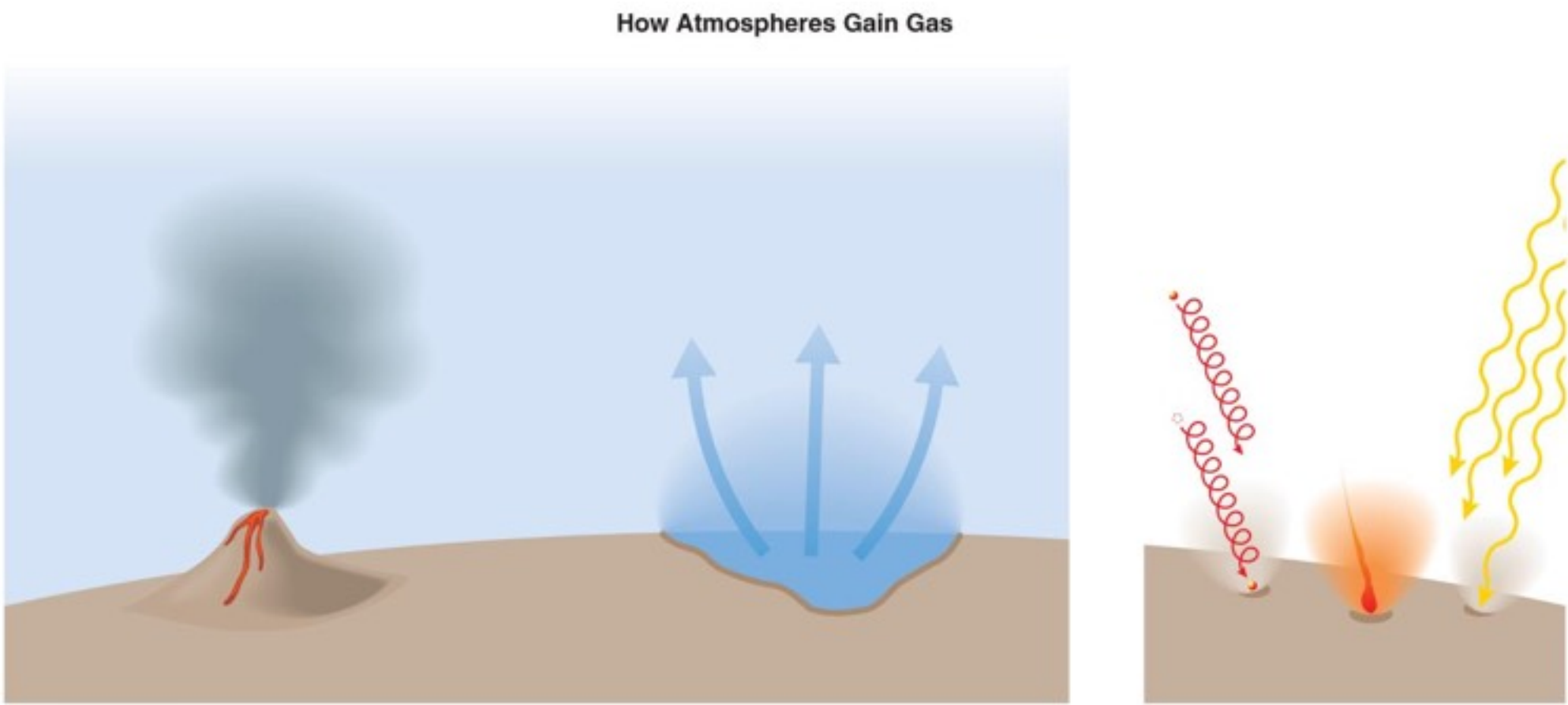
Today

- Terrestrial Planet Atmospheres (continued)

Events

- Homework DUE

Sources of Gas

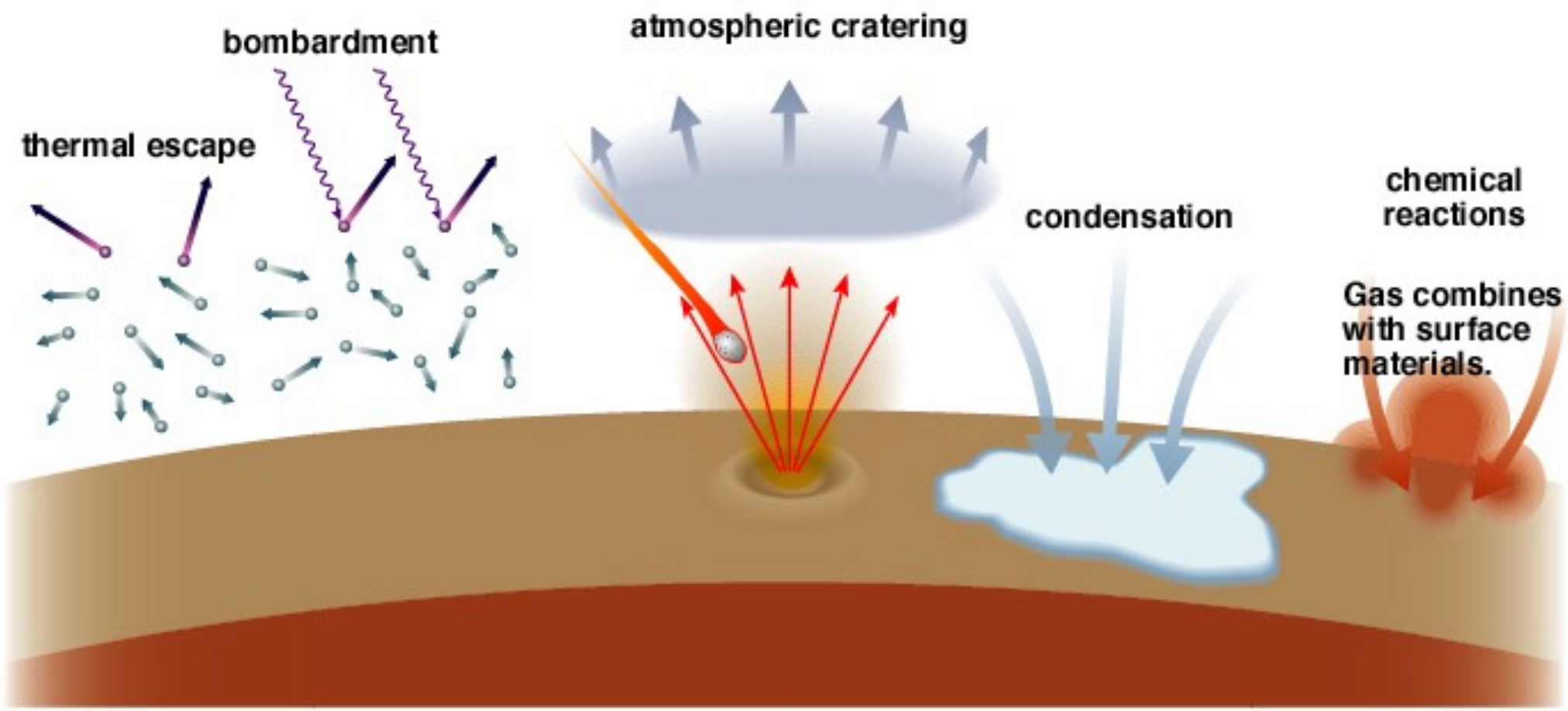


Outgassing from volcanoes

Evaporation of surface liquid; sublimation of surface ice (cometary coma)

Impacts of particles and photons e.g., comets

Loss of gas



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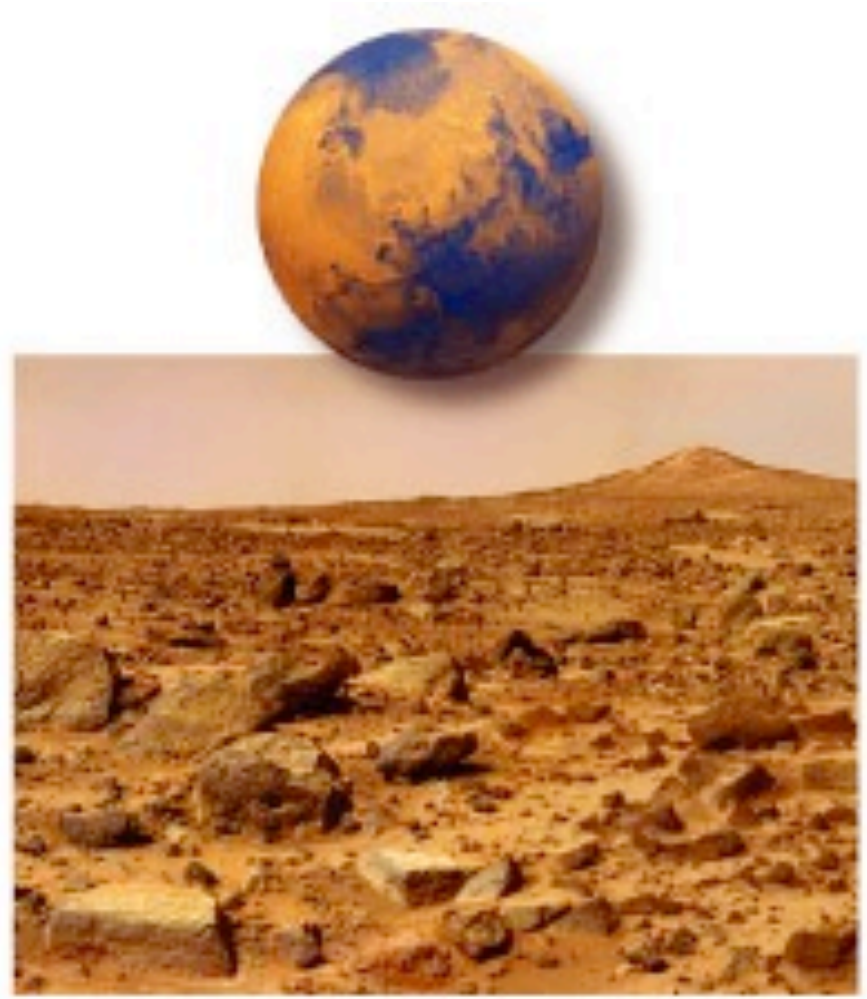
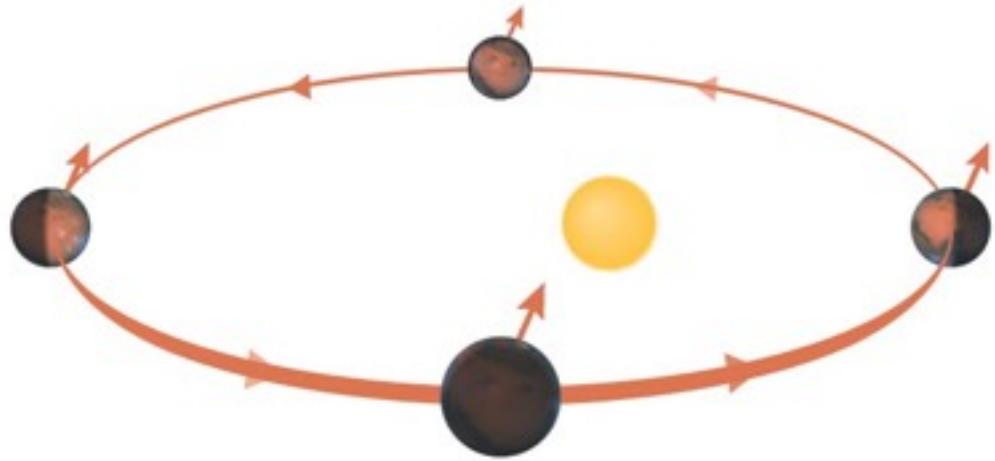
Mars: runaway icehouse



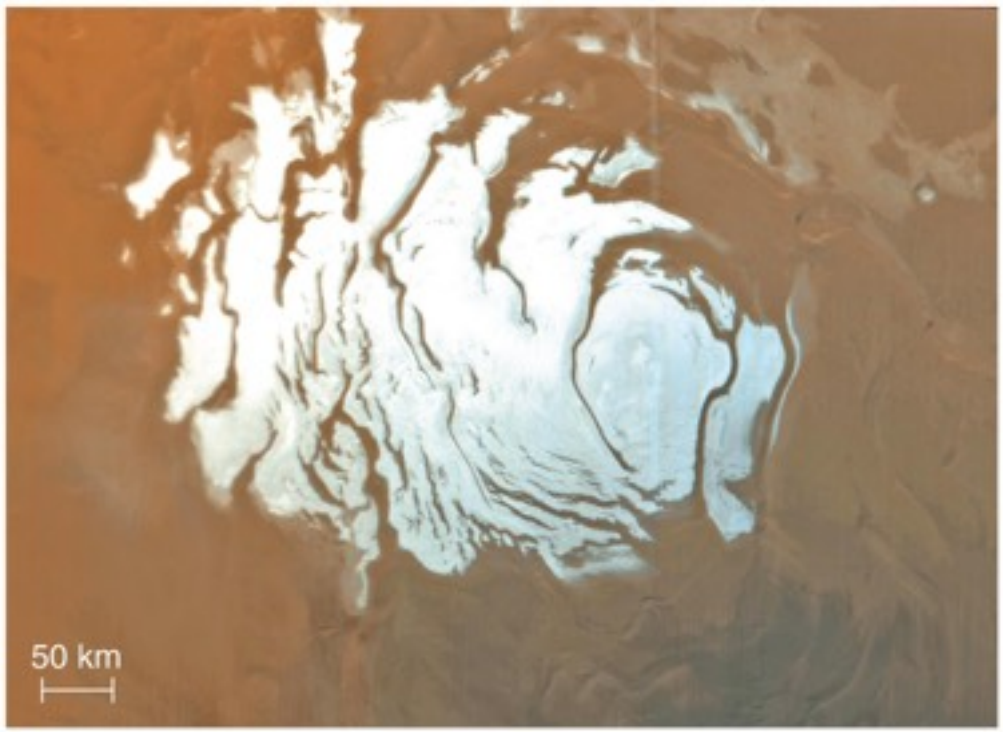
- Low gravity and a thinning atmosphere led to a runaway icehouse.
- Mars atmosphere currently ~1% as thick as Earth's

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.

