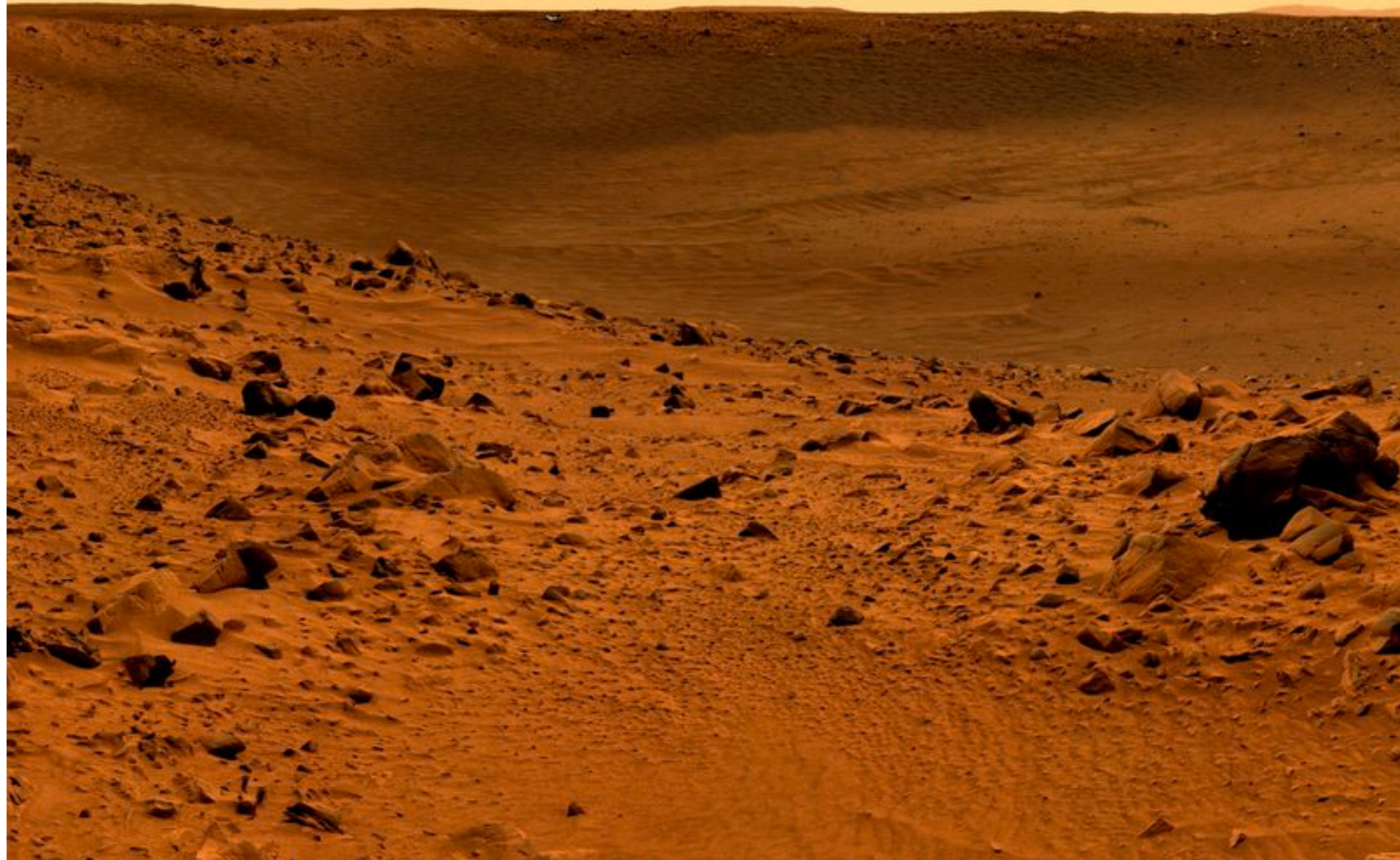




Today

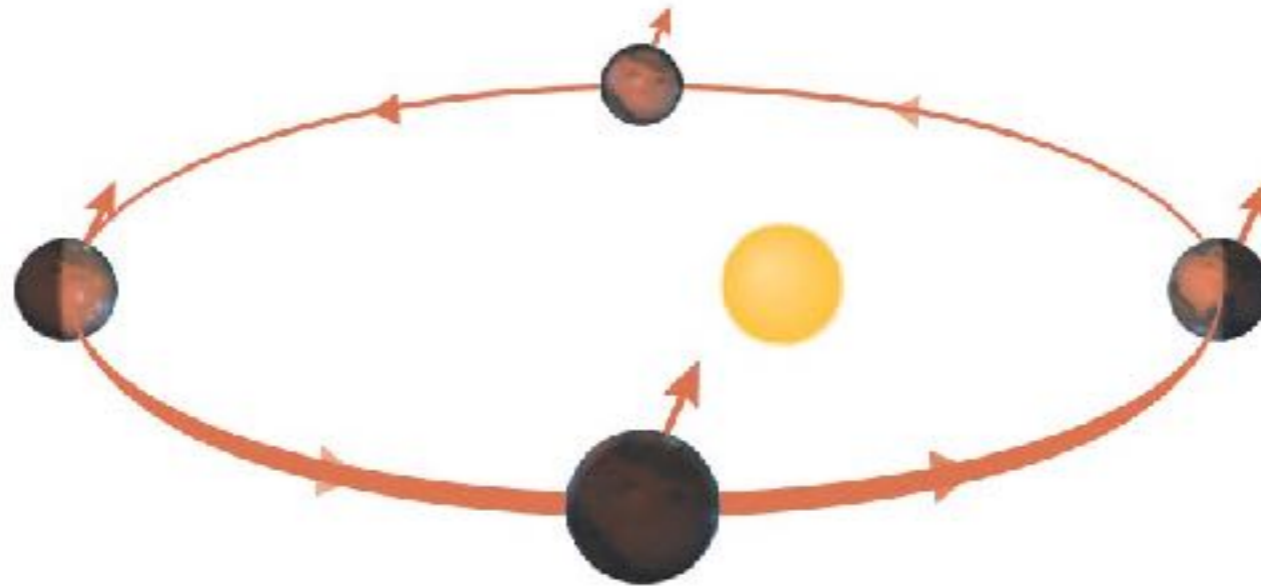
- Terrestrial planet climates
 - Mars - runaway icebox
 - Earth
- Factors affecting atmospheres

Mars: runaway icebox



- Low gravity and a thinning atmosphere led to a runaway icehouse.
- Mars atmosphere currently $\sim 1\%$ as thick as Earth's

Seasons on Mars

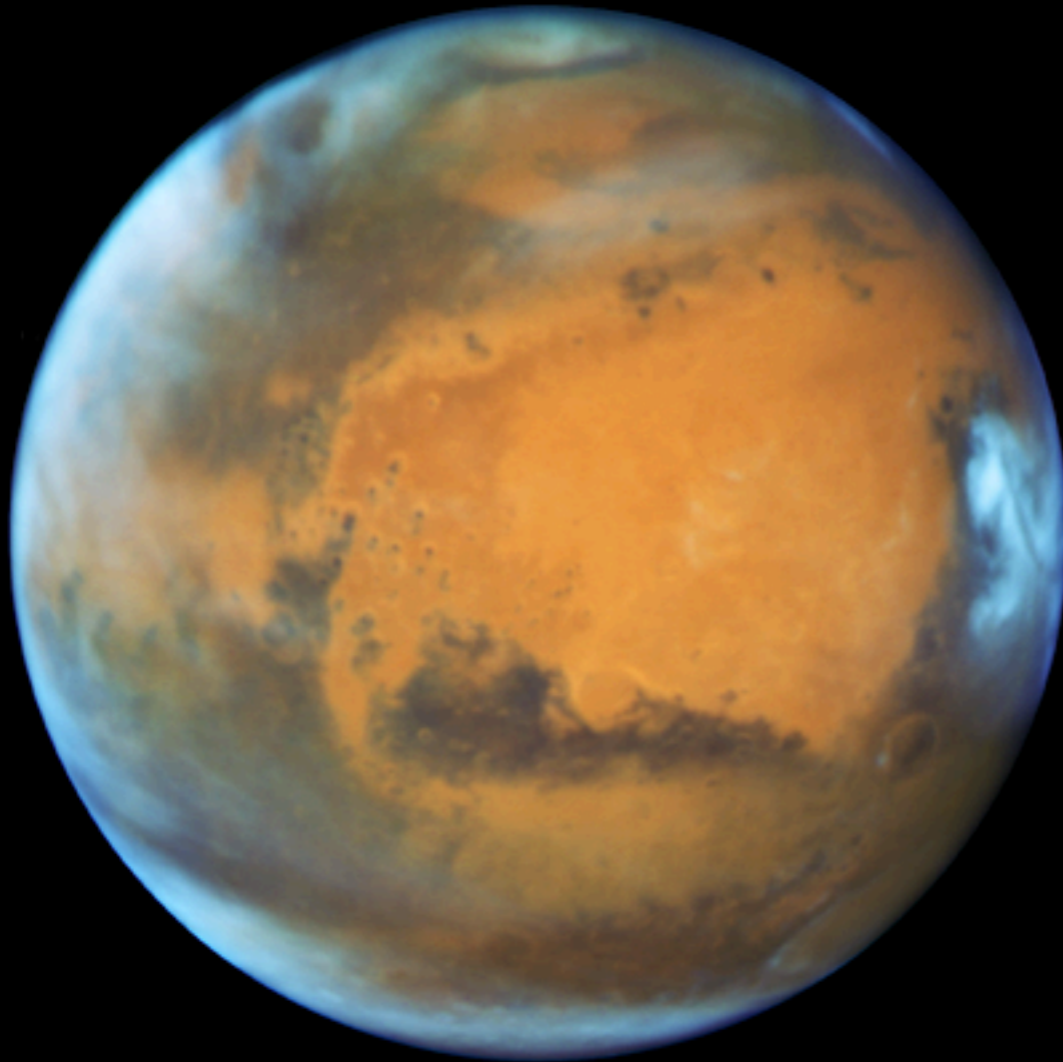


- Mars does have seasons; both axial tilt and distance from the sun matter.
- Seasons on Mars are more extreme in the southern hemisphere because of its elliptical orbit.

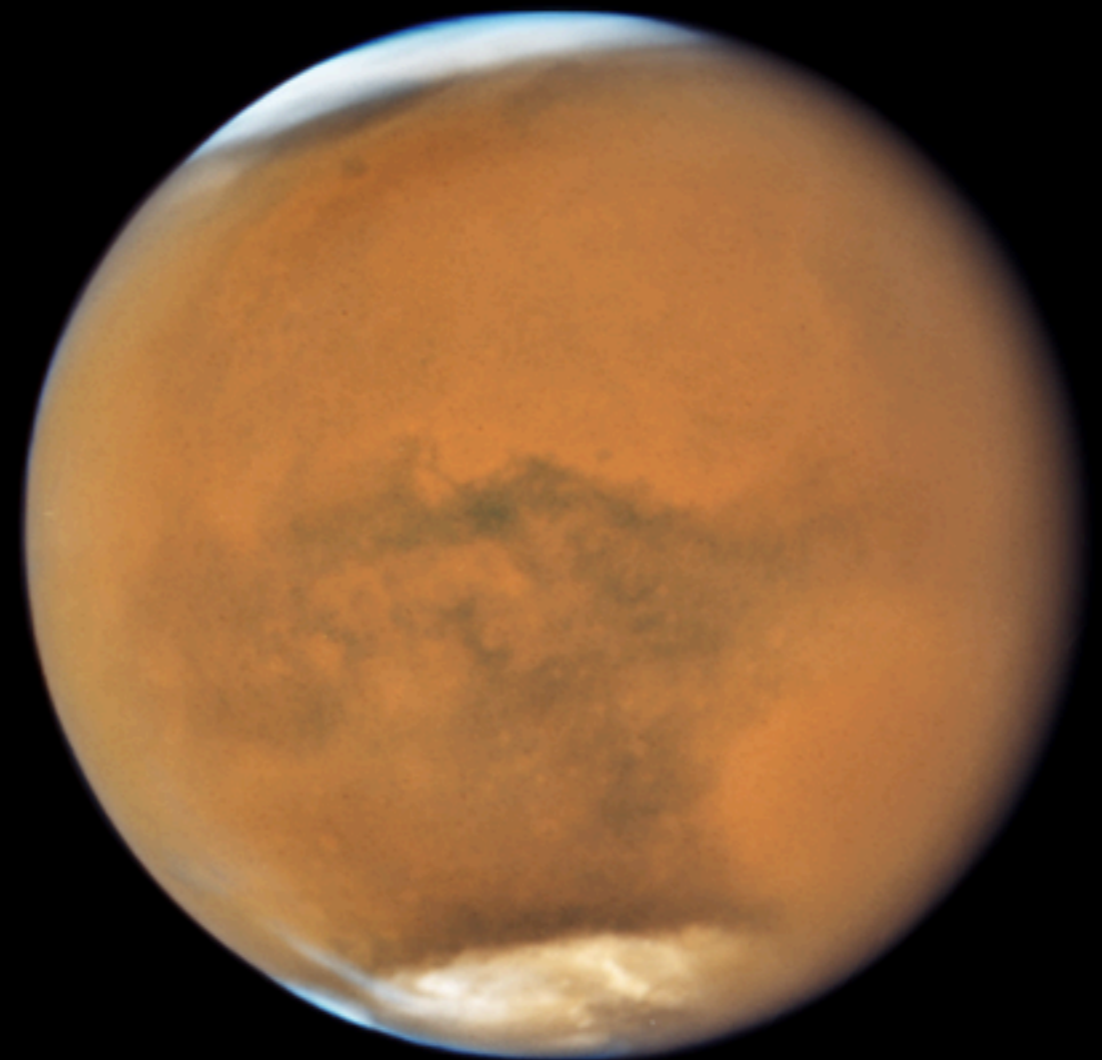
Storms on Mars

- Seasonal winds on Mars can drive huge dust storms.
- Drives ongoing wind erosion

