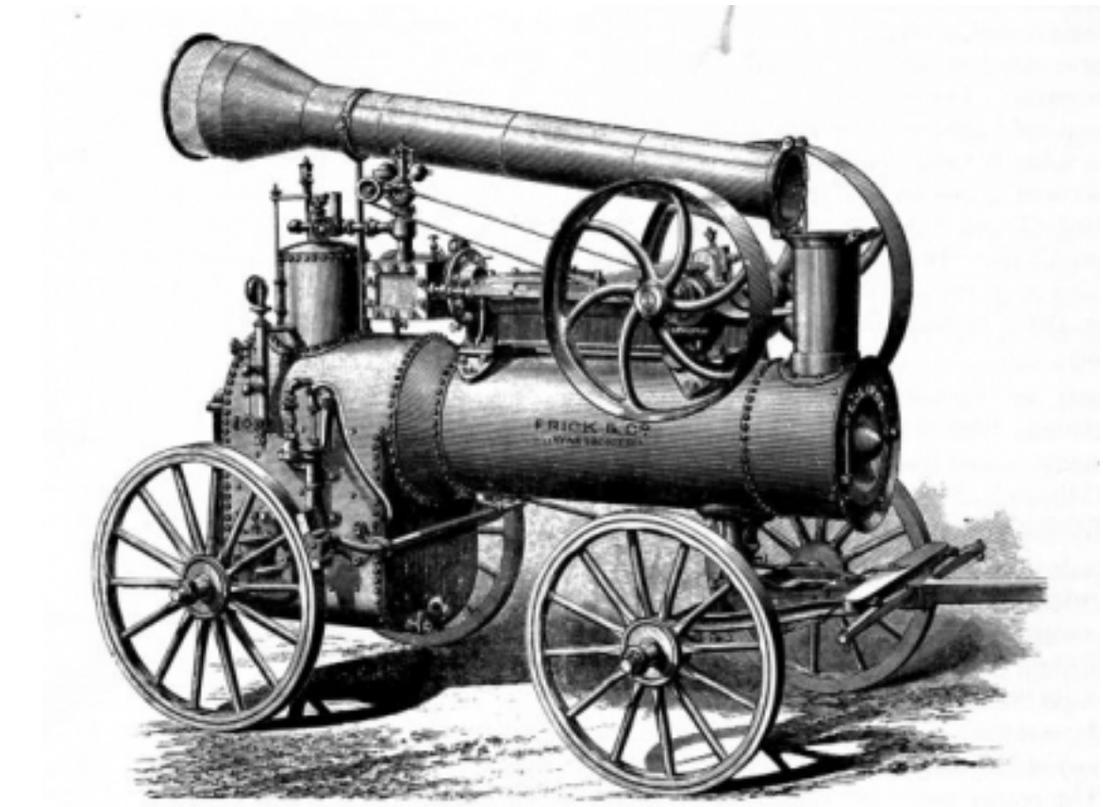
Today

- Terrestrial Planet Climate

Events

- Homework DUE
- Review next time
- Exam next week

Wonders of the Industrial Age



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.

From 1912

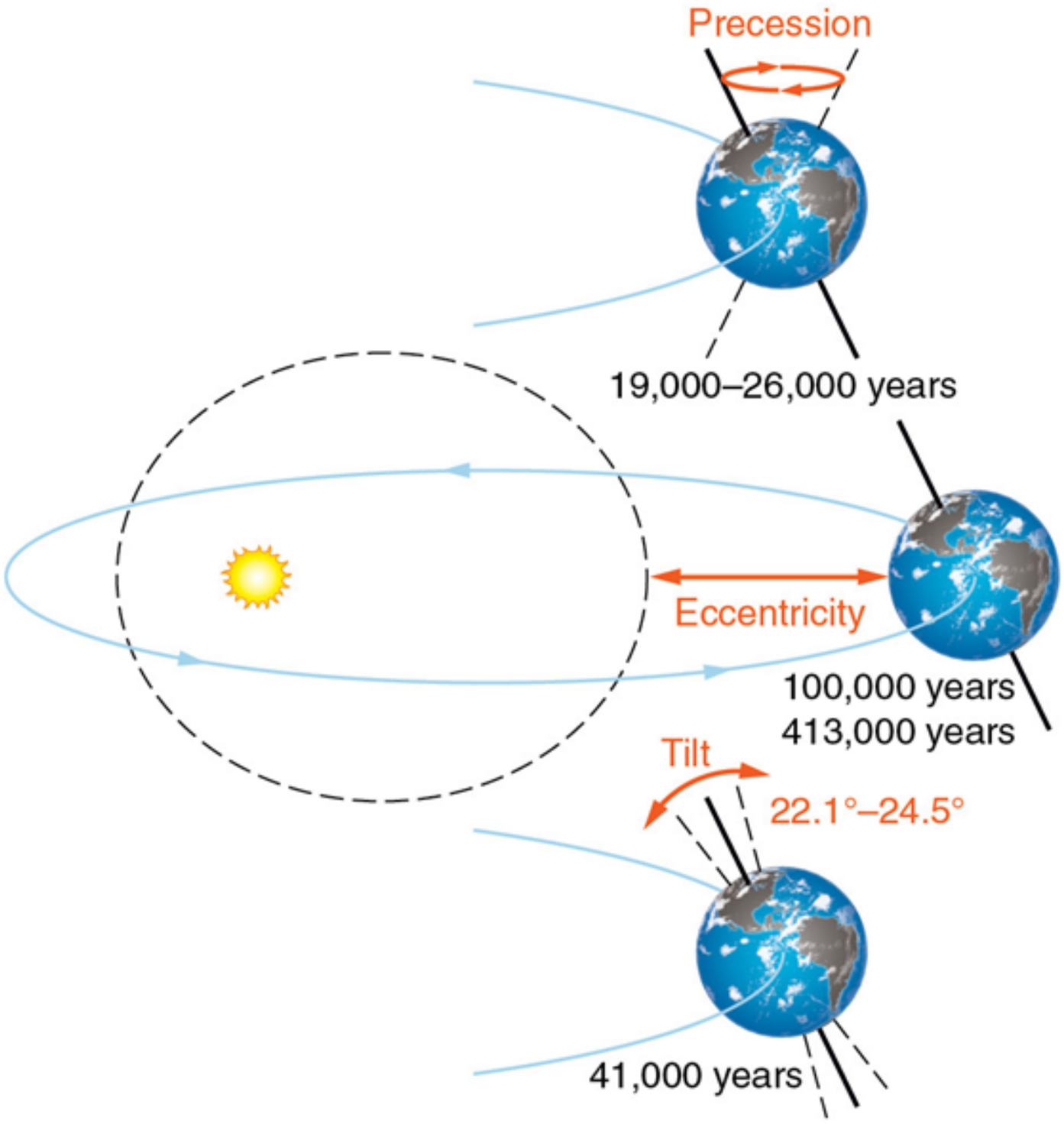
Weather and Climate

- 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



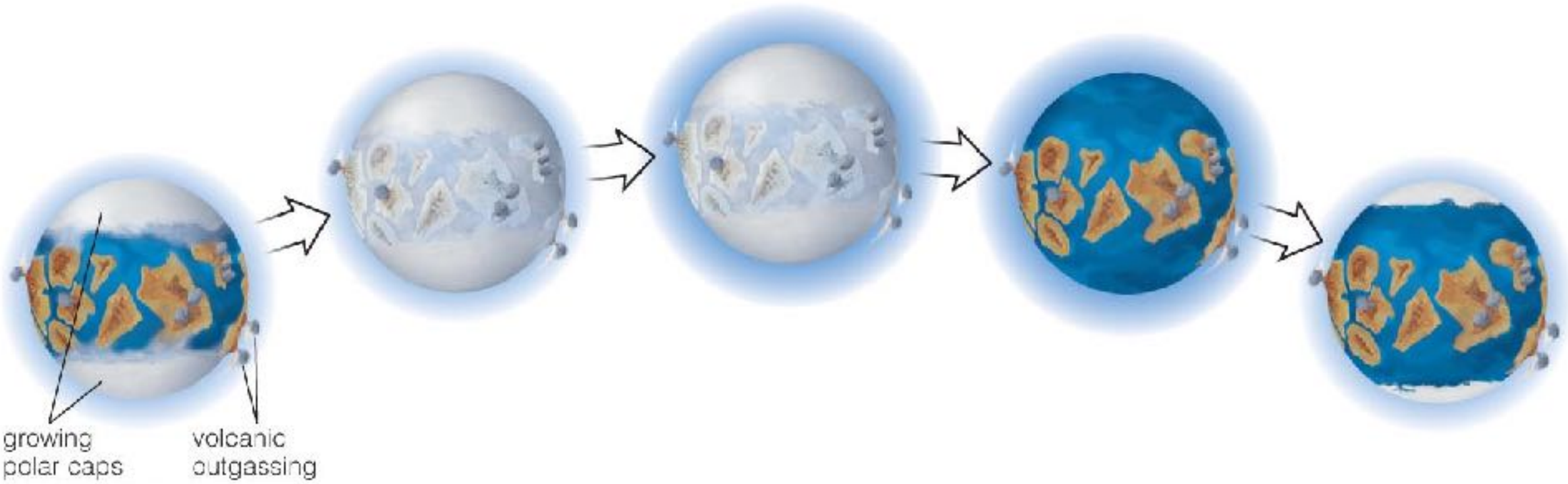
Subtle variations in Earth's orbit can impact long term climate.

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.