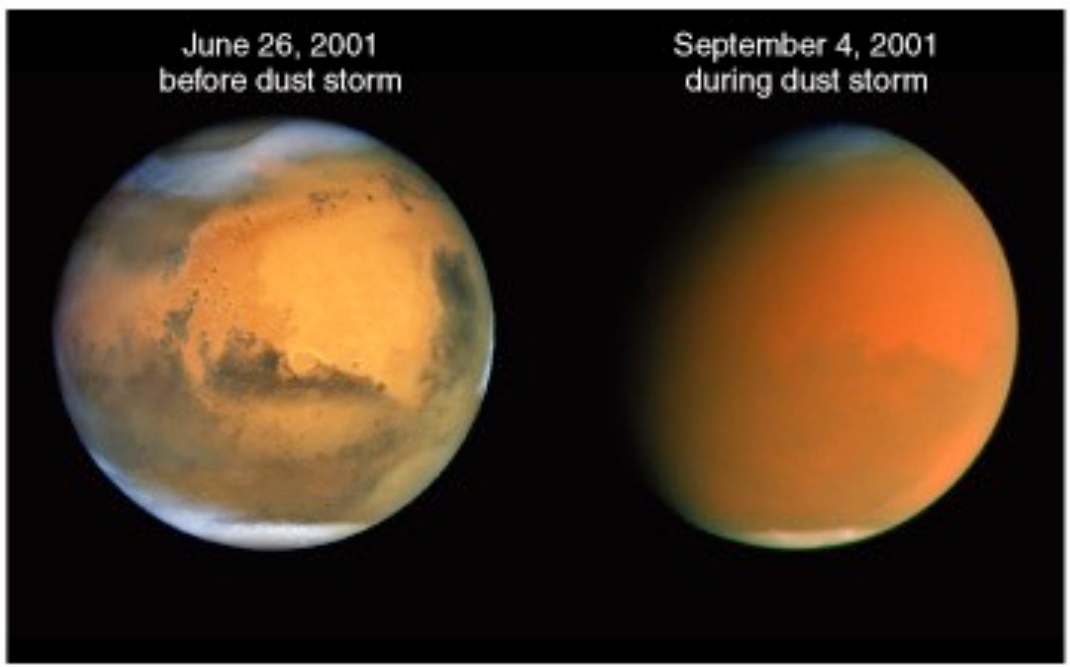
Polar Ice Caps of Mars

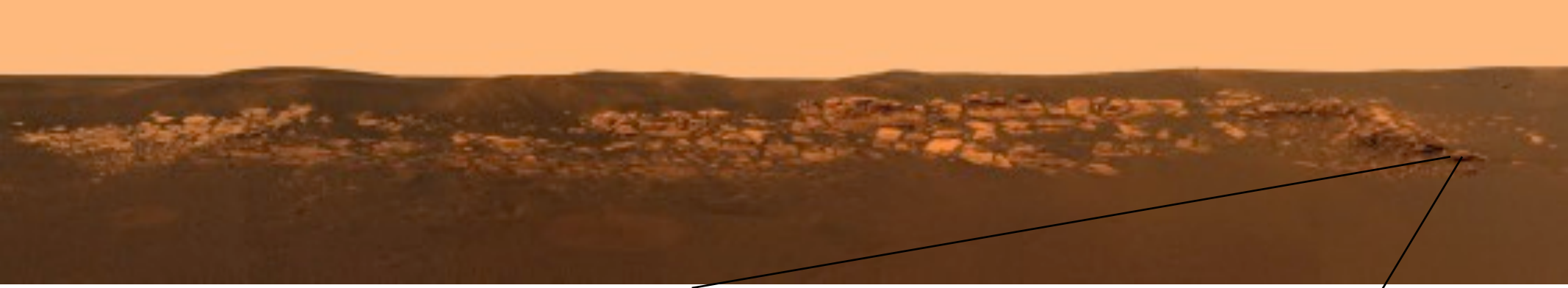


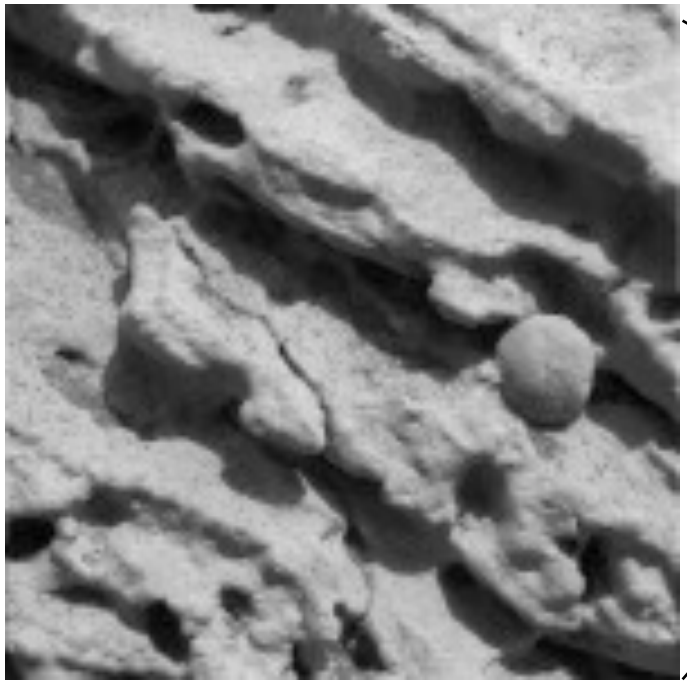
- Residual ice of the south polar cap remaining during summer is primarily water ice.
- Carbon dioxide ice of polar cap sublimates as summer approaches and condenses at opposite pole.

Storms on Mars

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

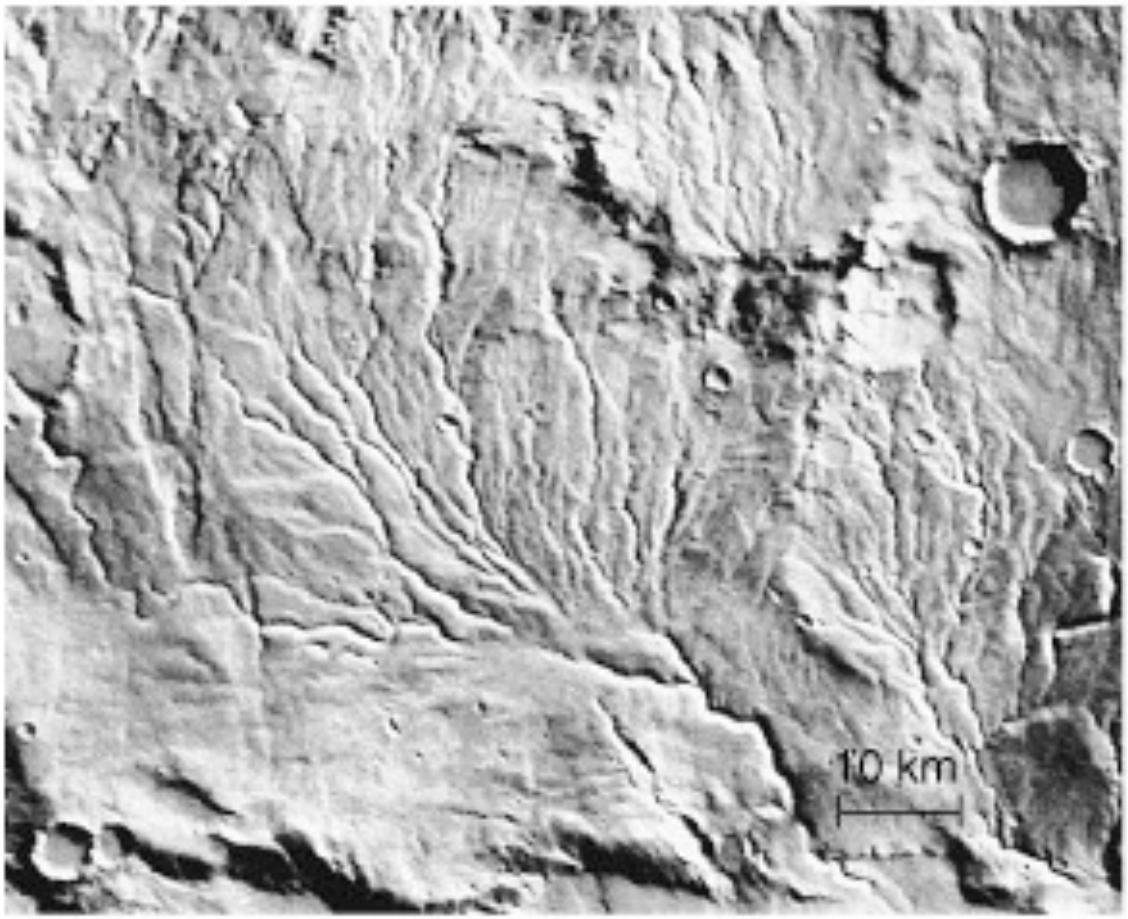






- 2004 *Opportunity* Rover provided strong evidence for abundant liquid water on Mars in the distant past.
- How could Mars have been warmer and wetter in the past?

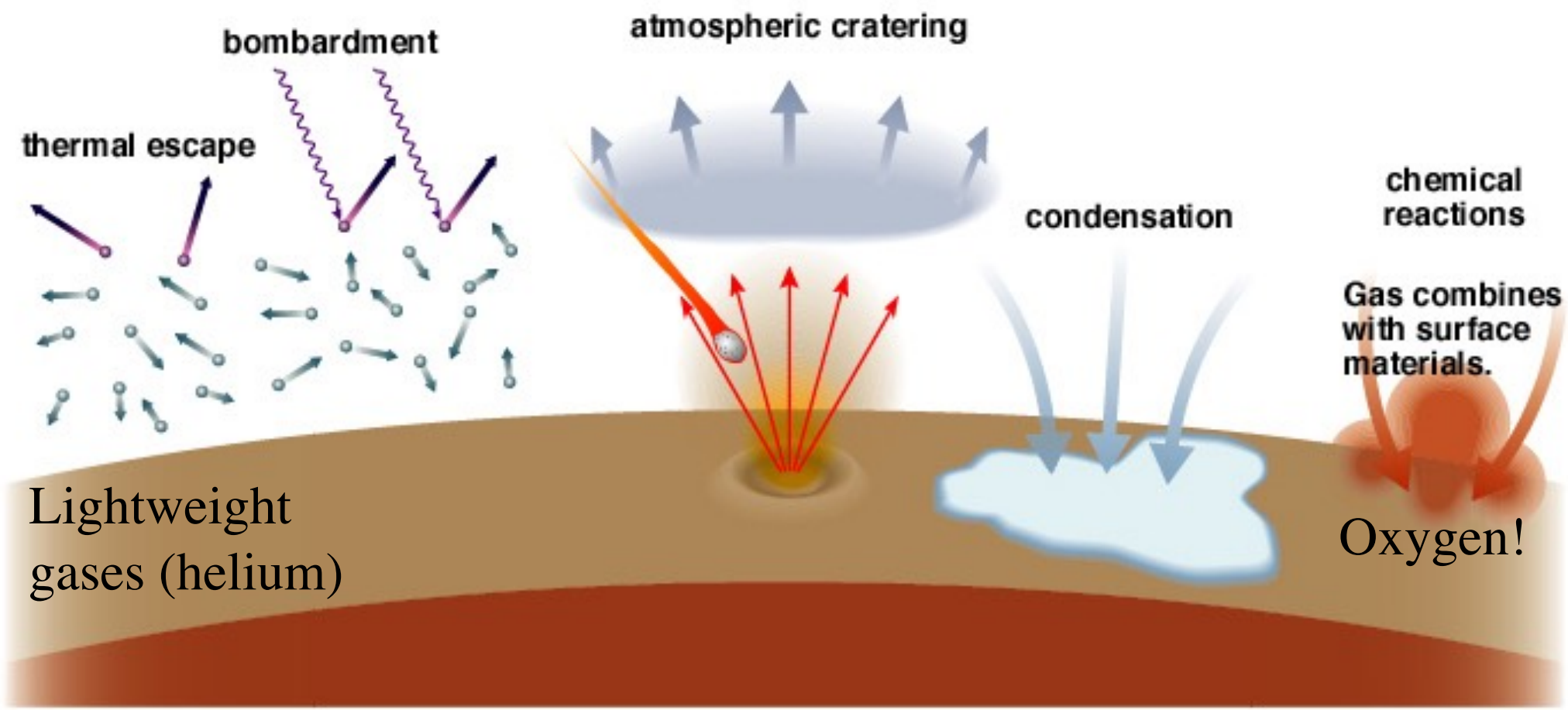
Climate Change on Mars



Erosion from water runoff on Mars
- an ancient riverbed!