Mars Opposition

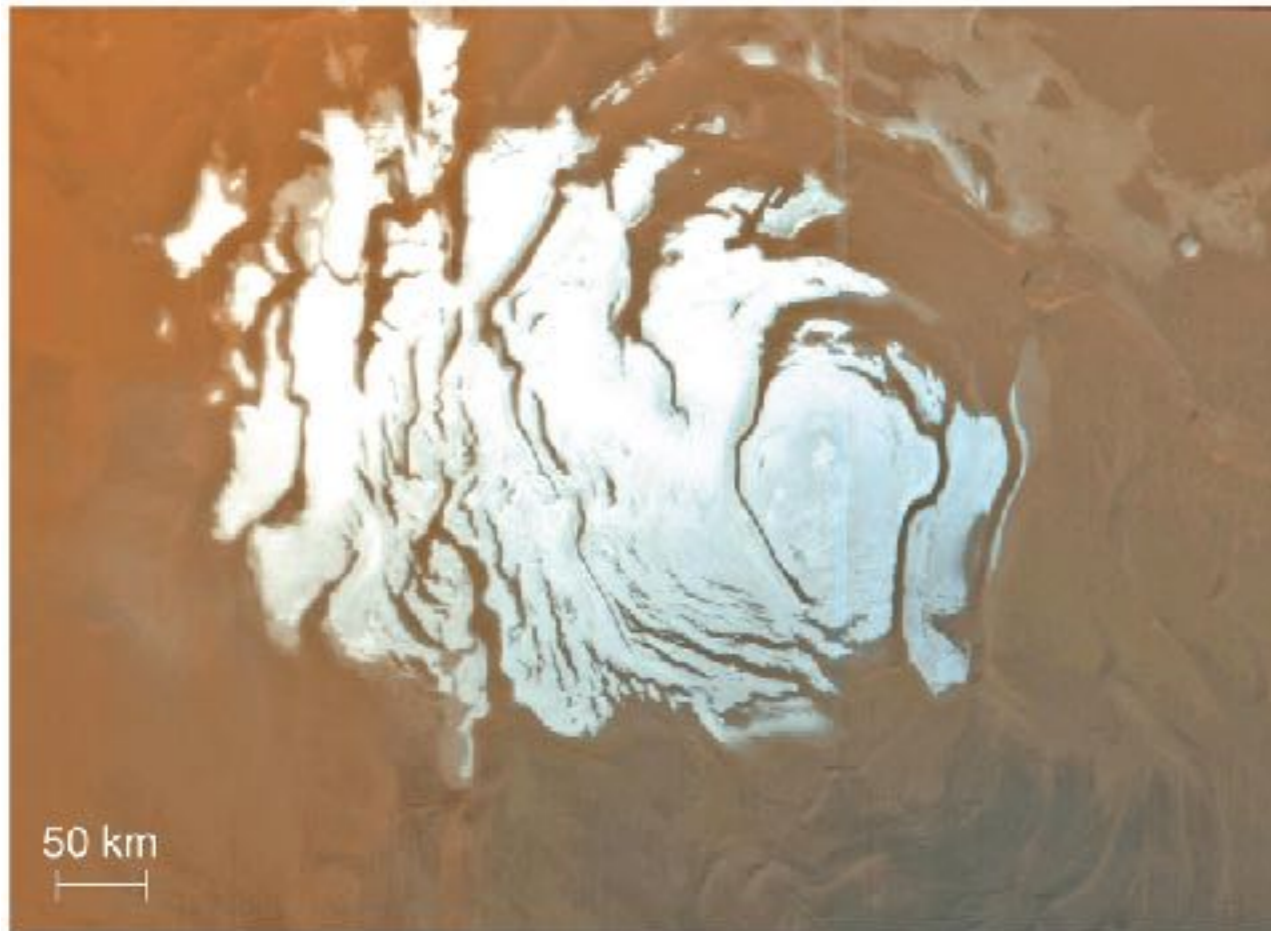


2016

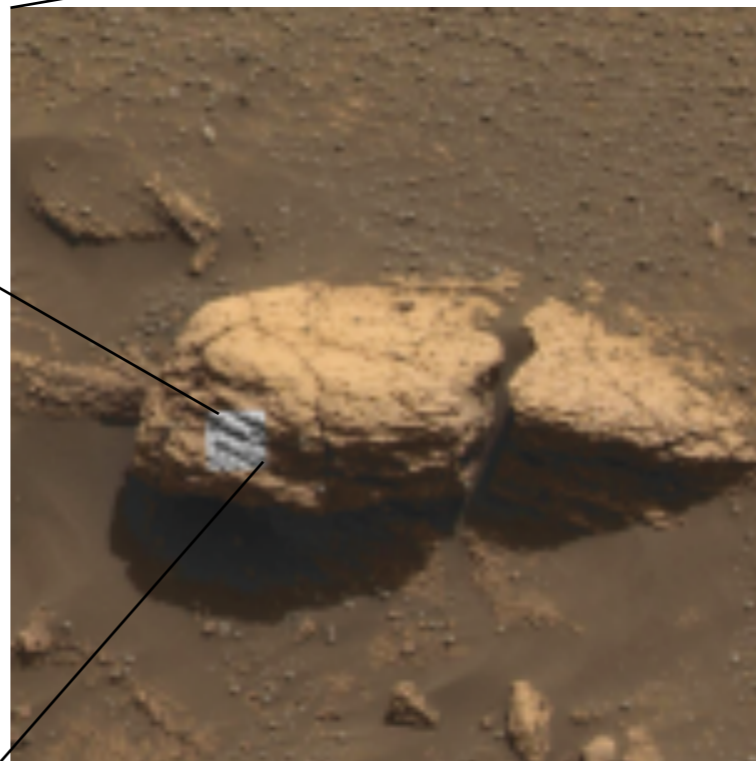
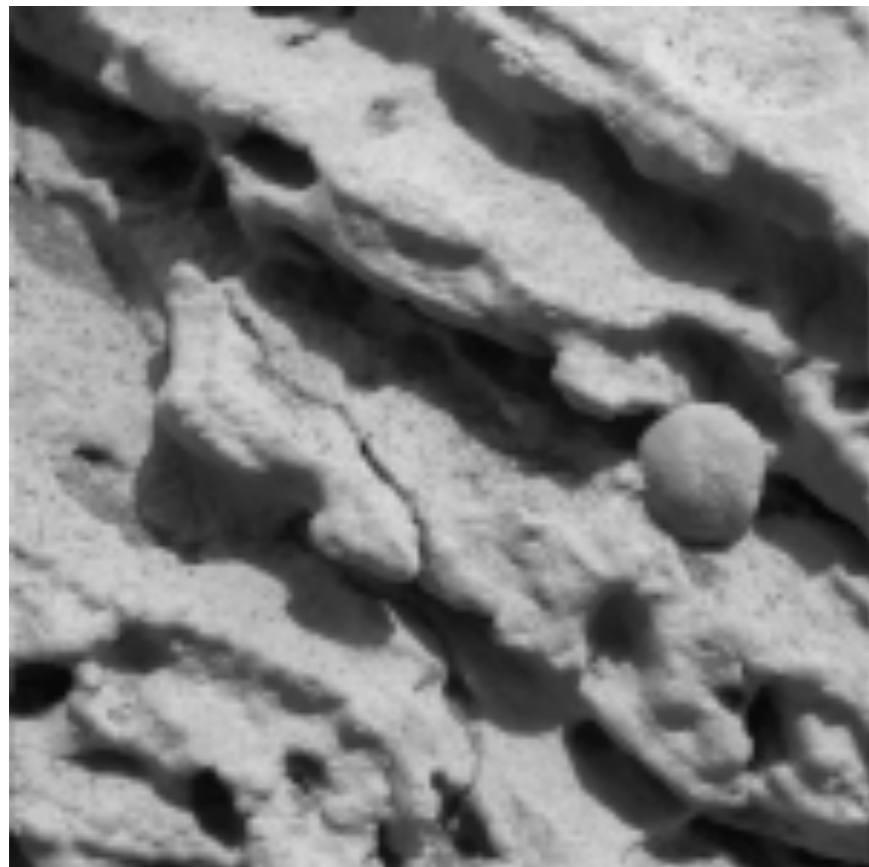
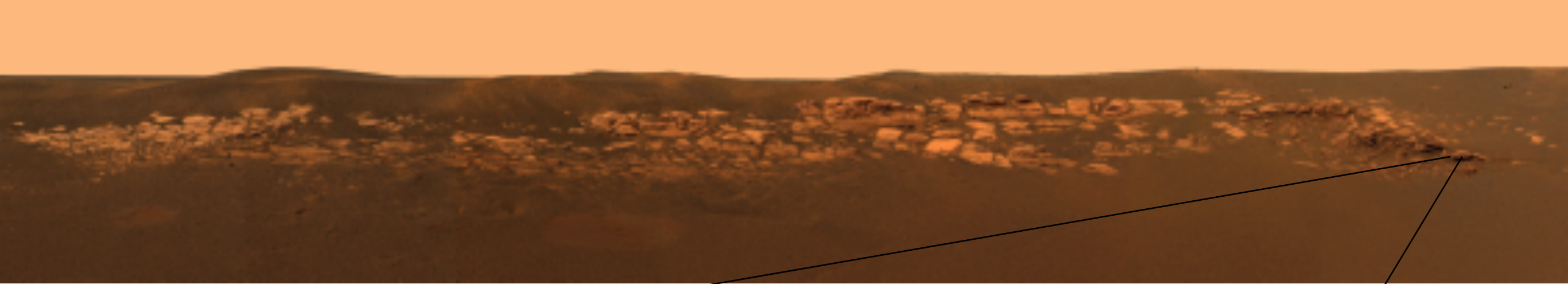


2018

Polar Ice Caps of Mars

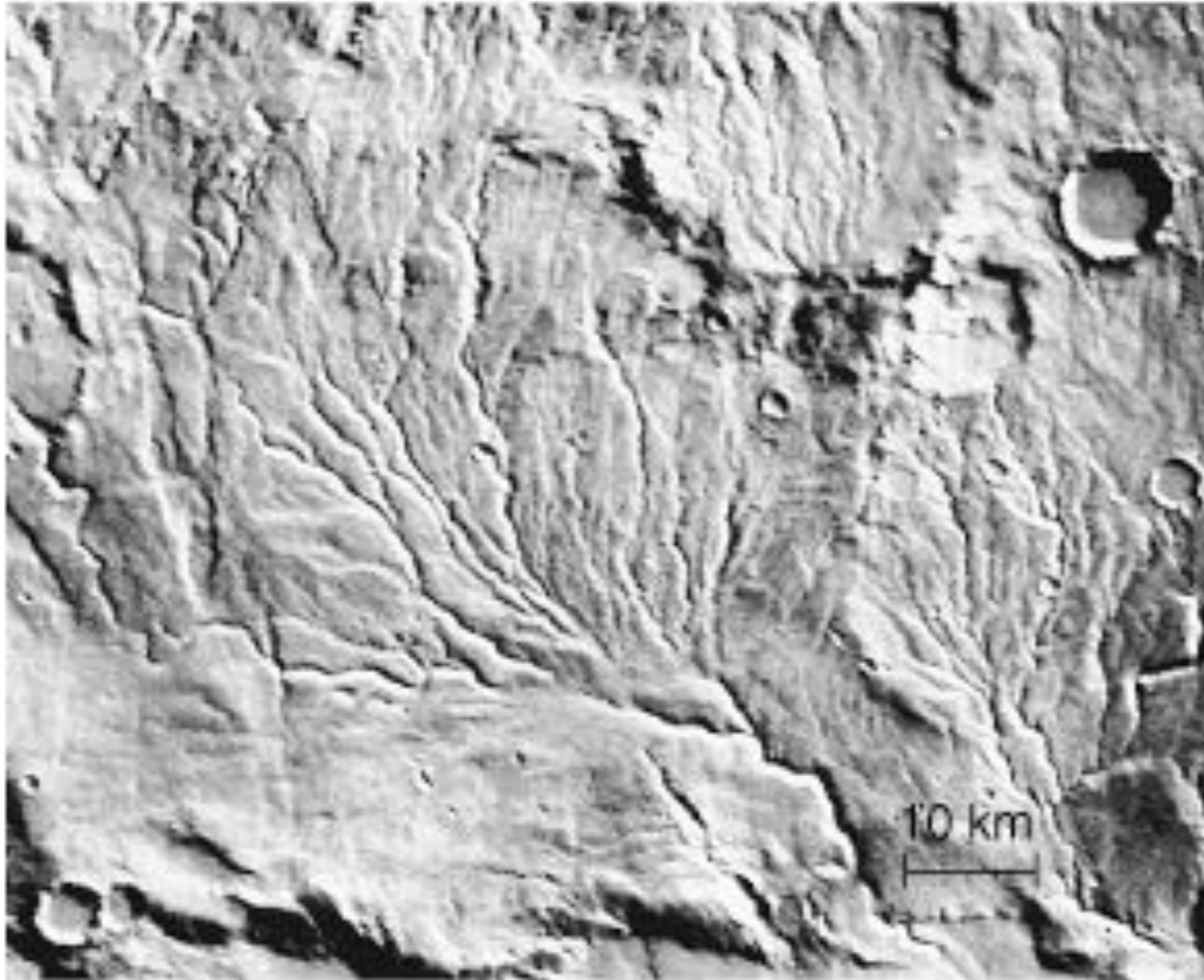


- Residual ice of the south polar cap remaining during summer is primarily water ice.
- Carbon dioxide ice of polar cap sublimates as summer approaches and condenses at opposite pole.



