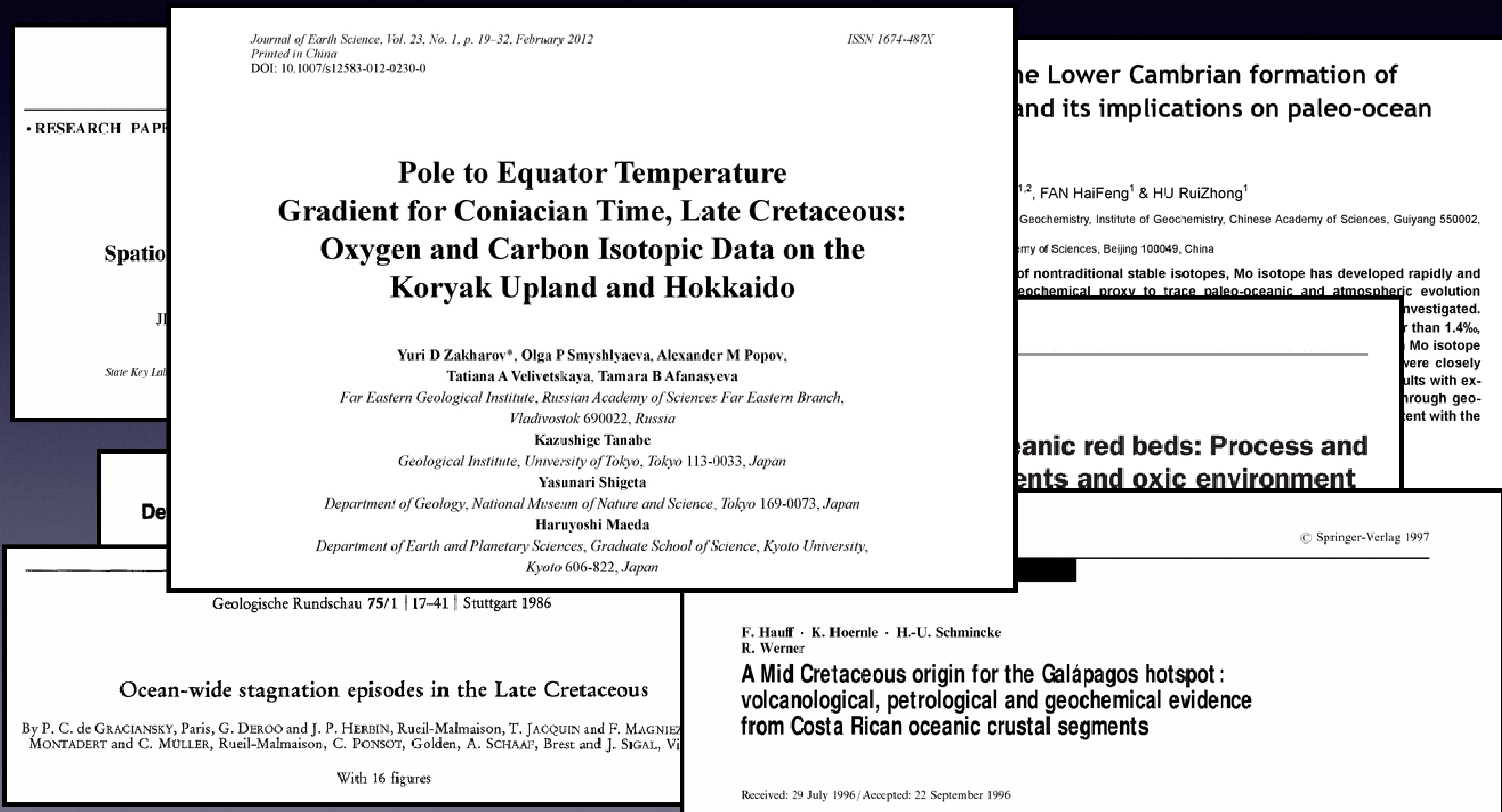
A better question to ask is . . .

“whether the global warming we are experiencing is caused by human activity or just part of a natural cycle that occurs on earth?”

To answer and understand this question we must first discuss . . .

- 1) . . . how scientists gather data on an ancient earth
- 2) . . . the natural processes on Earth that control climate (i.e. solar radiation, albedo, greenhouse gases etc.)
- 3) . . . Natural feedback processes that control climate
- 4) . . . how carbon is stored on earth

How do we gather data. (i.e. how do we know the CO^2 levels, oxygen levels, temperatures etc. of the earth – present, past and distant past?)



Journal of Earth Science, Vol. 23, No. 1, p. 19–32, February 2012
Printed in China
DOI: 10.1007/s12583-012-0230-0
ISSN 1674-487X

Pole to Equator Temperature Gradient for Coniacian Time, Late Cretaceous: Oxygen and Carbon Isotopic Data on the Koryak Upland and Hokkaido

Yuri D Zakharov*, Olga P Smyshlyaeva, Alexander M Popov, Tatiana A Velivetskaya, Tamara B Afanasyeva
Far Eastern Geological Institute, Russian Academy of Sciences Far Eastern Branch, Vladivostok 690022, Russia
Kazushige Tanabe
Geological Institute, University of Tokyo, Tokyo 113-0033, Japan
Yasunari Shigeta
Department of Geology, National Museum of Nature and Science, Tokyo 169-0073, Japan
Haruyoshi Maeda
Department of Earth and Planetary Sciences, Graduate School of Science, Kyoto University, Kyoto 606-822, Japan

Geologische Rundschau 75/1 | 17–41 | Stuttgart 1986

Ocean-wide stagnation episodes in the Late Cretaceous

By P. C. de Graciansky, Paris, G. Deroo and J. P. Herbin, Rueil-Malmaison, T. Jacquin and F. Magniez
Montadert and C. Müller, Rueil-Malmaison, C. Ponsot, Golden, A. Schaaf, Brest and J. Sigal, Vi

With 16 figures

© Springer-Verlag 1997

F. Hauff · K. Hoernle · H.-U. Schmincke
R. Werner

A Mid Cretaceous origin for the Galápagos hotspot: volcanological, petrological and geochemical evidence from Costa Rican oceanic crustal segments

Received: 29 July 1996 / Accepted: 22 September 1996

he Lower Cambrian formation of
and its implications on paleo-ocean

1,2, FAN HaiFeng[1] & HU RuiZhong[1]

Geochemistry, Institute of Geochemistry, Chinese Academy of Sciences, Guiyang 550002,
emy of Sciences, Beijing 100049, China

of nontraditional stable isotopes, Mo isotope has developed rapidly and

eanic red beds: Process and
ents and oxic environment

• RESEARCH PAPE

Spatio

Proxies

Paleoclimate indicators for temperature

- A climate proxy is something that records or reflects a change in temp or rainfall but does not DIRECTLY measure temperature or precipitation

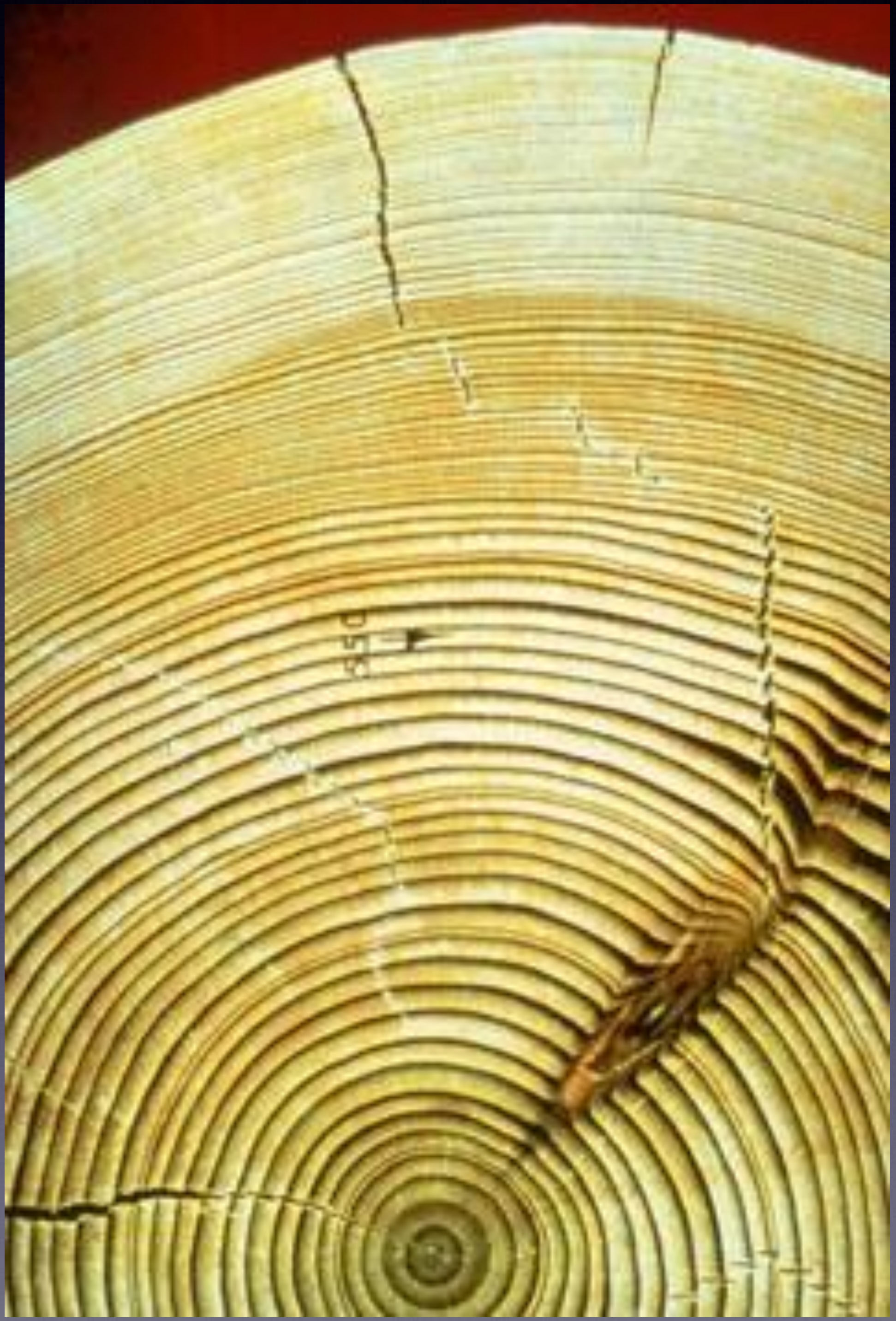
For example…

For more recent temperatures (~1000 yrs) we can utilize tree ring data

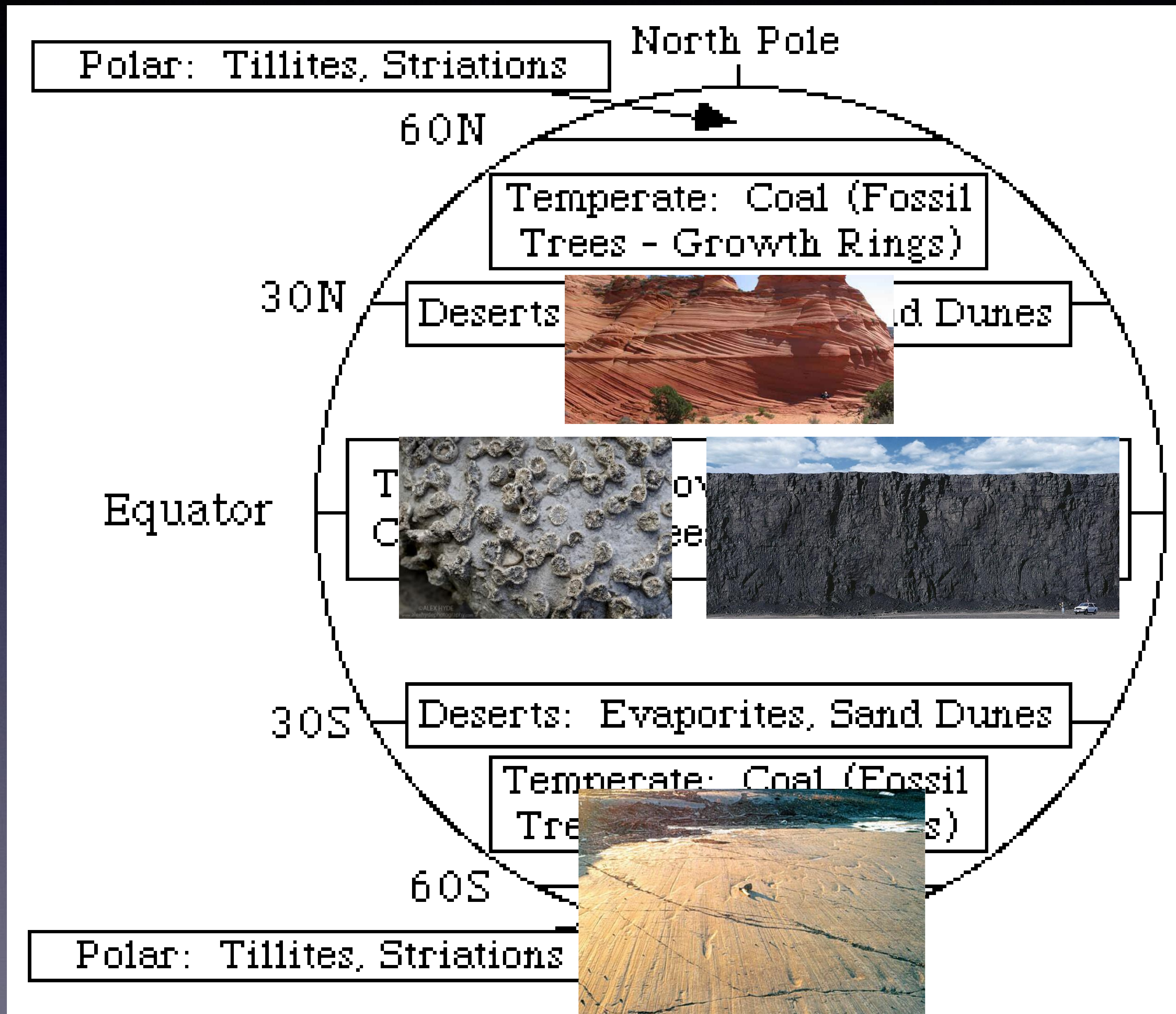
- In the tropics there is no difference in growing seasons thus tree rings are not well developed.

- In cold regions temperature is the limiting factor for tree growth.

- In dry environments rain fall is the main driver for tree growth



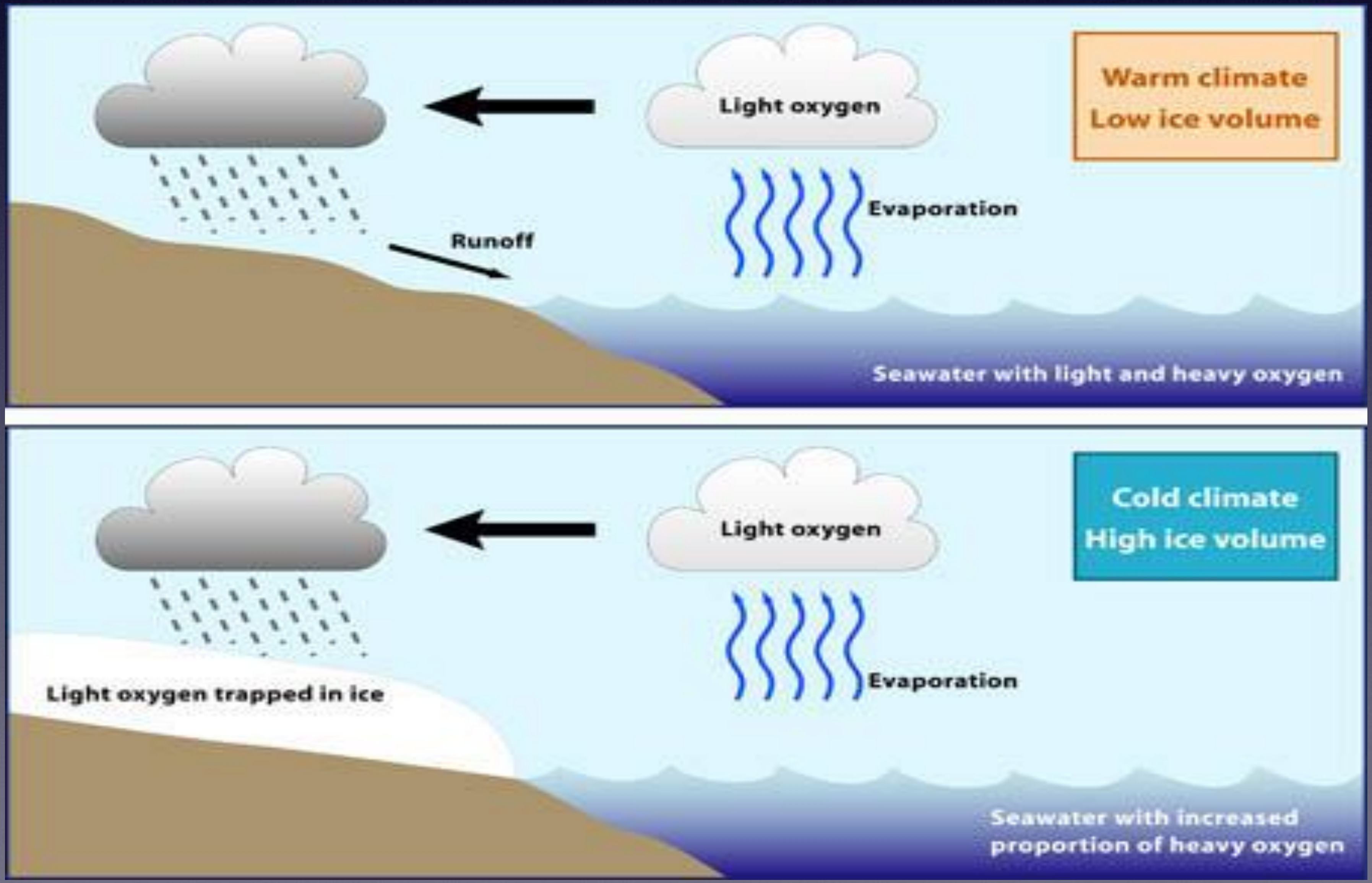
Rock types as proxies for climate



Stable Isotopes as Proxies

Stable isotopes of oxygen: a proxy for temperature but now considered almost a direct measurement

Stable isotopes: do not decay over time.
Ex, O_{16} and O_{18}.