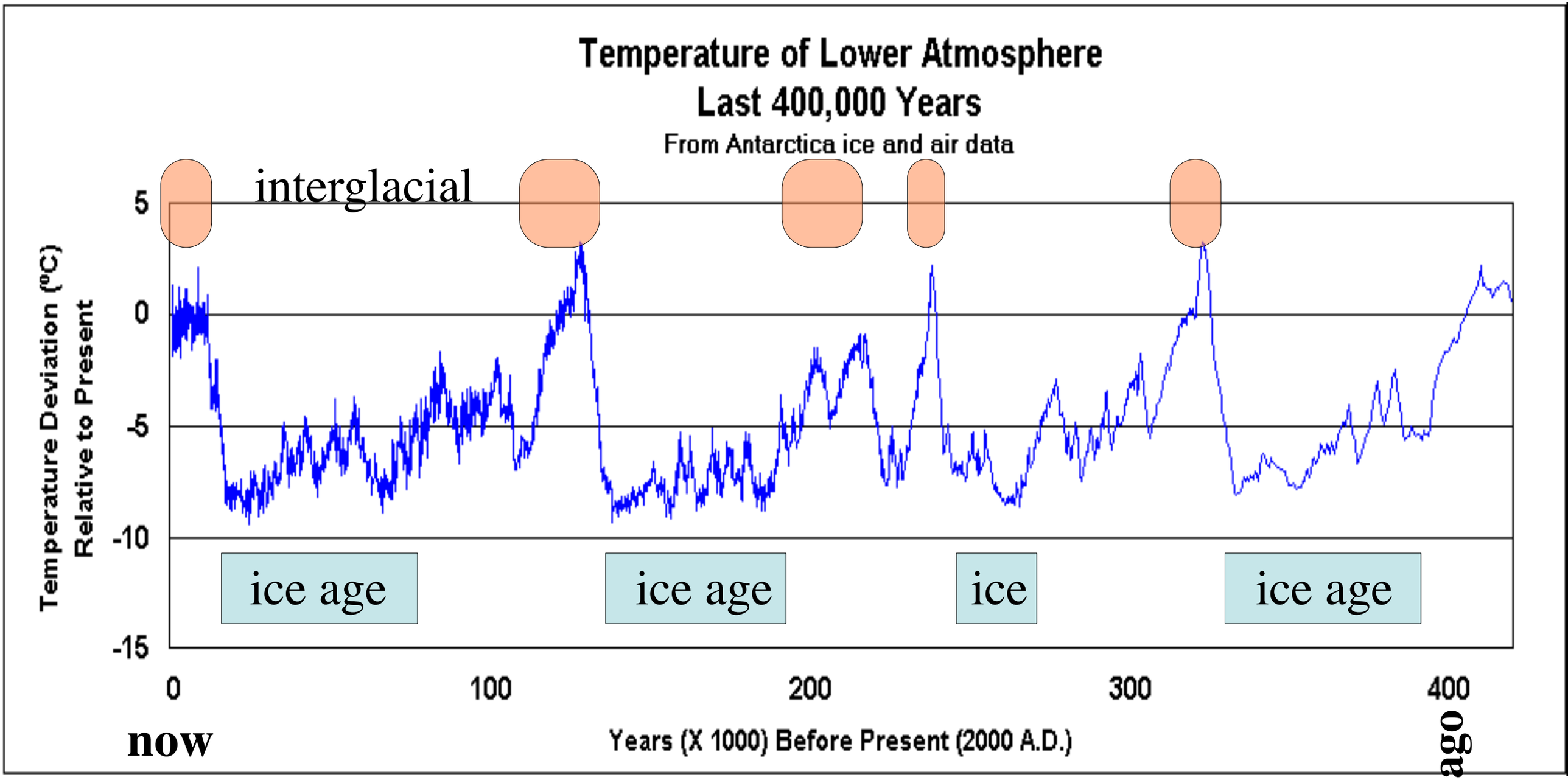
Long-Term Climate Change (e.g., Ice Ages)



- Changes in Earth's axis tilt might lead to ice ages.
- Widespread ice tends to lower global temperatures by increasing Earth's reflectivity.
- CO_2 from outgassing will build up if oceans are frozen, ultimately raising global temperatures again.

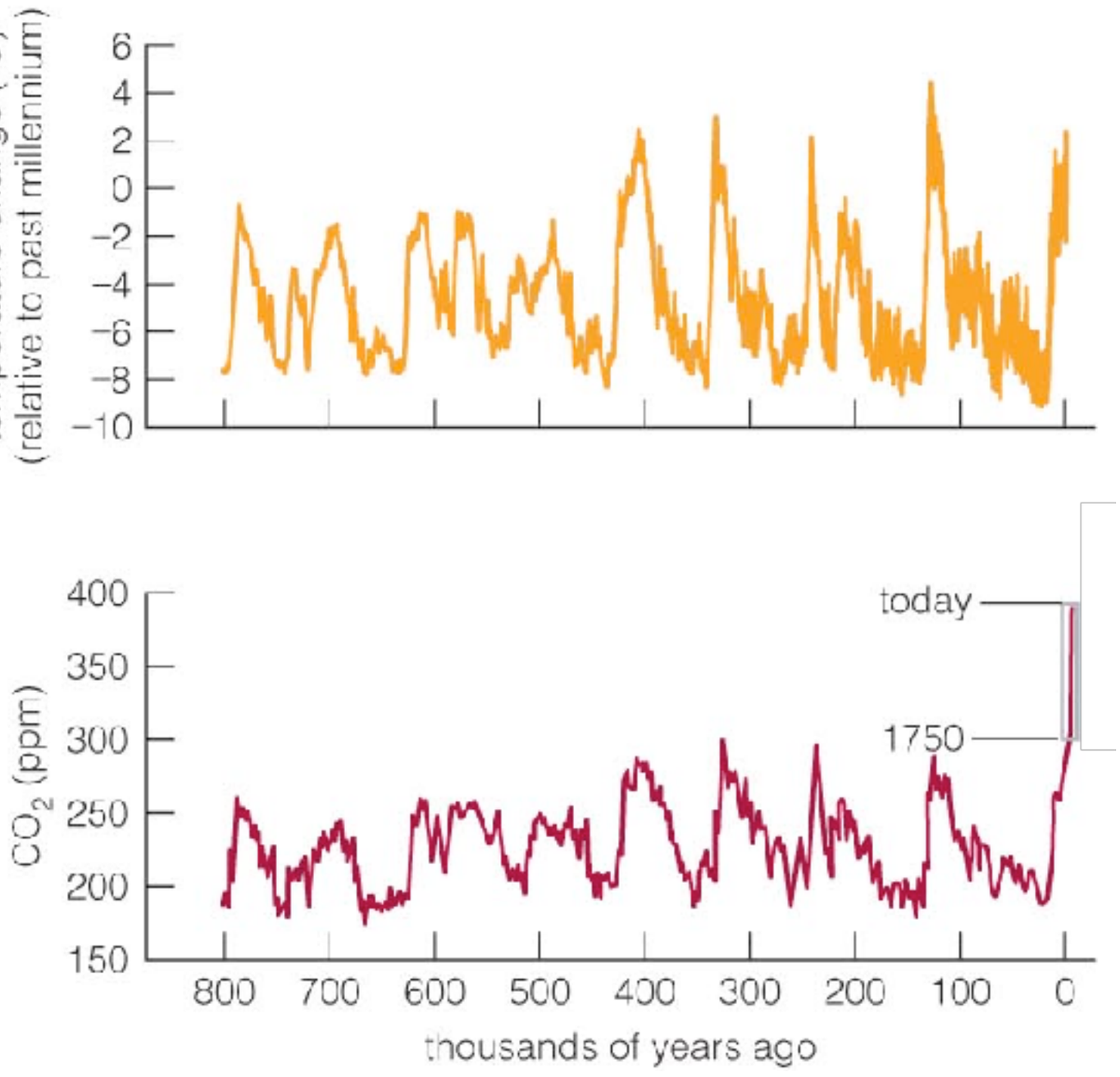
Earth's climate variable on ~10,000 yr timescale: ice ages

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

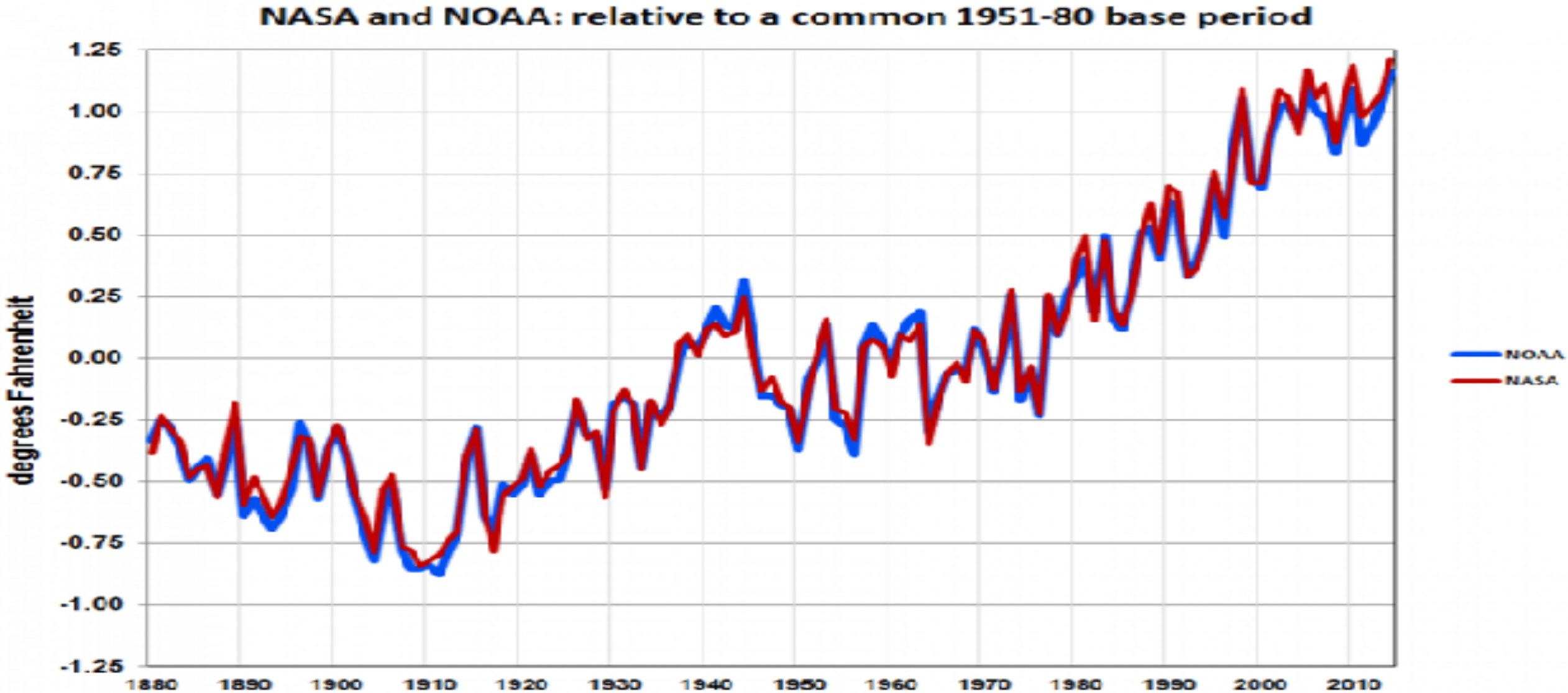
CO_2 Concentration



- Temperature and CO_2 concentration vary in lockstep
- This coupling is expected from known physics
- Current CO_2 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?