- 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

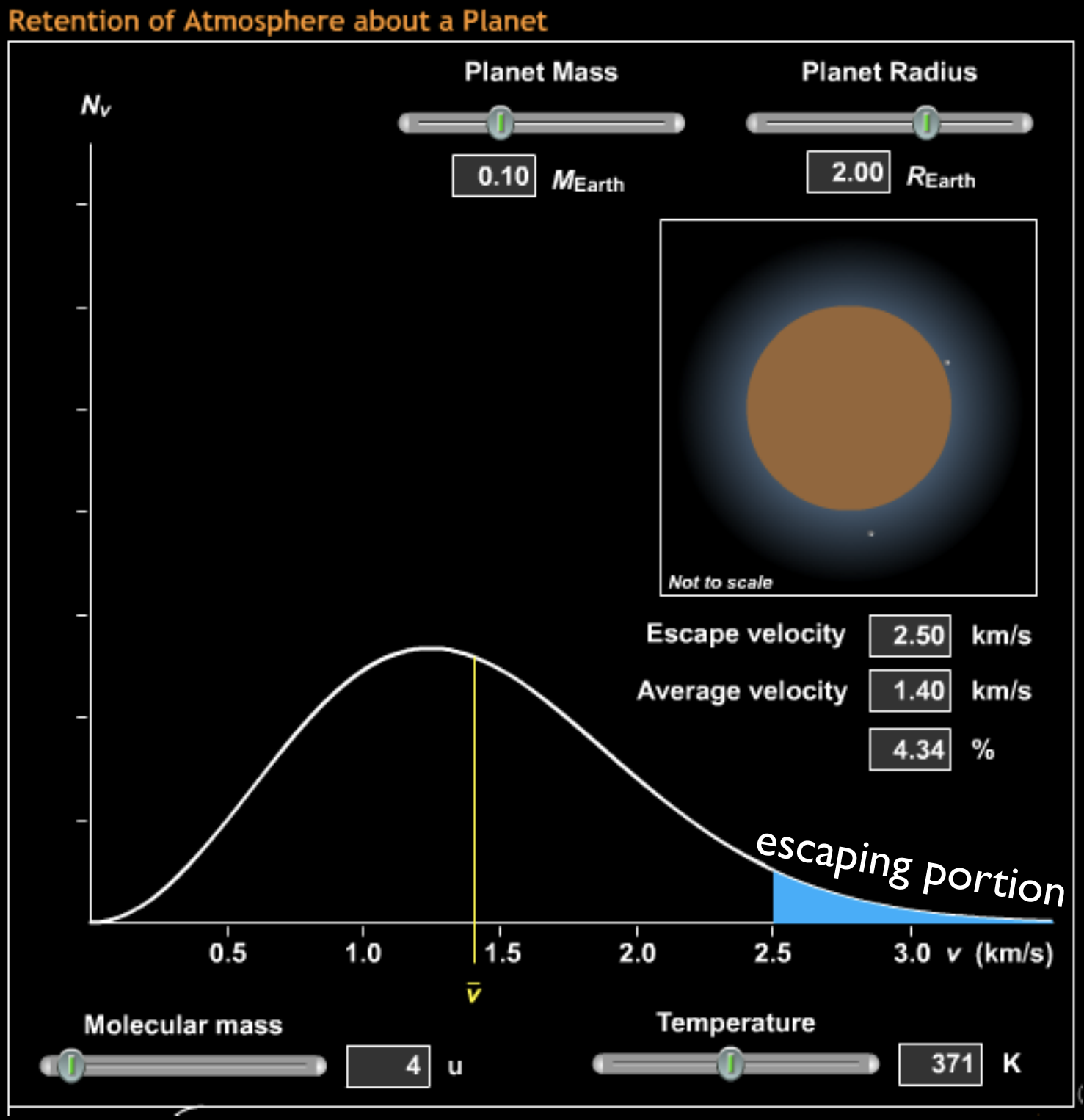


Can break up water vapor; hydrogen escapes

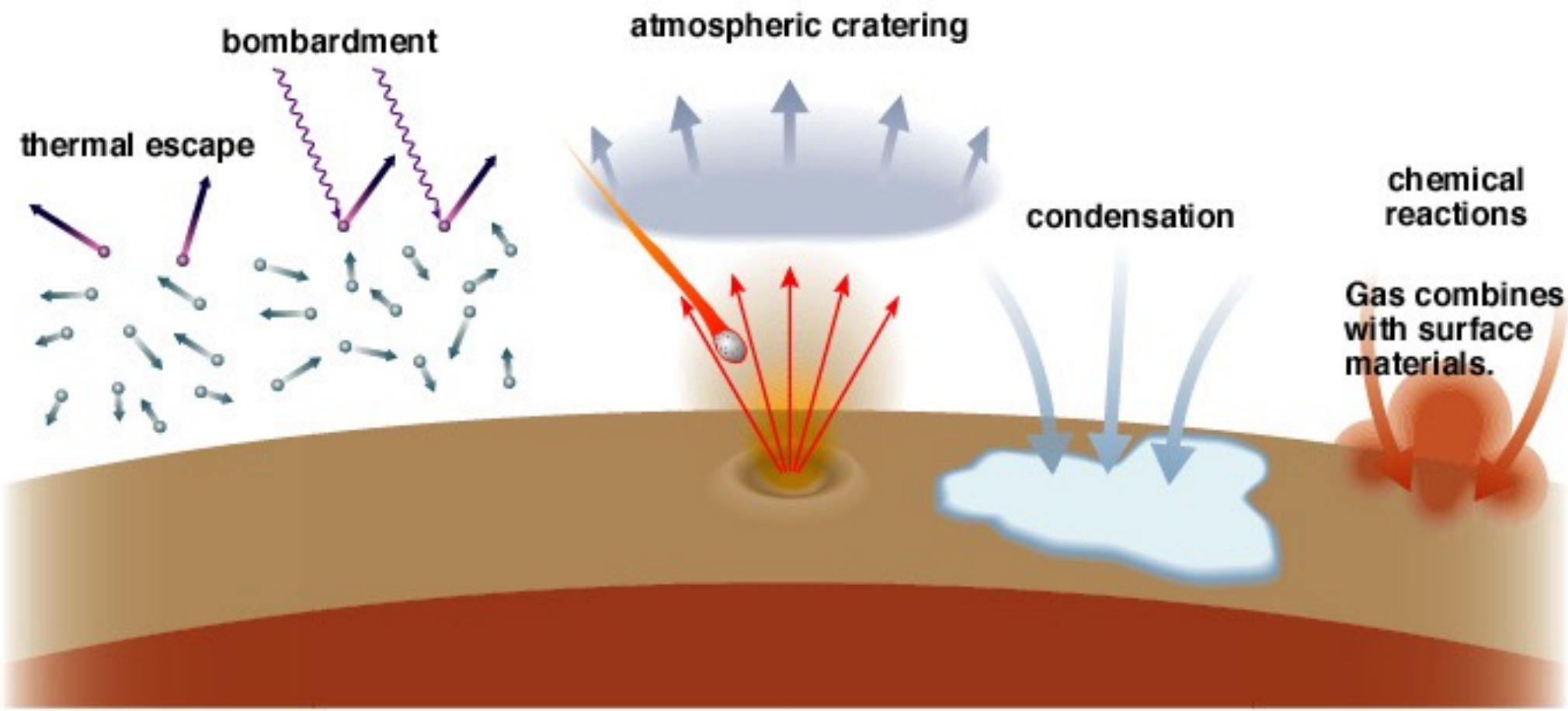
Water can freeze out

Thermal escape

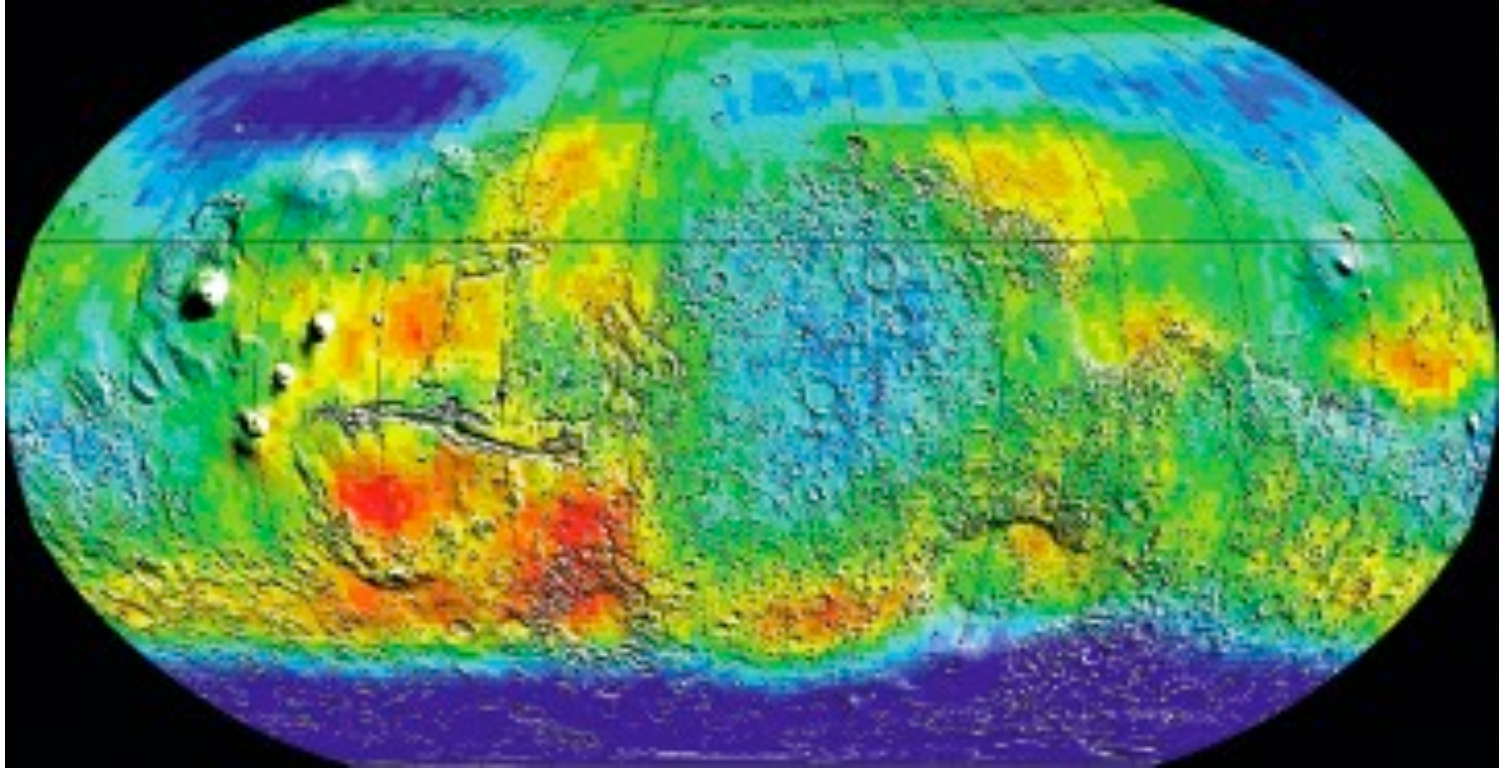
If atmospheric gas is hot enough, some of it exceeds escape velocity and leaks into space.