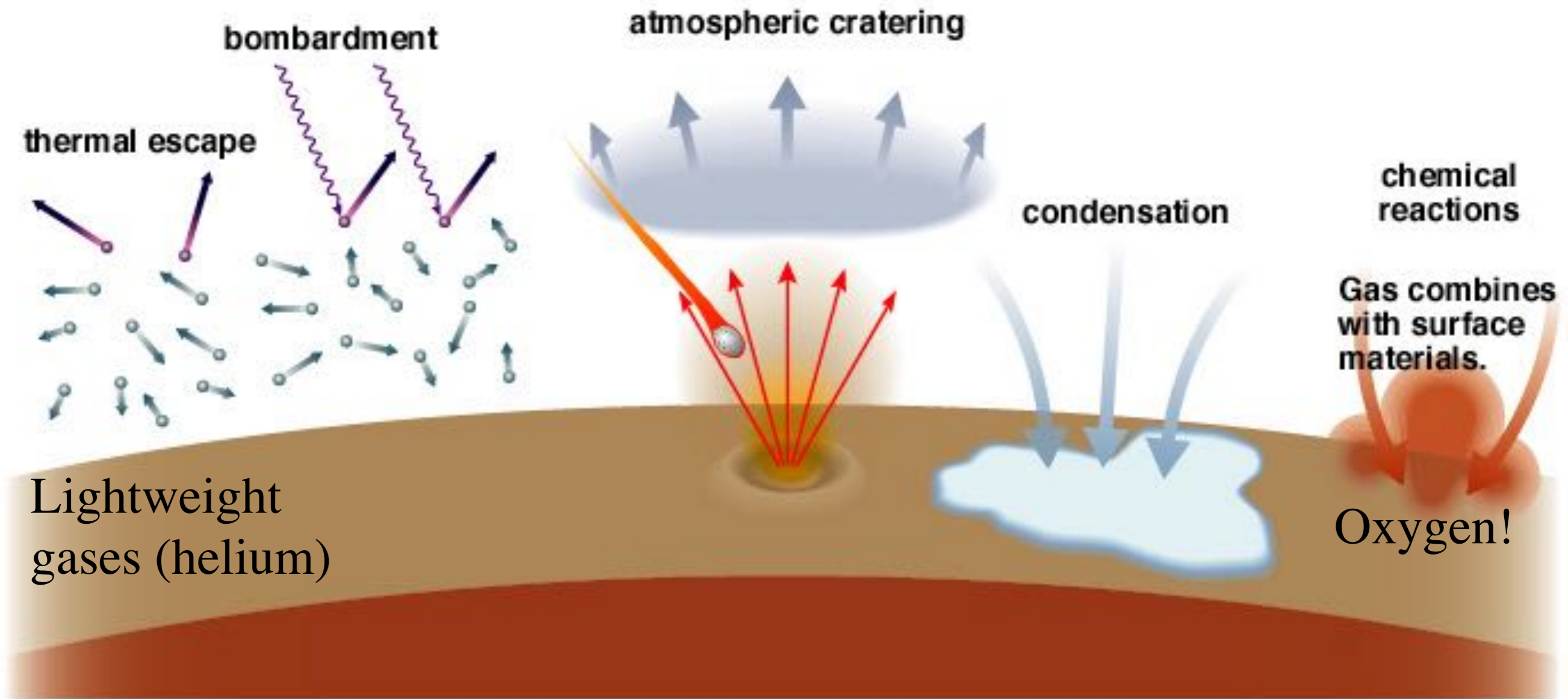
- 2004 *Opportunity* Rover provided strong evidence for abundant liquid water on Mars in the distant past.
- How could Mars have been warmer and wetter in the past?

Climate Change on Mars



- Mars has not had widespread surface water for 3 billion years.
- The greenhouse effect probably kept the surface warmer before that.
- Over time, Mars lost most of its atmosphere.

Factors affecting atmospheres



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Can break up
water vapor;
hydrogen escapes

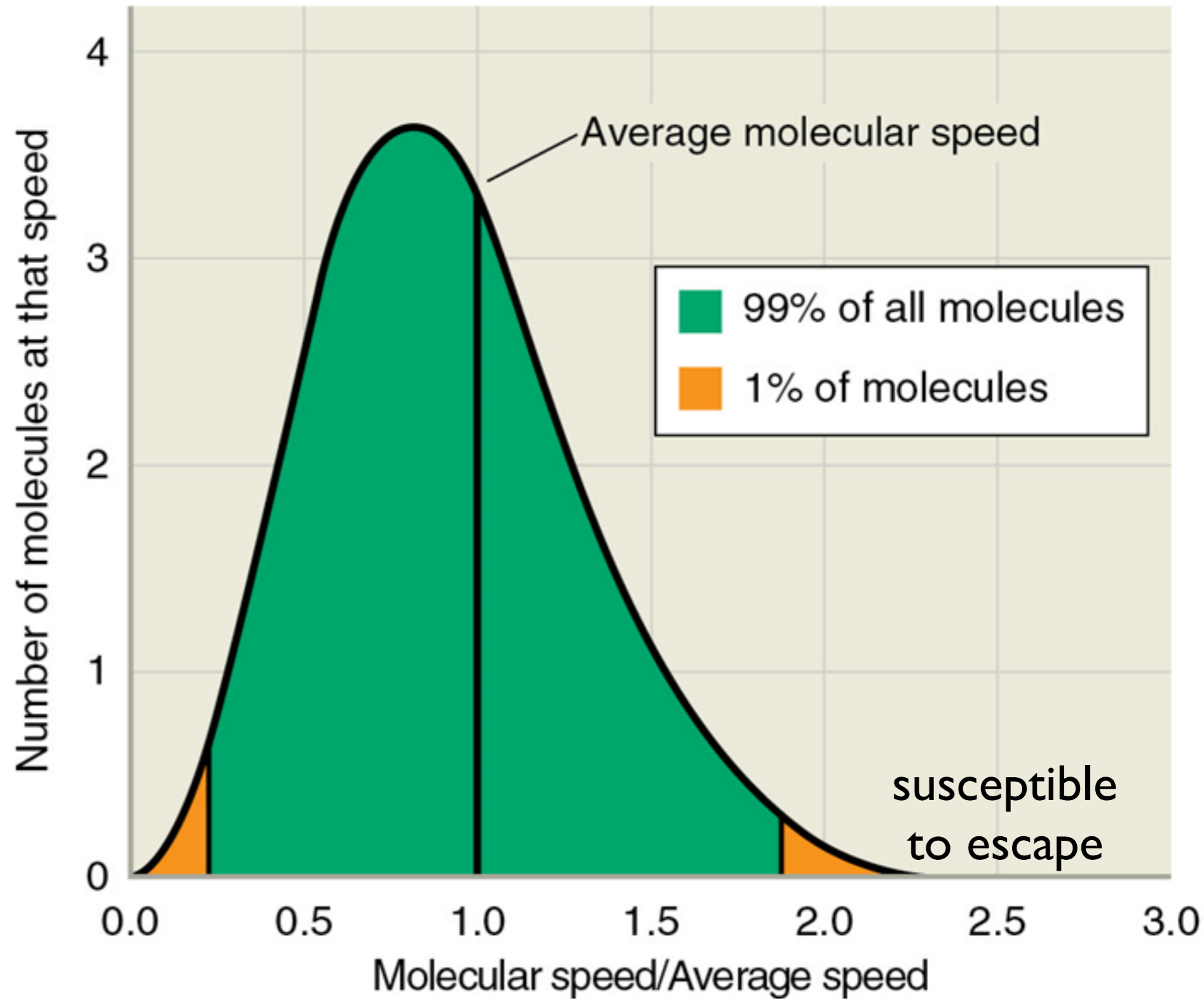
Water can
freeze out

Climate change on Mars

- Early Mars had thicker atmosphere
 - warmer climate
 - liquid water on surface (> 3 billion years ago!)
- Over time, most of Mars's atmosphere either
 - escaped into space
 - froze out onto surface
- Current atmosphere thin
 - Mostly CO₂, but not much of a greenhouse effect

Thermal escape

If atmospheric gas is hot enough, some of it exceeds escape velocity and leaks into space.



Factors affecting atmospheres

- Thermal Escape
- Bombardment (escape enhanced by molecular disintegration caused by energetic particles)
- Atmospheric cratering (important for thin atmospheres and/or major impact)
- Condensation (e.g., Martian polar caps; permafrost)
- Chemical Reactions (O_2 very reactive - won't last without replenishment. E.g., Permian-Triassic mass extinction)

Weather and Climate

Back on Earth

- **Weather** is the ever-varying combination of wind, clouds, temperature, and pressure.
 - Local complexity of weather makes it difficult to predict.
- **Climate** is the long-term average of weather.
 - generally more predictable than weather
 - Stability of climate depends on global conditions
 - Long term climate prone to instability
 - Venus, Mars evolved to stable points
 - Earth still varying (e.g., ice ages come & go)

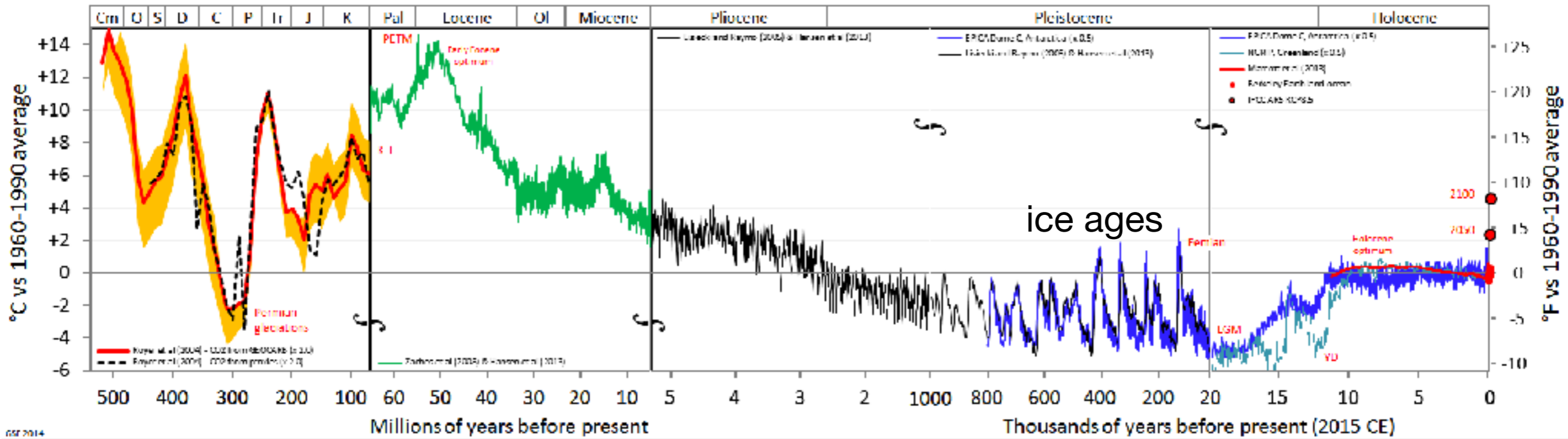
Climate is what you expect

Weather is what you get

Climate change over time

The average temperature has gradually decreased as the CO₂ content of atmosphere declined