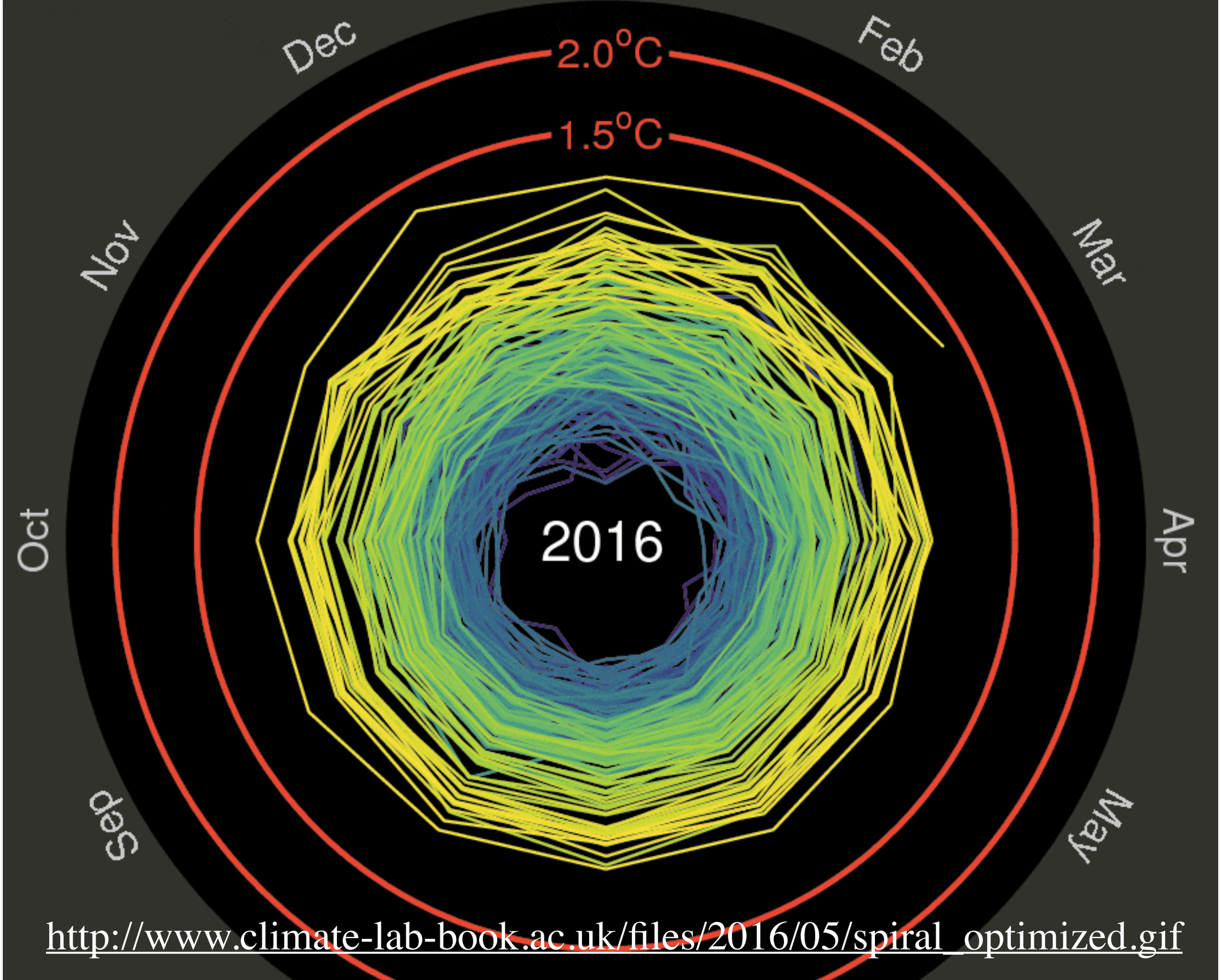
Basic facts

(non-partisan)

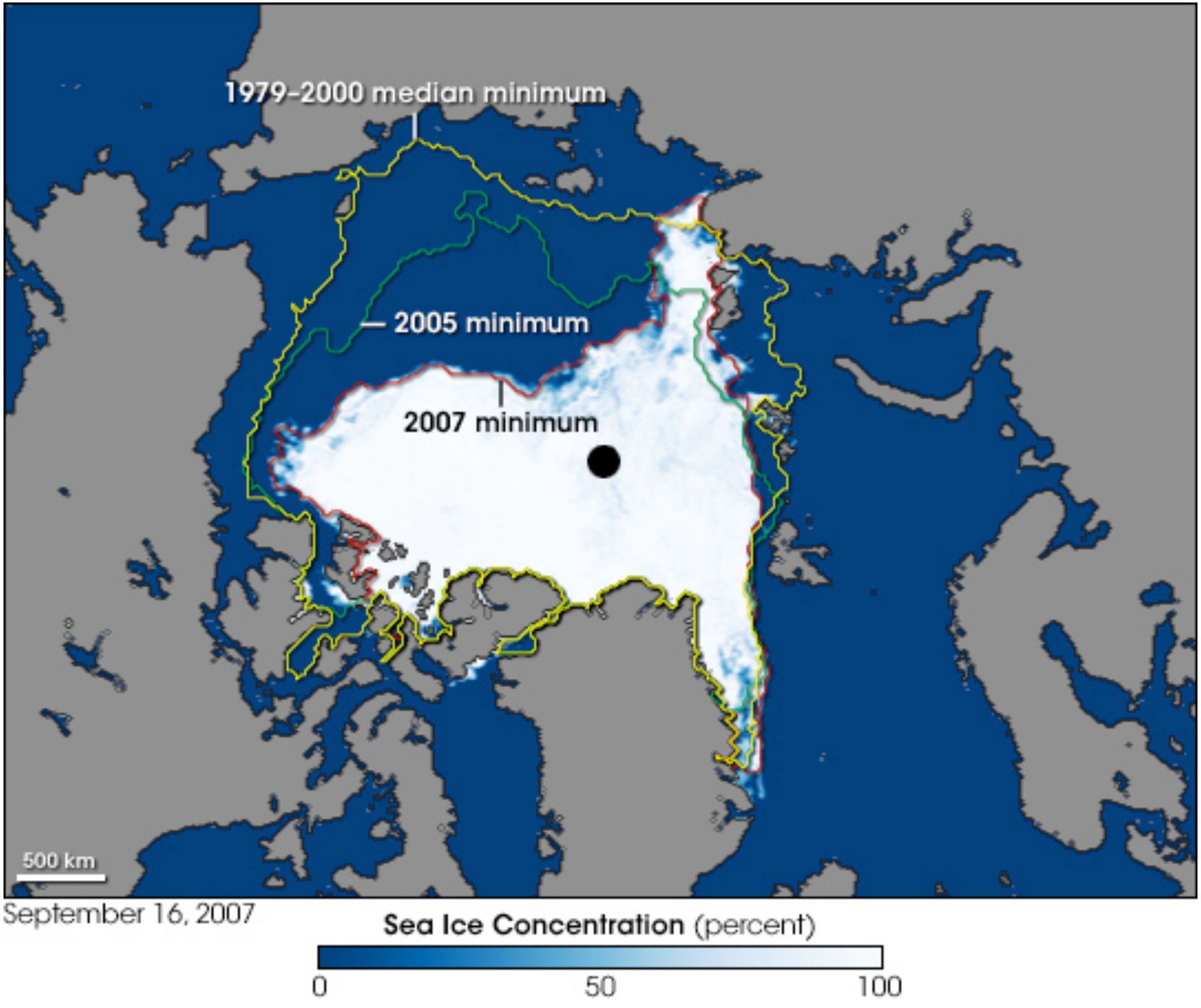
- The globe is warming (measured)
- The concentration of CO_2 in the atmosphere is increasing (measured)
- The CO_2 increase is roughly equal to the amount of fossil fuel we've burned (measured)
- Climate change is the expected result of changing greenhouse gases in the atmosphere
  – (e.g., Venus, Mars)