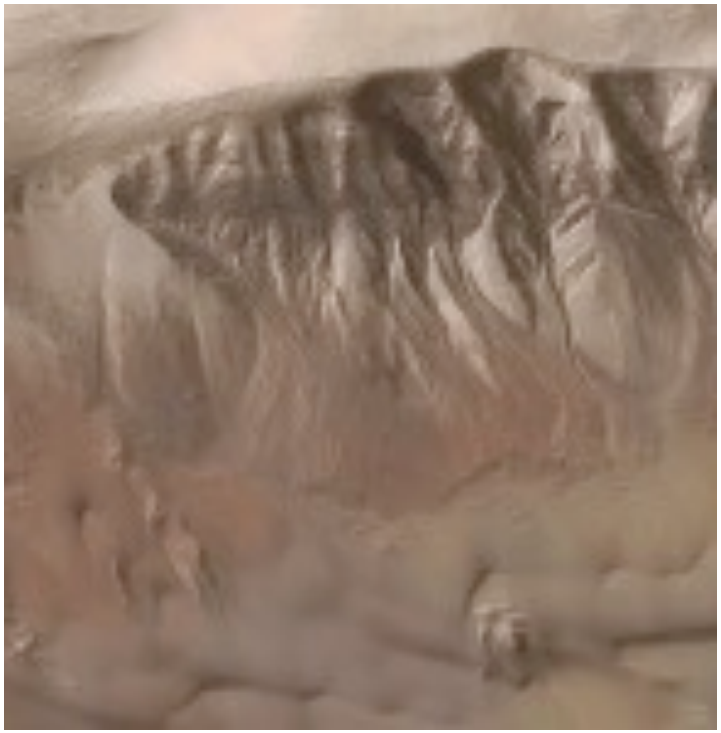
- Mars atmosphere was thicker in the past; its climate was warmer - liquid water!
- The atmosphere was gradually lost to space or frozen onto surface



Today, most water lies frozen underground (blue regions) "permafrost"



Some scientists believe accumulated snowpack melts carve gullies even today.



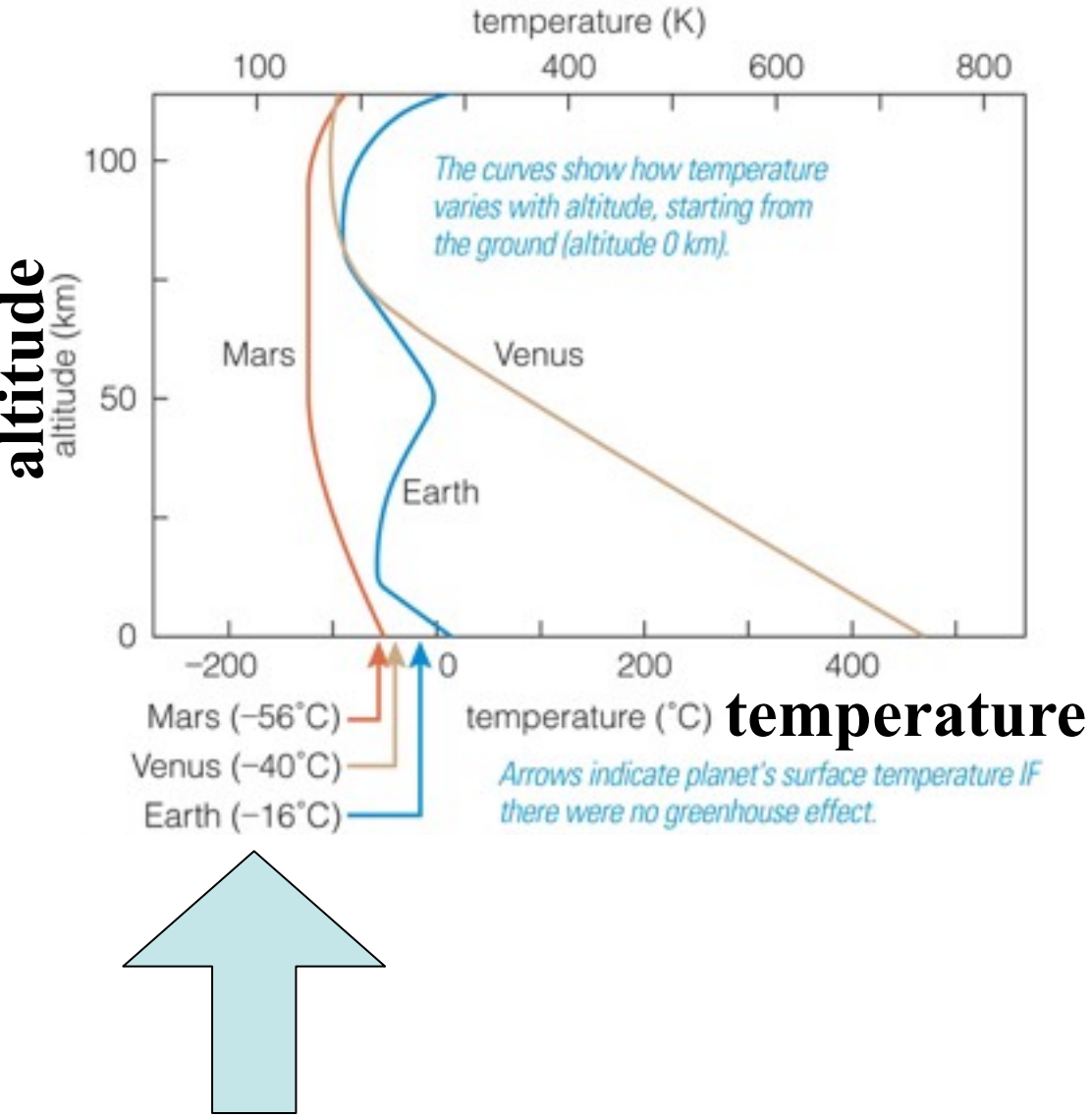
Climate change on Mars

- 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 CO_2, but not much of a greenhouse effect

"Normal" terrestrial atmosphere

- Atmospheric retention depends on
  - surface gravity
  - temperature
- Most common atmospheric composition
  - CO_2, N_2 (Venus, Mars)
  - or none at all (Mercury, Moon)
- Earth is the exception
  - H_2O plays crucial role in Carbon cycle
  - O_2 a biological byproduct

Atmospheres of Other Planets



"No greenhouse" temperatures

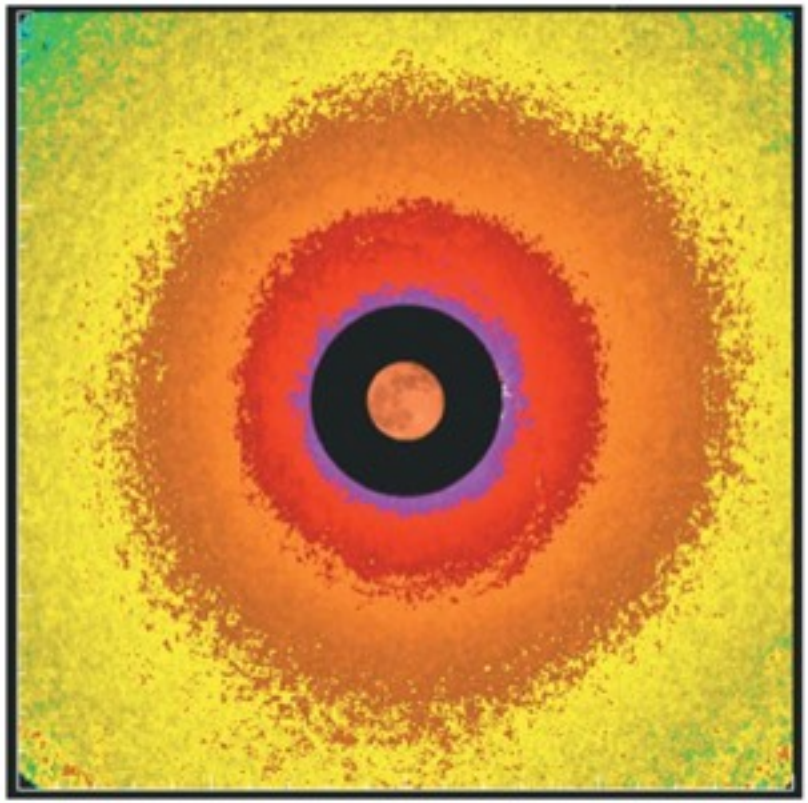
- Earth is only planet with a stratosphere because of UV-absorbing ozone molecules (O_3).
- Those same molecules protect us from Sun's UV light.

Do the Moon and Mercury have any atmosphere?

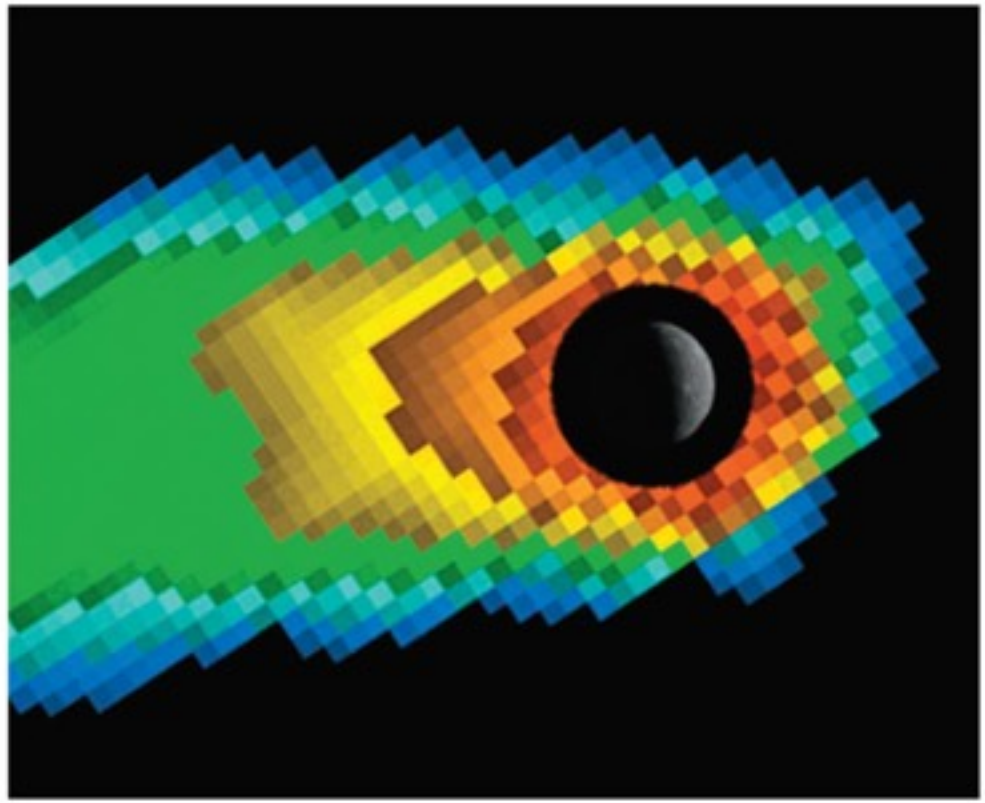
Moon

Mercury

Exospheres of the Moon and Mercury



a The Moon's exosphere, which extends high above the surface.

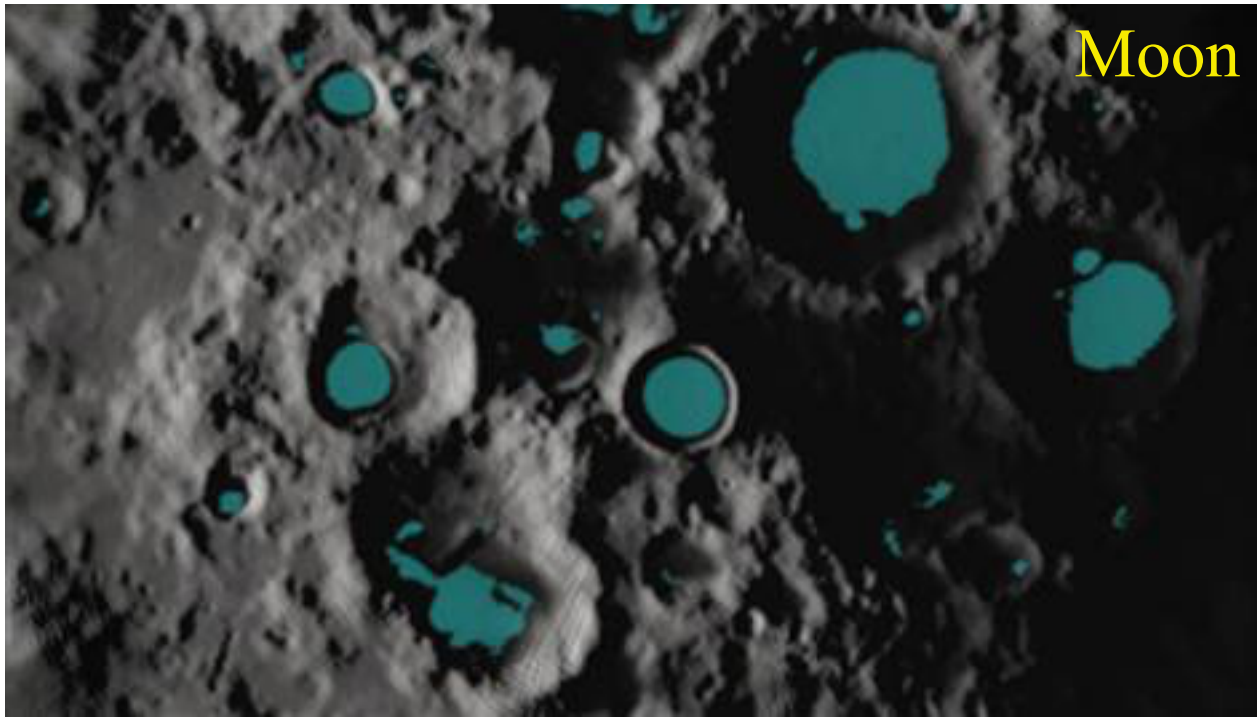


b Mercury's exosphere, much of which is escaping in this image.