Temperature of Planet Earth

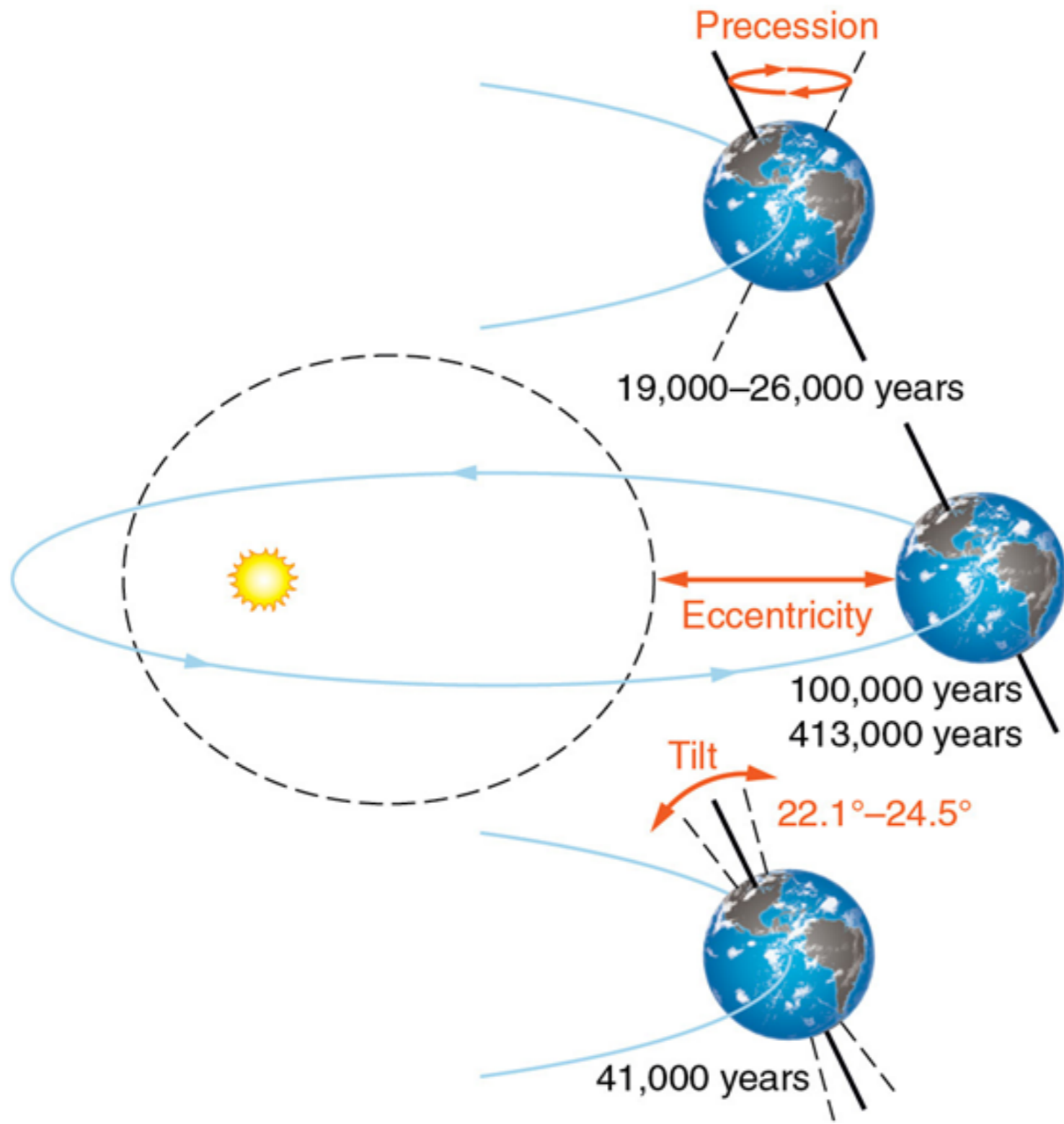


dinosaurs appear

dinosaurs disappear

Note highly variable time axis

humans appear



Subtle variations in Earth's orbit can impact long term climate.

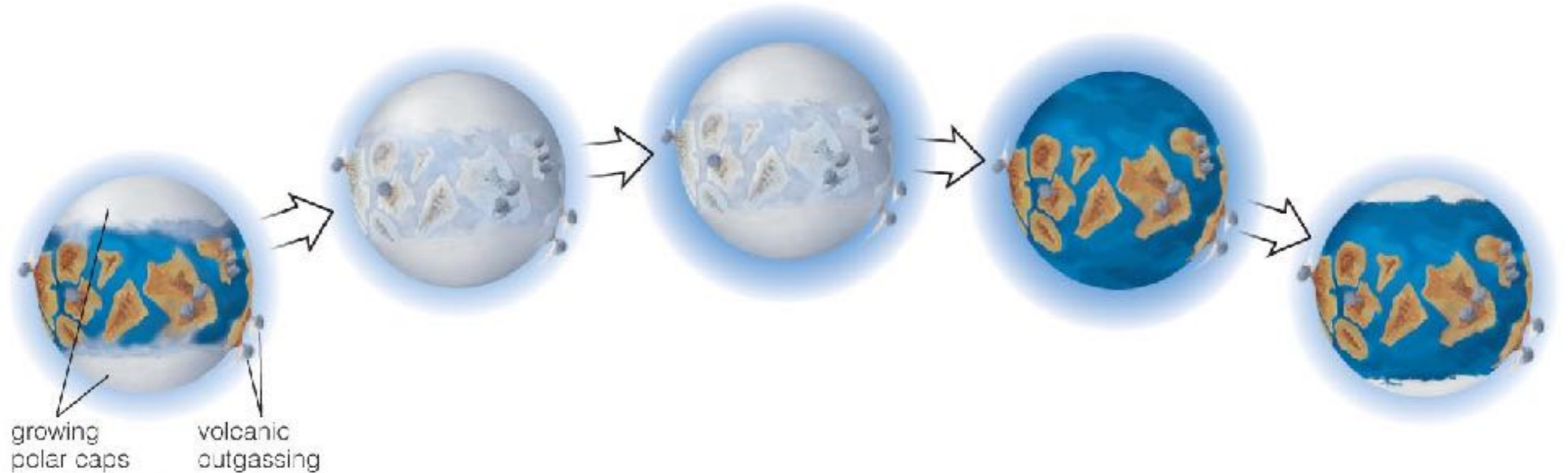
Precession means the north pole isn't always tipped towards the sun when the earth is farthest from it.

The tilt of the Earth's axis oscillates between 22 and 24.5 degrees, slightly varying seasonal extremity.

Though subtle, it is thought that these effects could contribute to the coming and going of the ice ages.

Long-Term Climate Change (e.g., Ice Ages)

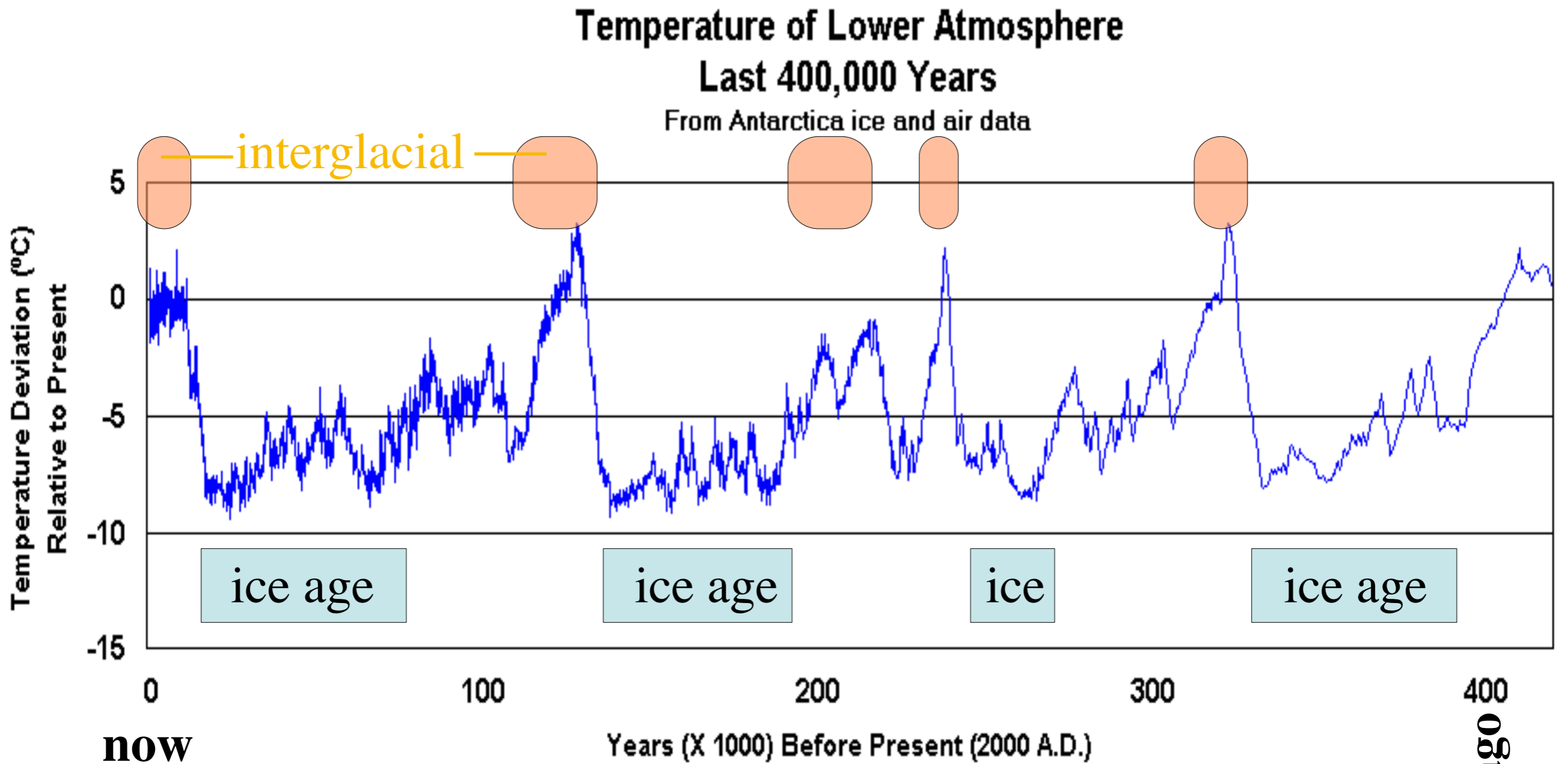
over 10,000s & 100,000s years



- Changes in Earth's axis tilt might lead to ice ages.
- Widespread ice tends to lower global temperatures by increasing Earth's reflectivity.
- CO₂ from outgassing will build up if oceans are frozen, ultimately raising global temperatures again.

Earth's climate variable on ~10,000 yr timescale: ice ages

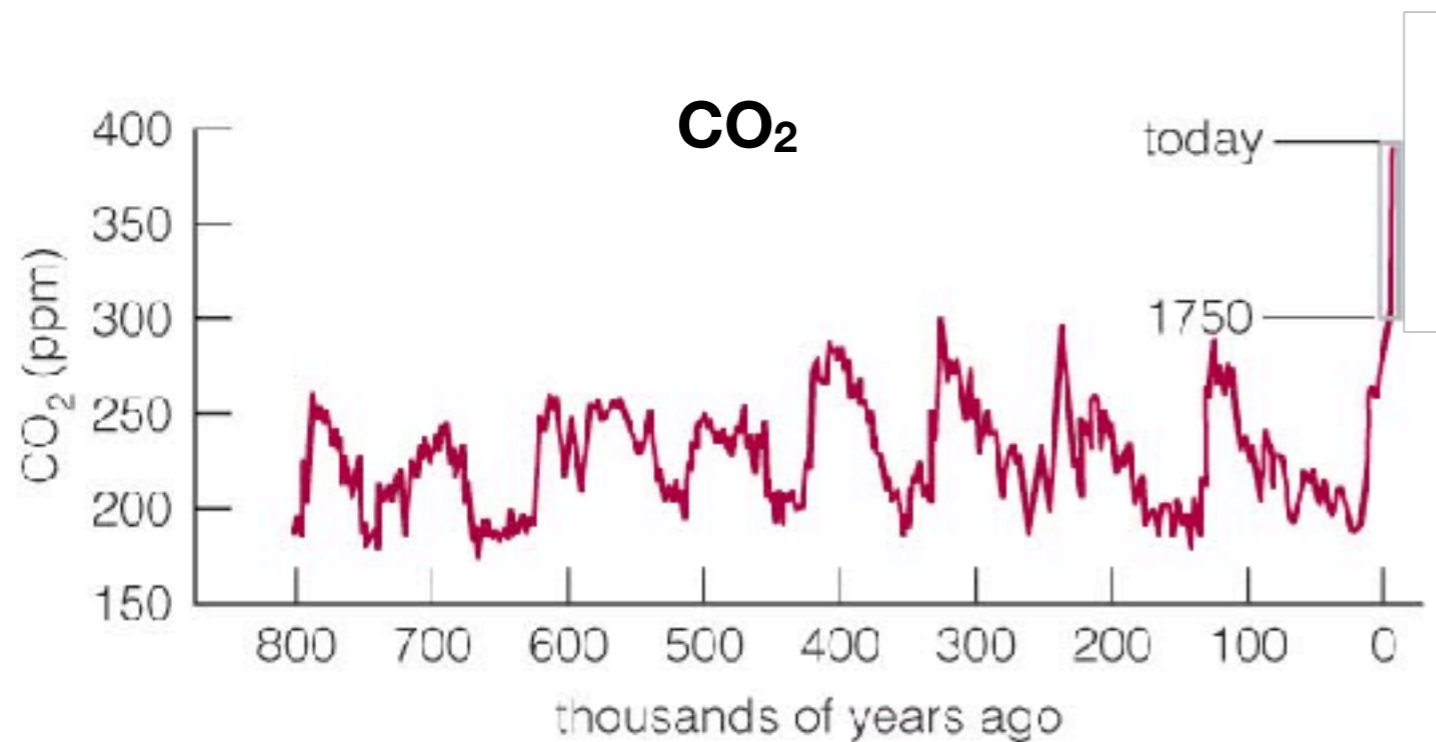
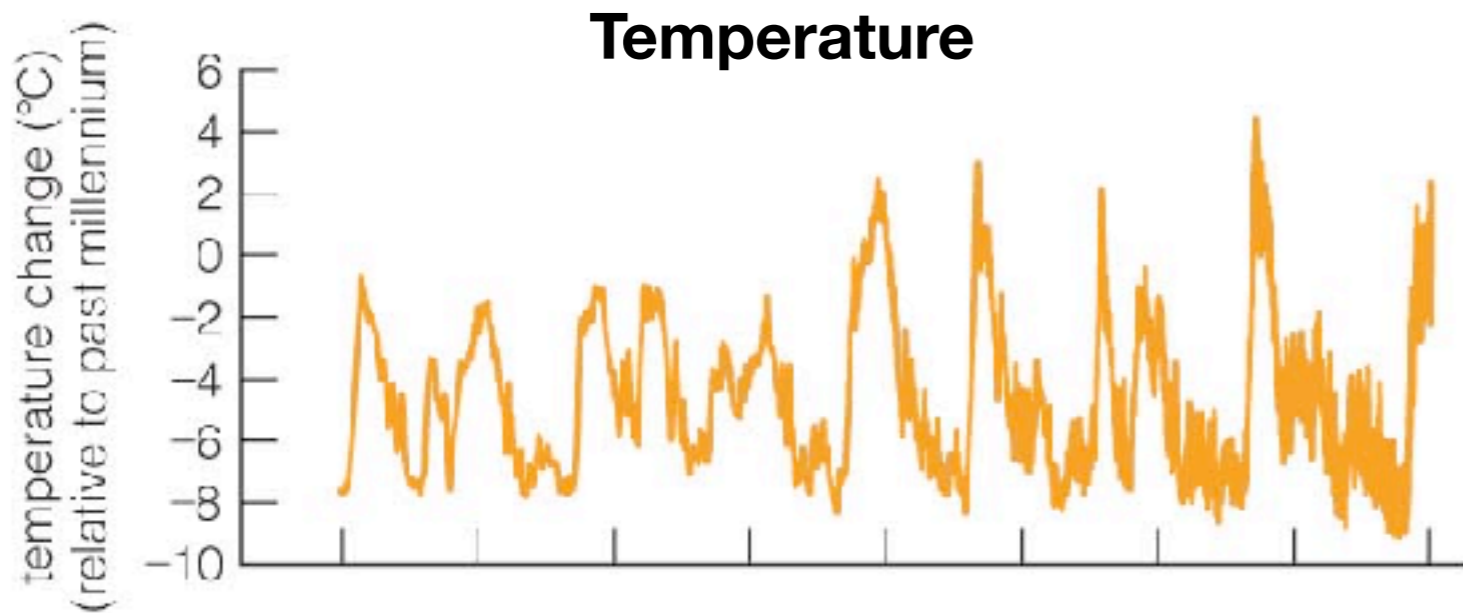
Humans have been around > 100,000 years, but civilization only arose at the end of the last ice age