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

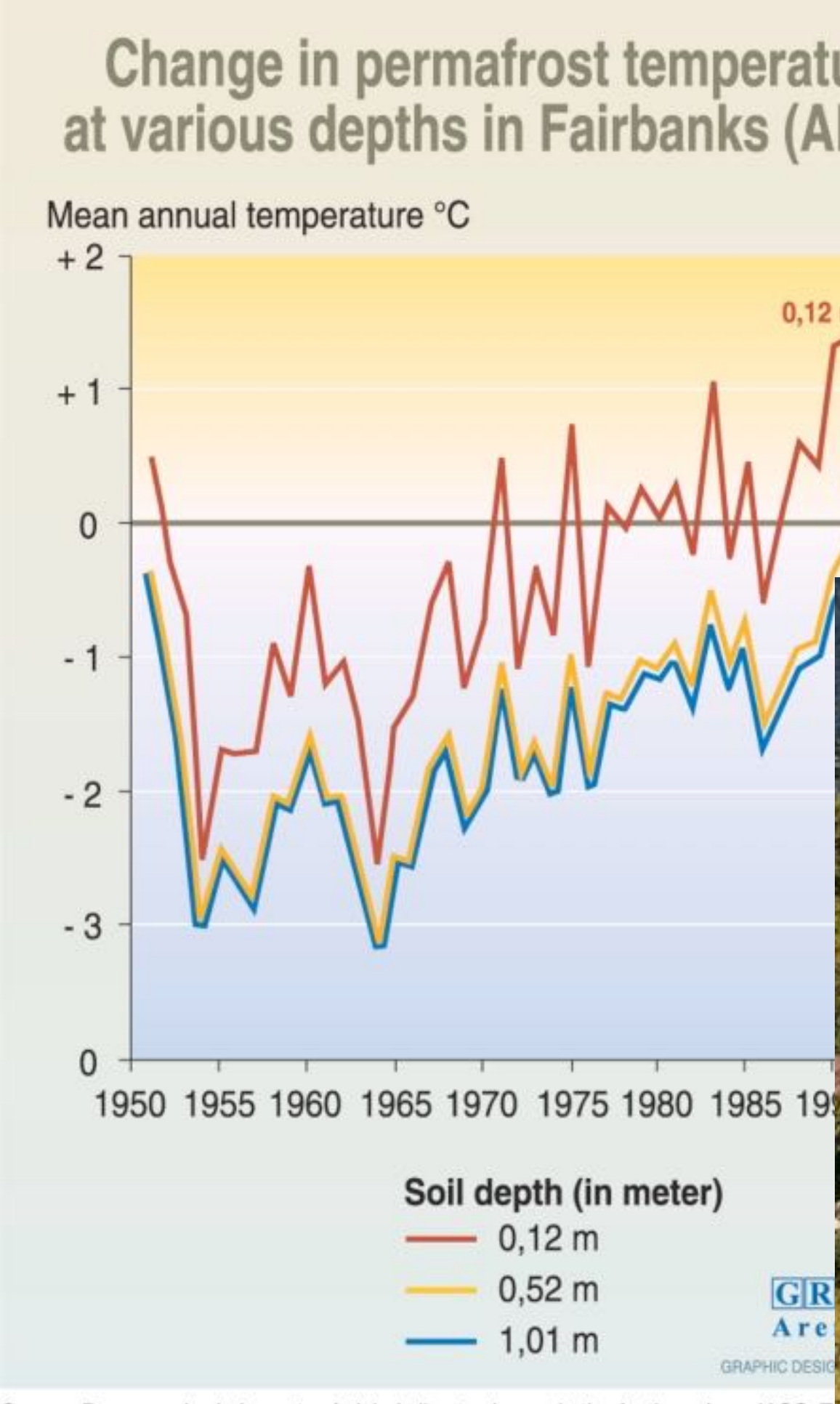


http://www.climate-lab-book.ac.uk/files/2016/05/spiral_optimized.gif



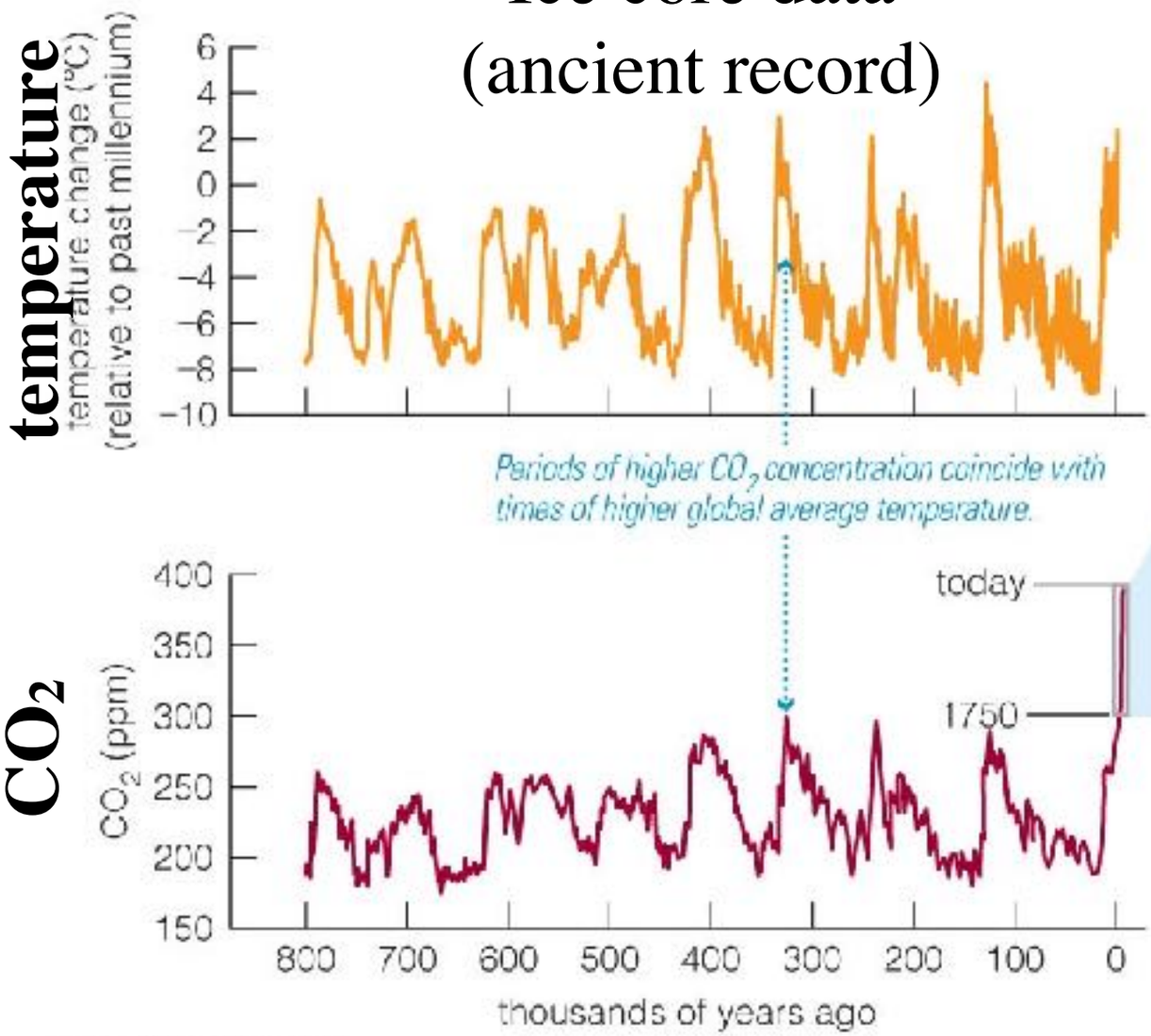
Fabled Northwest passage opened for first time in history in 2007

Arctic
permafrost
is melting



CO_2 Concentration

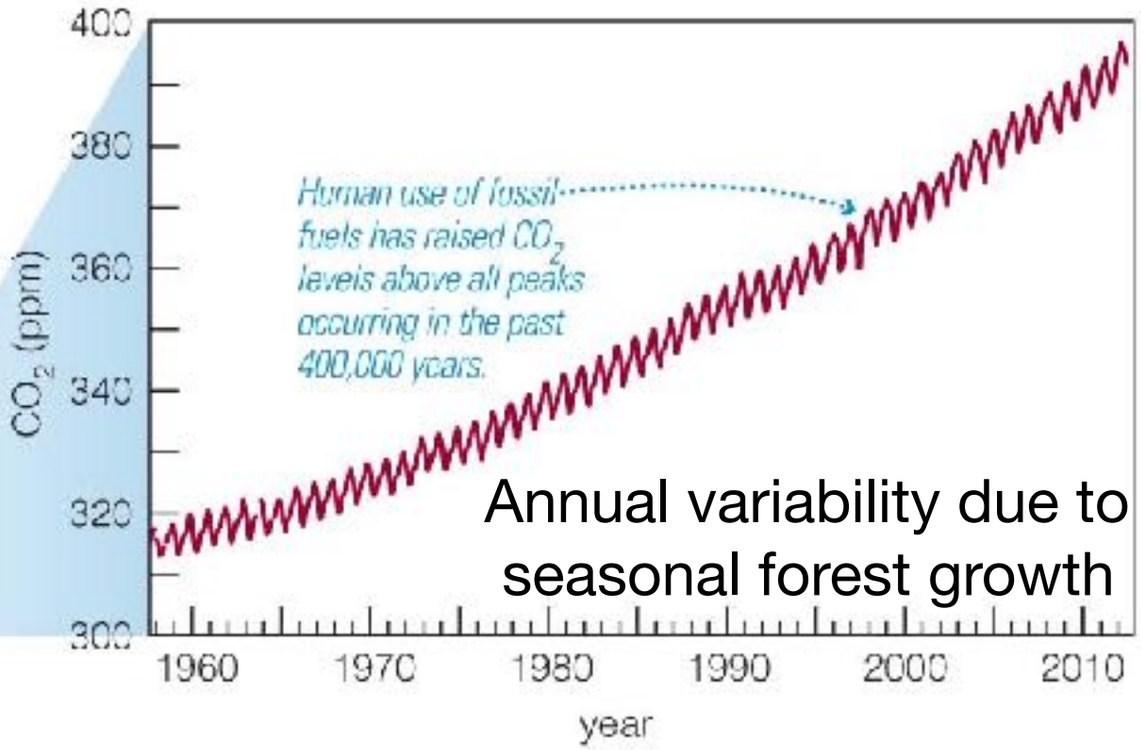
Ice core data
(ancient record)



time

(thousands of years)

Mauna Loa Observatory
(modern record)

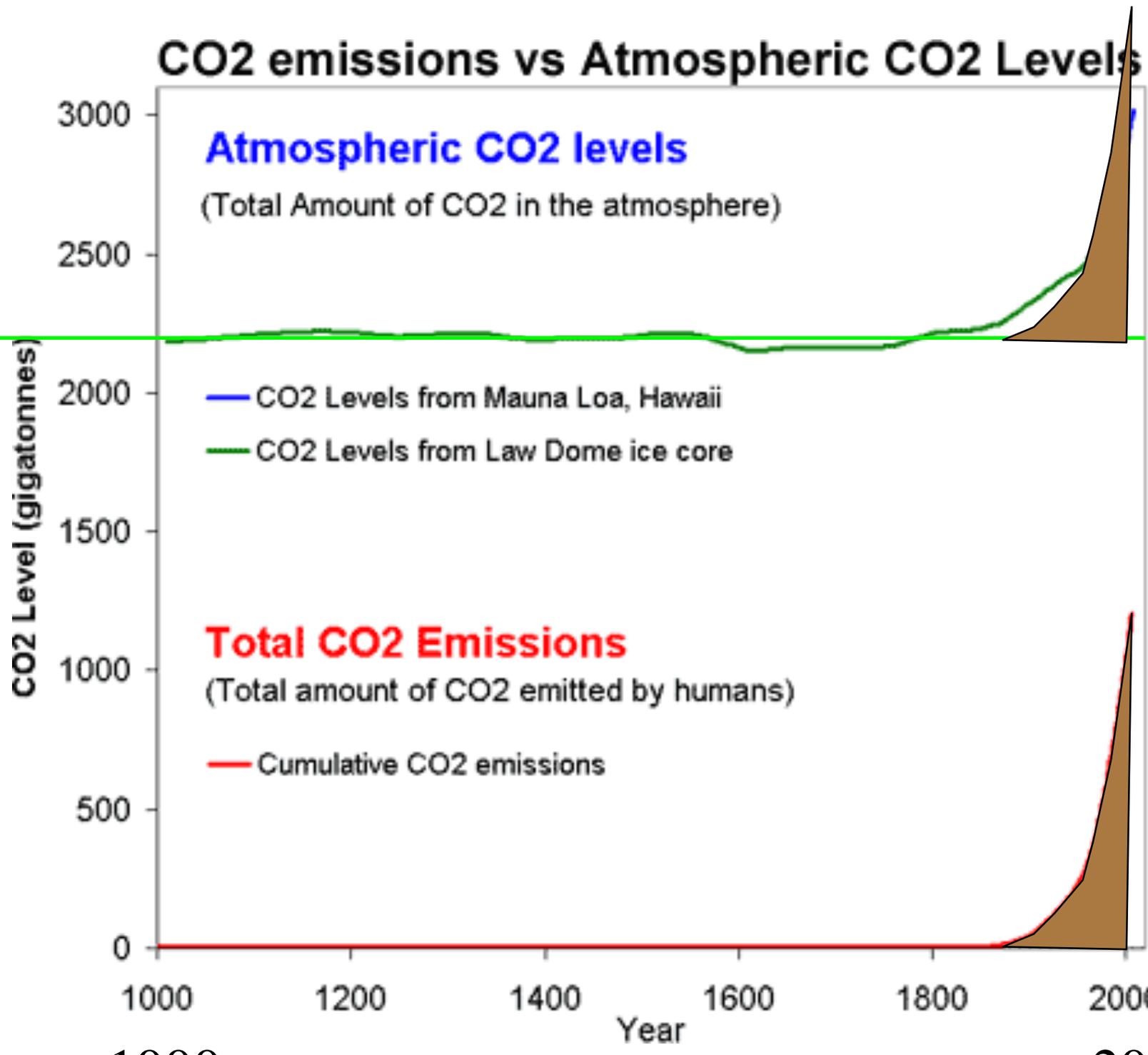


time

(years)