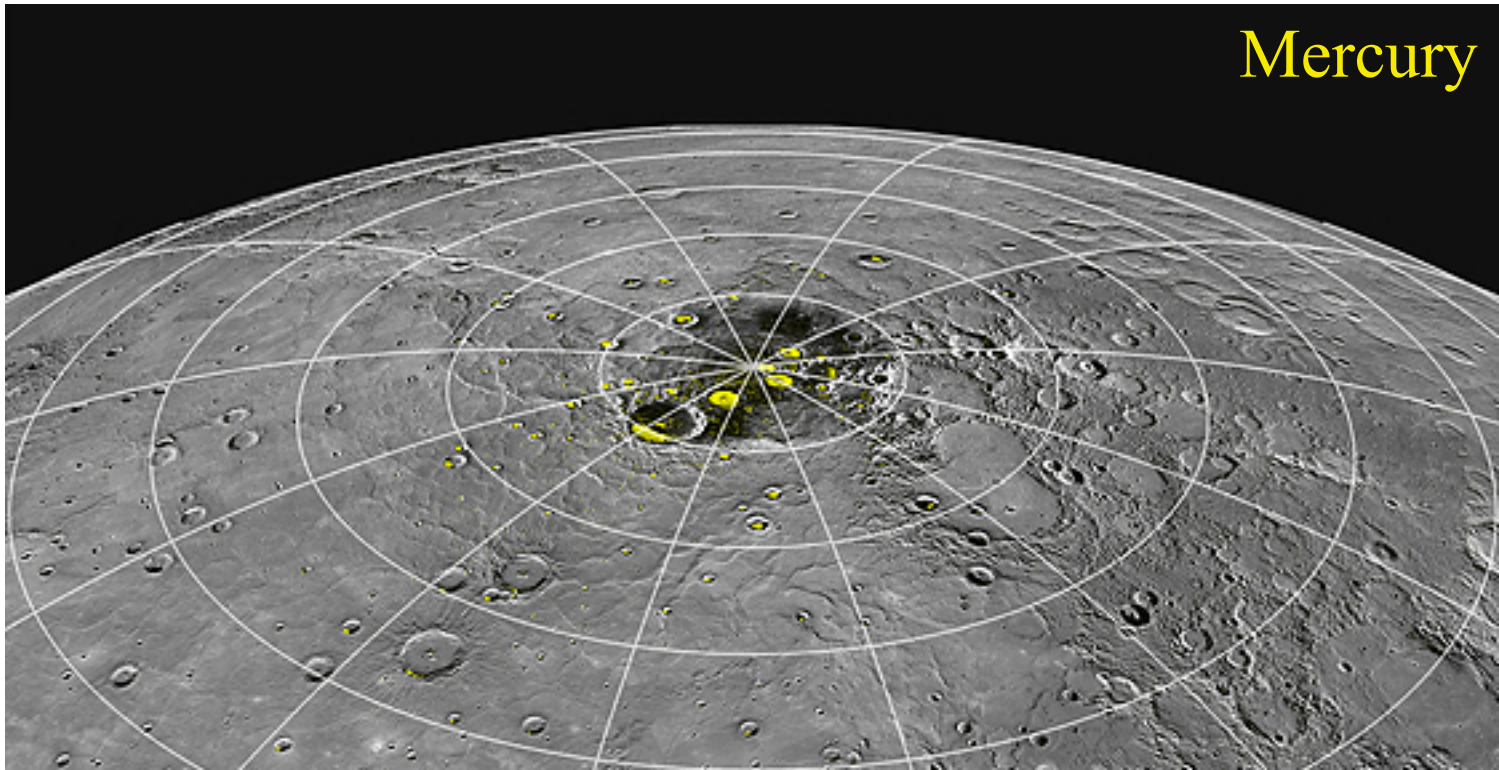
- Sensitive measurements show that the Moon and Mercury have extremely thin atmospheres.
- Gas comes from impacts that eject surface atoms.

Ice in Polar Craters

- Radar reflectivity show evidence of water ice near the **poles** of the Moon and Mercury in **permanently shaded craters**



- May have been delivered by comets



Weather and Climate

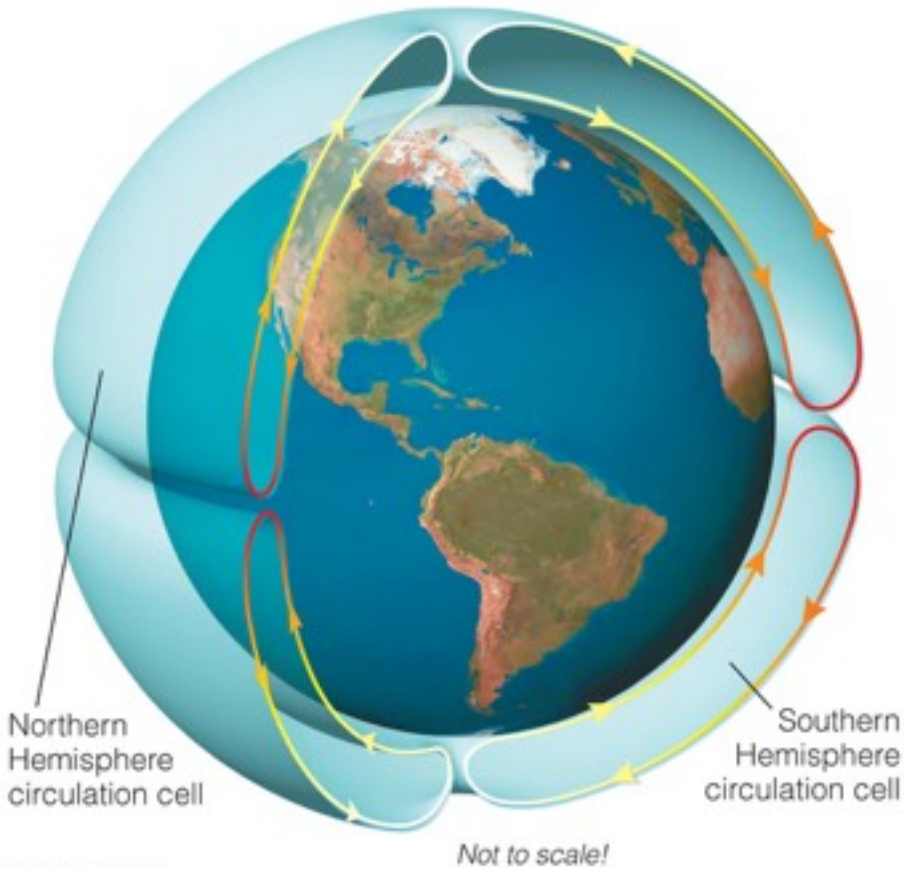
- **Weather** is the ever-varying combination of wind, clouds, temperature, and pressure.
  - Local complexity of weather makes it difficult to predict.

- **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)

Global Wind Patterns

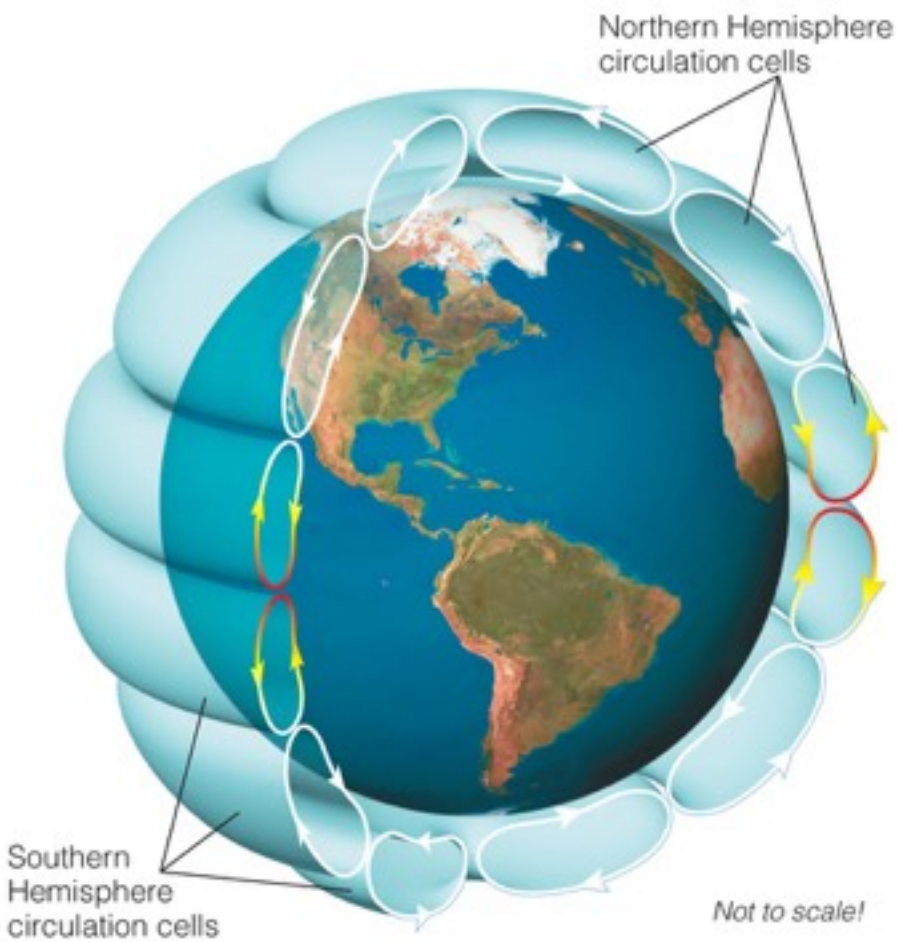
- Heat transport
- Global winds blow in distinctive patterns:
  - Equatorial: E to W
  - Mid-latitudes: W to E
  - High latitudes: E to W

Circulation Cells: No Rotation



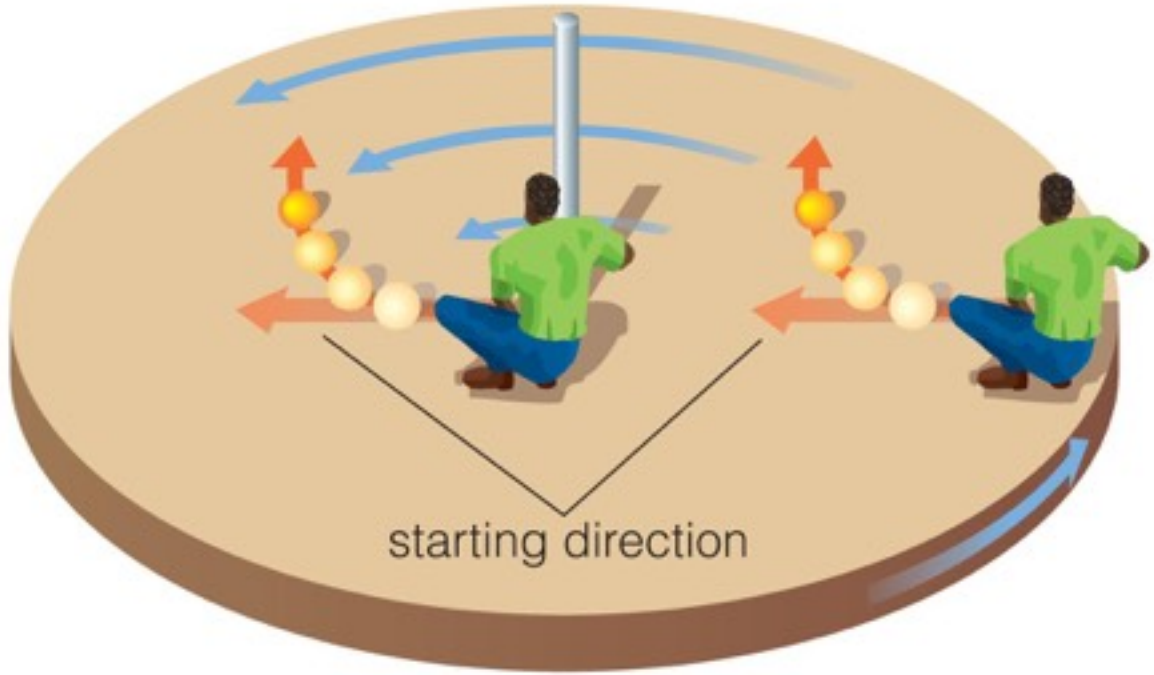
- Heated air rises at equator.
- Cooler air descends at poles.
- Without rotation, these motions would produce two large circulation cells.