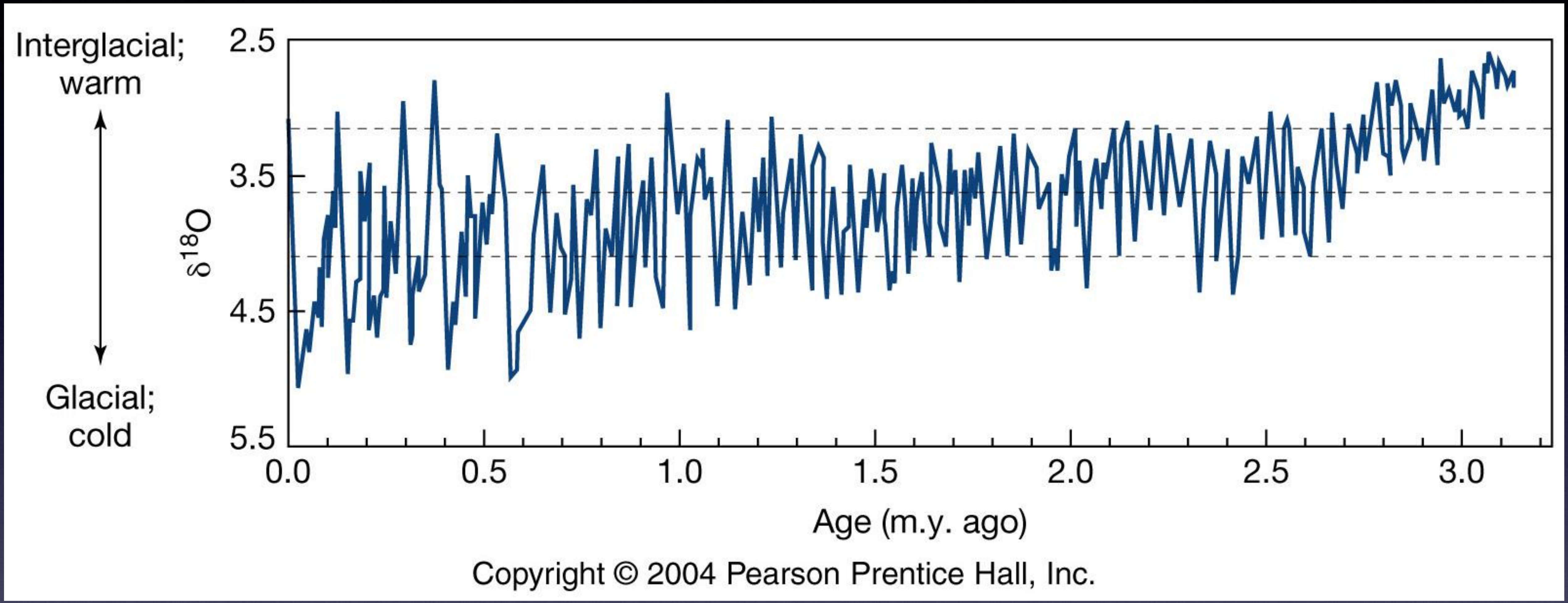
If we collect a shell made out of $Ca(PO_4)^3$, we can analyze the O_{18}:O_{16} ratio by the following formula:

$$\text{delta } O_{18} = [(O_{18}/O_{16} \text{ sample}/O_{18}/O_{16} \text{ standard}) - 1] \times 1000$$

The standard that your sample is compared to is either one prepared from ocean water or from a fossil standard.

Positive delta O_{18} values mean that your sample is enriched in the heavy O isotope (warm periods); negative delta O_{18} values mean it's depleted in the heavy O_{18}.(cold periods)

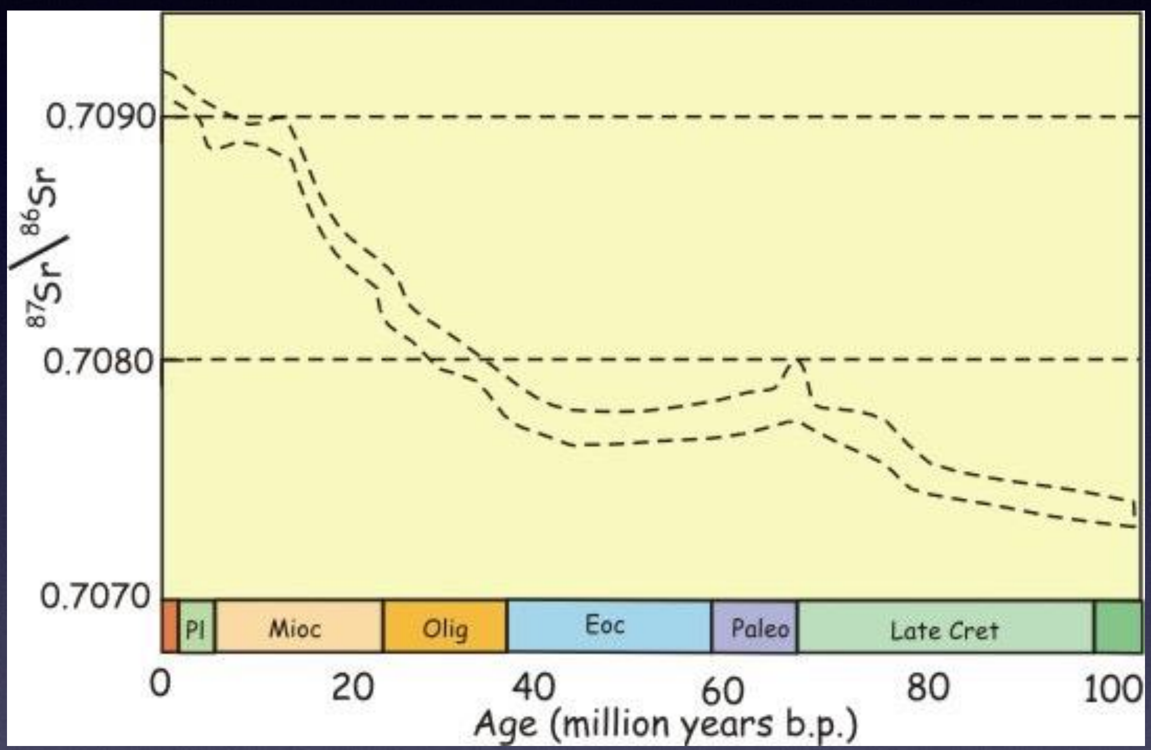
Oxygen Isotopes Reveal Higher Frequency Variation



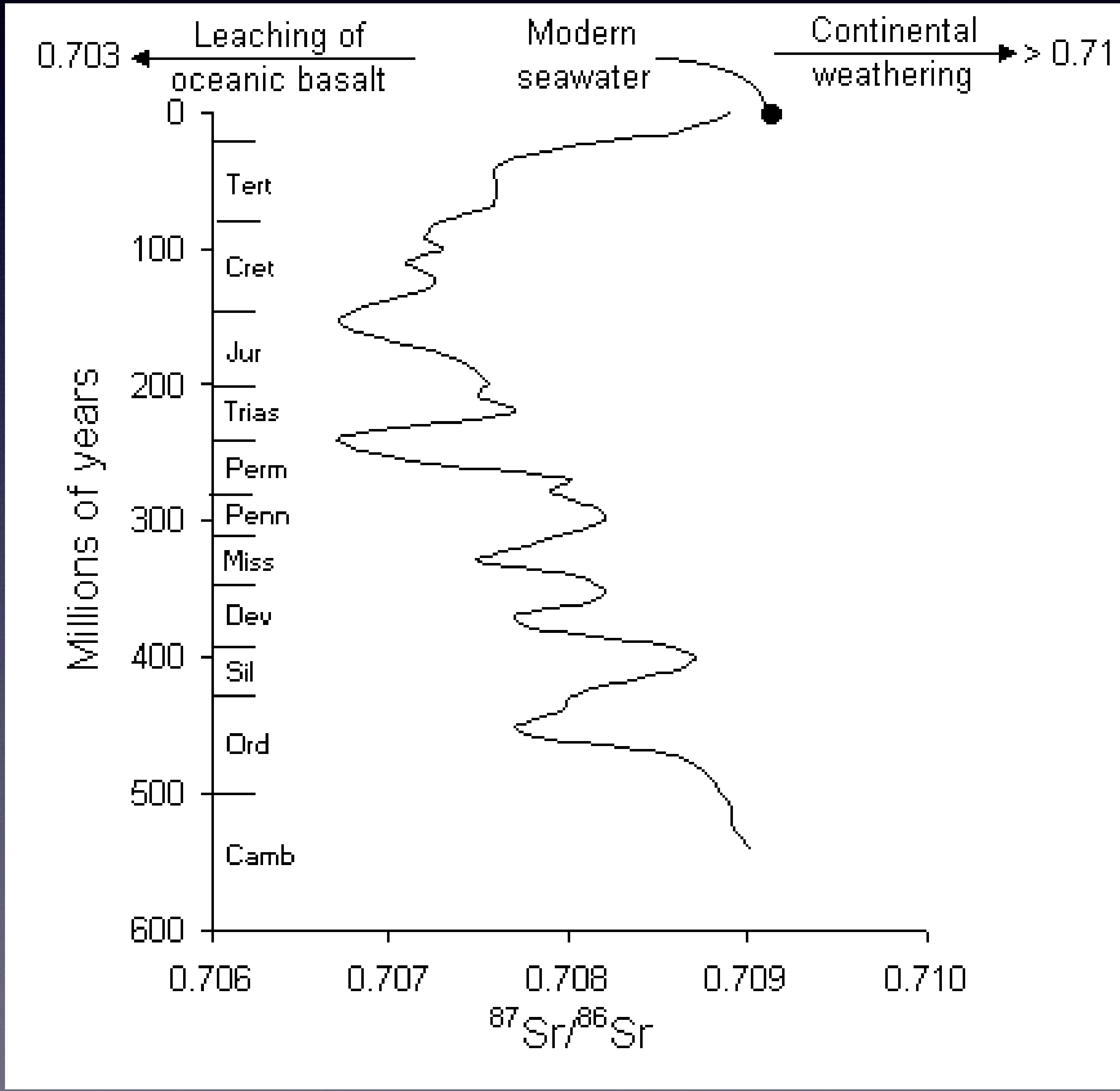
\+ delta O_{18} values mean that your sample is enriched in the heavy O isotope = **warm period (Interglacial)**

\- delta O_{18} values mean that your sample is depleted in the heavy O isotope = **cold periods (Glacial)**

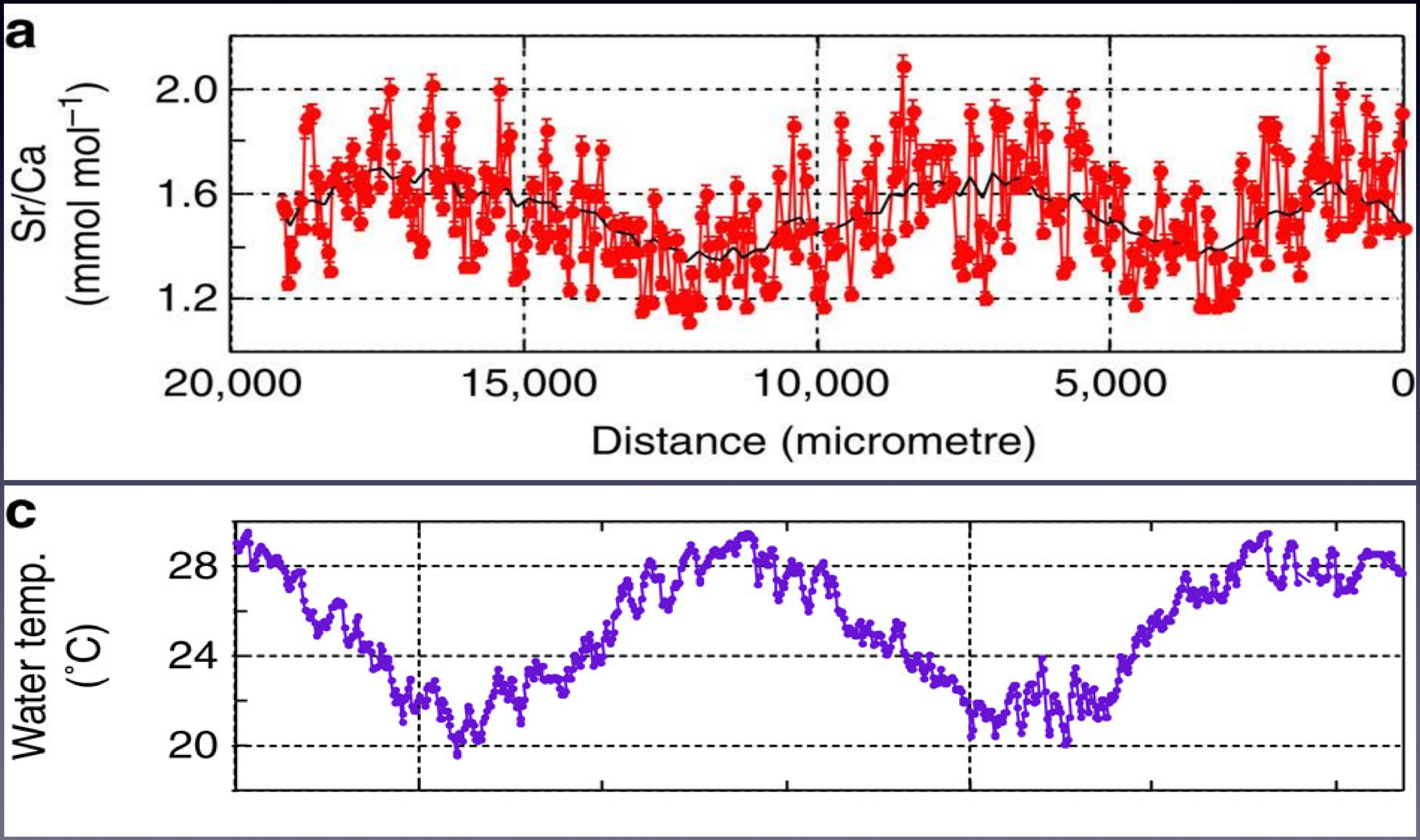
Sr_{87}/Sr_{86}
a proxy for salinity/rainfall (evap. vs ppt)



During wet climates, more Sr is released from weathering minerals in granite

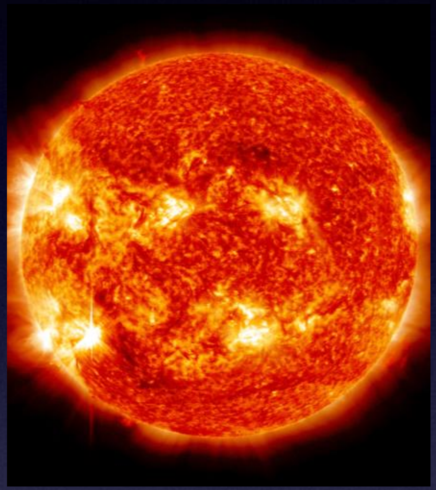


Not proxies, but direct measures Sr:Ca ratios in aragonite: a measure of seawater temperature




Earth’s Natural
Climate Processes

The Earth's surface temperature depends on three factors:

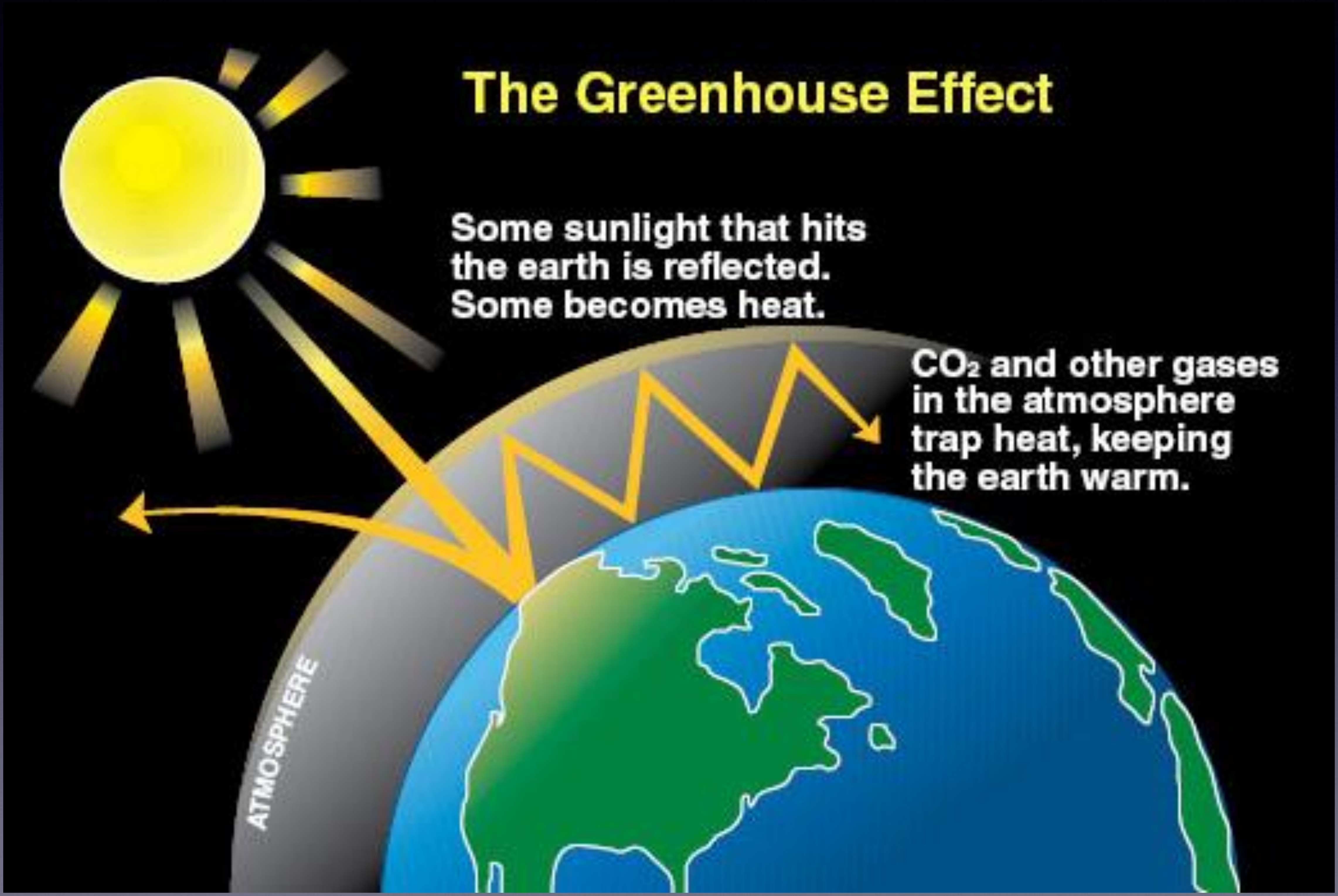


(1) The solar flux

(2) Earth's reflectivity (albedo)

(3) The amount of warming provided by the atmosphere (i.e., the greenhouse effect)

Greenhouse gases warm the planet's surface by absorbing infrared radiation and reradiating some of it back toward the surface.



Without our Greenhouse Effect, our average surface temperature would be about 33°C (59°F) colder.

0°F

The Earth would be icy and desolate.

The three most abundant components in the atmosphere—nitrogen, oxygen, and argon. (these are not greenhouse gases)

Other less abundant gases exert strong greenhouse effects.

The defining property of a greenhouse gas is its ability to absorb and (re)emit infrared radiation.

TABLE 3-2

Major Constituents of Earth's Atmosphere Today

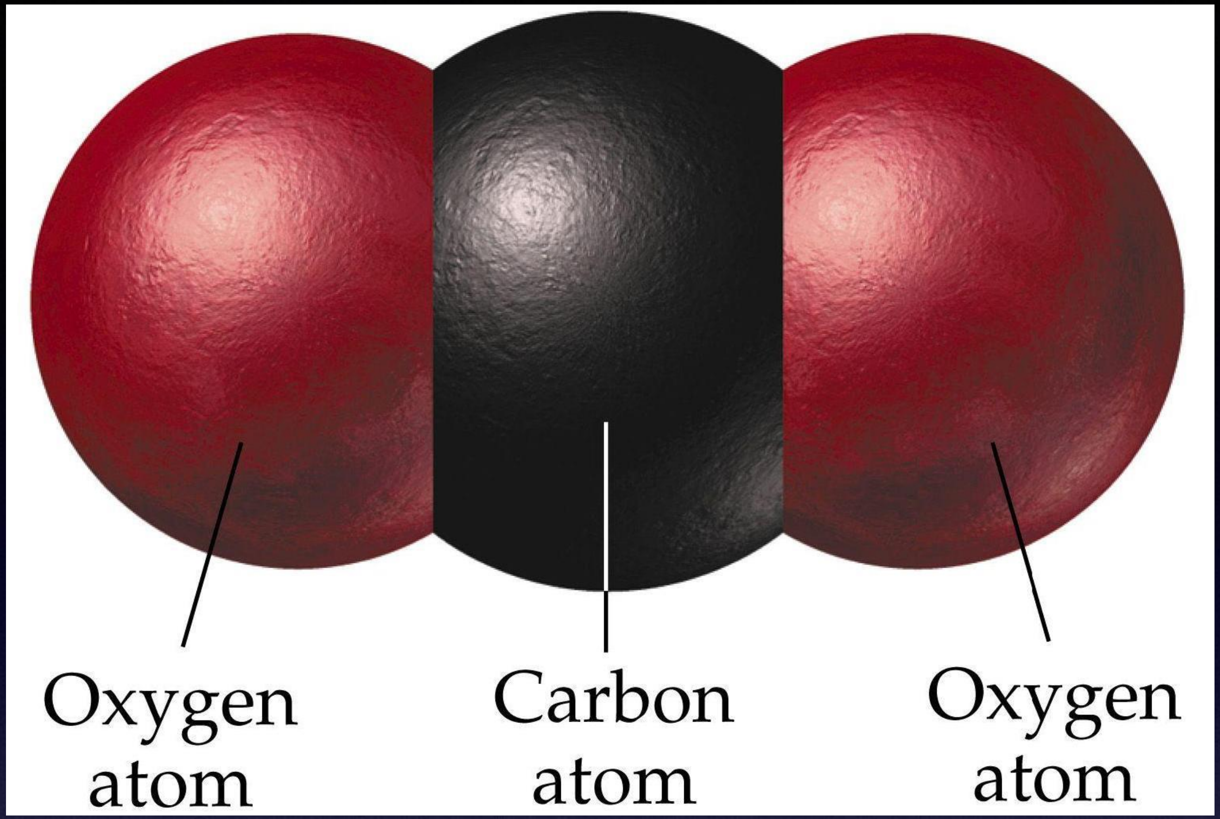
Name and Chemical Symbol	***Concentration (% by volume)***
Nitrogen, N_2	78
Oxygen, O_2	21
Argon, Ar	0.9
Water vapor, H_2O	0.00001 (South Pole)–4 (tropics)
Carbon dioxide, CO_2	0.037*

*In 2002

Trace Gases / Greenhouse Gases

TABLE 3-3

Important Atmospheric Greenhouse Gases	
Name and Chemical Symbol	***Concentration (ppm by volume)***
Water vapor, H_2O	0.1 (South Pole)–40,000 (tropics)
Carbon dioxide, CO_2	**409 in 2017**
Methane, CH_4	1.7
Nitrous oxide, N_2O	0.3
Ozone, O_3	0.01 (at the surface)
Freon-11, CCl_3F	0.00026
Freon-12, CCl_2F_2	0.00054



Different gases absorb efficiently at different wavelengths (beyond those dominated by CO_2 and H_2O)—thus increasing the importance of the low concentration gases. Nevertheless, the Earth's surface emits strongly in CO_2 wavelength region.

CO_2 is a critical greenhouse gas.

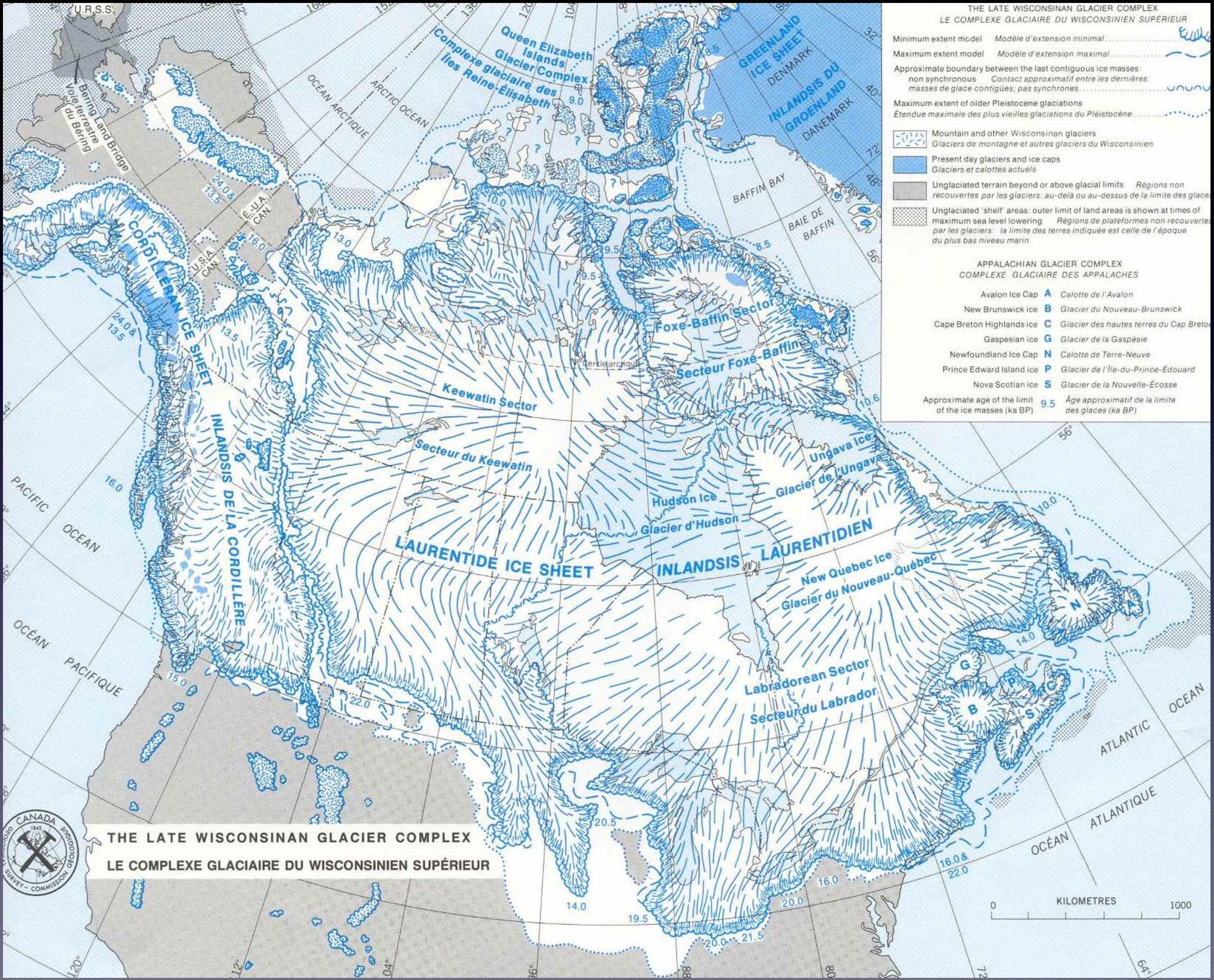
Concentrations and contributions of the main greenhouse gases in the atmosphere.

Relative molecular efficiency is also given, relative to that of CO_2.

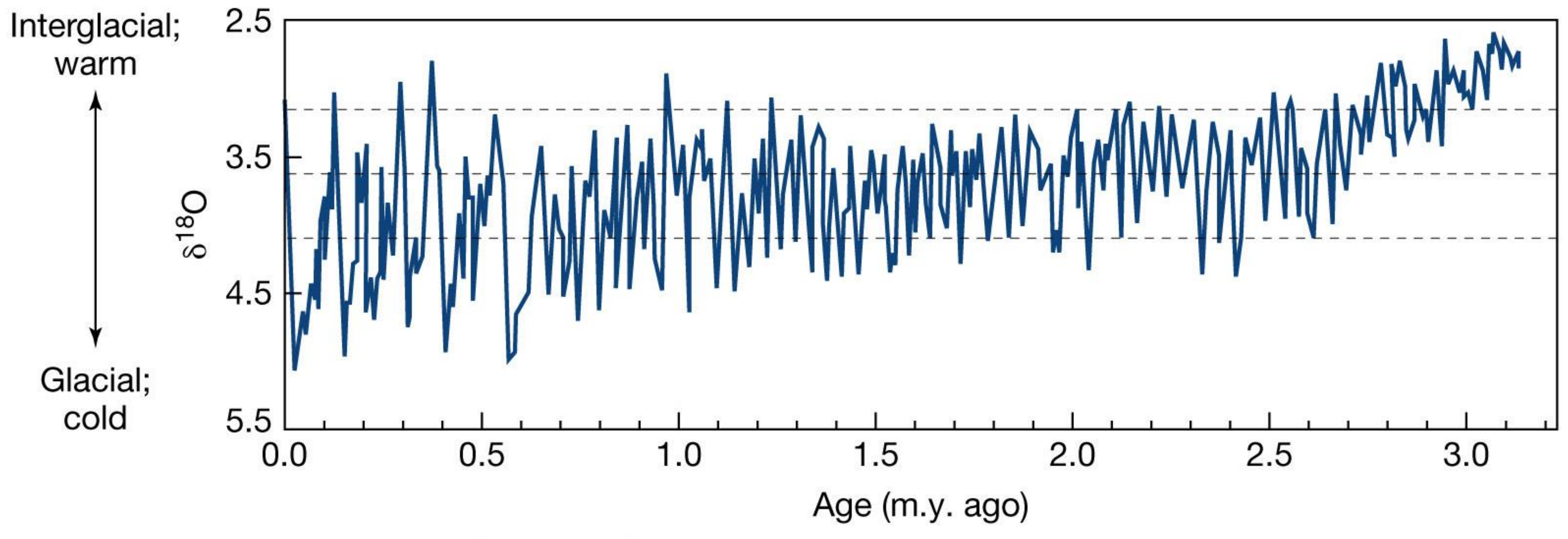
	H_2O	CO_2	CH_4	N_2O	O_3	O_2	N_2
% conc. in atmos.	0.3	0.04	0.00018	0.00003	0.000003	21	78
Contrib. to GHG effect in %	55	39	2	2	2	_	_
Relative efficiency of contrib.	0.15	1	10	60	600		

Natural and Unnatural Drivers of Climate

The Carbon Cycle


THE LATE WISCONSINAN GLACIER COMPLEX
LE COMPLEXE GLACIAIRE DU WISCONSINIEN SUPÉRIEUR
Minimum extent model Modèle d'extension minimal
Maximum extent model Modèle d'extension maximal
Approximate boundary between the last contiguous ice masses: non synchronous Contact approximatif entre les dernières masses de glace contigües; pas synchrones
Maximum extent of older Pleistocene glaciations Étendue maximale des plus vieilles glaciations du Pléistocène
Mountain and other Wisconsinan glaciers Glaciers de montagne et autres glaciers du Wisconsinien
Present day glaciers and ice caps Glaciers et calottes actuels
Unglaciated terrain beyond or above glacial limits Régions non recouvertes par les glaciers: au-delà ou au-dessus de la limite des glaces
Unglaciated 'shelf' areas: outer limit of land areas is shown at times of maximum sea level lowering Régions de plateformes non recouvertes par les glaciers: la limite des terres indiquée est celle de l'époque du plus bas niveau marin
APPALACHIAN GLACIER COMPLEX
COMPLEXE GLACIAIRE DES APPALACHES
Avalon Ice Cap A Calotte de l'Avalon
New Brunswick ice B Glacier du Nouveau-Brunswick
Cape Breton Highlands ice C Glacier des hautes terres du Cap Breton
Gaspesian ice G Glacier de la Gaspésie
Newfoundland Ice Cap N Calotte de Terre-Neuve
Prince Edward Island ice P Glacier de l'Île-du-Prince-Édouard
Nova Scotian ice S Glacier de la Nouvelle-Écosse
Approximate age of the limit of the ice masses (ka BP) 9.5 Âge approximatif de la limite des glaces (ka BP)
Queen Elizabeth Islands Glacier Complex
Complexe glaciaire des îles Reine-Élisabeth
GREENLAND ICE SHEET
INLANDSIS DU GROENLAND
DENMARK
DANEMARK
BAFFIN BAY
BAIE DE BAFFIN
ARCTIC OCEAN
OCÉAN ARCTIQUE
U.R.S.S.
Bering Land Bridge
Voie terrestre du Béring
É.-U.A. CAN
U.S.A. CAN
CORDILLERAN ICE SHEET
INLANDSIS DE LA CORDILLÈRE
Foxe-Baffin Sector
Secteur Foxe-Baffin
Keewatin Sector
Secteur du Keewatin
Hudson Ice
Glacier d'Hudson
Ungava Ice
Glacier de l'Ungava
LAURENTIDE ICE SHEET
INLANDSIS LAURENTIDIEN
New Quebec Ice
Glacier du Nouveau-Québec
Labradorean Sector
Secteur du Labrador
Arctic Circle
Cercle arctique
PACIFIC OCEAN
OCÉAN PACIFIQUE
ATLANTIC OCEAN
OCÉAN ATLANTIQUE
KILOMETRES
0
1000
CANADA
SURVEY · COMMISSION GÉOLOGIQUE
THE LATE WISCONSINAN GLACIER COMPLEX
LE COMPLEXE GLACIAIRE DU WISCONSINIEN SUPÉRIEUR