Good global climate record for past half million years from Antarctic ice core measurements

400,000 yr ago

CO₂ Concentration



- Temperature and CO₂ concentration vary in lockstep
- This coupling is expected from known physics
- Current CO₂ concentration is the highest it's been in at least 500,000 years.
 - All of human existence

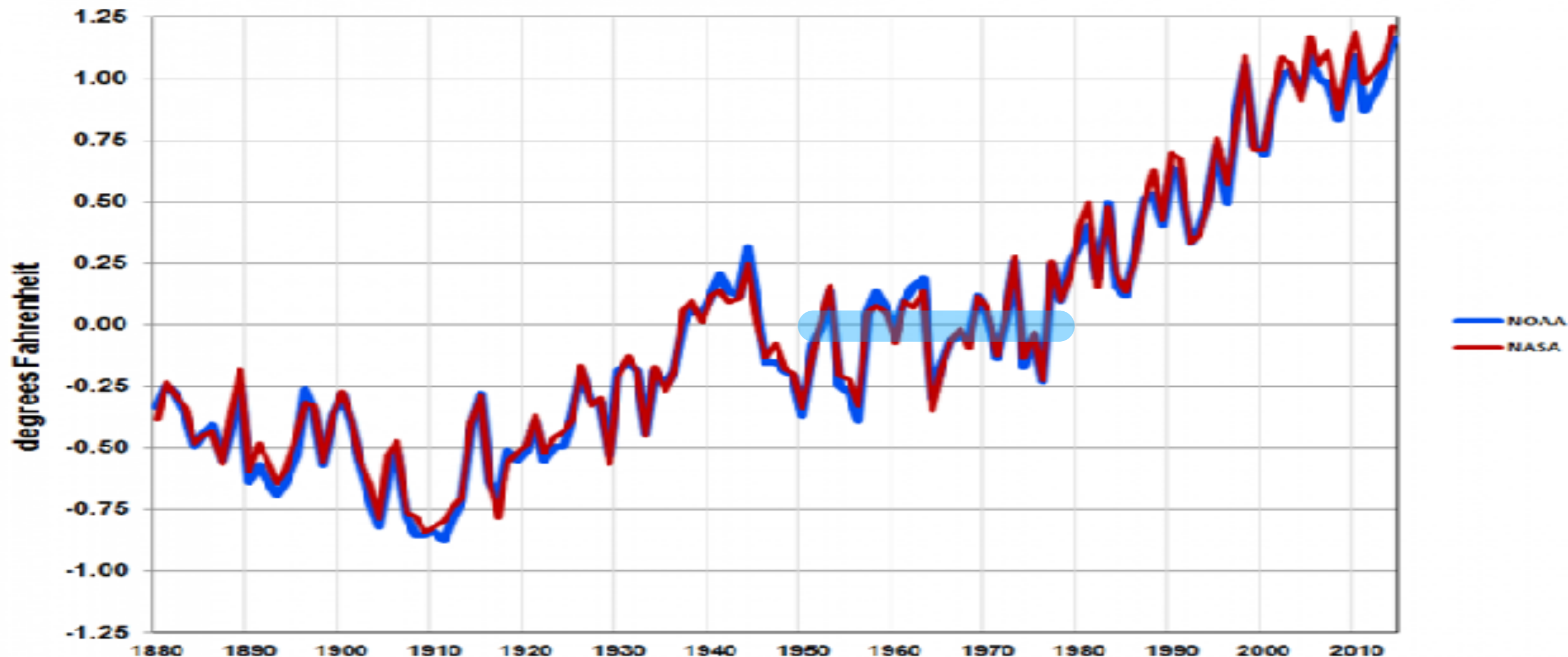
The anthropogenic greenhouse effect (Global Warming and human activity)

What is real information?

What is misleading?

Should we be worried?

NASA and NOAA: relative to a common 1951-80 base period



News clipping from 1912:

The potential for human-driven climate change has been known for a long time

In an **1827** paper **Fourier** stated, "*The establishment and progress of human societies, the action of natural forces, can notably change, and in vast regions, the state of the surface, the distribution of water and the great movements of the air. **Such effects are able to make to vary, in the course of many centuries, the average degree of heat; because the analytic expressions contain coefficients relating to the state of the surface and which greatly influence the temperature.***"

The Rodney & Otamatea Times

WAITEMATA & KAIPARA GAZETTE.

PRICE—10s per annum in advance

WARKWORTH, WEDNESDAY, AUGUST 14, 1912.

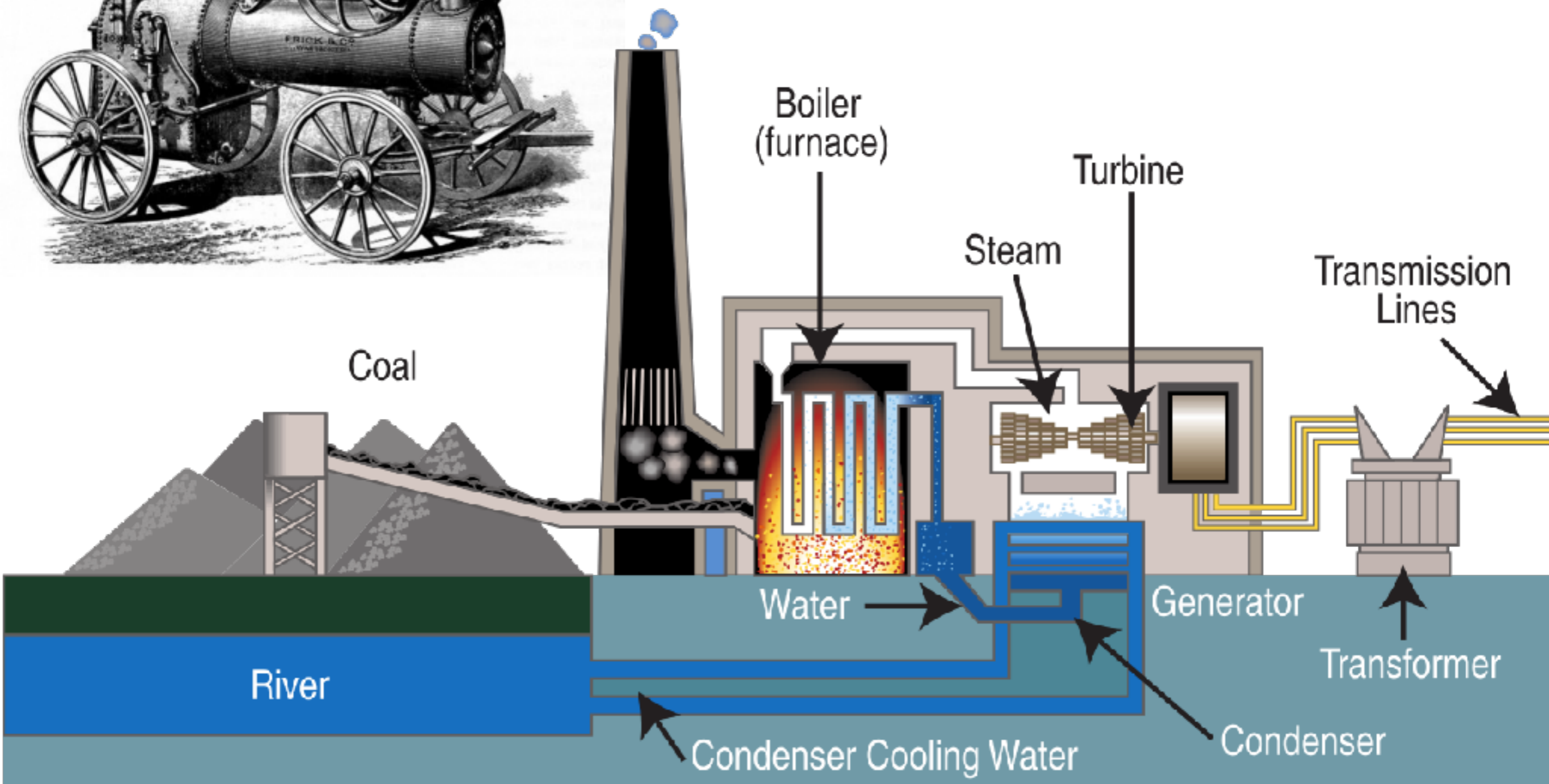
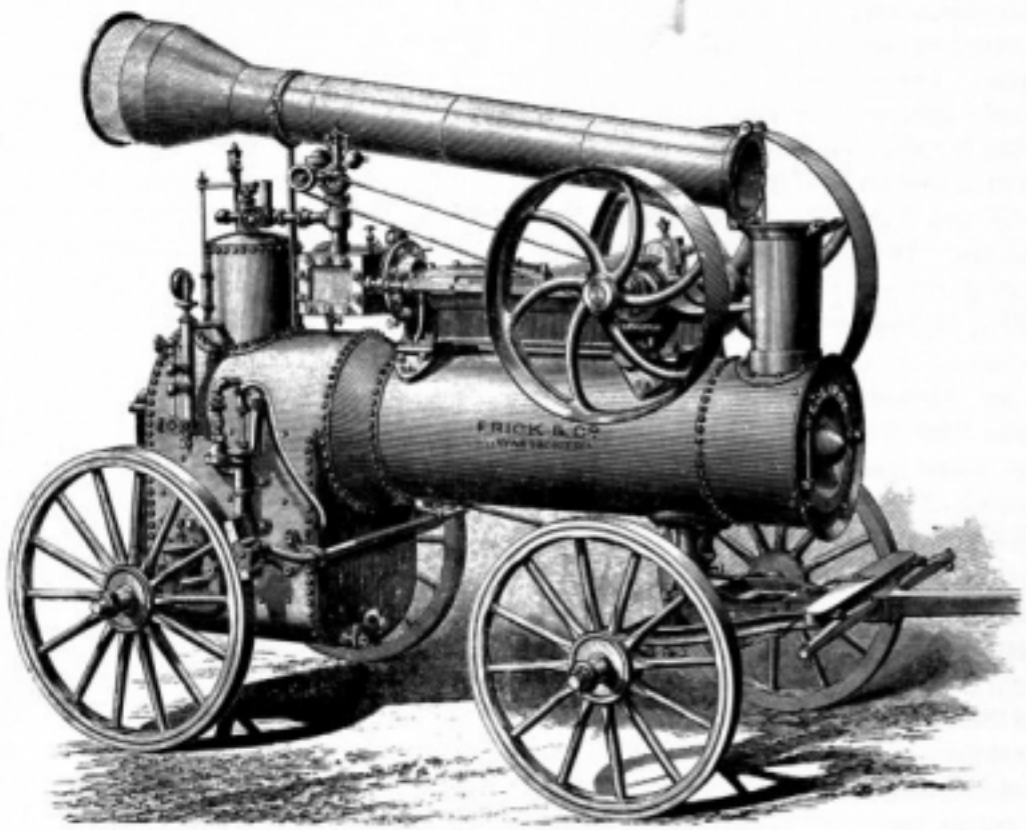
3d. per Copy.