- Most of the CO_2 increase has happened in last 50 years

Pre-industrial CO_2 concentration: 280 ppm. Current level: 410 ppm



Pre-industrial CO_2 level

CO_2 added to atmosphere

Human activity

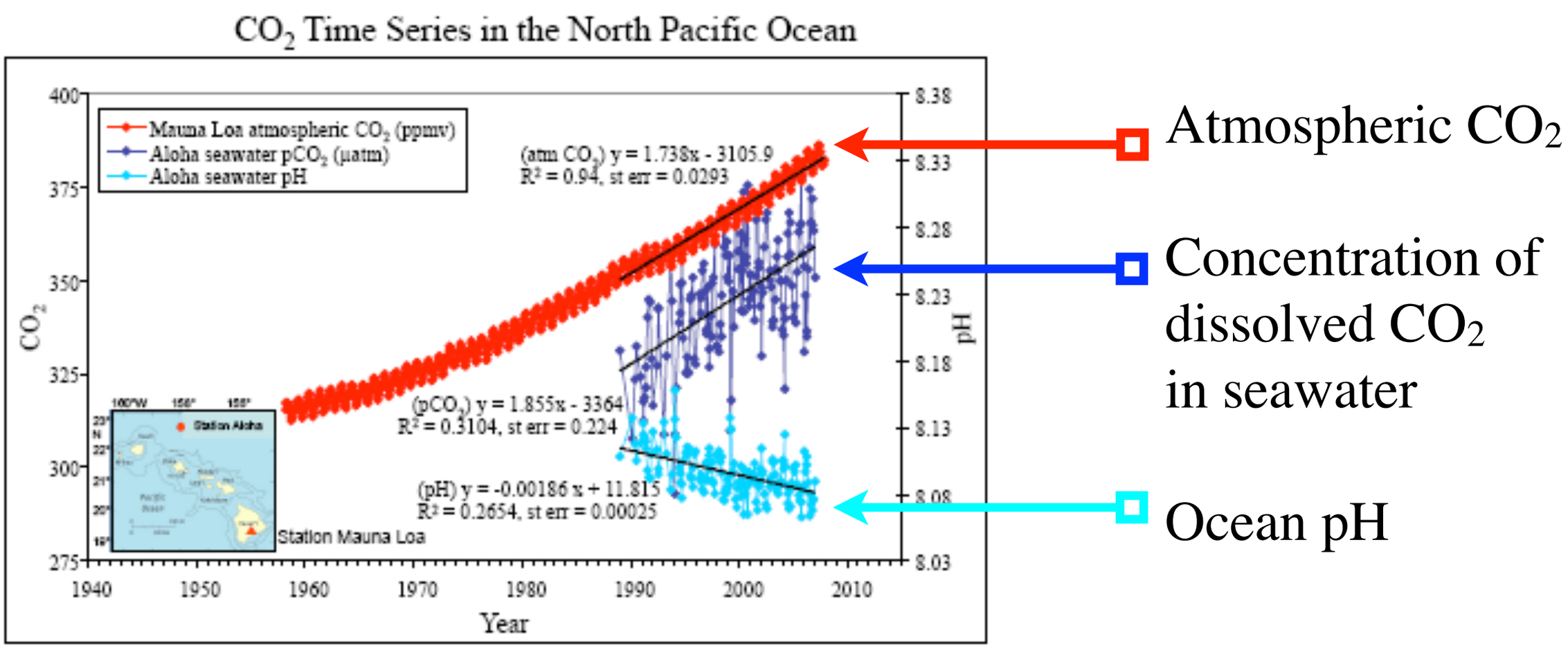
Carbon burned

1000

Year (A.D.)

2000

- Should be more CO_2 in atmosphere than there is
  - Some of what we've burned is missing
- Some CO_2 being sequestered in the ocean
  - Ocean acidity up due to increased amounts of CO_2 dissolved in seawater
  - pH = 8.25 to 8.14 over last two centuries



Atmospheric CO_2

Concentration of dissolved CO_2 in seawater

Ocean pH

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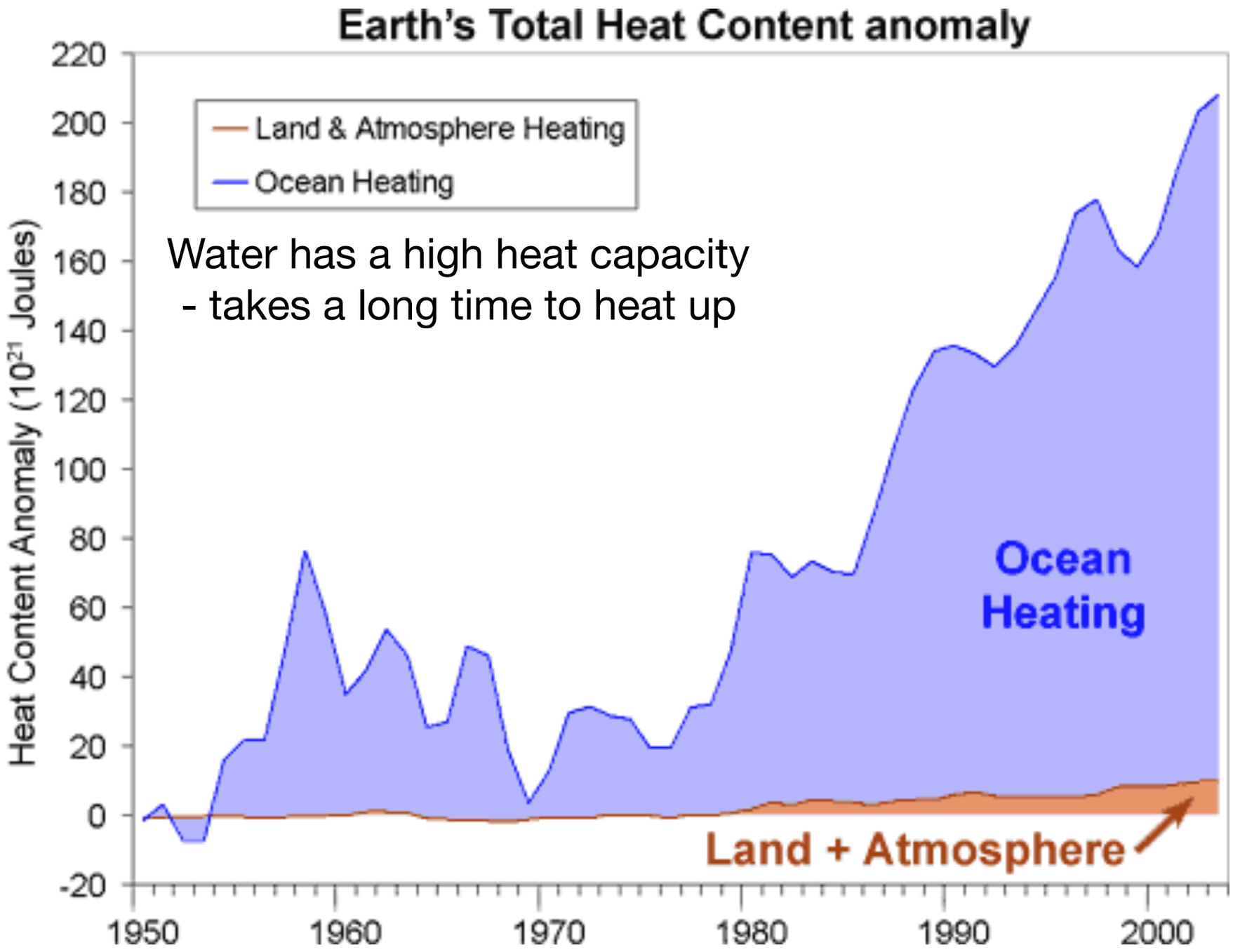


The Earth's climate is out of equilibrium - heat is accumulating in the ocean faster than it is being radiated into space.

Climate Change Forecasts

- Gradual increase of average temperature
  - average increase modest but noticeable
  - winter not cancelled by 2^{o} 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)
  - 3’ forecast by 2100 - mostly thermal expansion

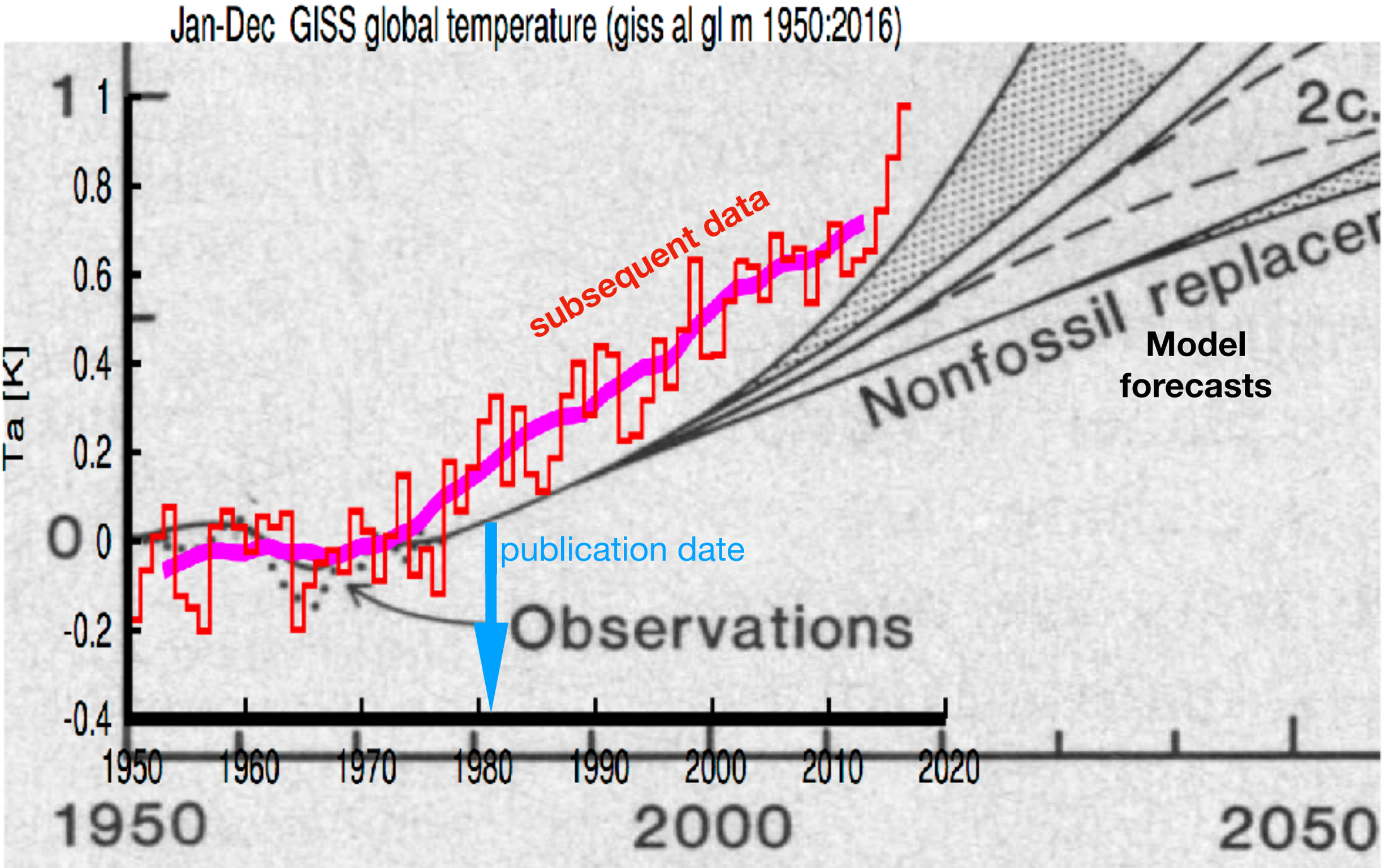
adios, Miami Beach

- Drought *model dependent*
  - California, southwest dry out (more)
  - due to enhanced evaporation, smaller snowpack

Climate Models

Hansen et al. (1981) compared to later data

Exxon scientists had reached the same conclusion by this time. The corporate response was to cover it up at first, then launch a disinformation campaign.