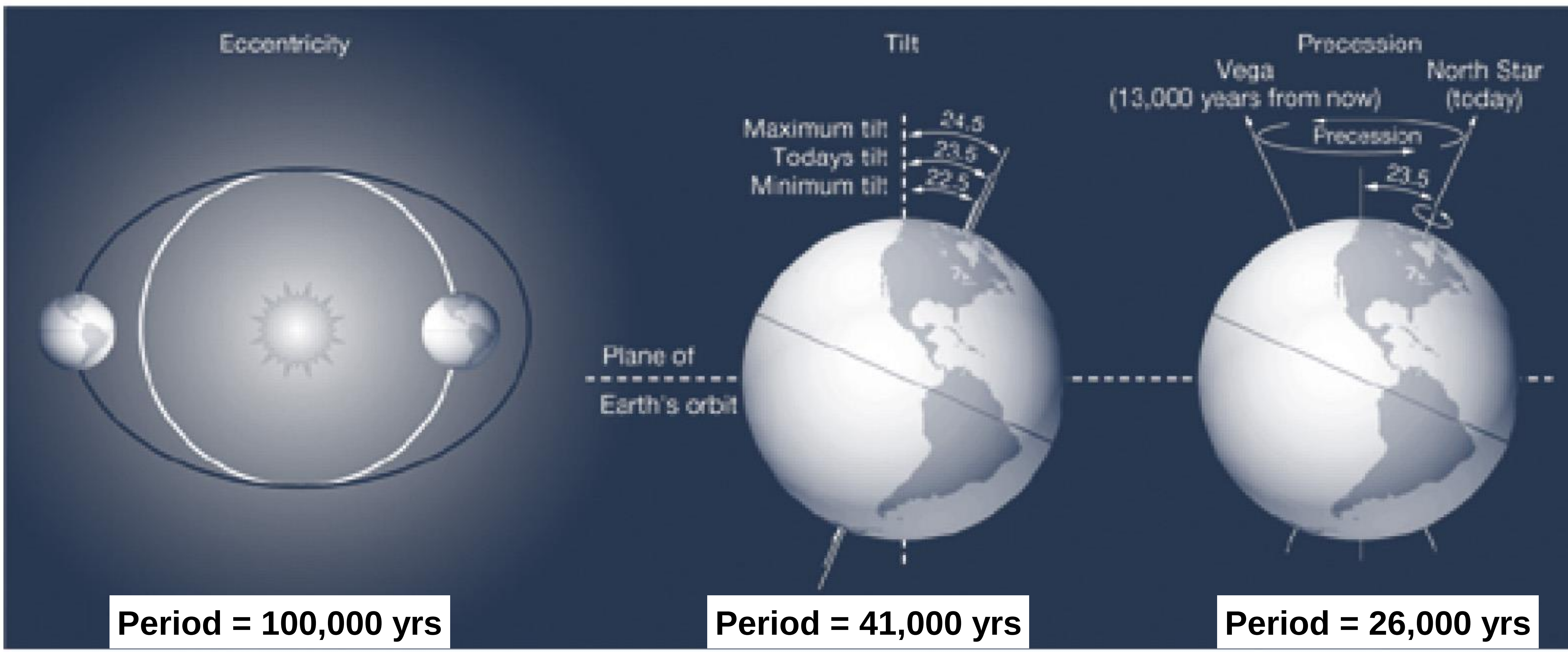
Oxygen Isotopes Reveal Higher Frequency Variation



[Tracking Temperature and Ice Volume]

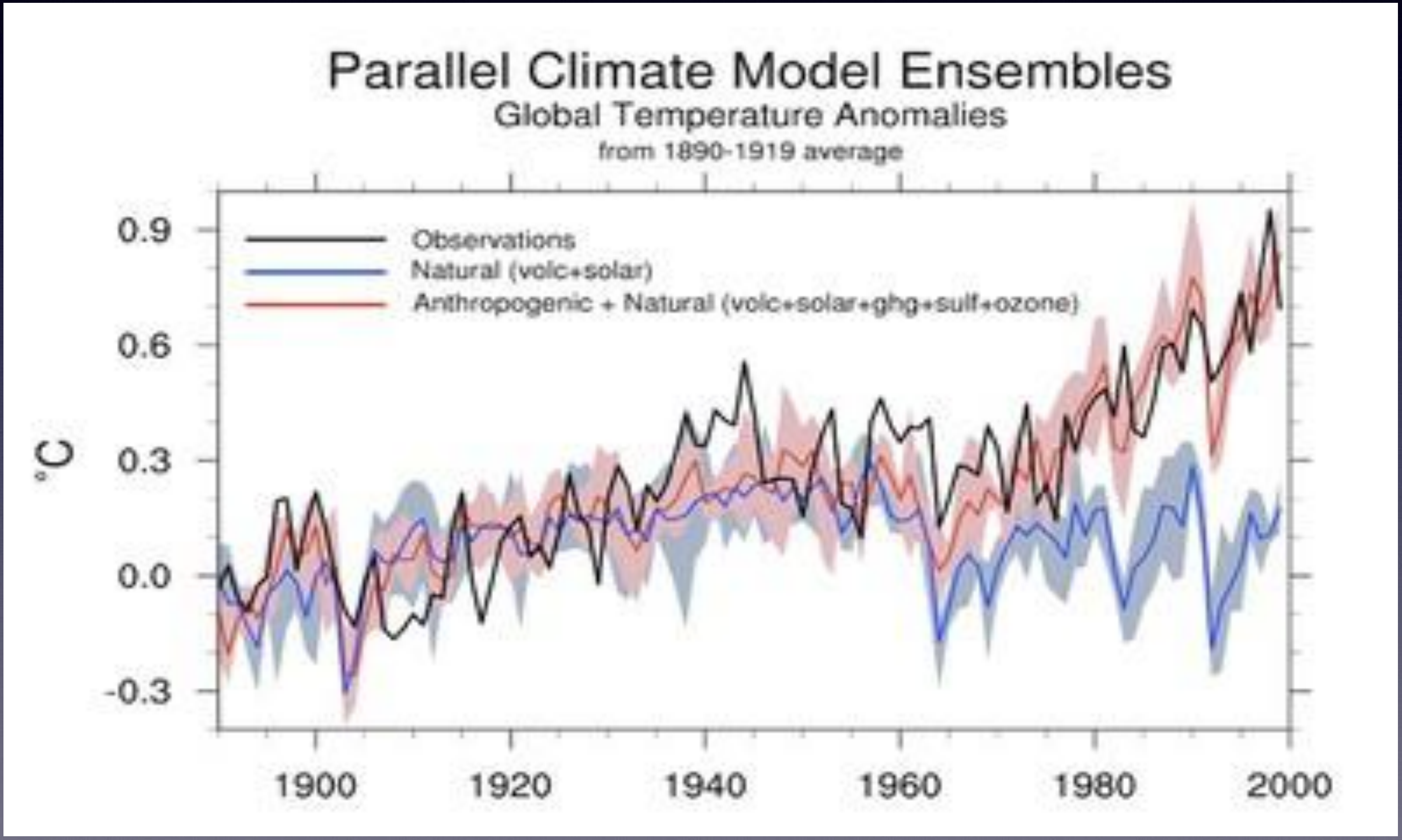
But what drives glaciation?

Milankovitch Cycles
(The Heartbeat of Glaciation)



<u>This natural phenomenon drives glacial patterns on earth.</u>

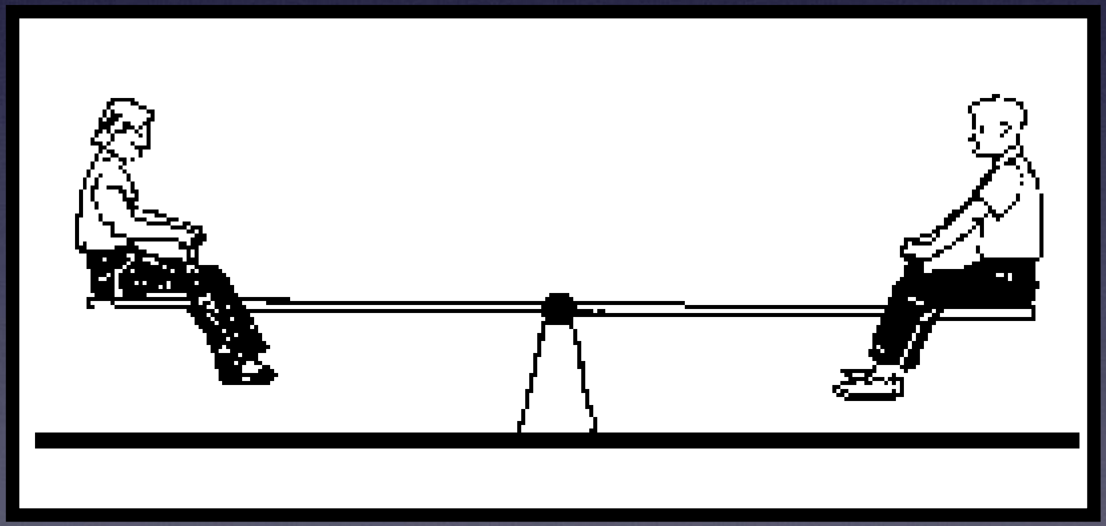
. . . based on where the Earth is in these Miankovitch cycles global temperatures should be much lower.



Equilibrium and Feedbacks

Equilibrium

It is the state in which a system will remain unless something disturbs it.



Feedbacks

Feedback:
A response to a change in a system

Feedbacks can enhance or buffer changes that occur in a system. Positive feedbacks enhance or amplify changes; this tends to move a system away from its equilibrium state and make it more unstable. Negative feedbacks tend to dampen or buffer changes; this tends to hold a system to some equilibrium state making it more stable.

Negative feedback:

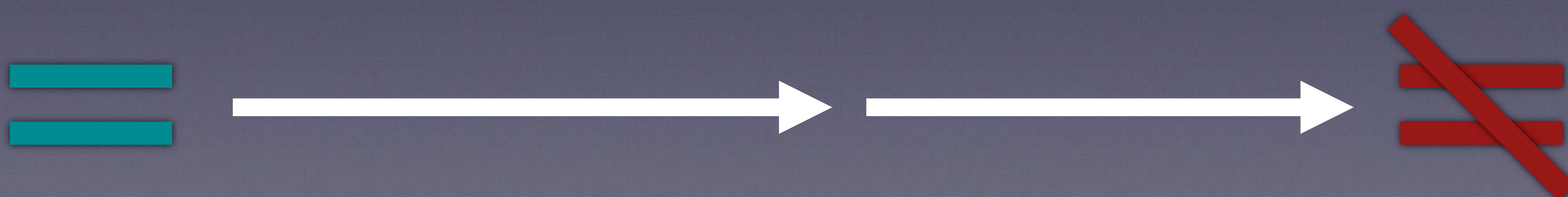
A response to a change in a system that tends to reverse the direction of the change—thus moving the system back to its original (equilibrium) state.

Since this process tends to keep things constant, it is a stabilizing influence. It reduces the deviation from an initial state.

Positive feedback:

A response to a change in a system that tends to enhance/magnify the direction of the change—thus moving the system further away from its original (equilibrium) state.

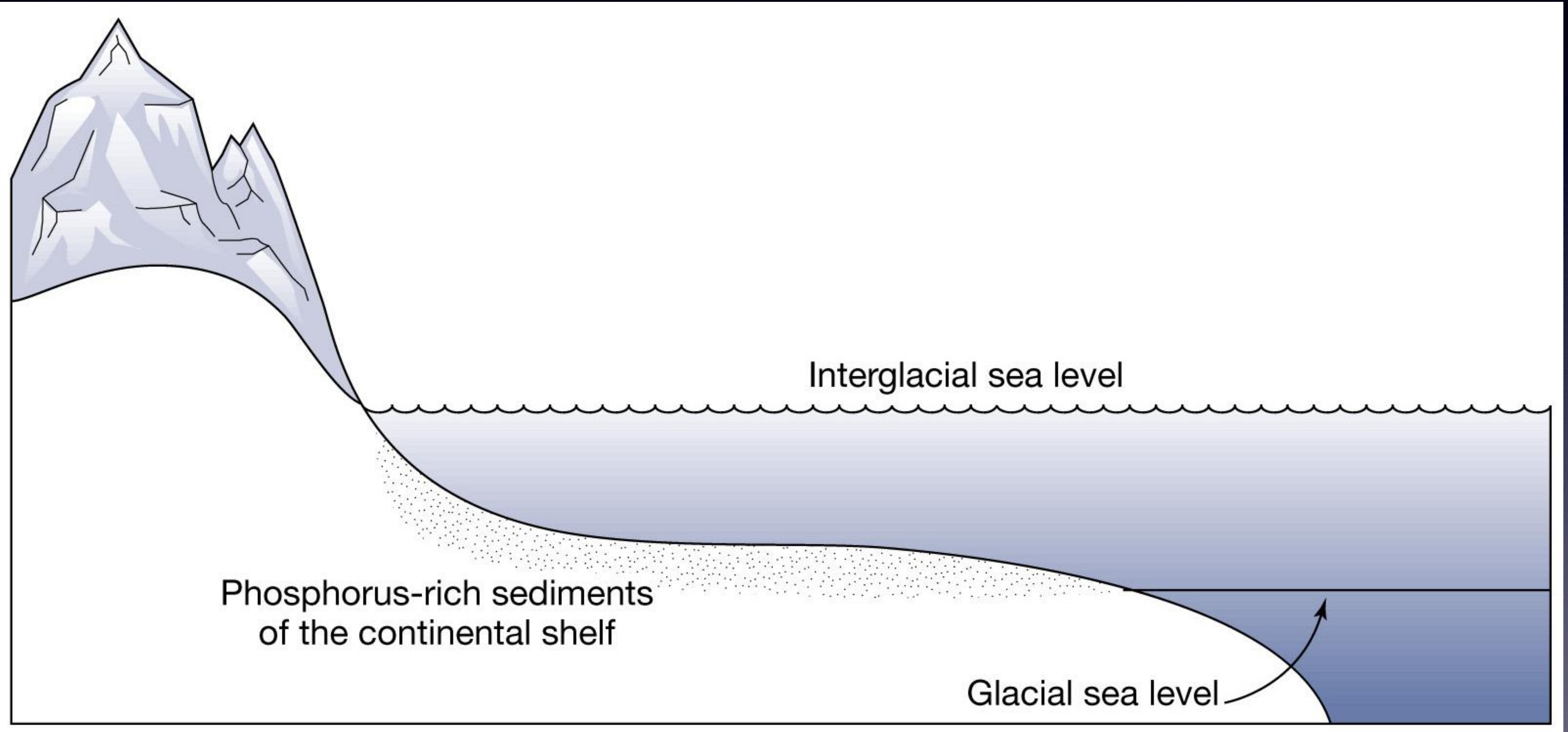
This is a destabilizing influence, which increases the deviation from an initial state.