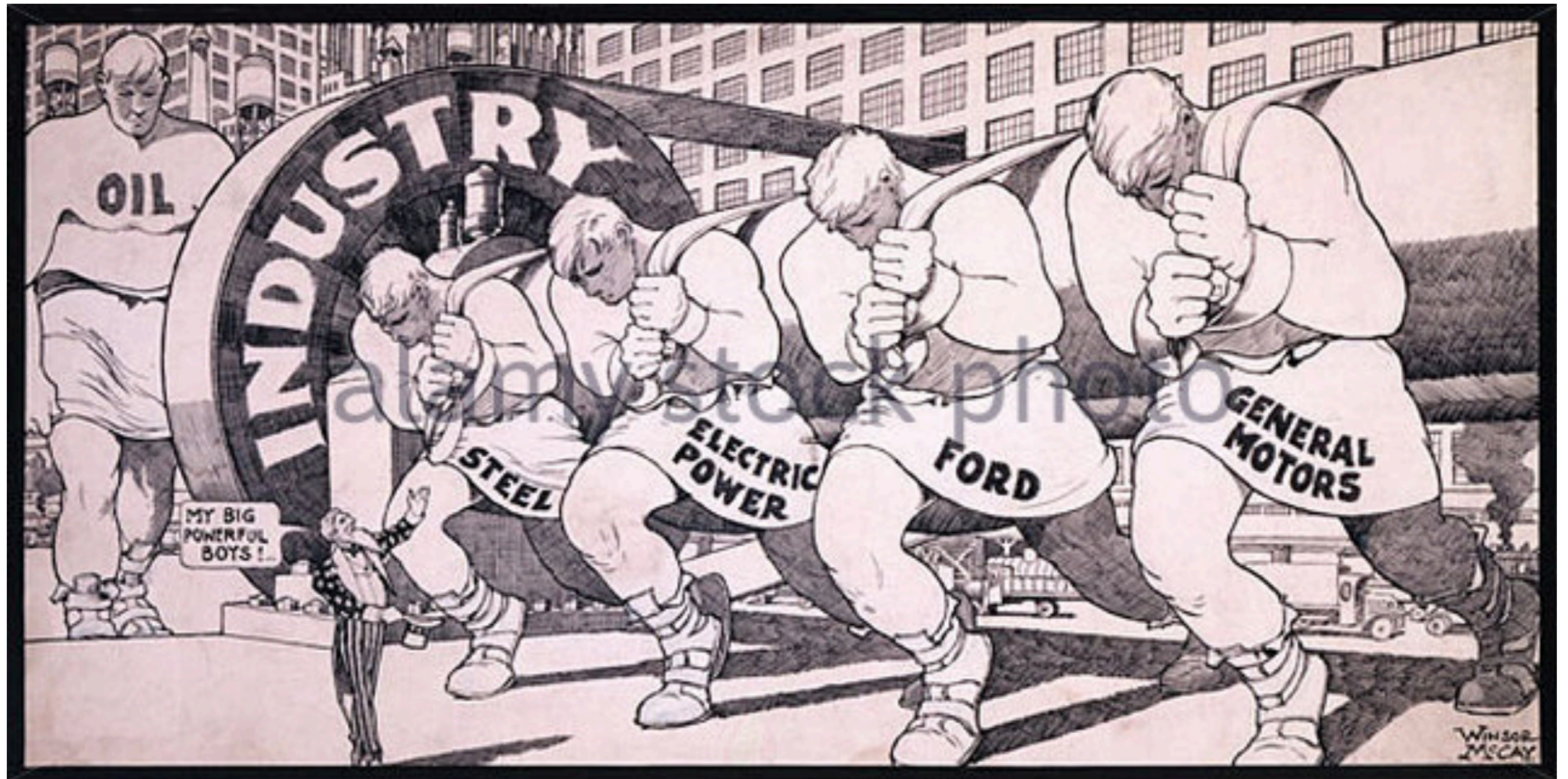
Science Notes and News.

COAL CONSUMPTION AFFECTING CLIMATE.

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 rate at which we burn fossil fuels has accelerated.





Global Warming

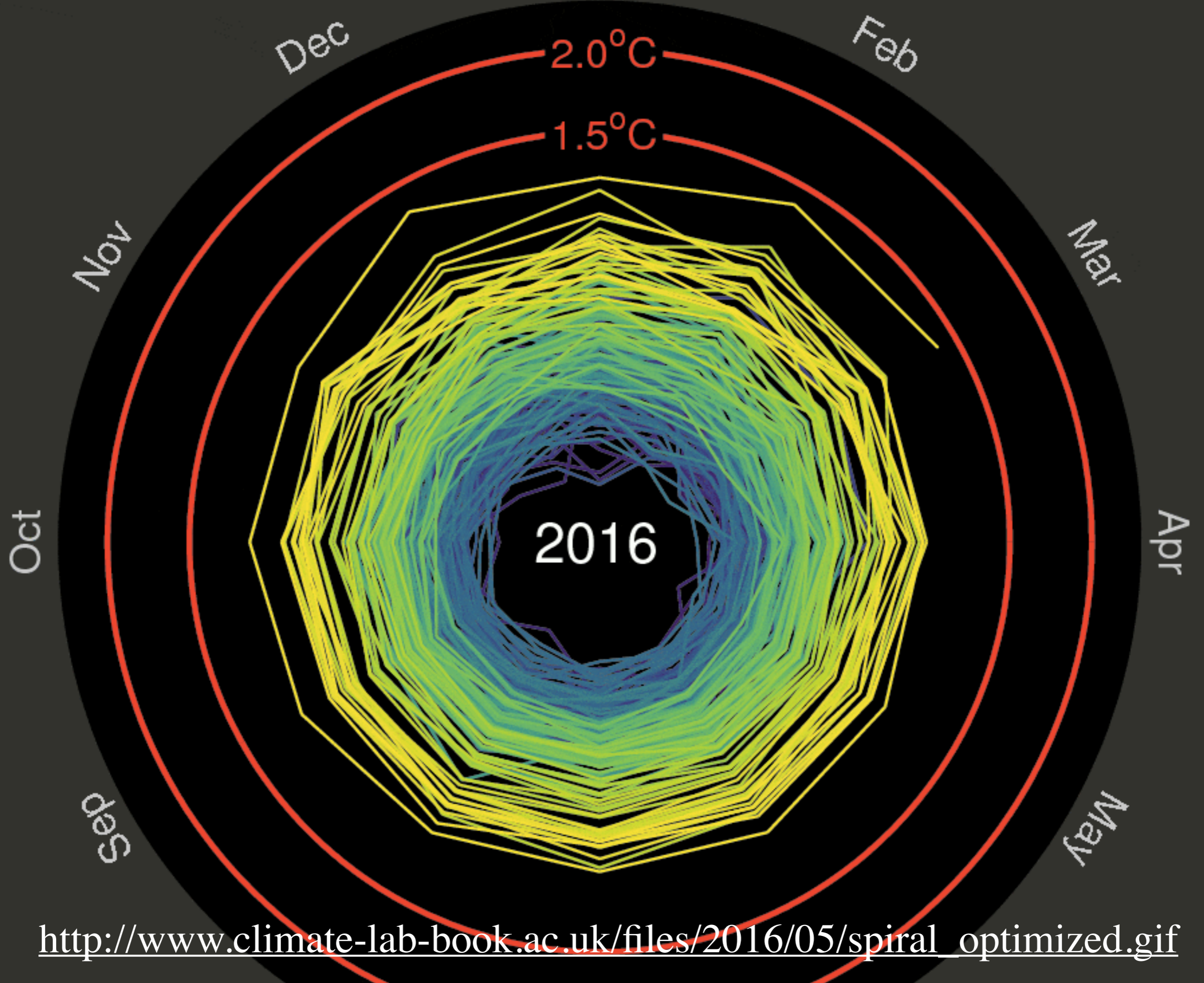
Basic facts

(non-partisan)

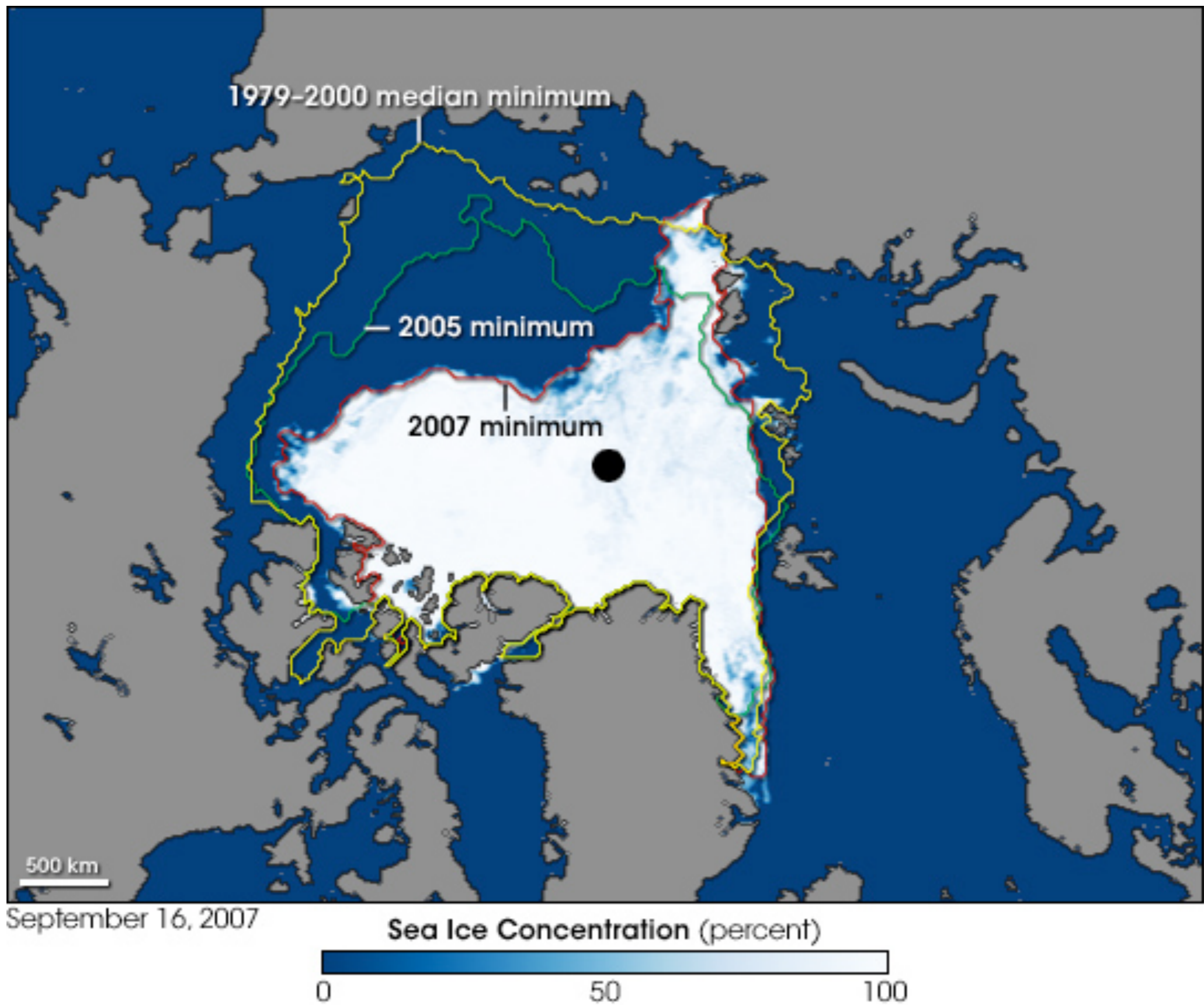
- The globe is warming (*measured*)
- The concentration of CO₂ in the atmosphere is increasing (*measured*)
- The CO₂ increase is roughly equal to the amount of fossil fuel we've burned (*measured*)
- Climate change is the expected result of changing greenhouse gases in the atmosphere
 - (e.g., Venus, Mars)