Circulation Cells with Rotation



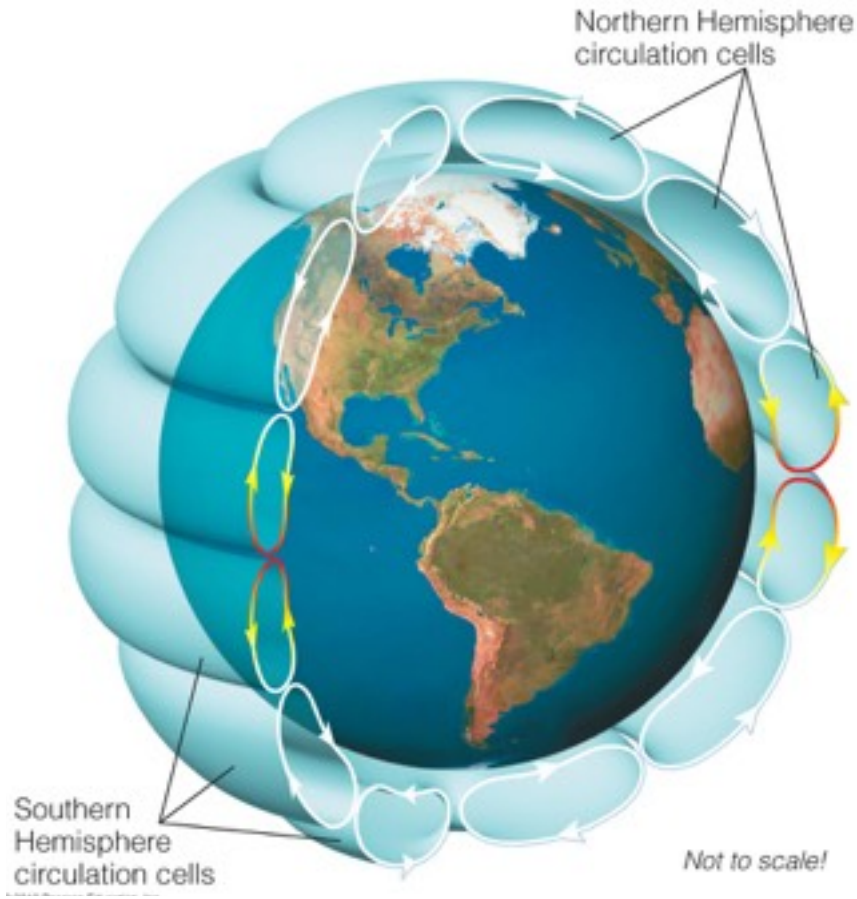
- Coriolis effect deflects north-south winds into east-west winds.
- Deflection breaks each of the two large "no-rotation" cells into three smaller cells in each hemisphere.
  - Tropical
  - Mid-latitude
  - Polar

Coriolis Effect



- Conservation of angular momentum causes a ball's apparent path on a spinning platform to change direction.

Prevailing Winds



- Prevailing surface winds at mid-latitudes blow from W to E because the Coriolis effect deflects the S to N surface flow of mid-latitude circulation cells.

Coriolis Effect on Earth

a Low-pressure regions ("L") draw in air from surrounding areas, and the Coriolis effect causes this air to circulate counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere.

Interactive Figure

- Air moving from a pole to the equator is going farther from Earth's axis and begins to lag behind Earth's rotation.
- Air moving from the equator to a pole moves closer to the axis and travels ahead of Earth's rotation.

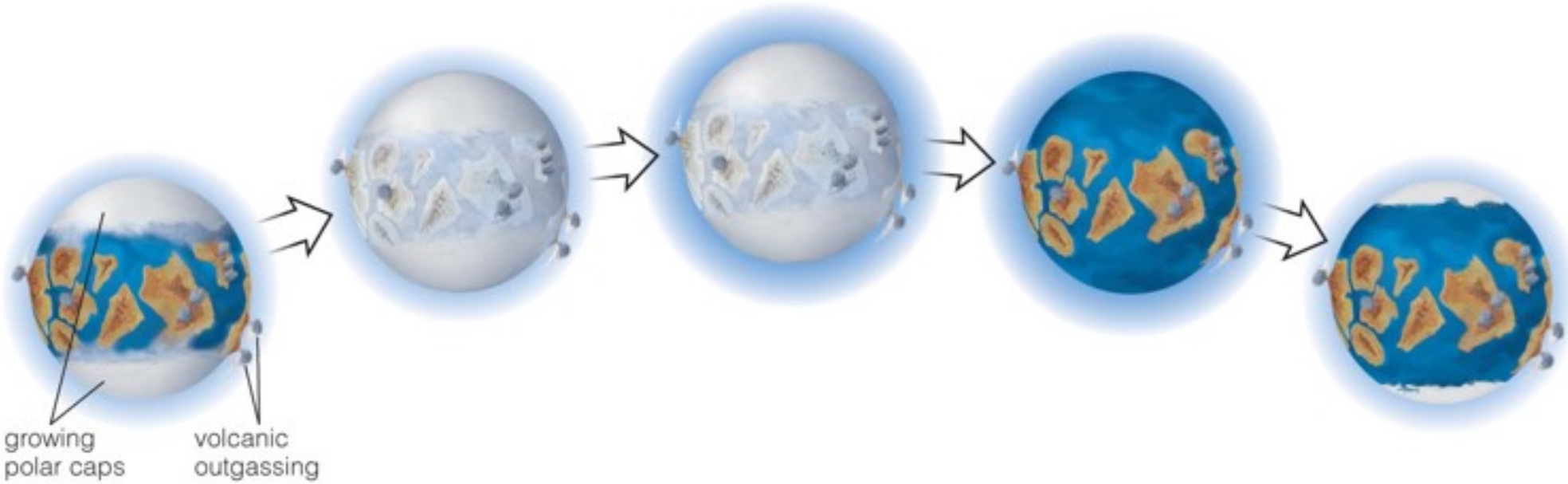
Coriolis Effect on Earth

- Conservation of angular momentum causes large storms to swirl.

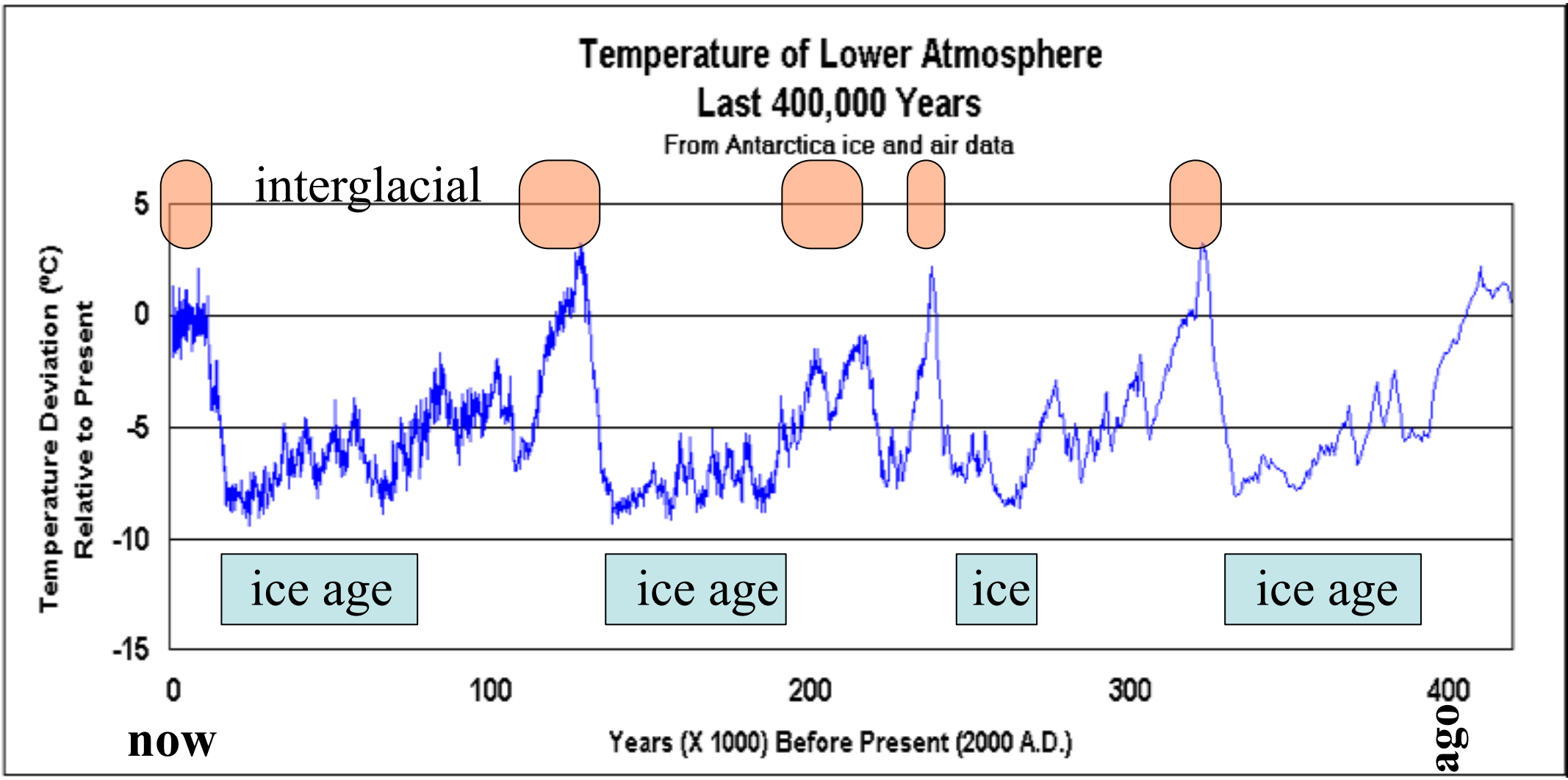
- Direction of circulation depends on hemisphere:
  - N: counterclockwise
  - S: clockwise

b This photograph shows the opposite directions of storm circulation in the two hemispheres.

Long-Term Climate Change



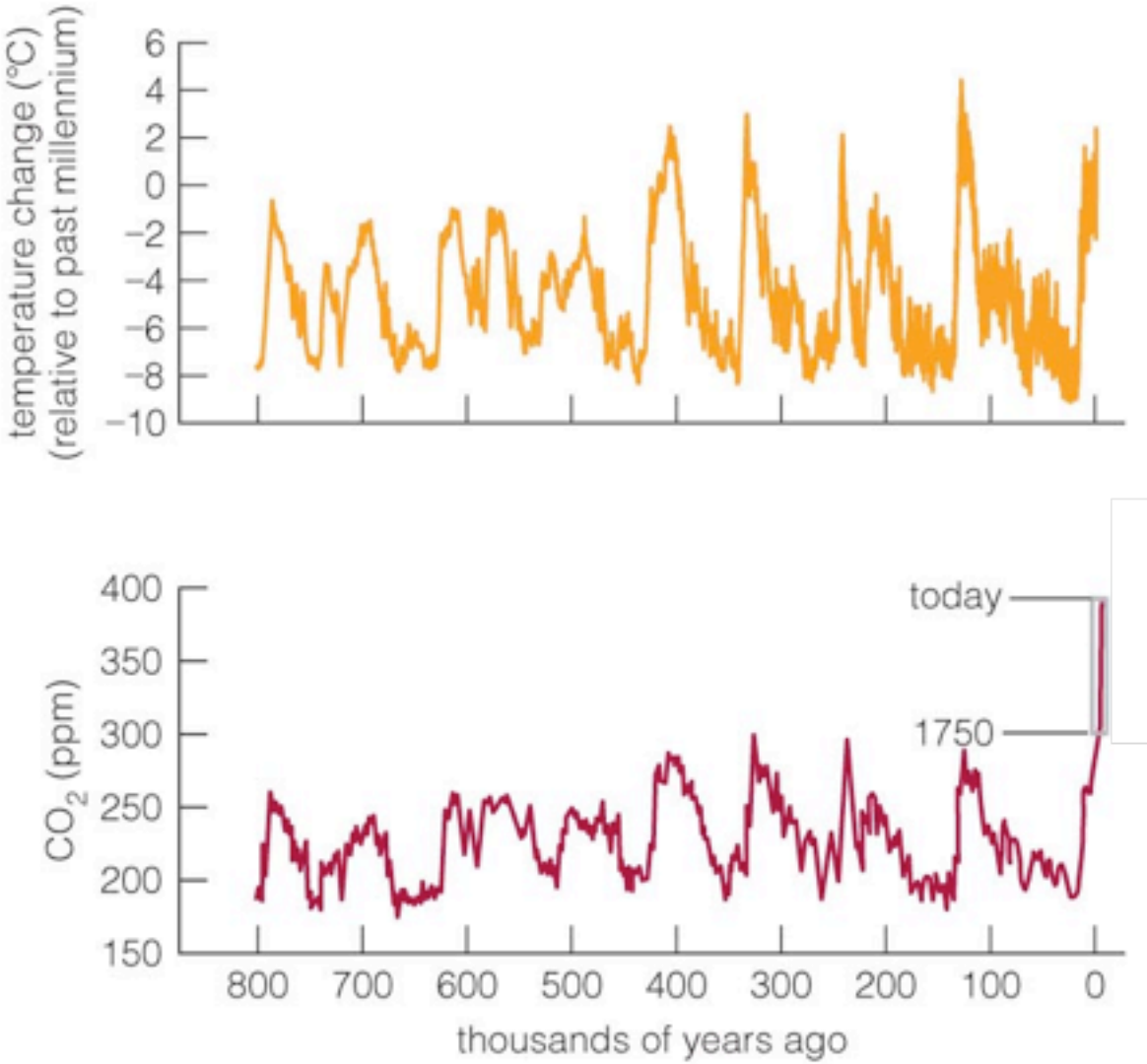
- Changes in Earth's axis tilt might lead to *ice ages*.
- Widespread ice tends to lower global temperatures by increasing Earth's reflectivity.
- CO_2 from outgassing will build up if oceans are frozen, ultimately raising global temperatures again.