Glacial and Ice Short-Term Feedbacks

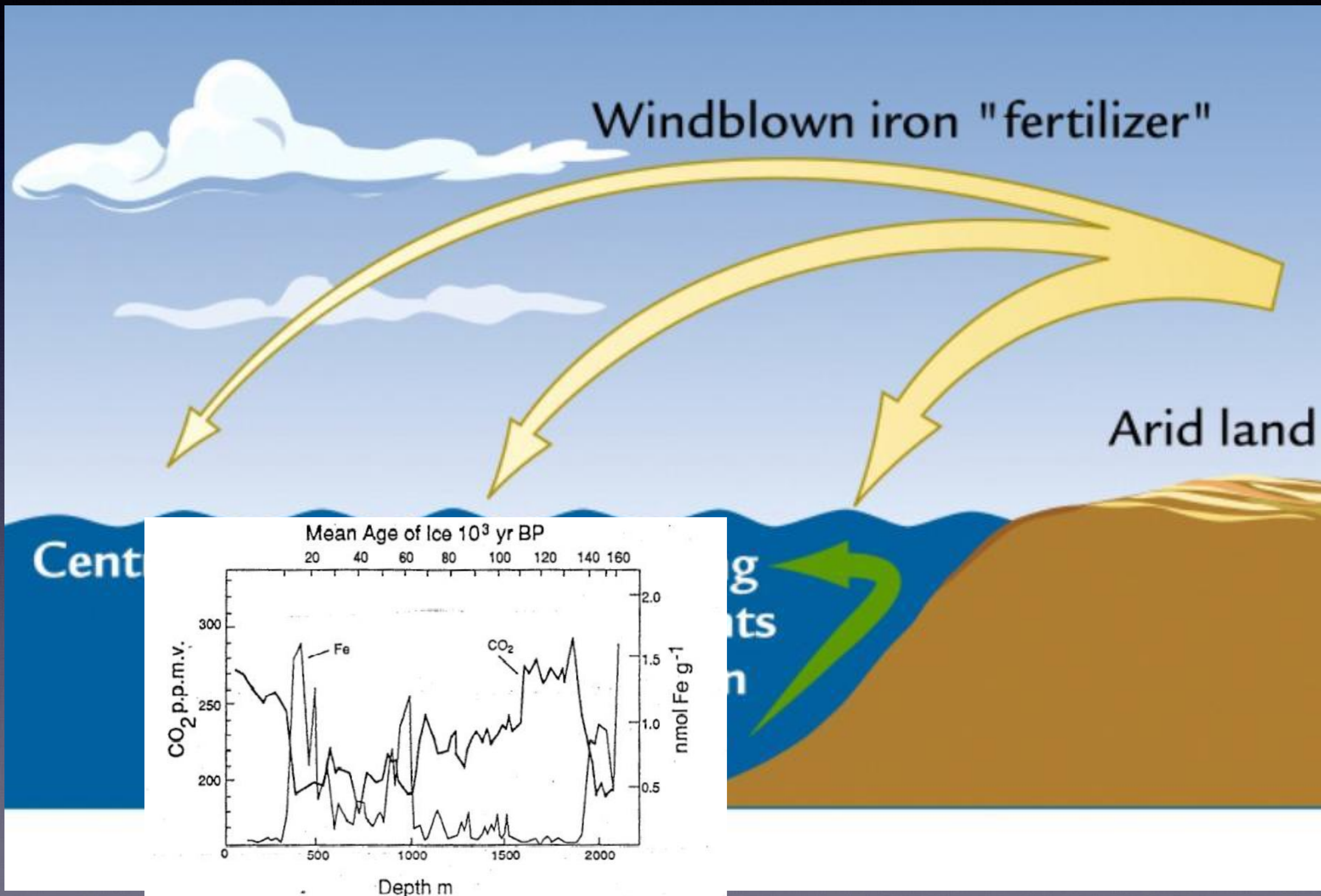
Glacial Ice and Shelf Nutrient Feedback

(+) Positive Feedback



Iron Fertilization

(+) Positive Feedback

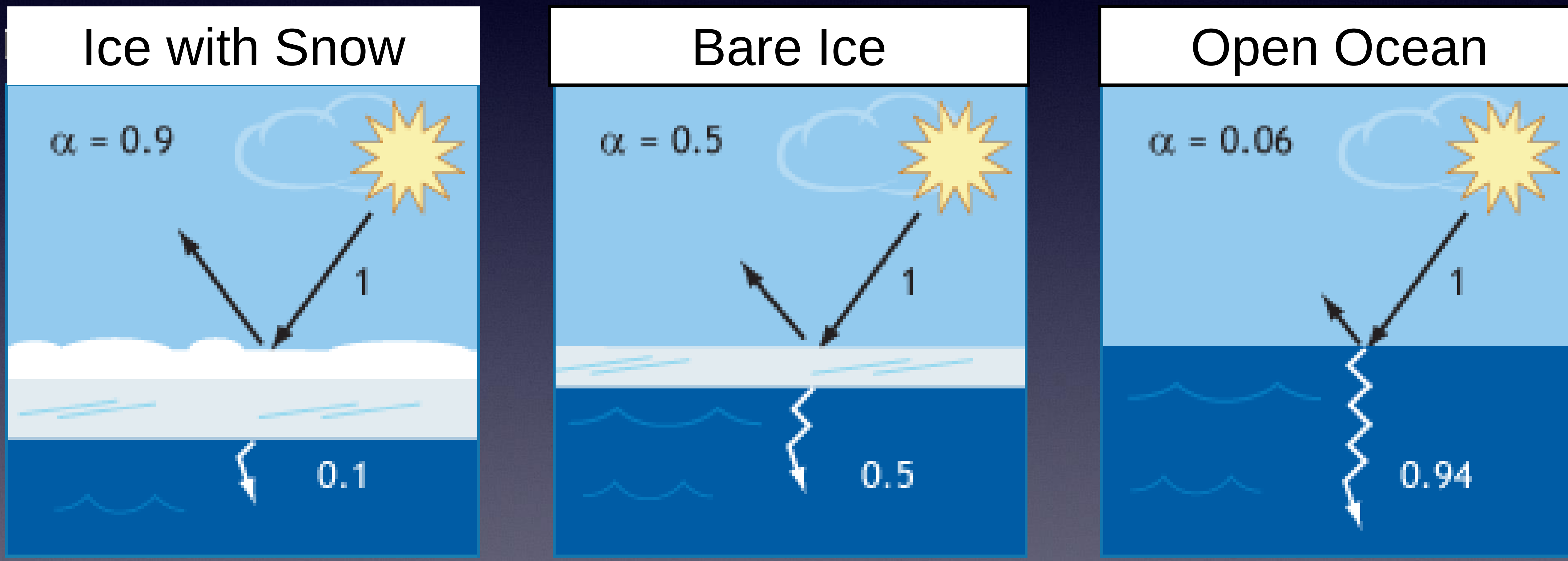


Coral Reef Feedback

(+) Positive Feedback

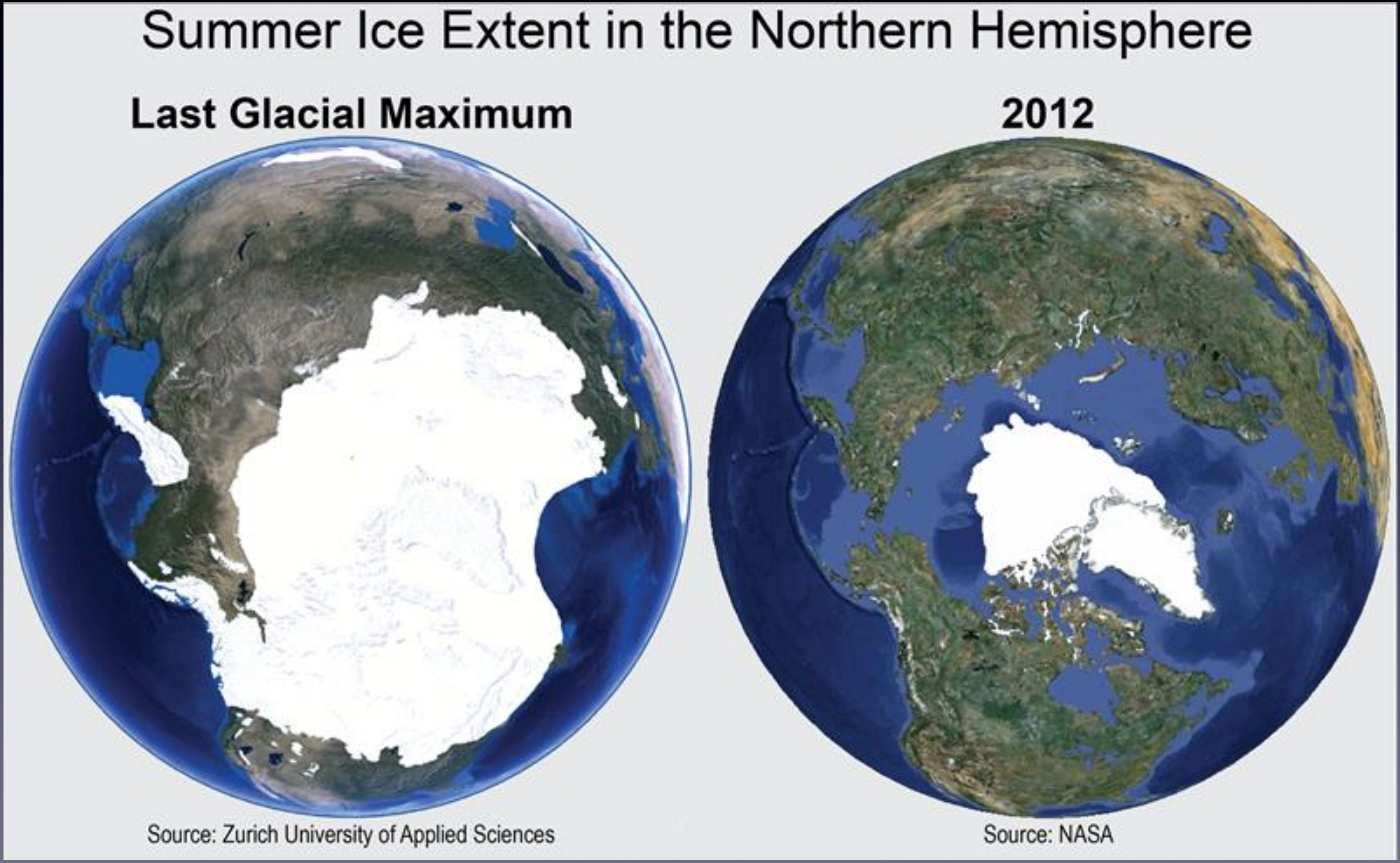
Ice Albedo Effect

(+) Positive Feedback

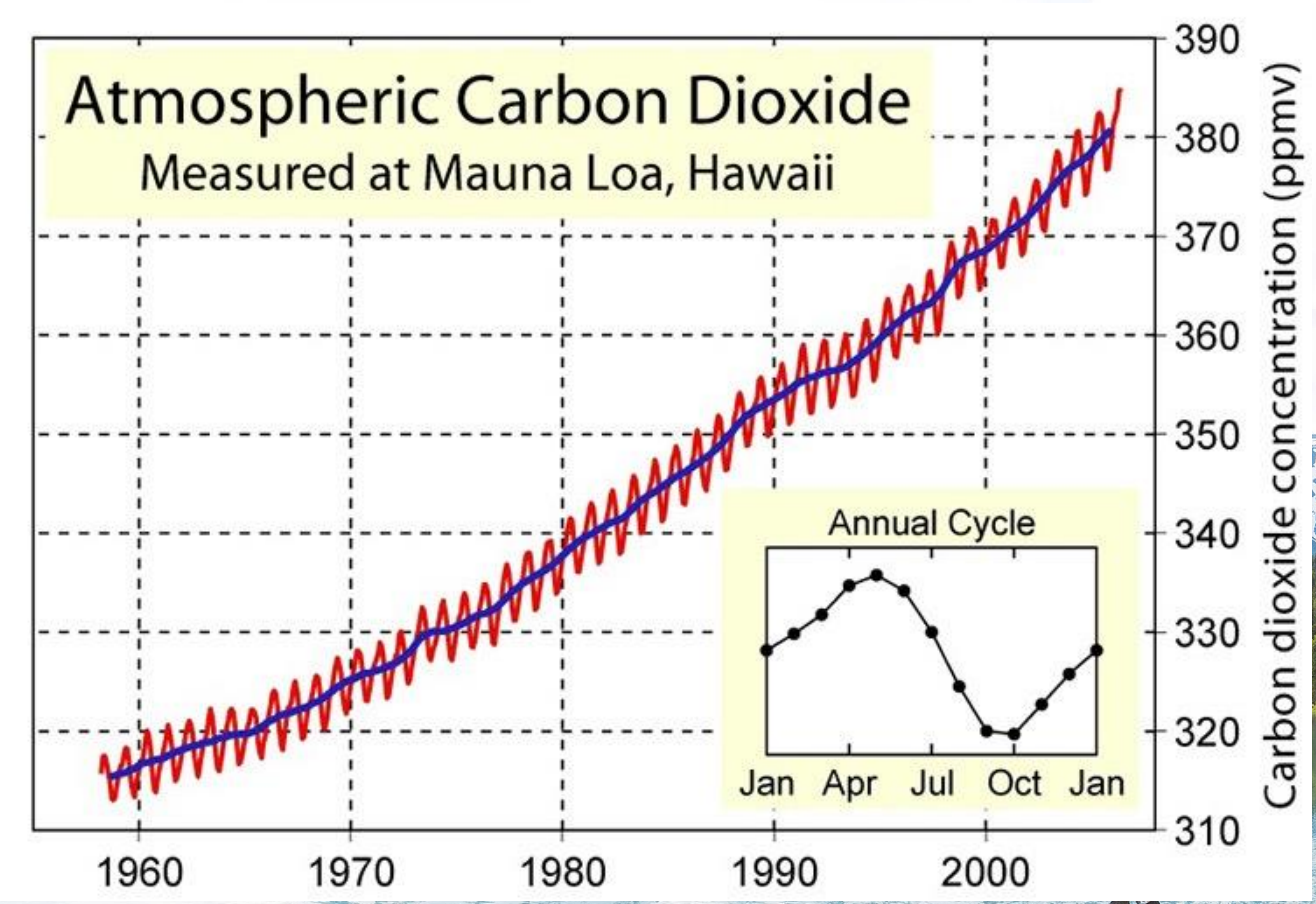


Terrestrial Biomass

(–) Negative Feedback



The growth of the terrestrial biomass during deglaciation and its destruction during the initiation of a glacial interval represent the only negative feedbacks that we know of for changing CO_2 in the atmosphere on glacial timescales

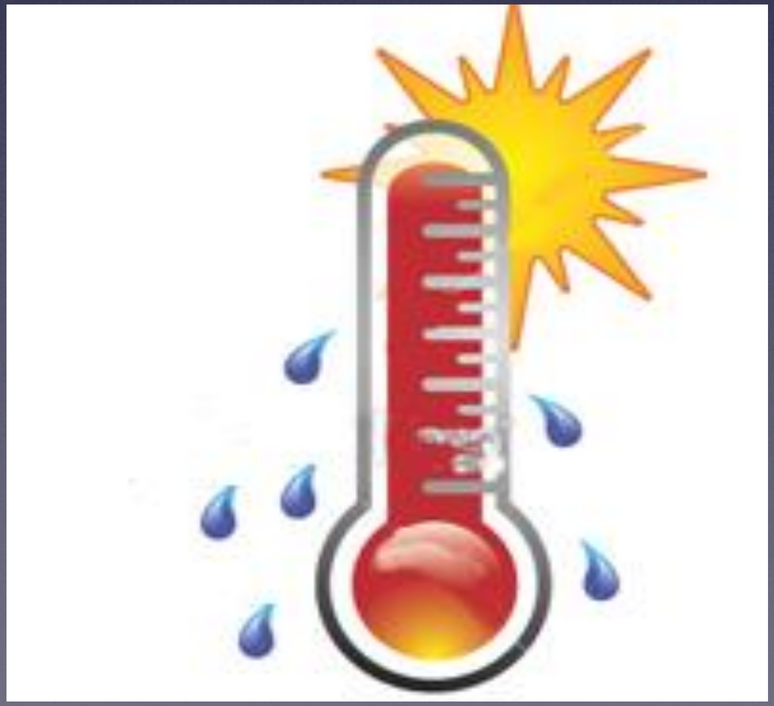


Seasonality linked to cycle in (land) plant activity: degree of photosynthesis vs. respiration

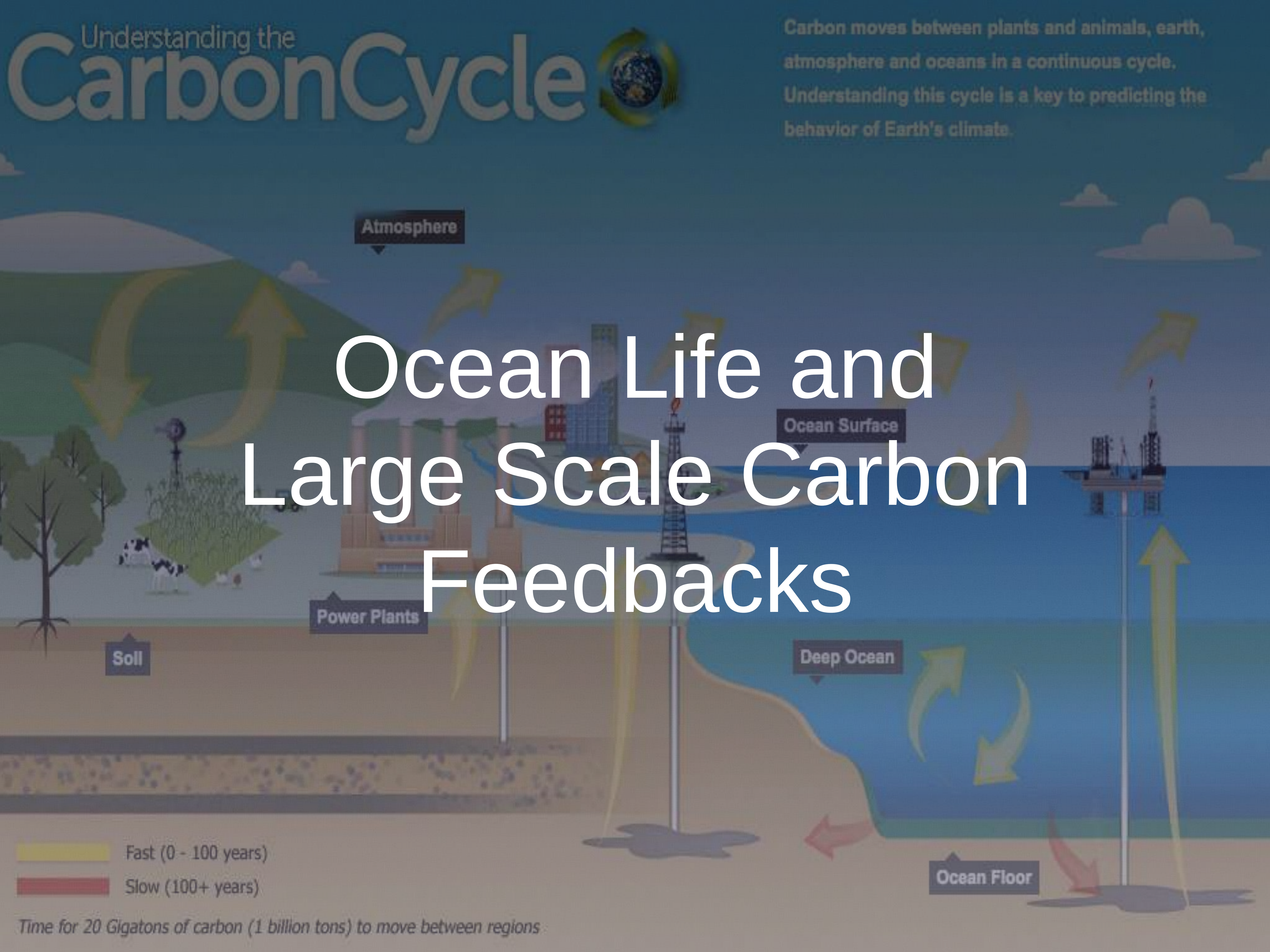
So . . . based on what we now know so far