Evidence of global warming

- Increase in greenhouse gas concentrations
- Surface temperature measurements
- Ocean temperature measurements
- Sea level rise (water expands as it warms)
- Melting arctic icecap; retreating glaciers
- Poleward migration of species
- More extreme weather events
 - both warm & cold; floods & draughts; extreme storms, hurricanes, etc
- Melting permafrost



http://www.climate-lab-book.ac.uk/files/2016/05/spiral_optimized.gif

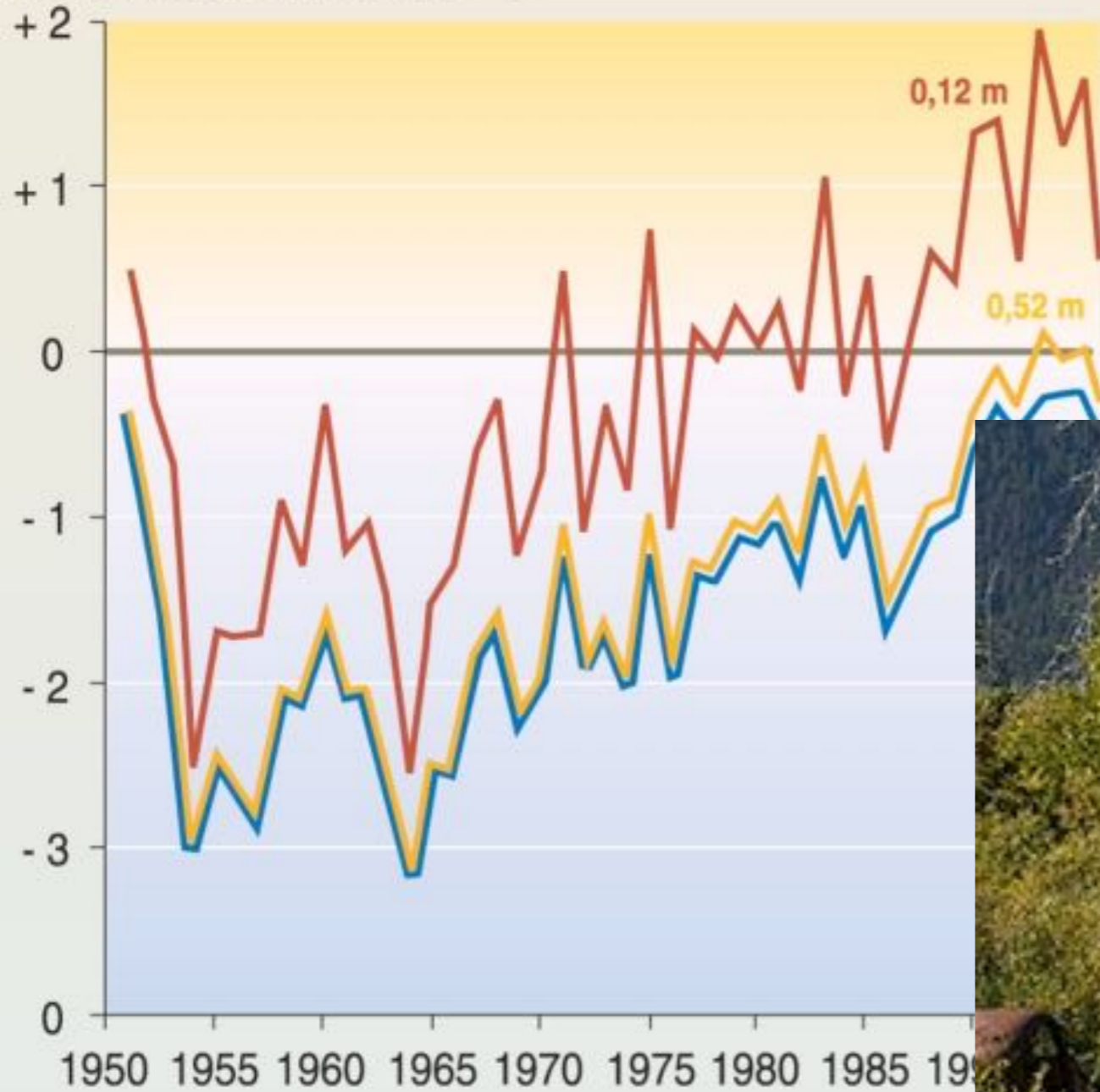


Fabled Northwest passage opened for first time in history in 2007

Change in permafrost temperatures at various depths in Fairbanks (Alaska)

Arctic permafrost is melting

Mean annual temperature °C



Soil depth (in meter)

— 0,12 m

— 0,52 m

— 1,01 m

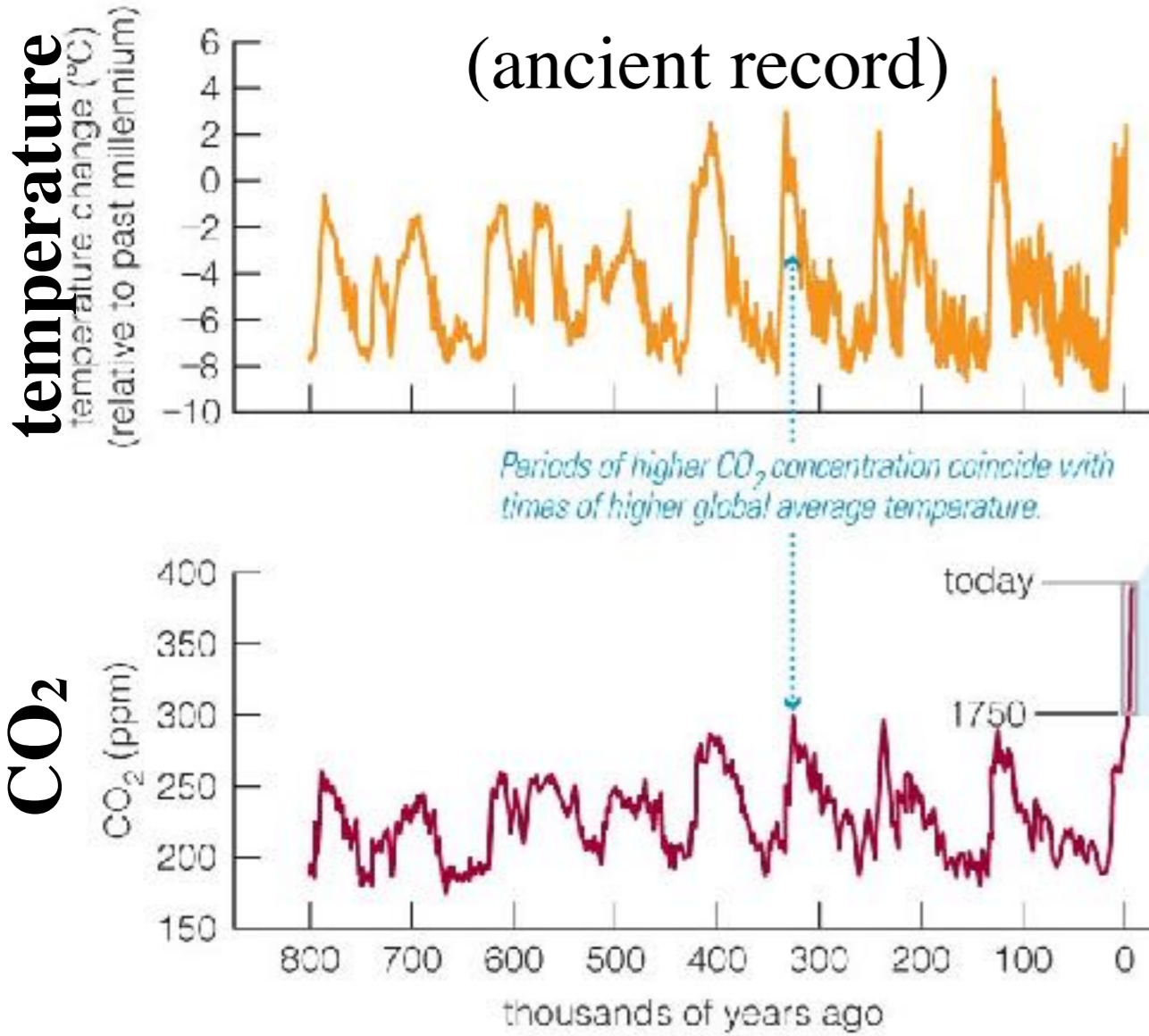
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Are

GRAPHIC DESIGN



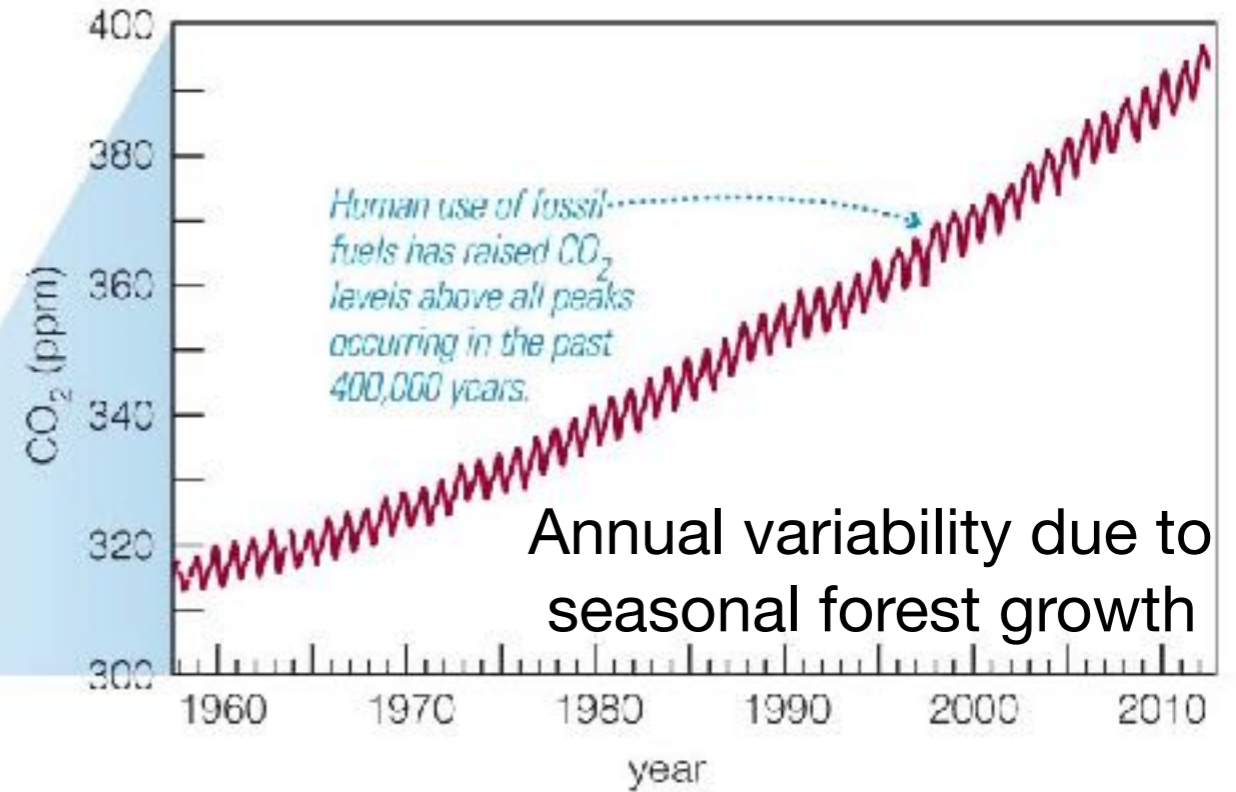
CO₂ Concentration

Ice core data
(ancient record)



time
(thousands of years)

Mauna Loa Observatory
(modern record)

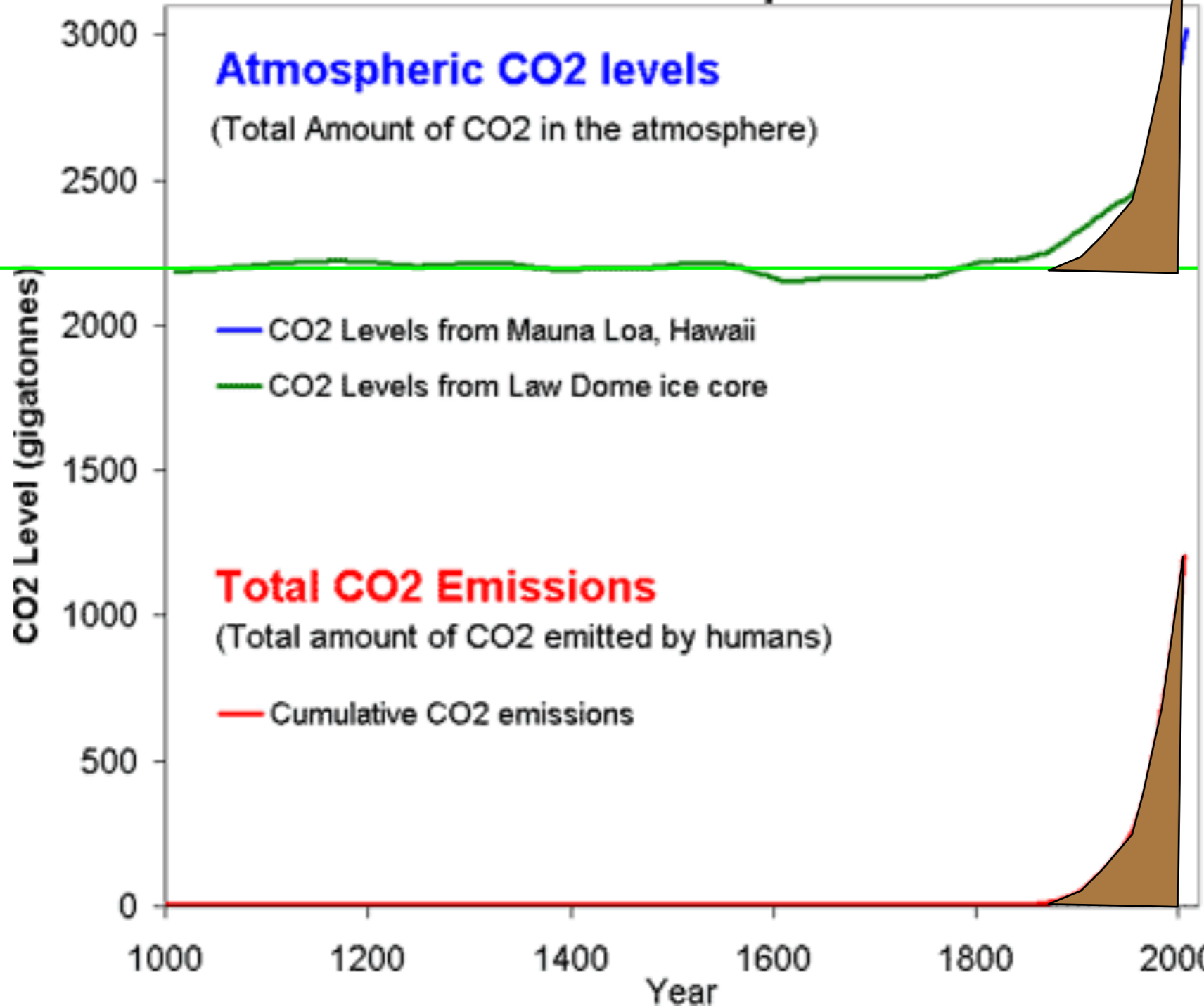


time
(years)