400,000 yr ago

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

CO_2 Concentration



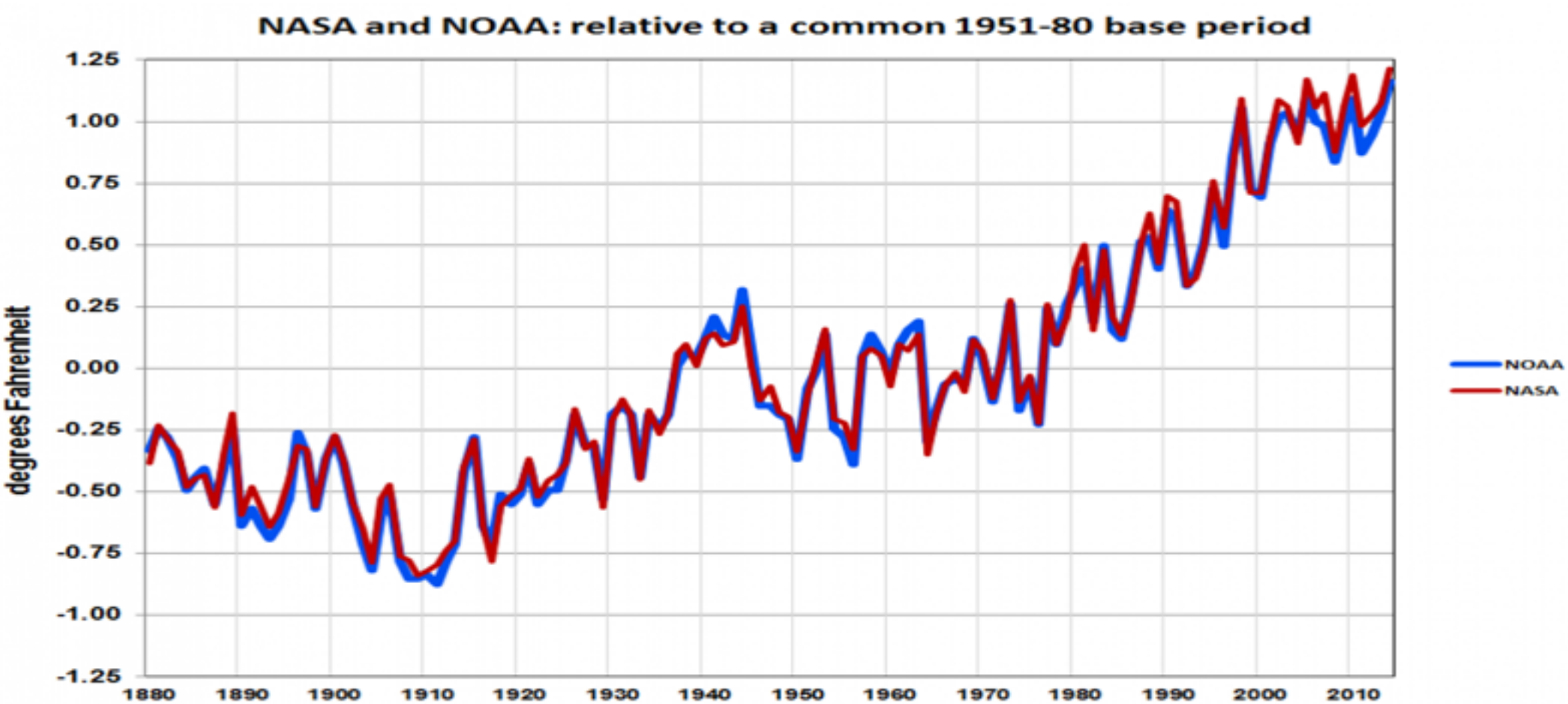
- Temperature and CO_2 concentration vary in lockstep
- This coupling is expected from known physics
- Current CO_2 concentration is the highest it's been in at least 500,000 years.

The anthropogenic greenhouse effect (Global Warming and human activity)

What is real information?

What is misleading?

Should we be worried?



2014

- Did we have a colder than average winter?

  Yes - winter in Ohio was colder than average.

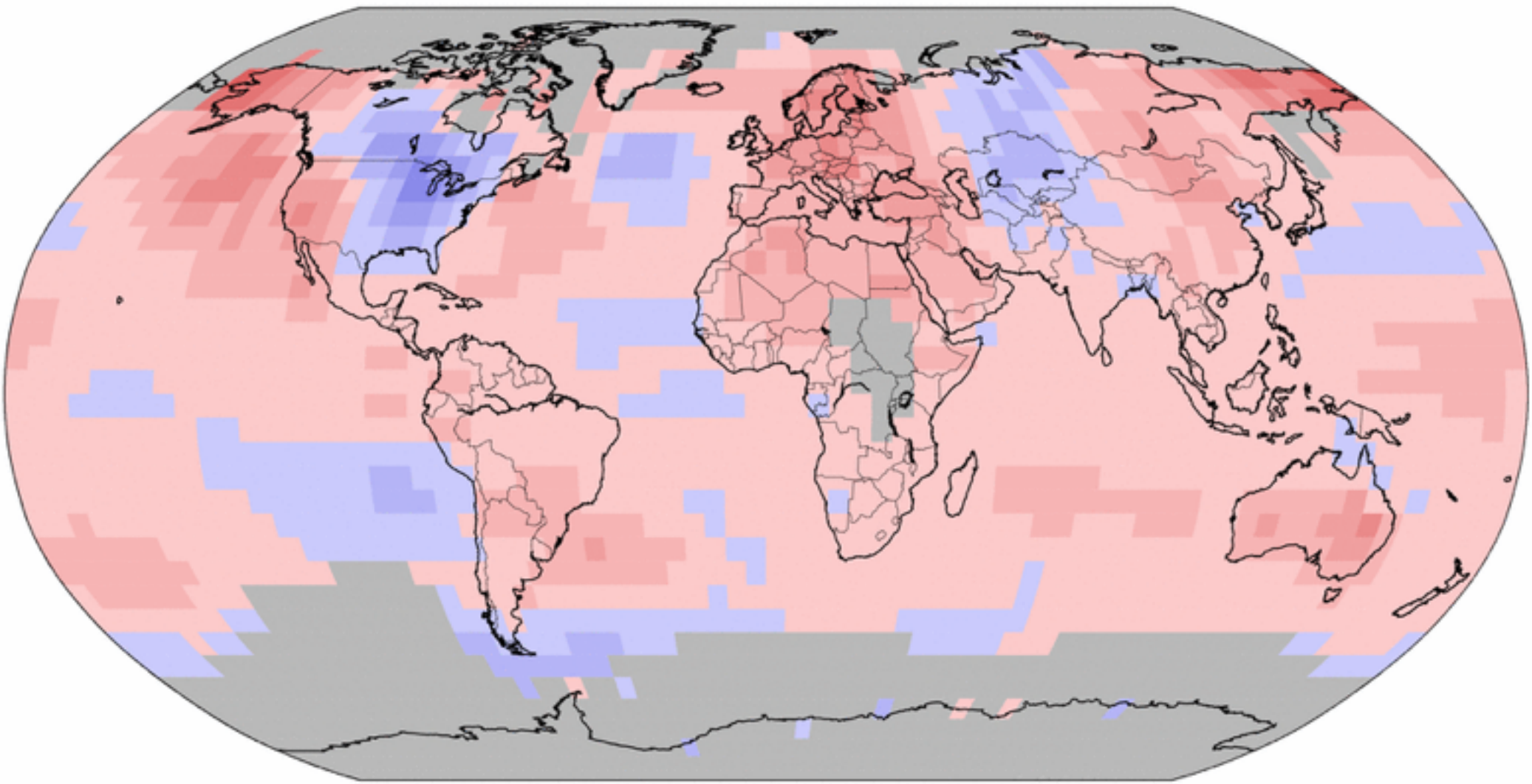
- Was the globe warmer or colder than average?

  Warmer - most of the globe was warmer
  despite it being colder locally.

Land & Ocean Temperature Departure from Average Jan–Dec 2014

(with respect to a 1981–2010 base period)

Data Source: GHCN–M version 3.2.2 & ERSST version 3b



−5 −4 −3 −2 −1 0 1 2 3 4 5

Degrees Celsius

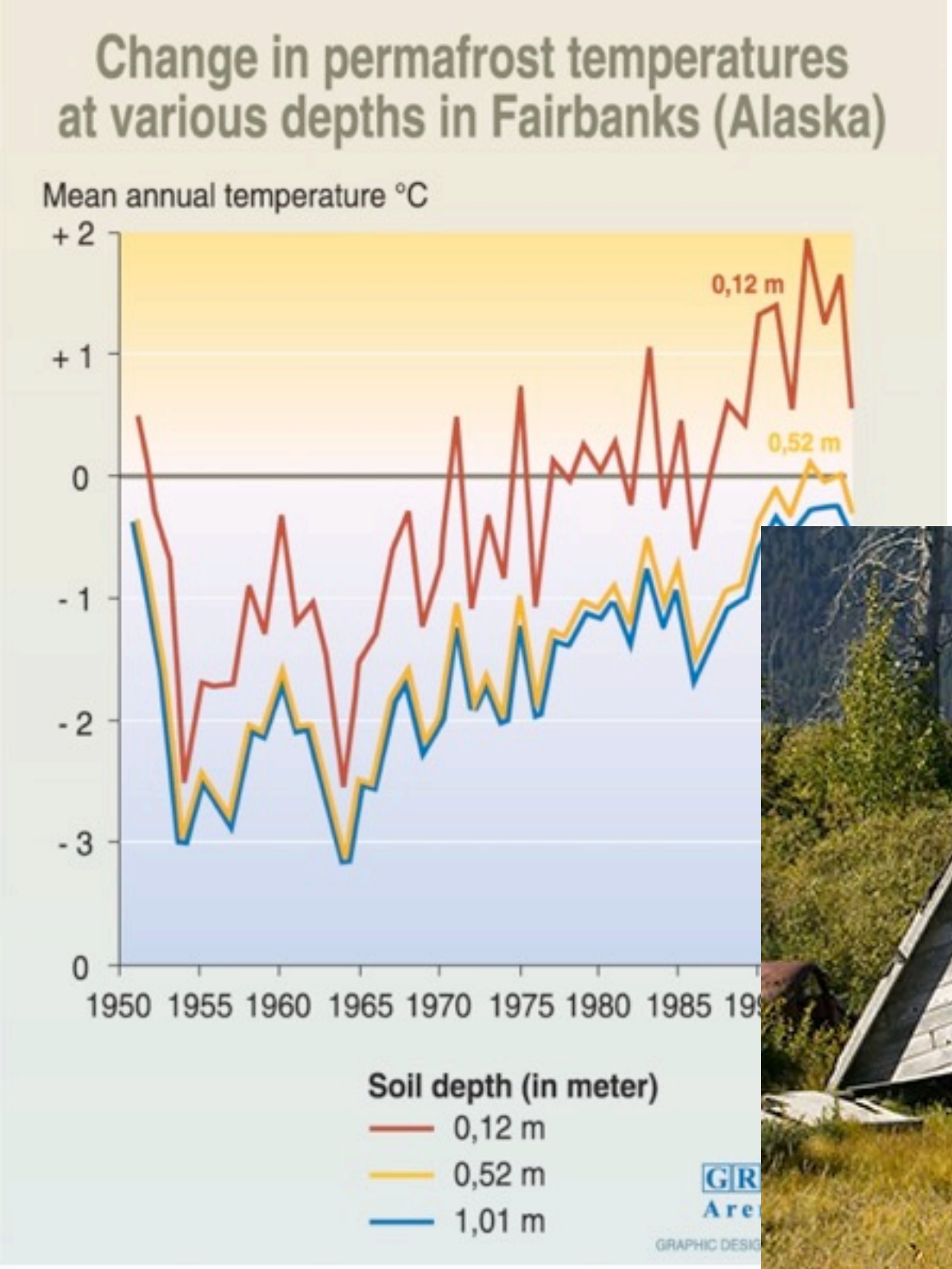
NOAA's National Climatic Data Center
Mon Jan 12 19:34:34 EST 2015