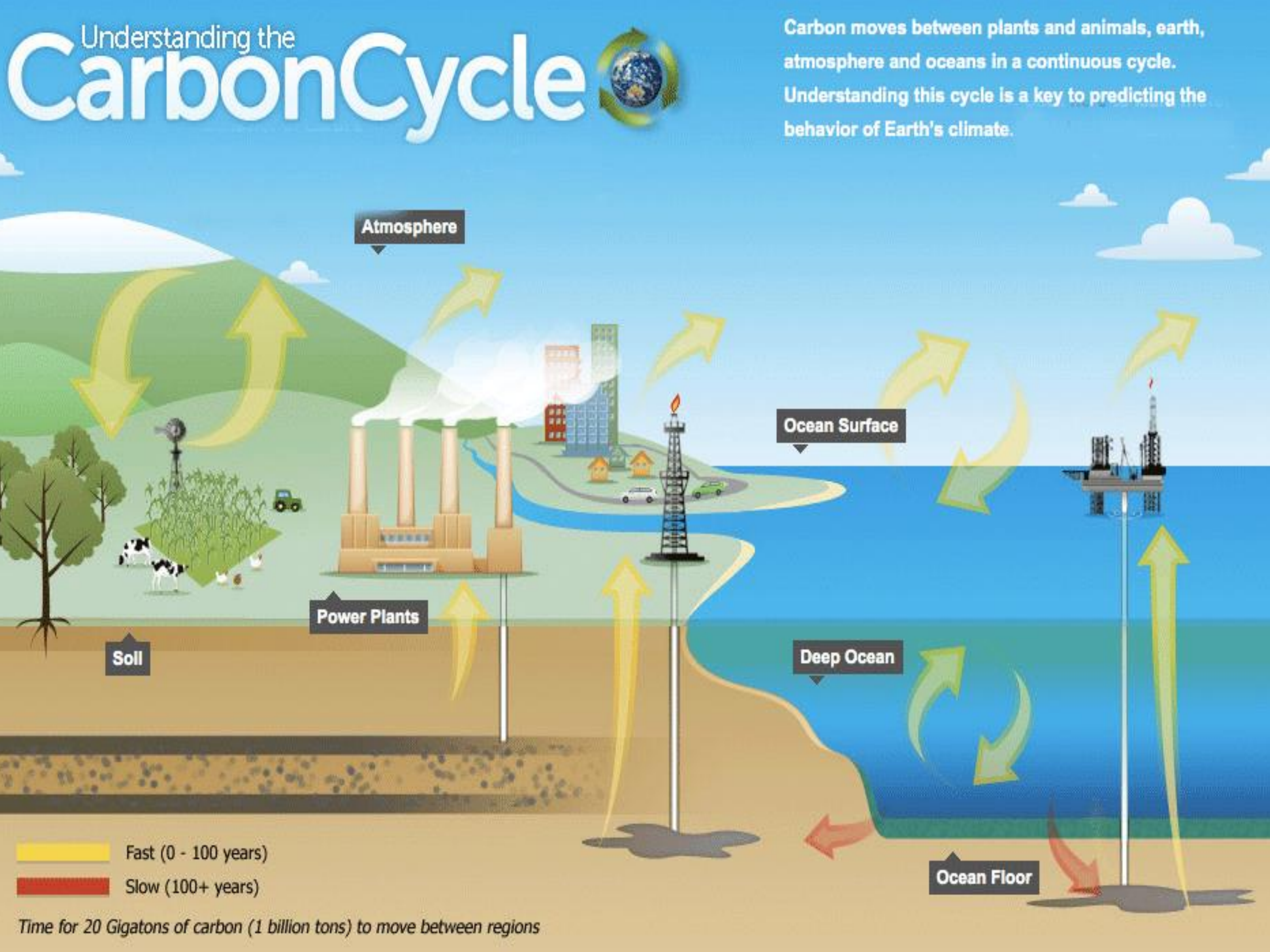
Given the feedbacks associated with **<u>long term</u>** climate patterns . . .

So, what happens when temperatures on Earth go up? (naturally assuming no humans on earth)



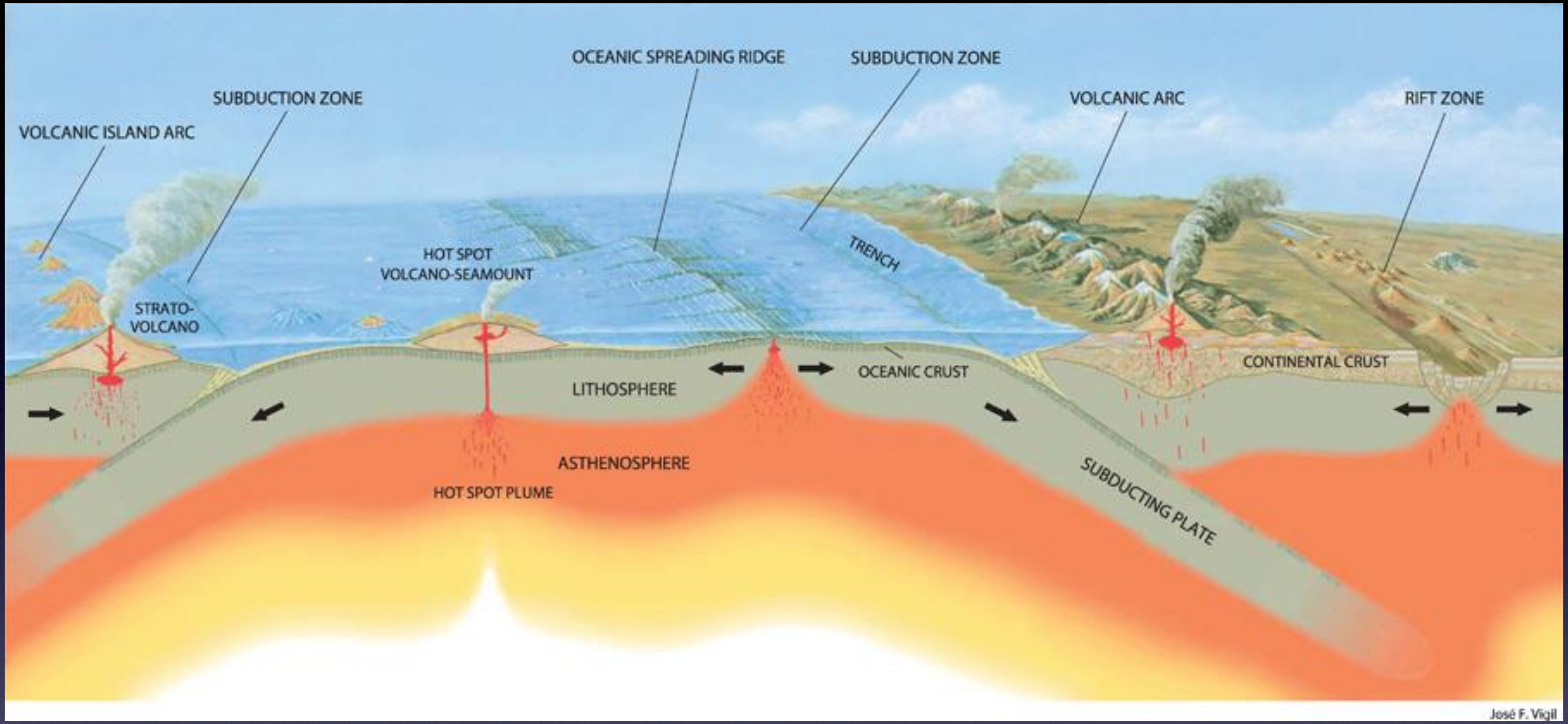
Ocean Life and Large Scale Carbon Feedbacks




Understanding the
CarbonCycle
Carbon moves between plants and animals, earth, atmosphere and oceans in a continuous cycle. Understanding this cycle is a key to predicting the behavior of Earth's climate.
Atmosphere
Ocean Surface
Power Plants
Soil
Deep Ocean
Ocean Floor
Fast (0 - 100 years)
Slow (100+ years)
Time for 20 Gigatons of carbon (1 billion tons) to move between regions

The recycling of essential elements (C, P, N, S, etc) -- nutrients.

This recycling is linked to the global processes of plate tectonics.



The link between tectonic activity and the C cycle is important to the regulation of carbon dioxide in the atmosphere and thus climate over geologic time scales.

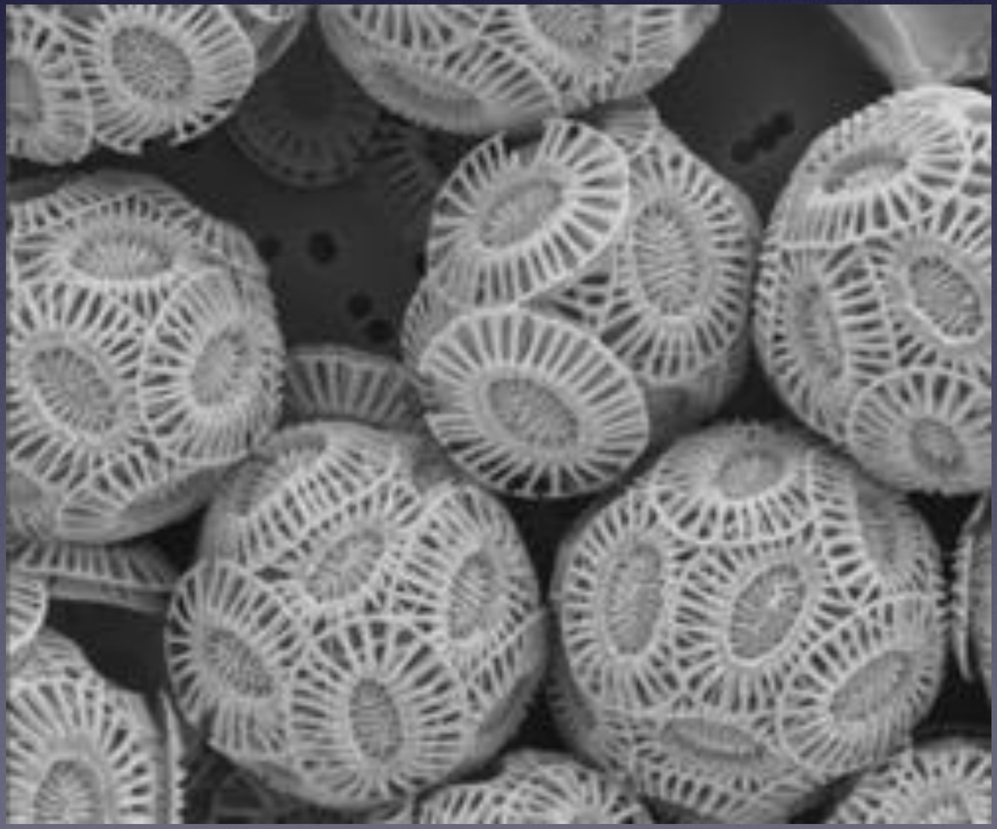
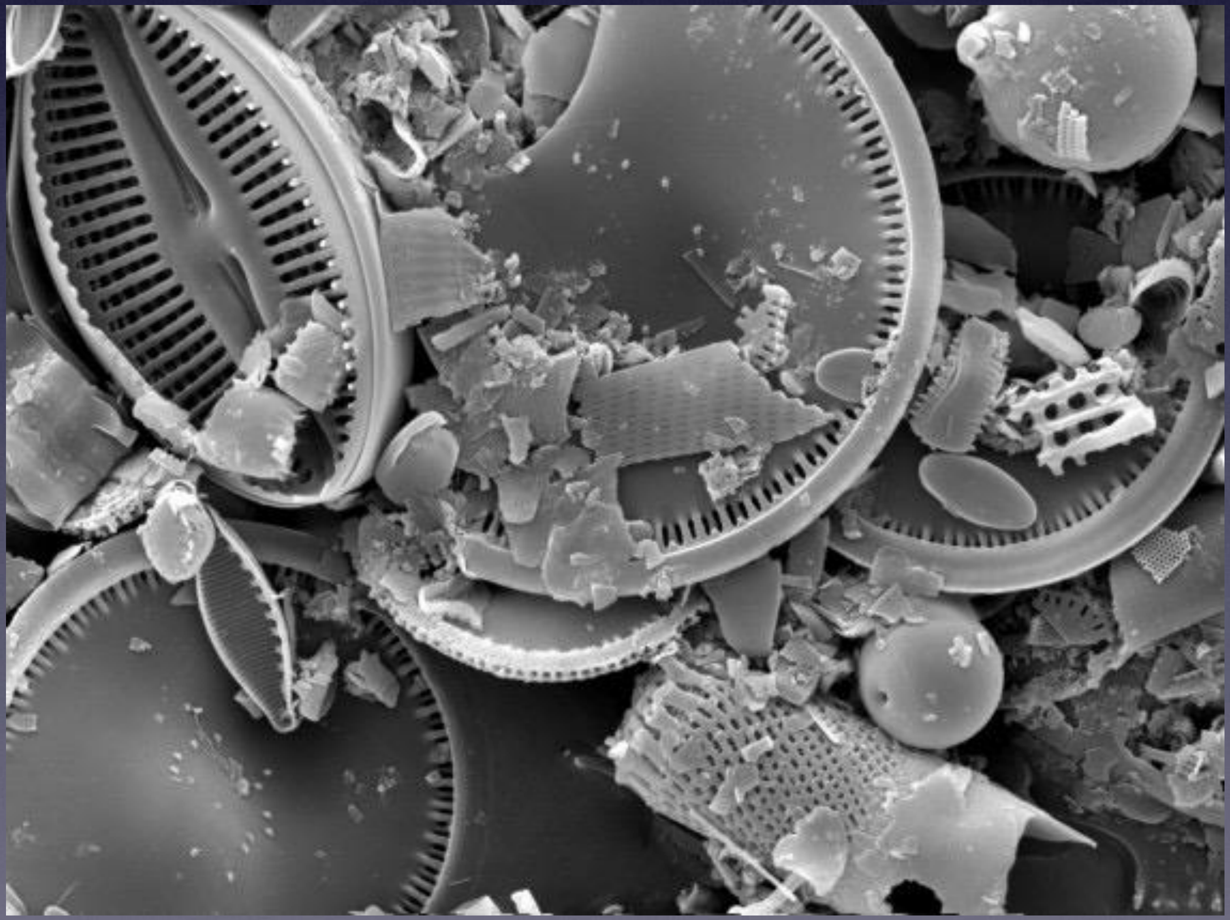
Carbon, the Ocean

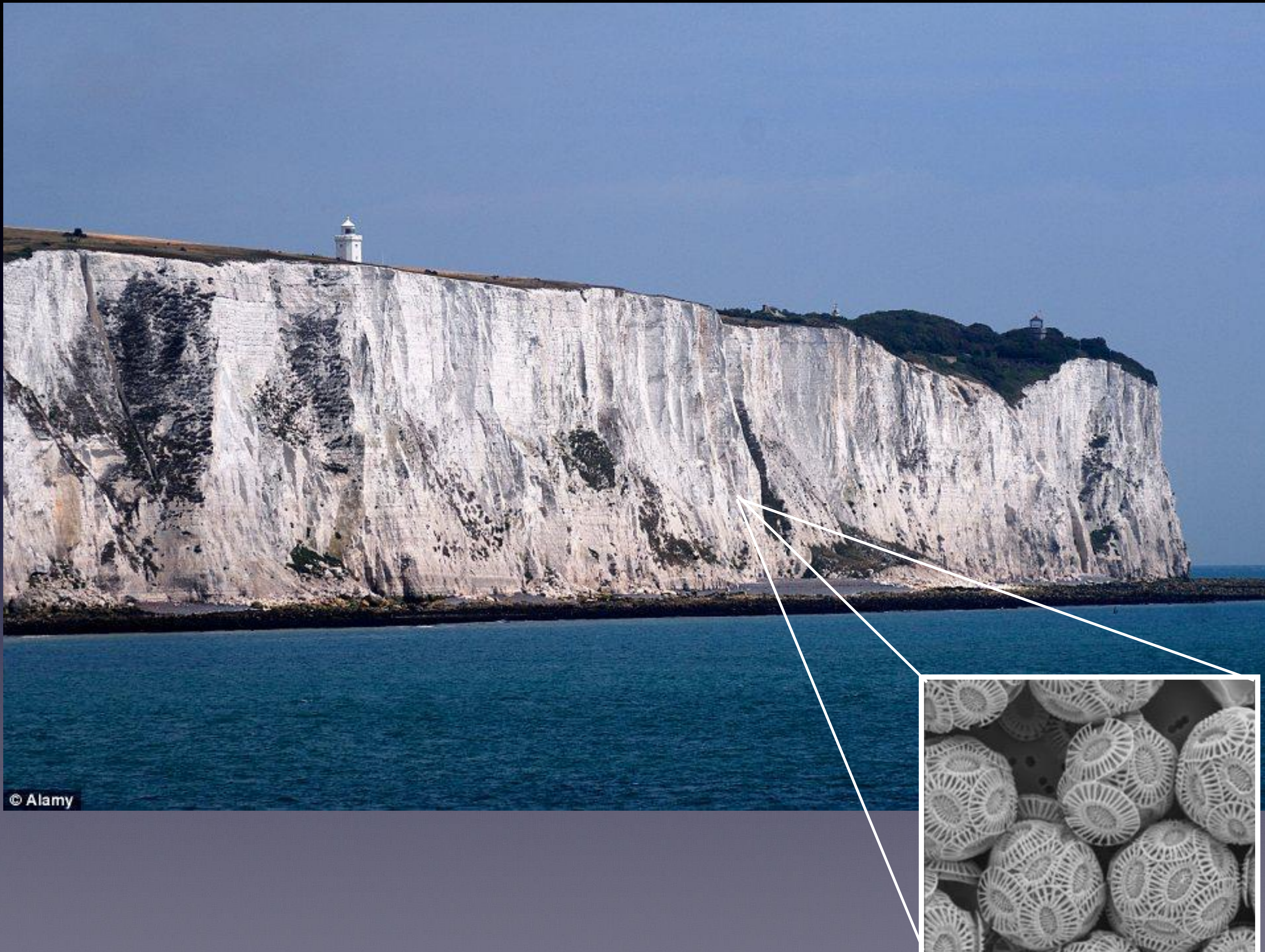
and

Geologic Time

The dominant primary producers in the ocean are the free-floating, photosynthetic marine microorganisms— **phytoplankton**