Hansen et al (1988) projections compared to Observations

Scenario A: High forcings
Scenario B: Business-as-usual
Scenario C: As B w/constant forcings from 2000
GISTEMP Land-Ocean Index

data

Updated Climate Models (1988)

publication date

Hindcast

Forecast

Temperature Anomaly (°C) (w.r.t. 1951-1980)

1.6
1.4
1.2
1.0
.8
.6
.4
.2
0.
-.2

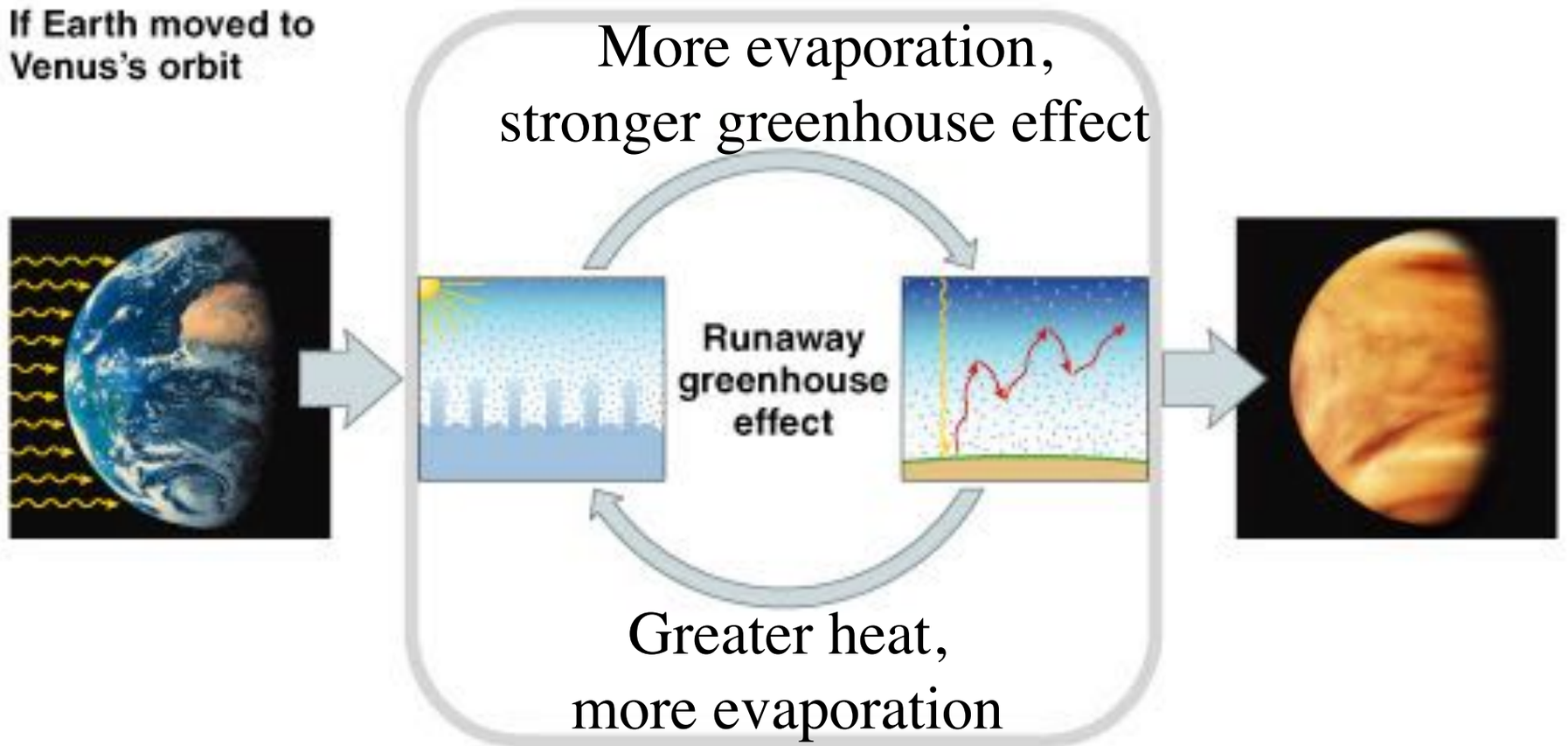
1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020

Year

Policy implications

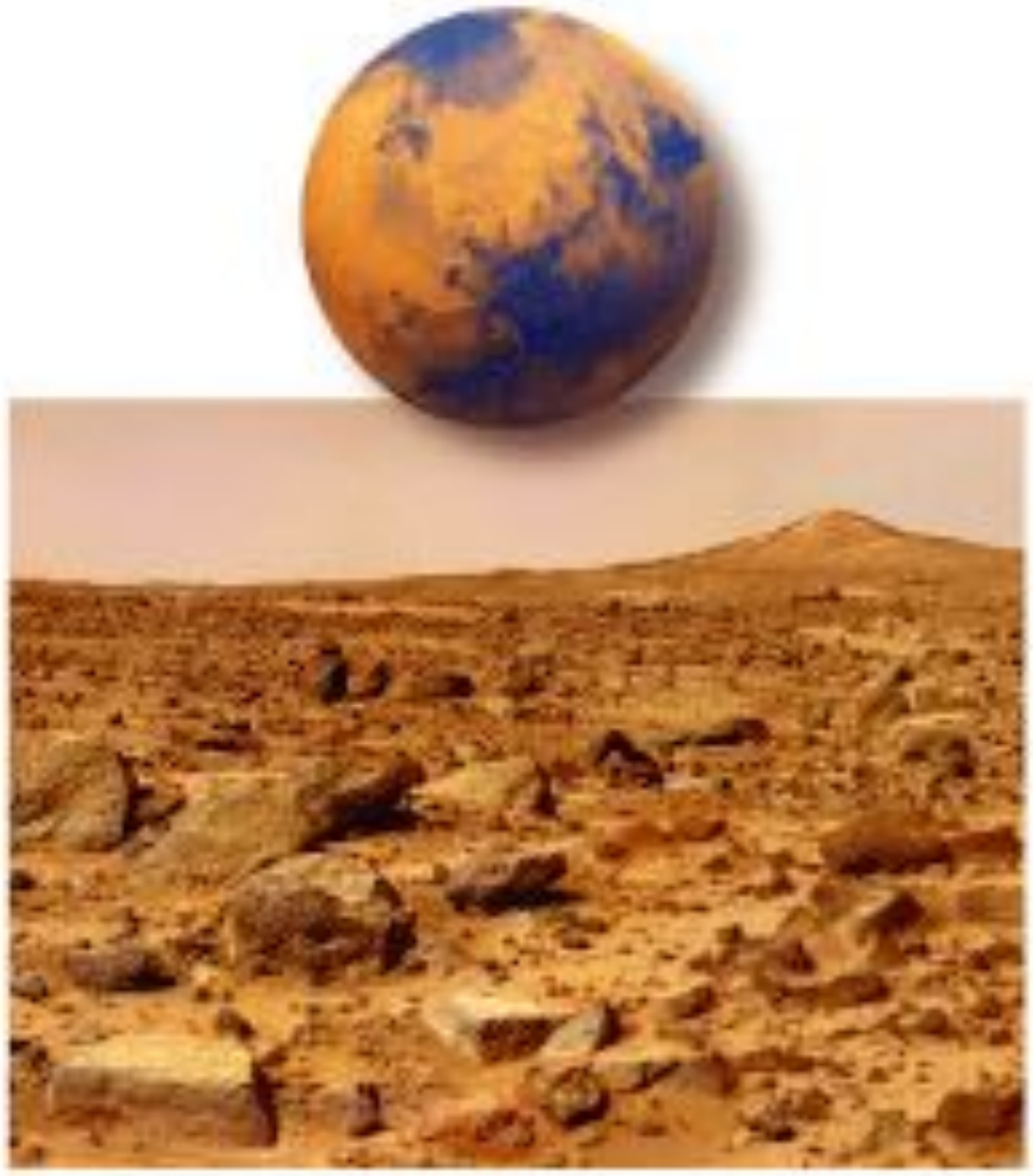
- Basic trend clear but detailed long range forecast challenging.
  - Probably some winners as well as losers
- Probably a bad idea to conduct an uncontrolled experiment on the atmosphere we all breathe & climate we depend on.
- There is finite energy available in coal, oil, natural gas, uranium...
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

Runaway Greenhouse Effect



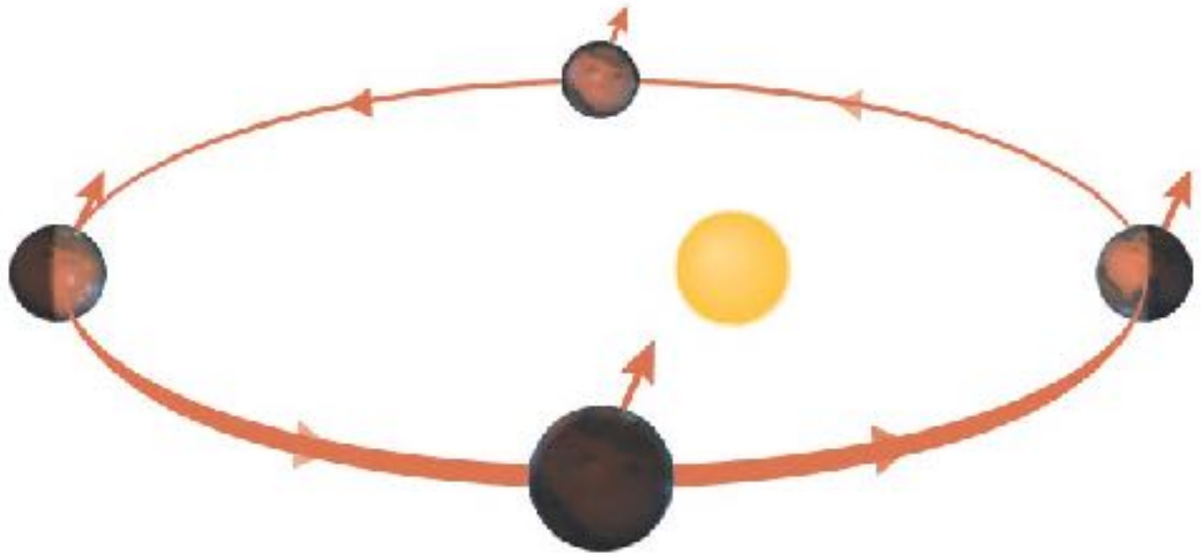
- Oceans evaporate; no longer absorb CO_2.
  - CO_2 builds up in atmosphere unchecked
  - "runaway greenhouse"