- Most of the CO₂ increase has happened in last 50 years

Pre-industrial CO₂ concentration: 280 ppm. Current level: 410 ppm

CO₂ emissions vs Atmospheric CO₂ Levels



CO₂ added to atmosphere

Human activity

Carbon burned

Pre-industrial CO₂ level

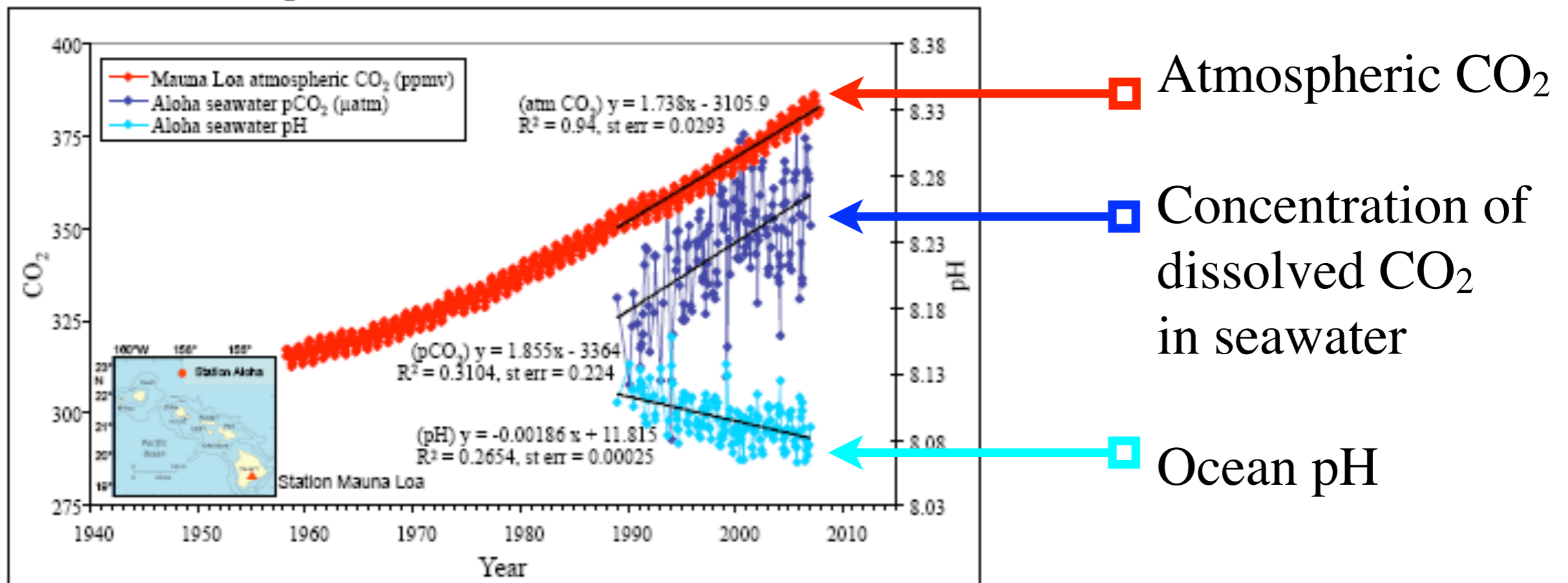
1000

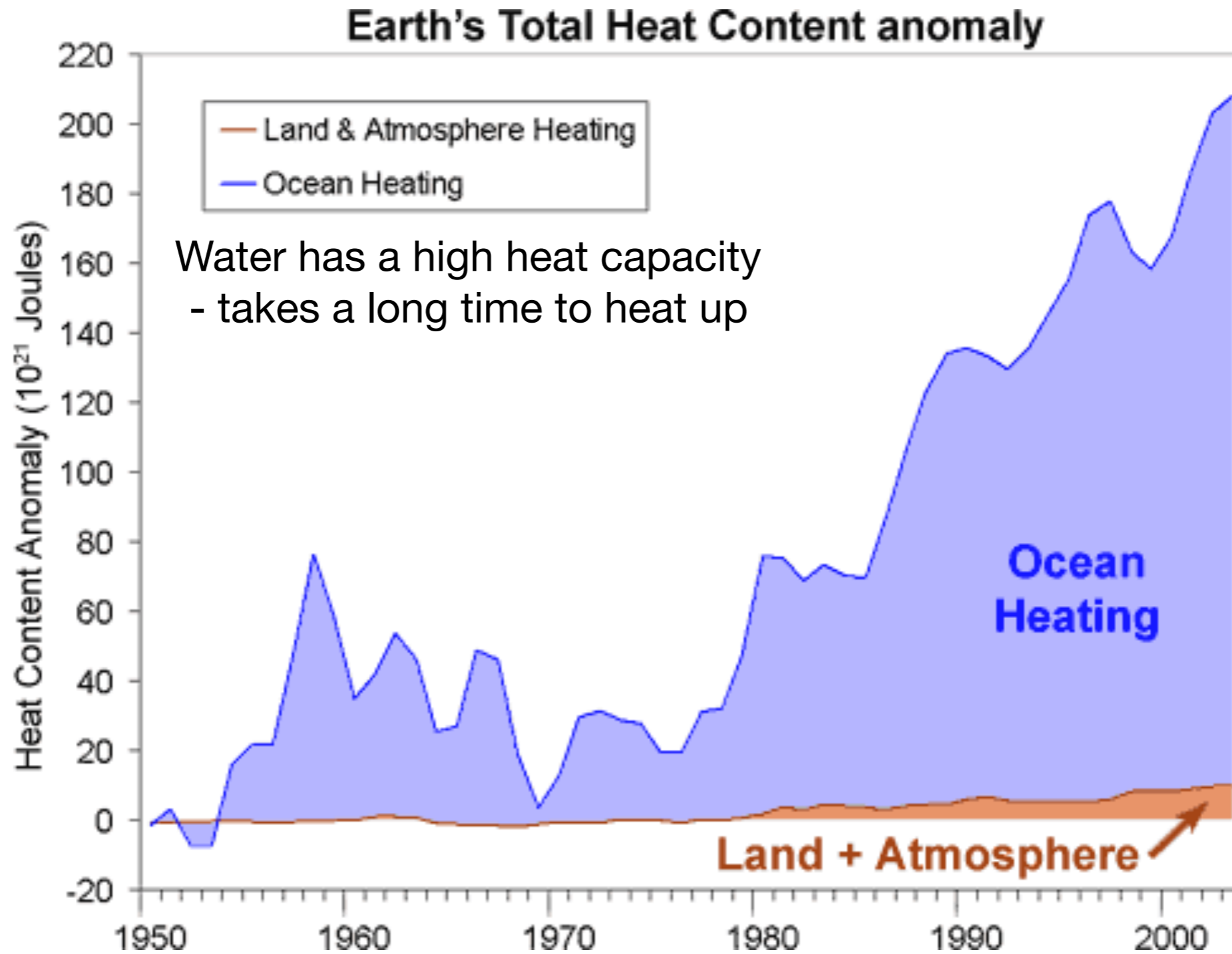
Year (A.D.)

2000

- Should be more CO₂ in atmosphere than there is
 - Some of what we've burned is missing
- Some CO₂ being sequestered in the ocean
 - Ocean acidity up due to increased amounts of CO₂ dissolved in seawater
 - pH = 8.25 to 8.14 over last two centuries

CO₂ Time Series in the North Pacific Ocean



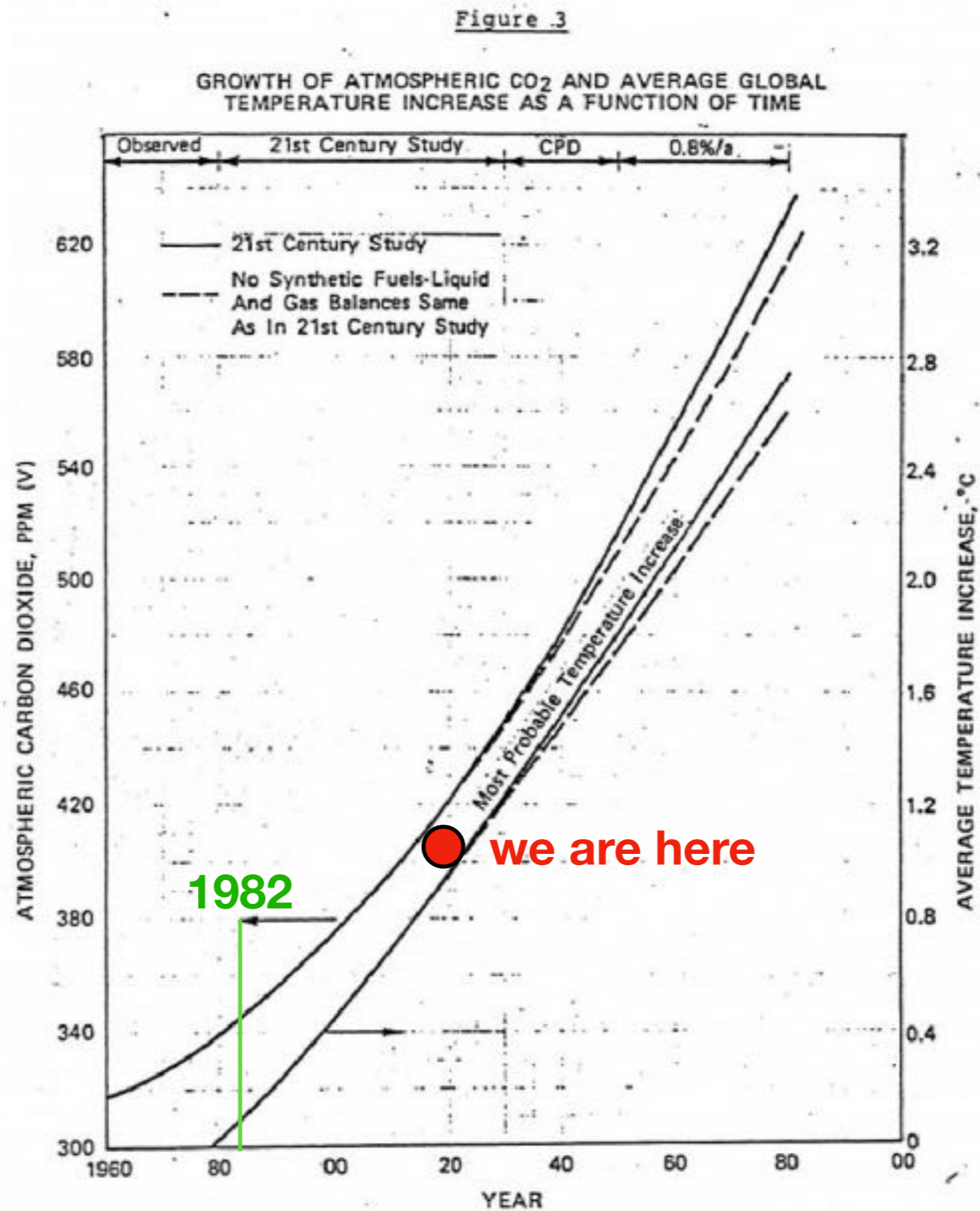


The Earth's climate is out of equilibrium - heat is accumulating in the ocean faster than it is being radiated into space.

Climate Change Forecasts

- Gradual increase of average temperature
 - average increase modest but noticeable
 - winter not cancelled by 2° of warming
- More wild swings in weather events
 - Heat waves *and* cold waves more extreme
 - Same for rainfall/snowfall
- Ocean levels rise
 - 8” since 1880 (measured) *adios, Miami Beach*
 - 3’ forecast by 2100 - mostly thermal expansion
- Drought *model dependent*
 - California, southwest dry out (more)
 - due to enhanced evaporation, smaller snowpack

this chart from a **1982 Exxon report**, projecting atmospheric CO₂ concentrations and increasing global temperatures.



The corporate response was to cover it up and launch a disinformation campaign.

Talking points of the disinformation campaign

By “recognize uncertainties” they mean obfuscate facts

Victory Will Be Achieved When

- Average citizens “understand” (recognize) uncertainties in climate science; recognition of uncertainties becomes part of the “conventional wisdom”
 - Media “understands” (recognizes) uncertainties in climate science.
 - Media coverage reflects balance on climate science and recognition of the validity of viewpoints that challenge the current “conventional wisdom”
 - Industry senior leadership understands uncertainties in climate science, making them stronger ambassadors to those who shape climate policy
 - Those promoting the Kyoto treaty on the basis of extant science appear to be out of touch with reality.
- The 1997 Kyoto Protocol extended the 1992 international recognition of climate change

This disinformation approach had been pioneered by the Tobacco industry

Policy implications

- Basic trend clear but detailed long range forecast challenging.
 - Probably some winners as well as losers
- Seems a bad idea to conduct an uncontrolled experiment on the atmosphere we all breathe & the climate we depend on.
- There is finite energy available in coal, oil, natural gas, uranium...
 - Are we *NOT* going to use these resources?