Live in **photic zone** (uppermost part of the ocean where there is sufficient light to support photosynthesis). Usually upper 100 m in the open ocean and shallower in less clear waters along the ocean margins.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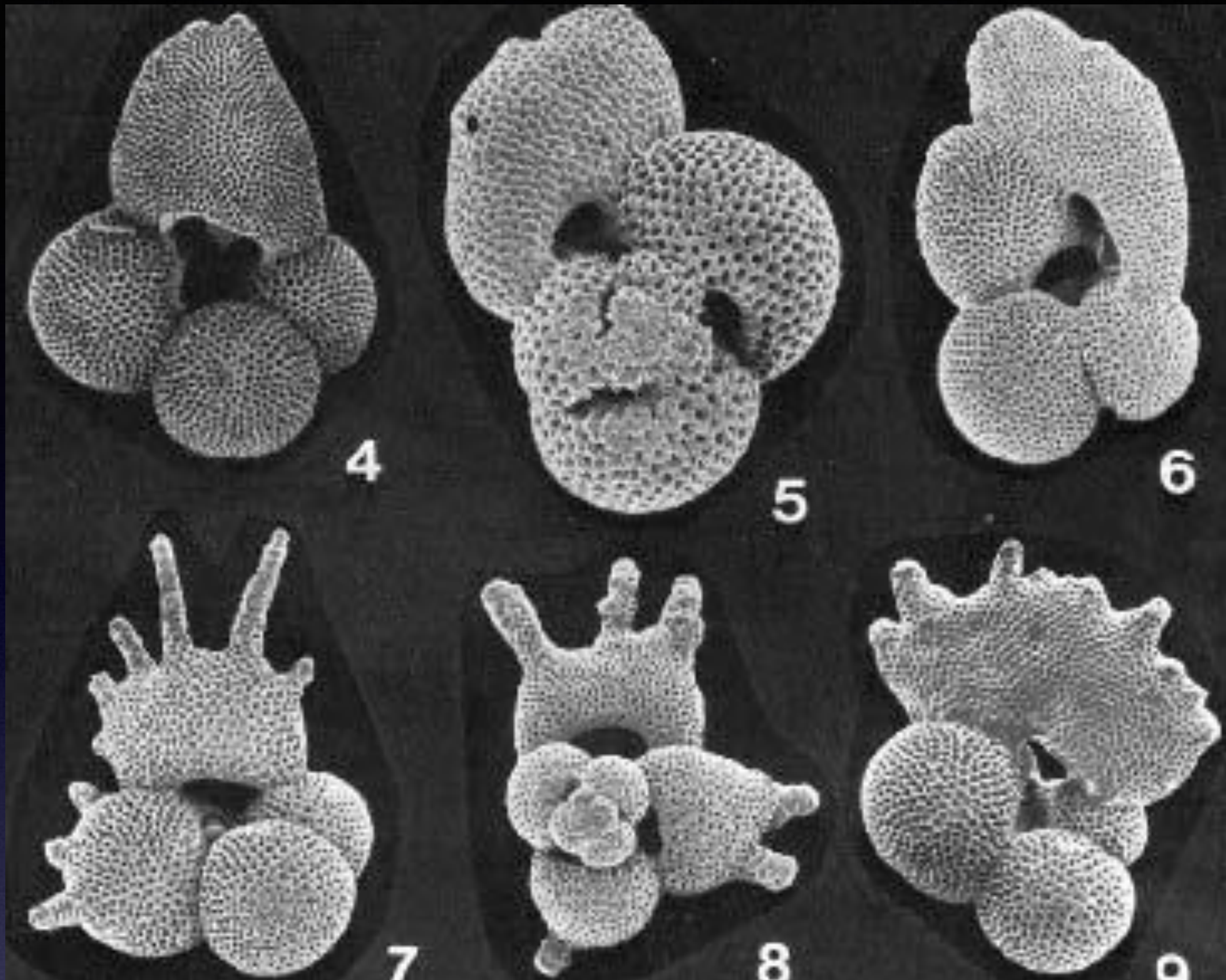
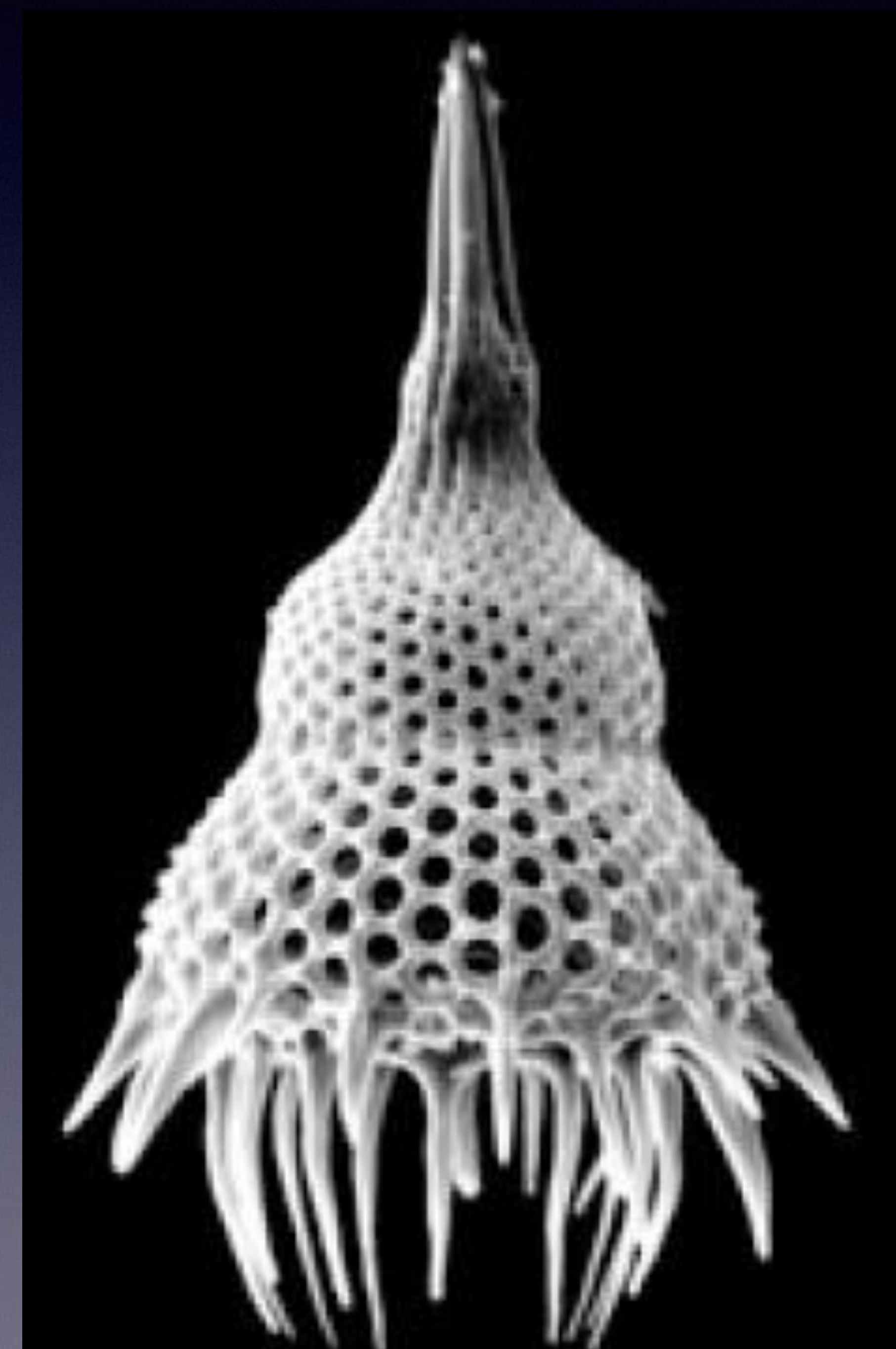
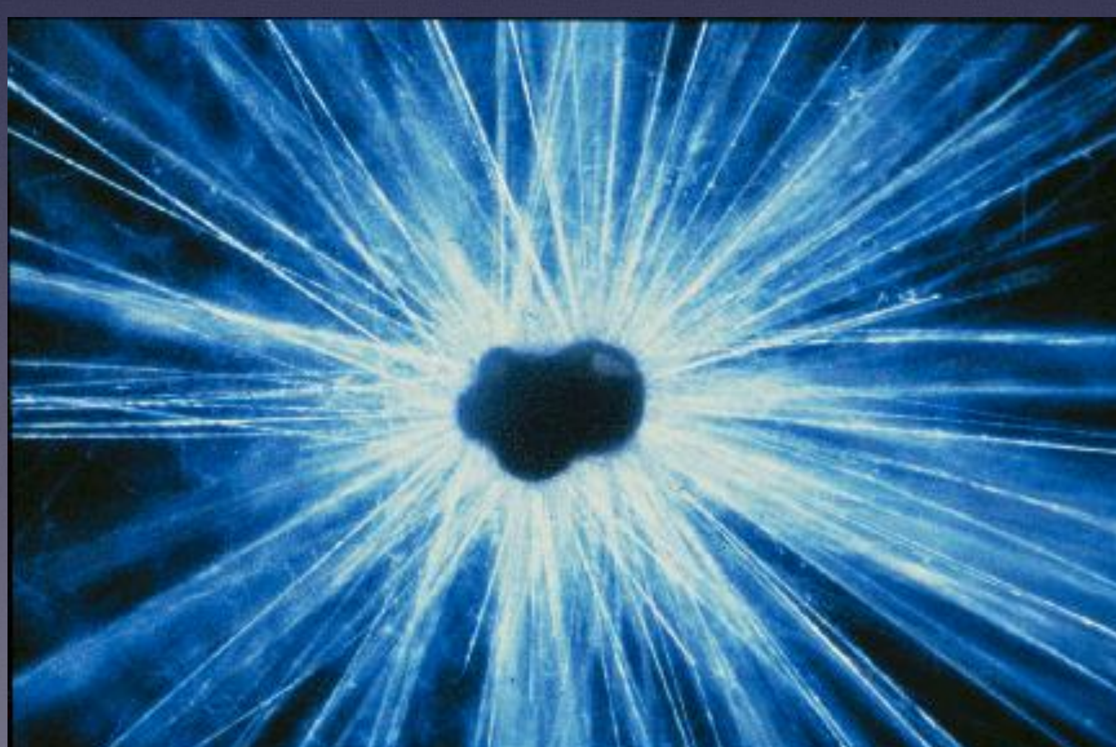


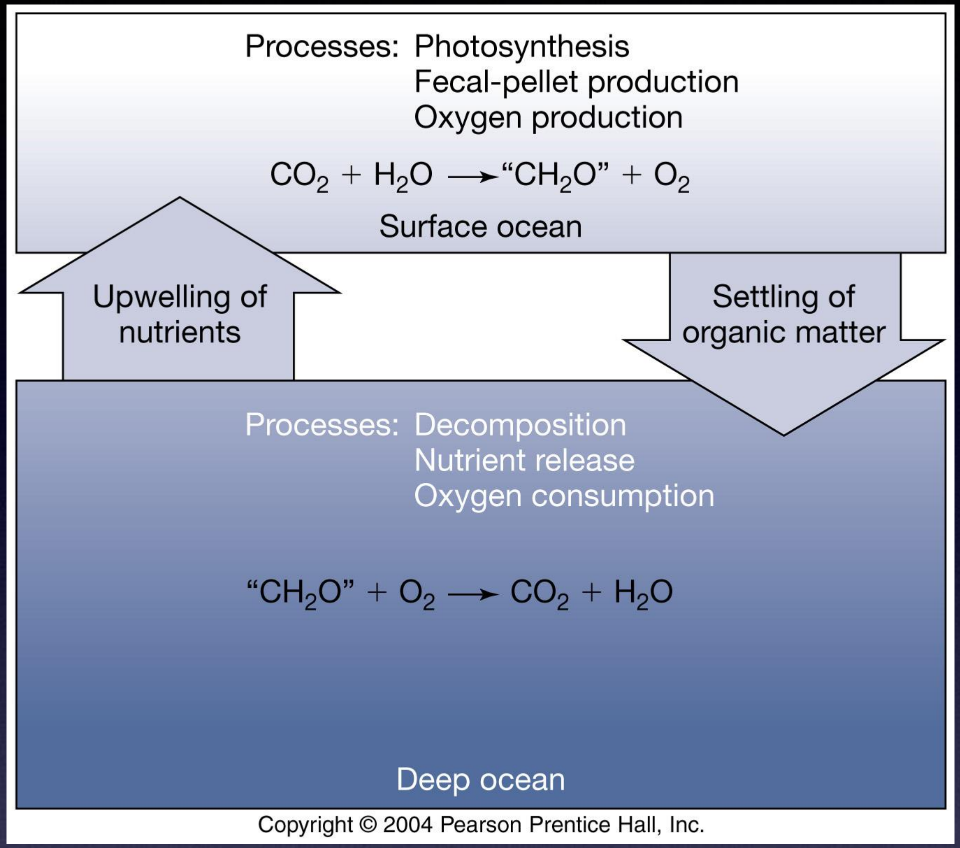
Foraminifera

Radiolarian





The Biological Pump.



Much of the organic matter produced in surface waters by phytoplankton is consumed by zooplankton

Only about 1% of primary production survives the trip to the seafloor where it is further decomposed, resulting in burial of only about 0.1% of export production.

Geological processes exert the most control on atmospheric CO_2 on longer time scales (i.e. storing carbon for extremely long periods of time and weathering processes)

Calcium carbonate forms and dissolves in the ocean, but some is buried. This represents leakage from the short-term cycle of inorganic carbon. Some of this is weathered on the continents.

Rocks exposed at the surface undergo chemical dissolution from rain with dilute acid.

Carbonate and silicate rocks weather chemically; carbonates dissolve more rapidly. Chemical weathering neutralizes the acid

$$CaCO_3 + H_2CO_3 = Ca^{2+} + 2HCO_3^-$$

(carbonate weathering)

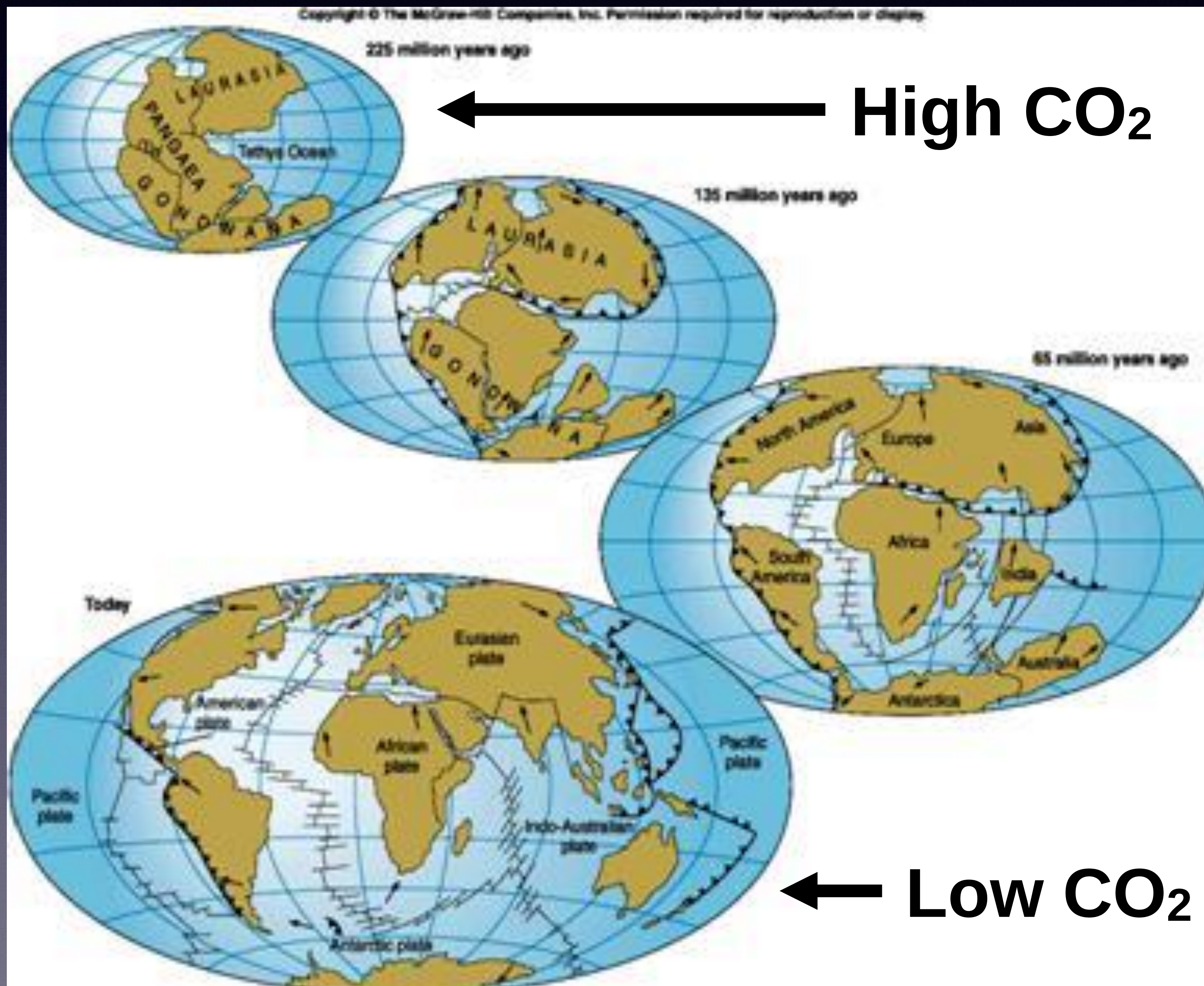
$$CaSiO_3 + 2H_2CO_3 = Ca^{2+} + 2HCO_3^- + SiO_2 + H_2O$$