Mars: the opposite extreme



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

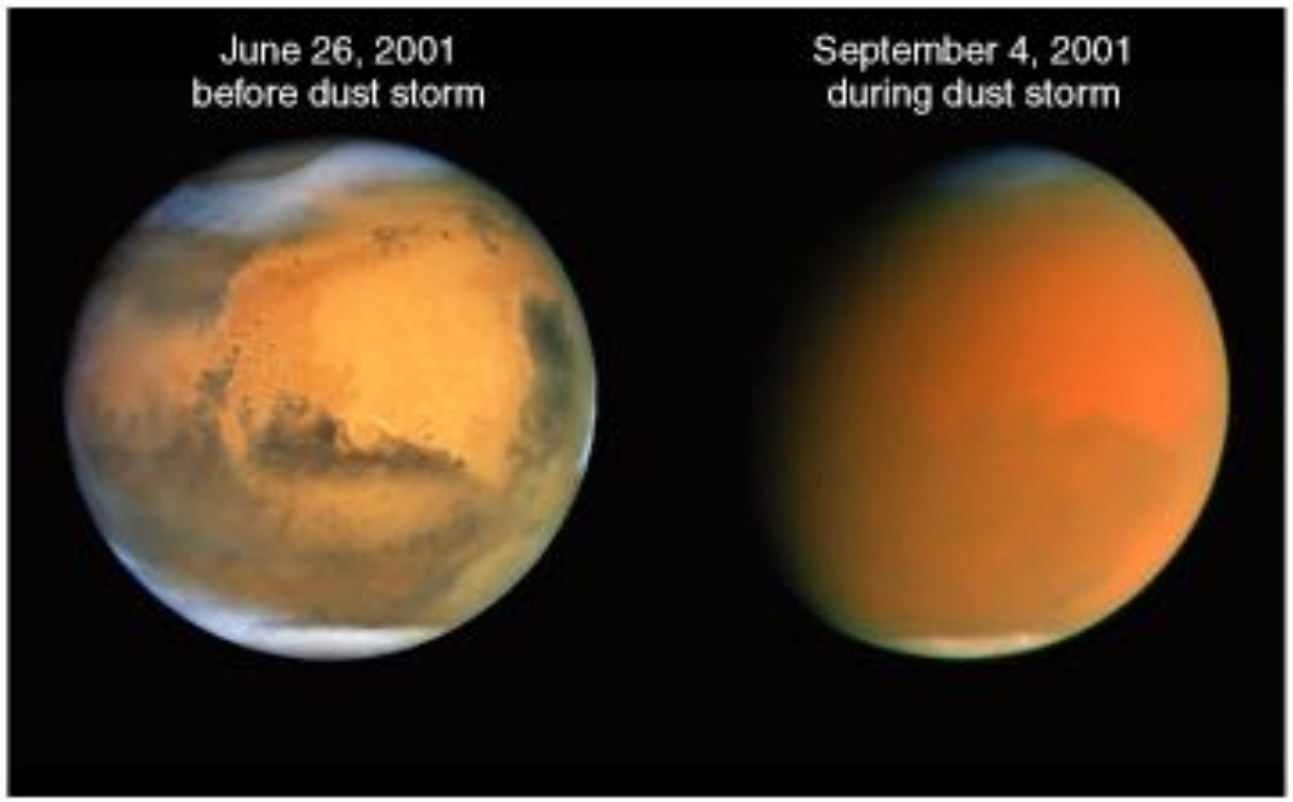
Seasons on Mars

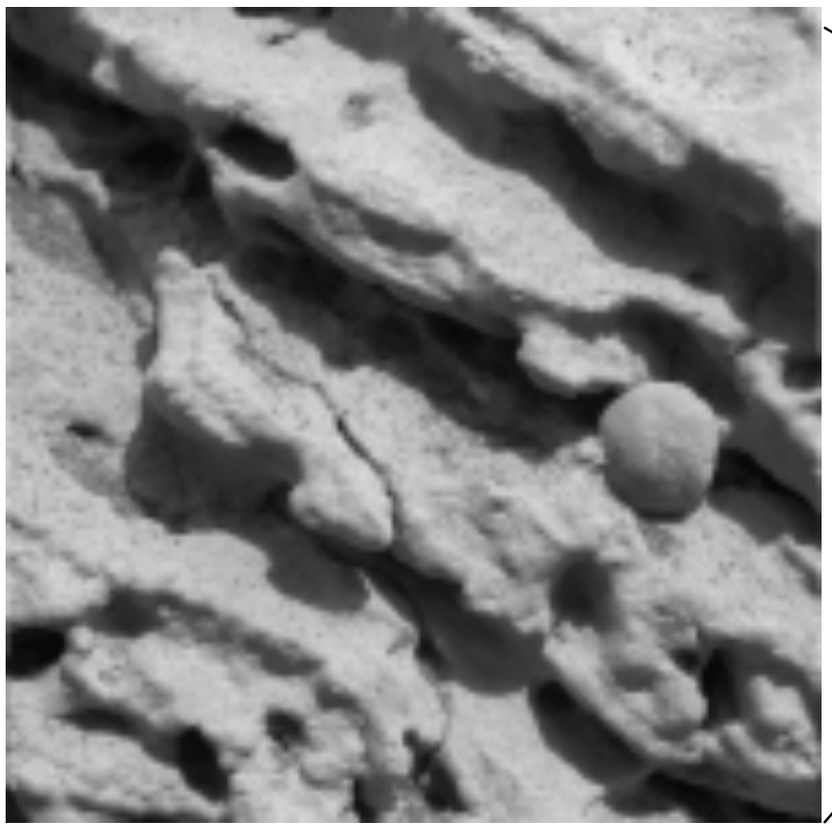


- Mars does have seasons; both axial tilt and distance from the sun matter.
- Seasons on Mars are more extreme in the southern hemisphere because of its elliptical orbit.

Storms on Mars

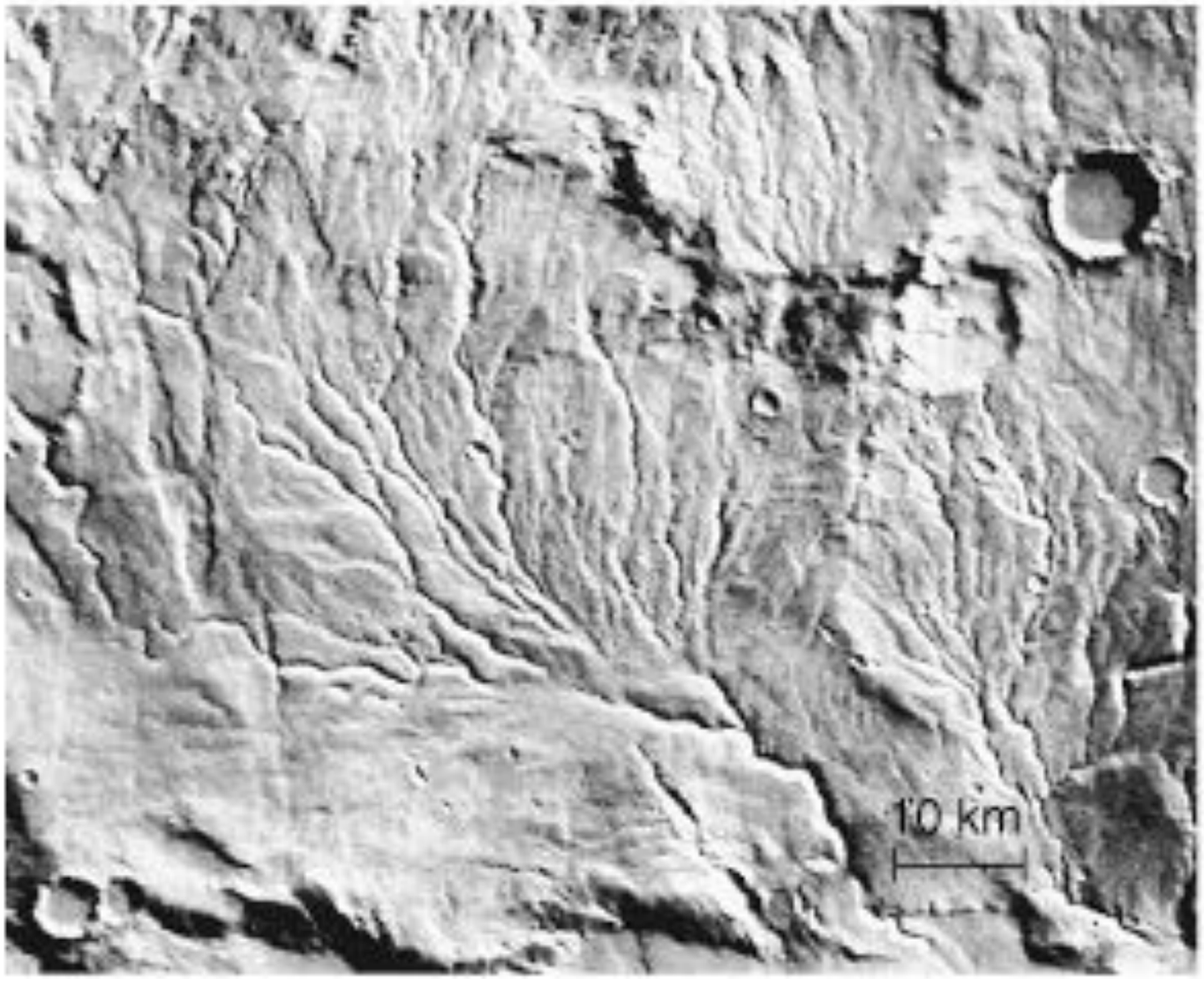
- Seasonal winds on Mars can drive huge dust storms.
- Drive ongoing wind erosion