(silicate weathering)

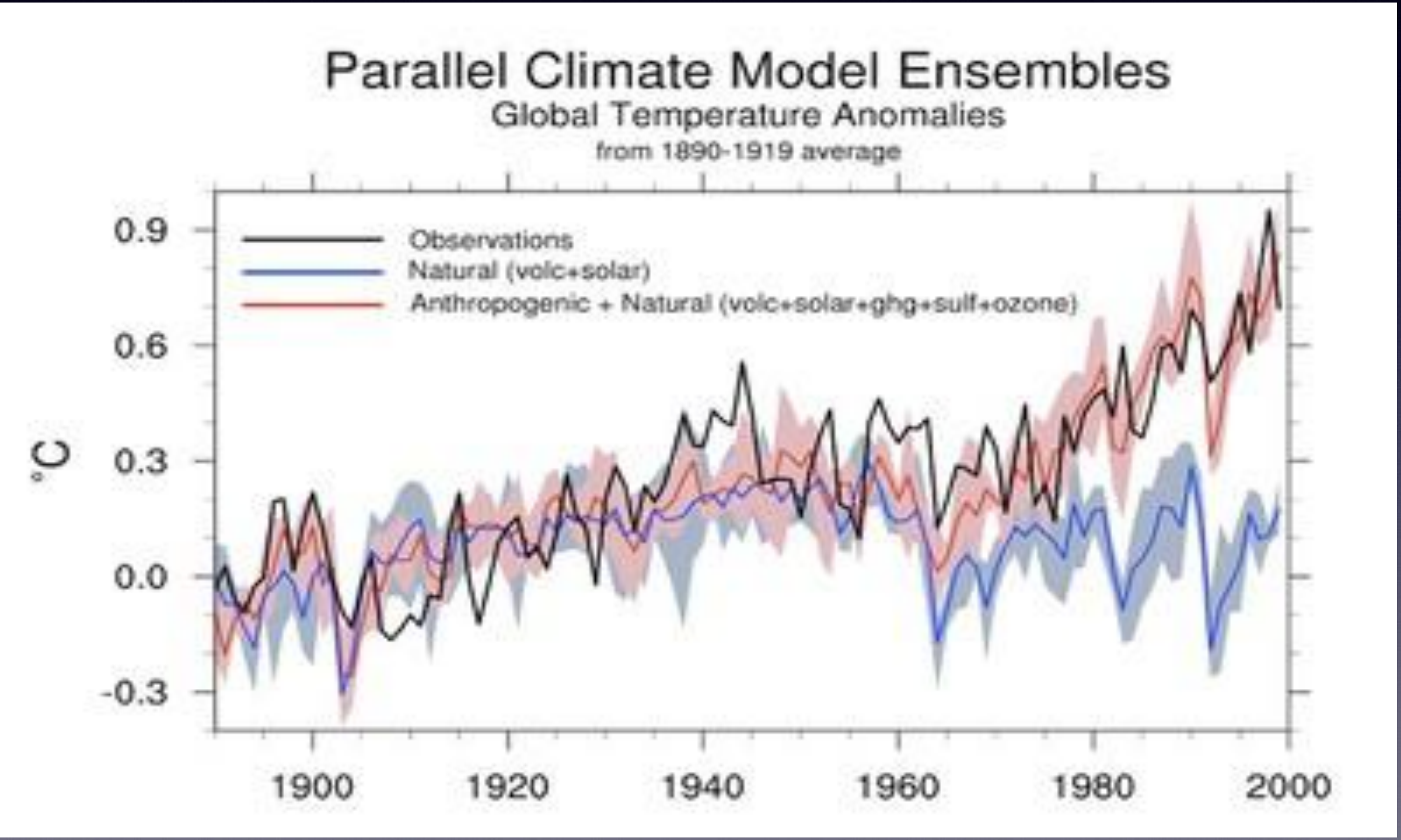
Silicate weathering consumes twice as much CO_2 per unit of rock dissolved

Continental Margin Surface Area

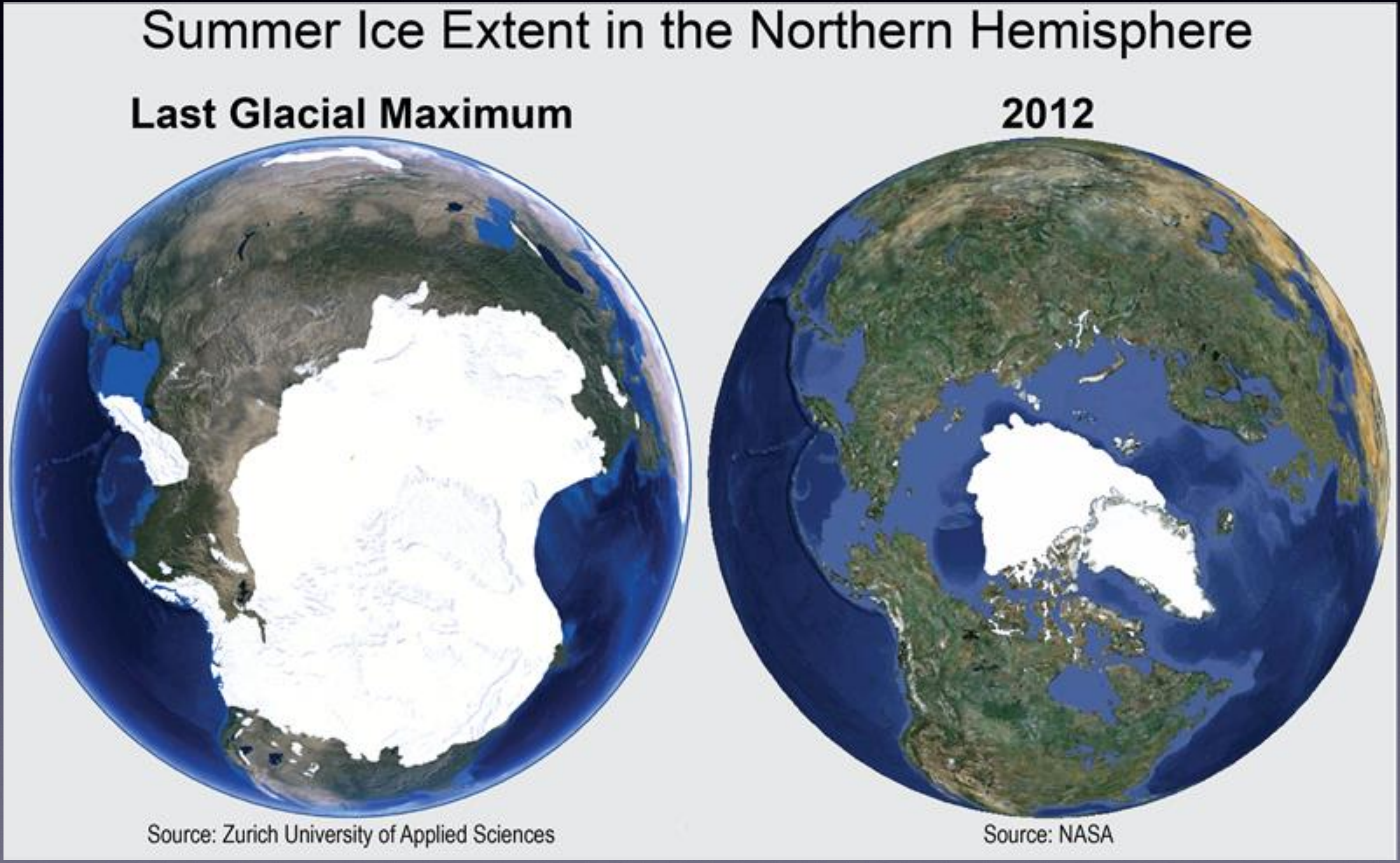
When continental masses on earth are spread out more surface area is available to weather, thus carbon dioxide levels in the atmosphere noticeably decrease.



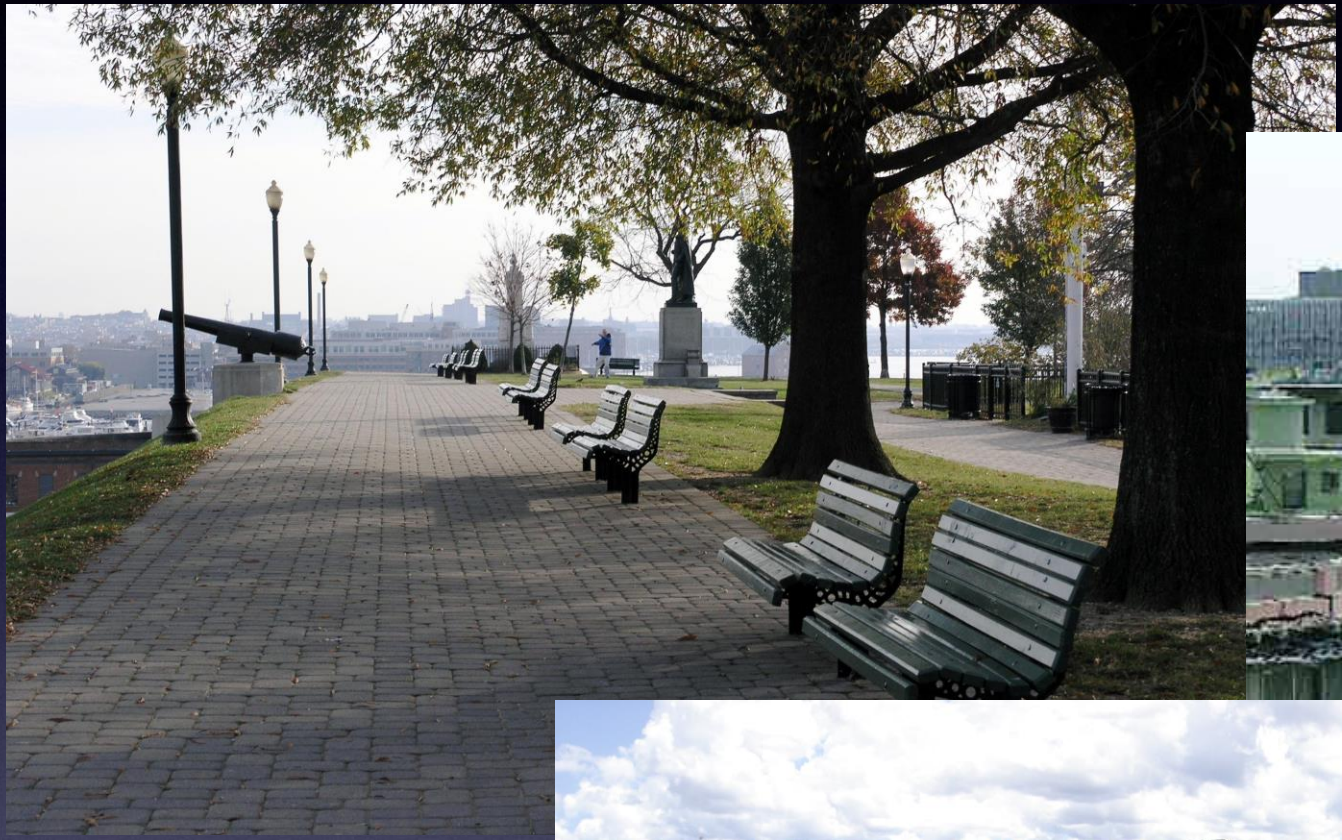
So why then are we deviating from the natural cycle?
What are we doing that has caused this?



Short-Term
Terrestrial Biomass Feedback



Long-Term
Rock Weathering Feedback



Long-Term Carbon Storage

Bottom Line

1) Is climate change natural?

Yes

2) Is the climate change we are currently experiencing part of that natural cycle?

No

The climate of Earth changes fluctuates, but the RATE of change we are currently experiencing is different than anything we have ever seen.

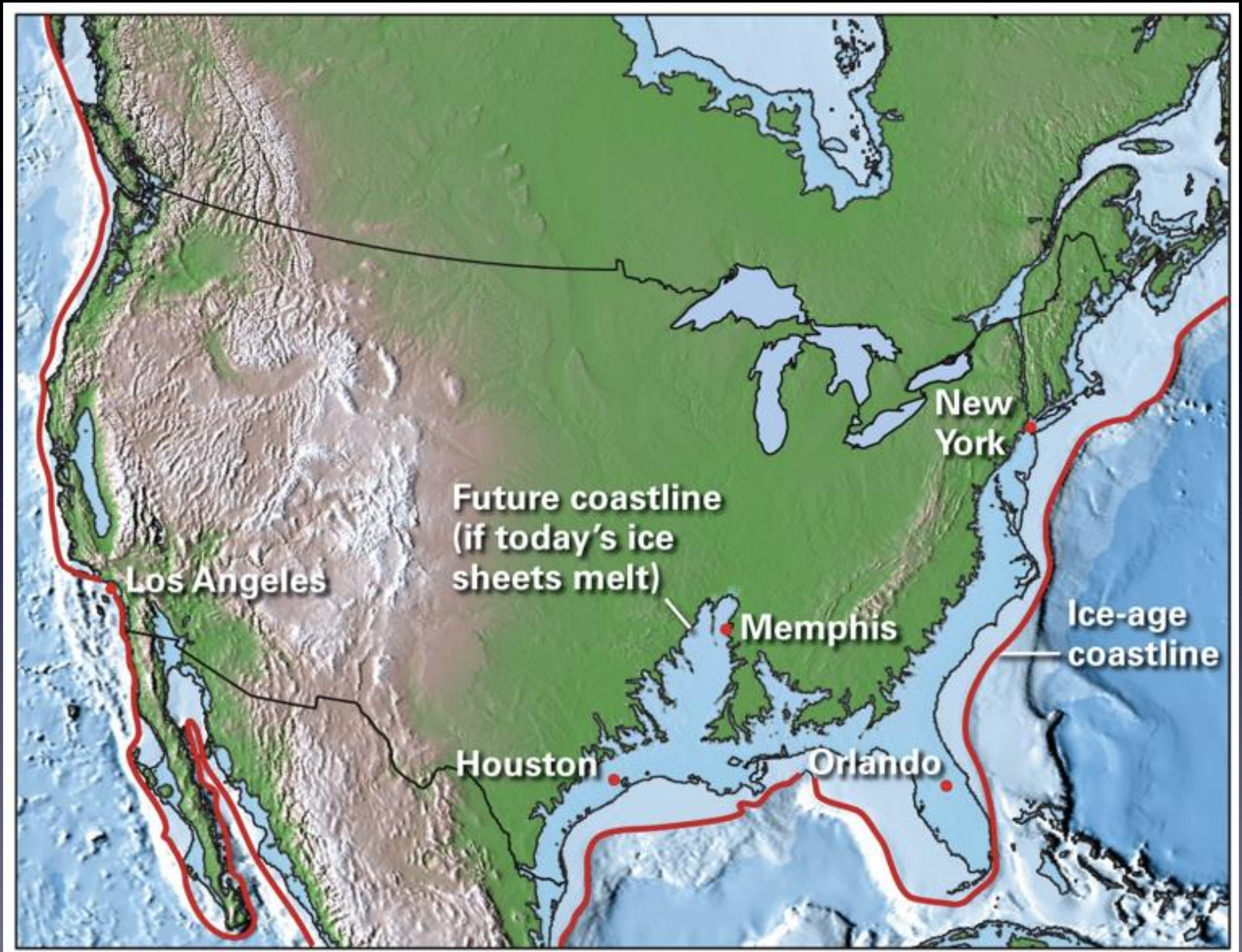
. . . for the first time in earth's history one of a species is hindering the natural feedbacks and "sinks" that operate in response to this temperature change.

Terrestrial Biomass Feedback — **(relatively short term)**

Rock Weathering Feedback

Carbon Storage

(relatively long term)


New
York
Future coastline
(if today's ice
sheets melt)
Los Angeles
Memphis
Ice-age
coastline
Houston
Orlando

Understanding all of this how is it that scientists predict what temperatures will be like in the future?

"What's the use of having developed a science well enough to make predictions if, in the end, all we're willing to do is stand around and wait for them to come true."

– F. Sherwood Rowland