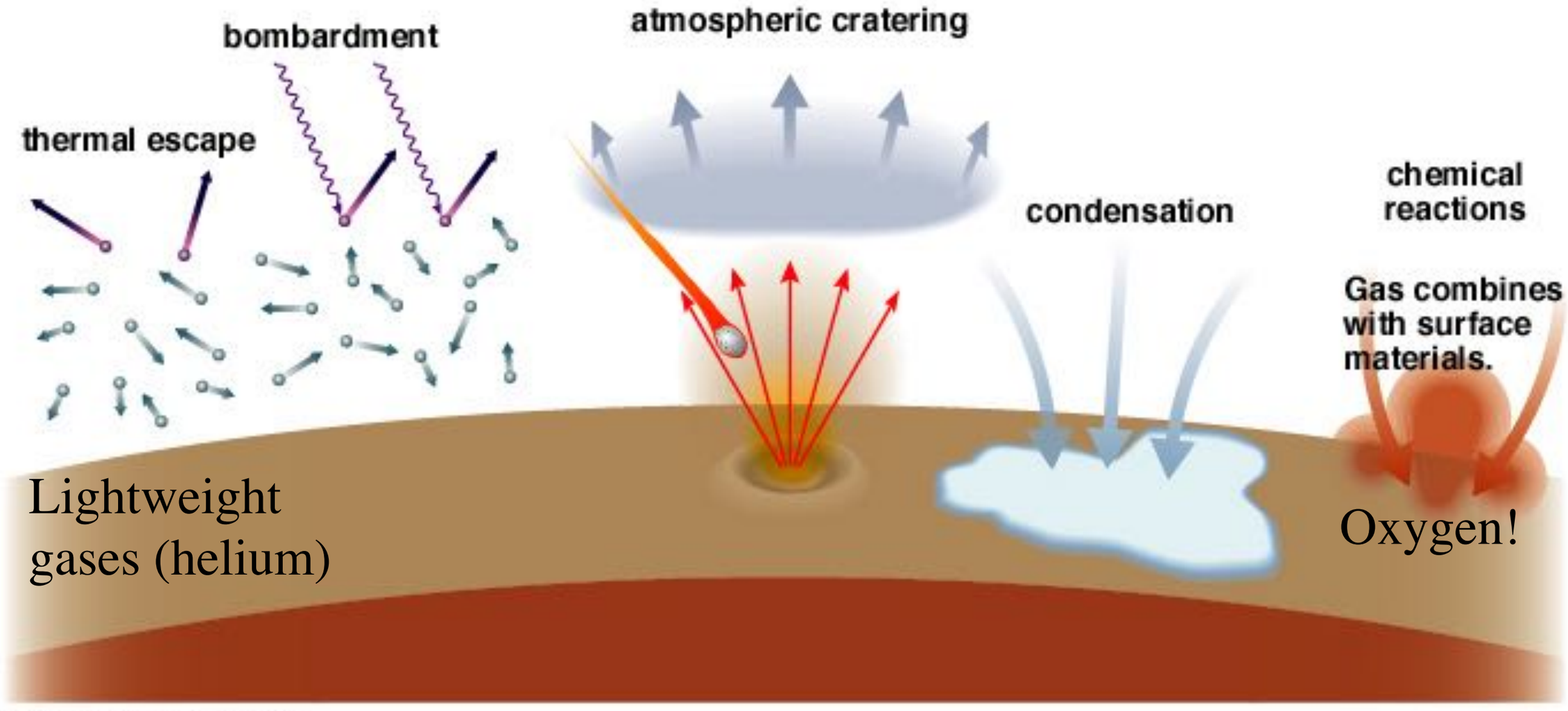
- 2004 *Opportunity* Rover provided strong evidence for abundant liquid water on Mars in the distant past.
- How could Mars have been warmer and wetter in the past?

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

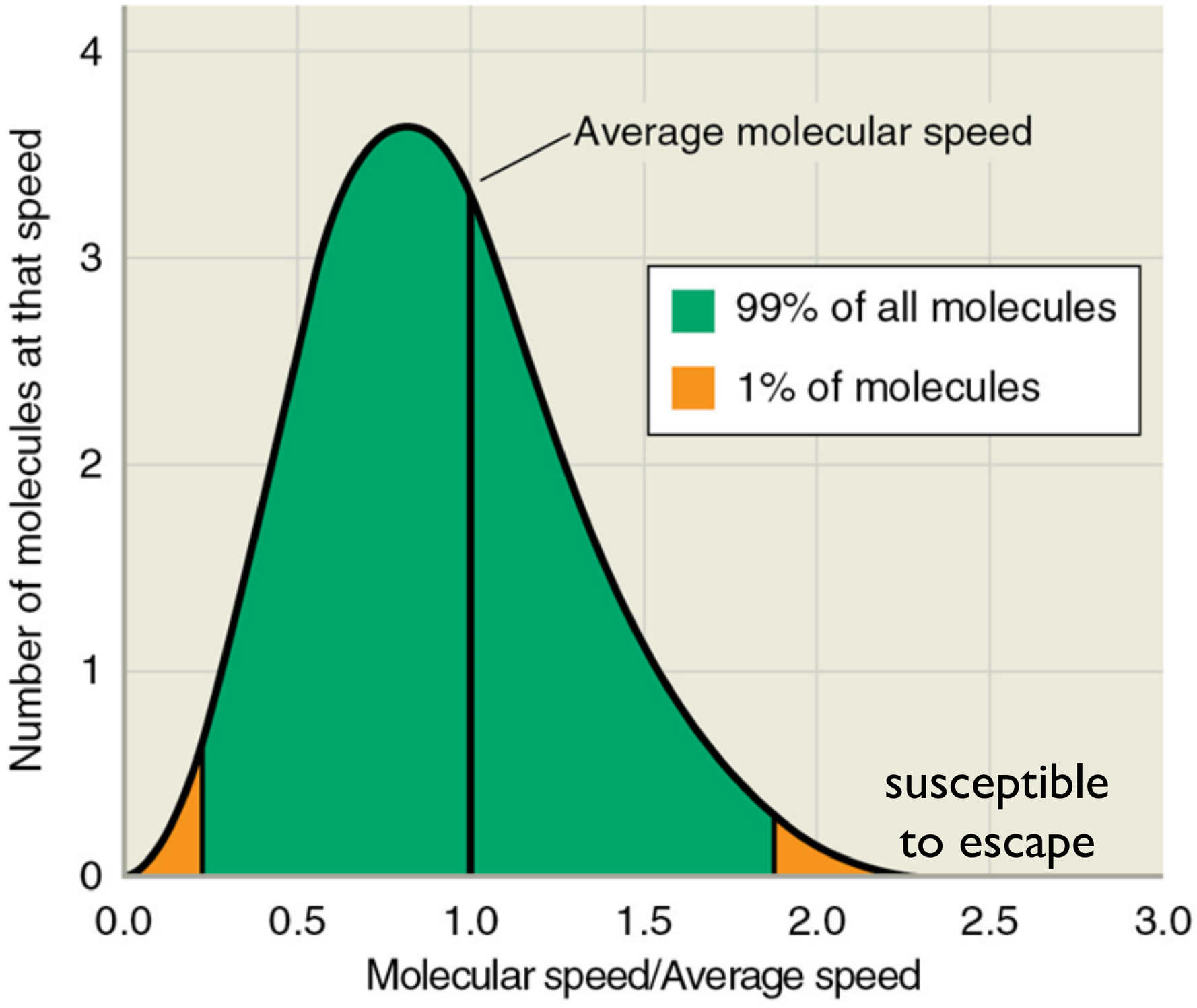


Can break up water vapor; hydrogen escapes

Water can freeze out

Thermal escape

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



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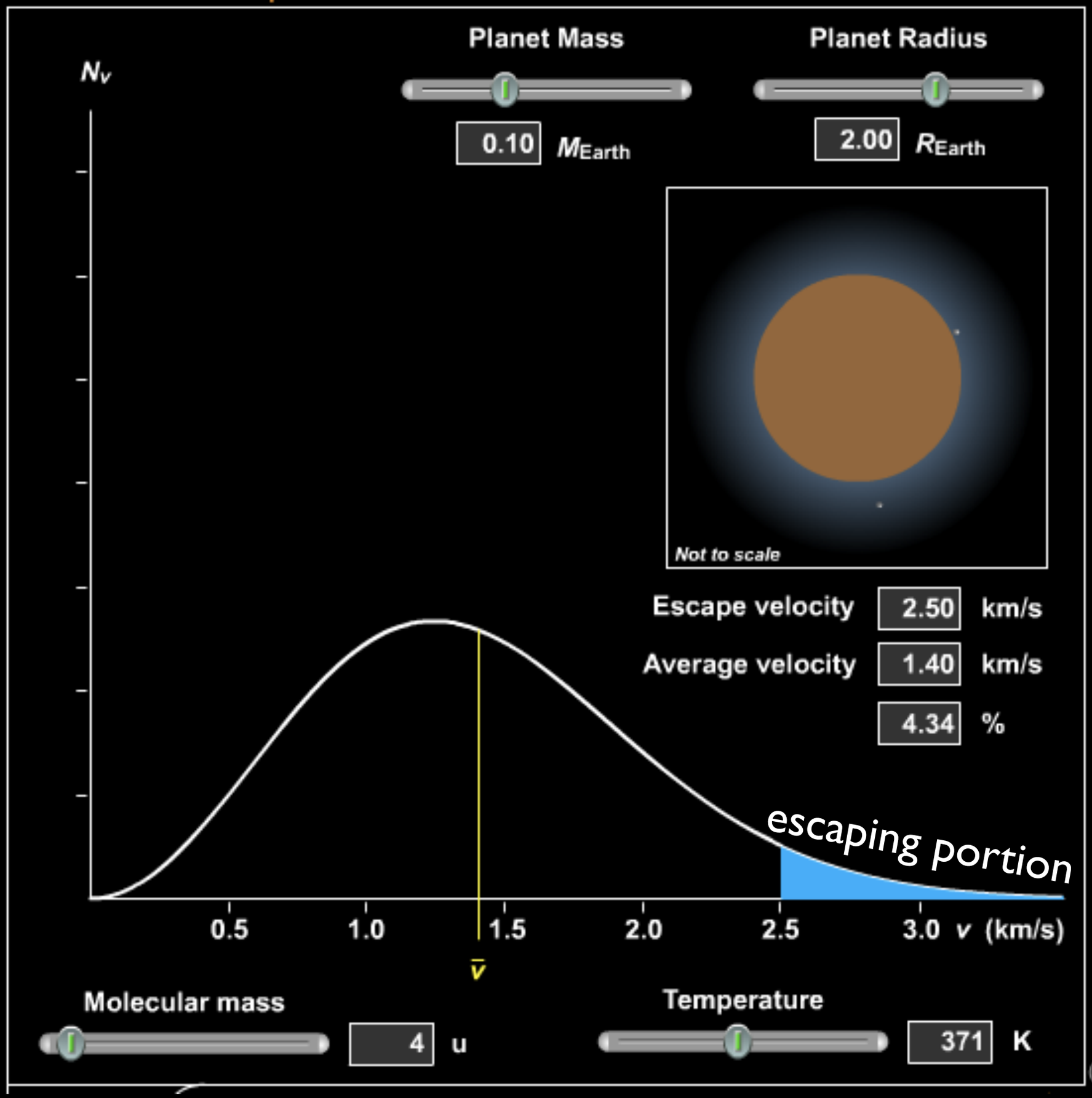

Factors affecting atmospheres

- Thermal Escape
- Bombardment (escape enhanced by molecular disintegration caused by energetic particles from space)
- 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)