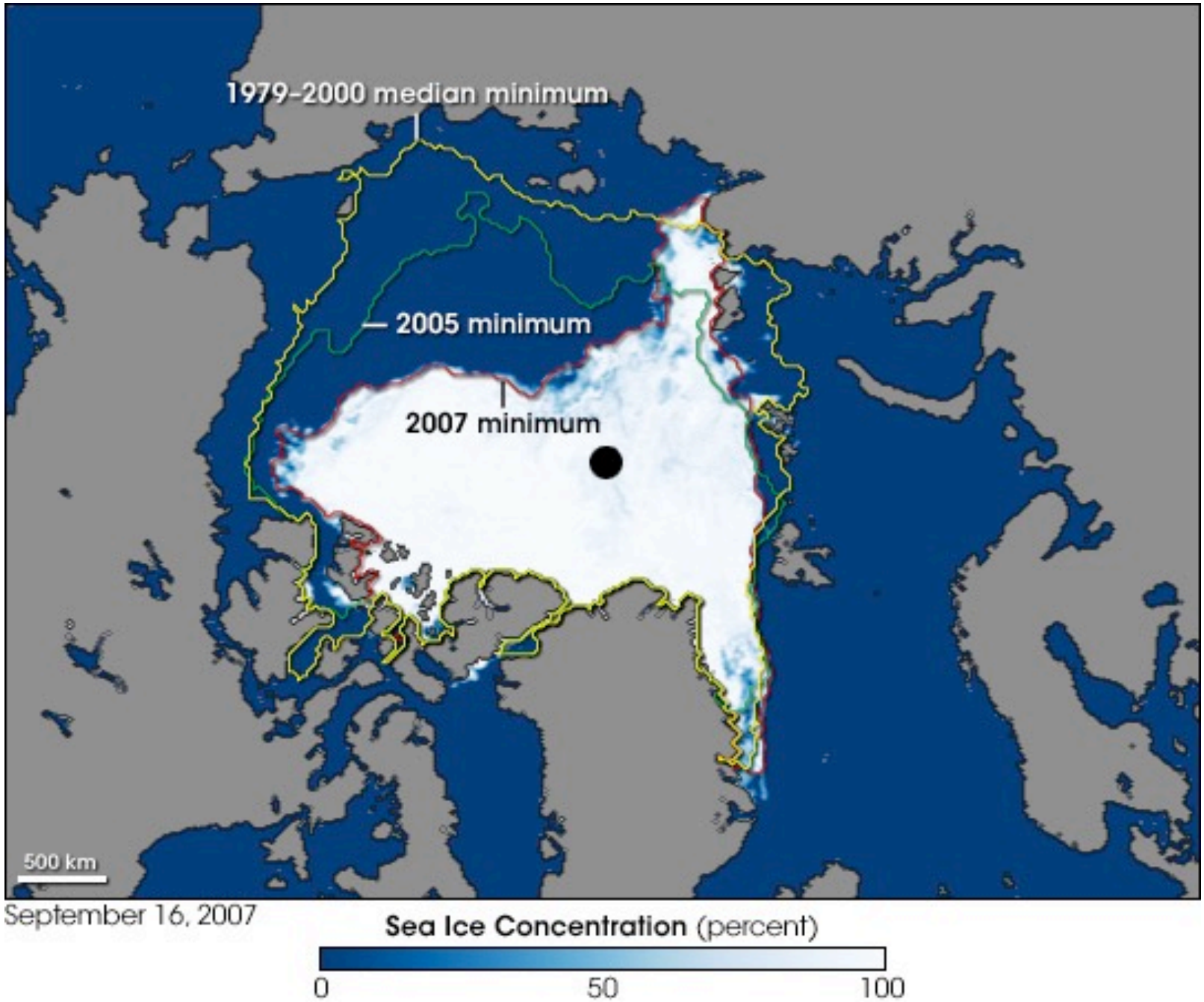
Please Note: Gray areas represent missing data
Map Projection: Robinson

Evidence of global warming

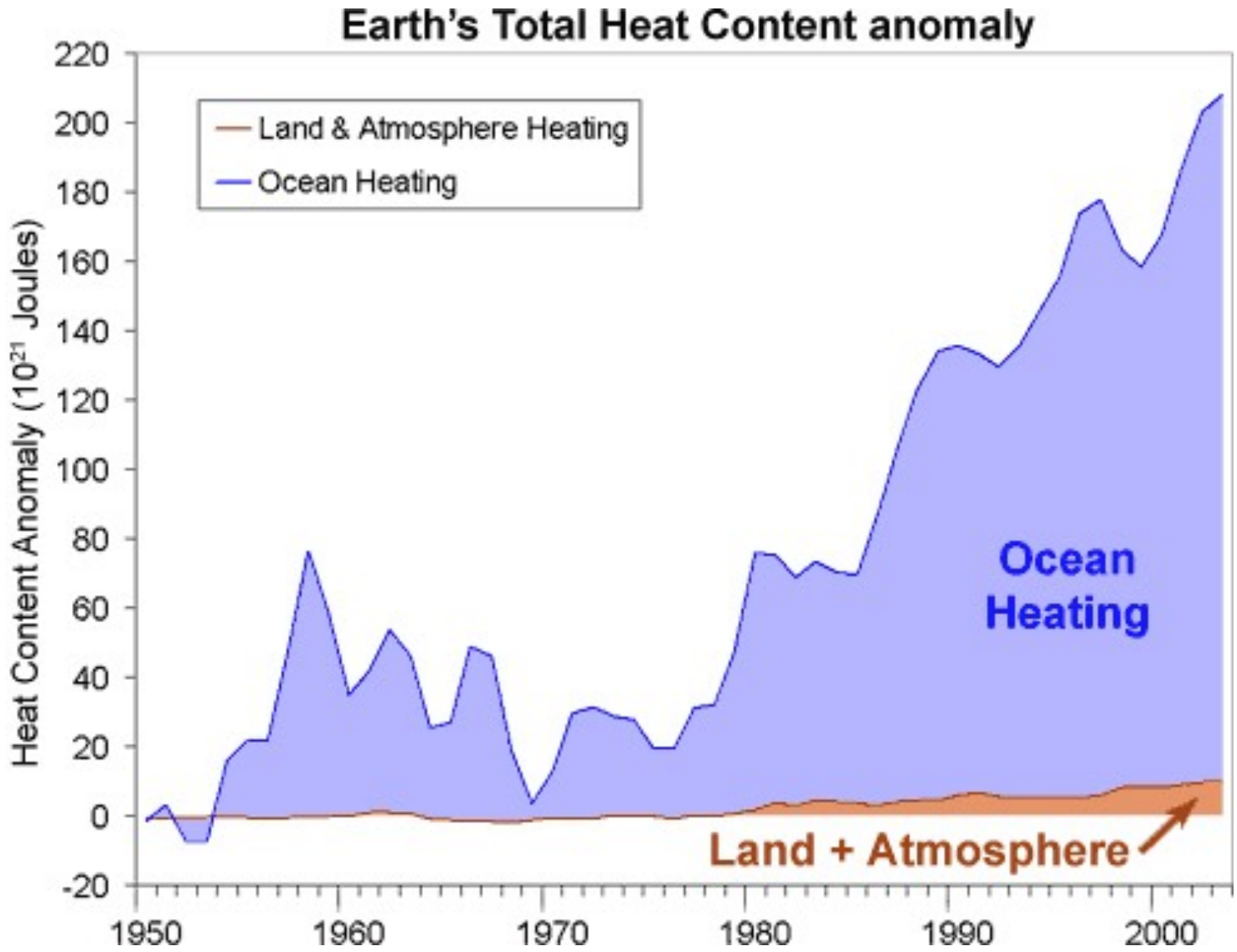
- Increase in greenhouse gas concentrations
- Surface temperature measurements
- Ocean temperature measurements
- Sea level rise (water expands as it warms)
- Melting arctic icecap; retreating glaciers
- Poleward migration of species
- More extreme weather events
  - both warm & cold; hurricanes; snowmageddon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

Arctic
permafrost
is melting





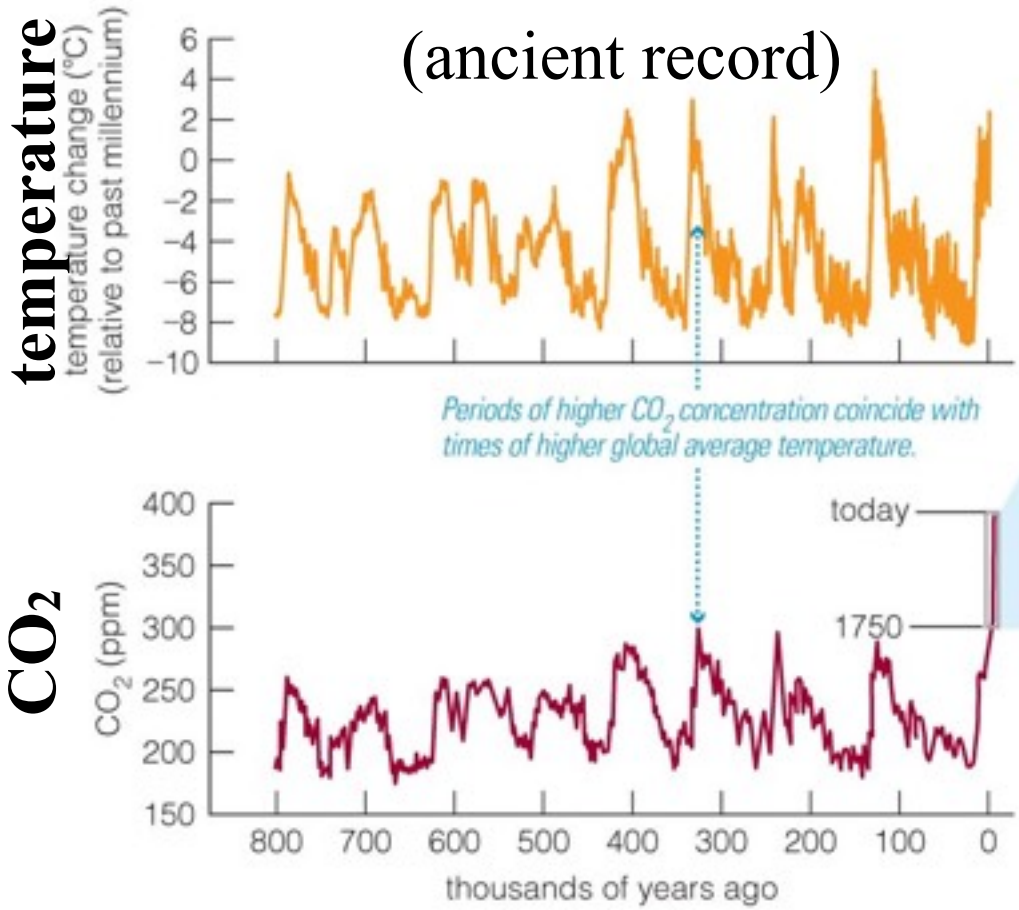
Fabled Northwest passage opened for first time in history in 2007



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

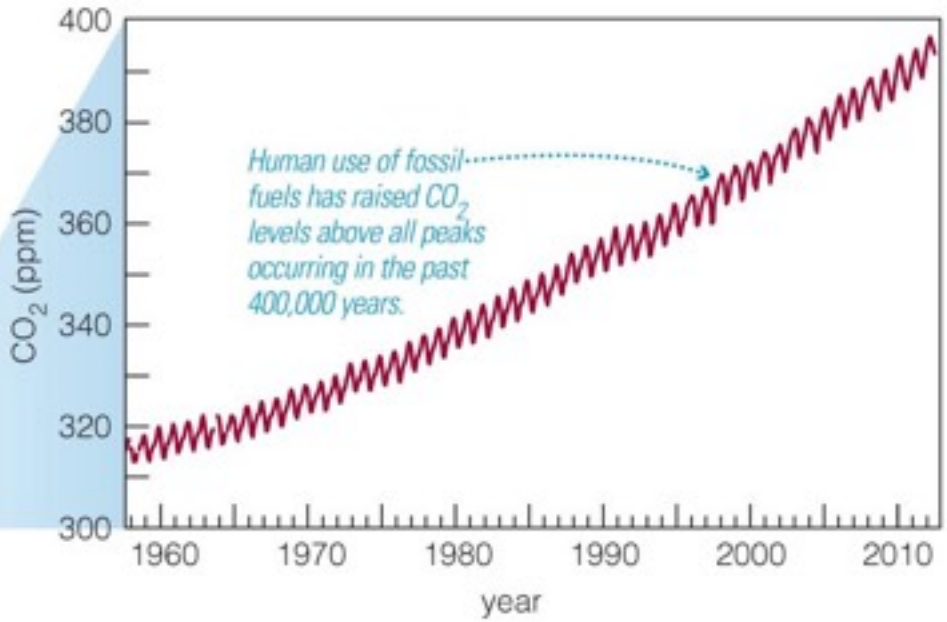
CO_2 Concentration

Ice core data
(ancient record)



time
(thousands of years)

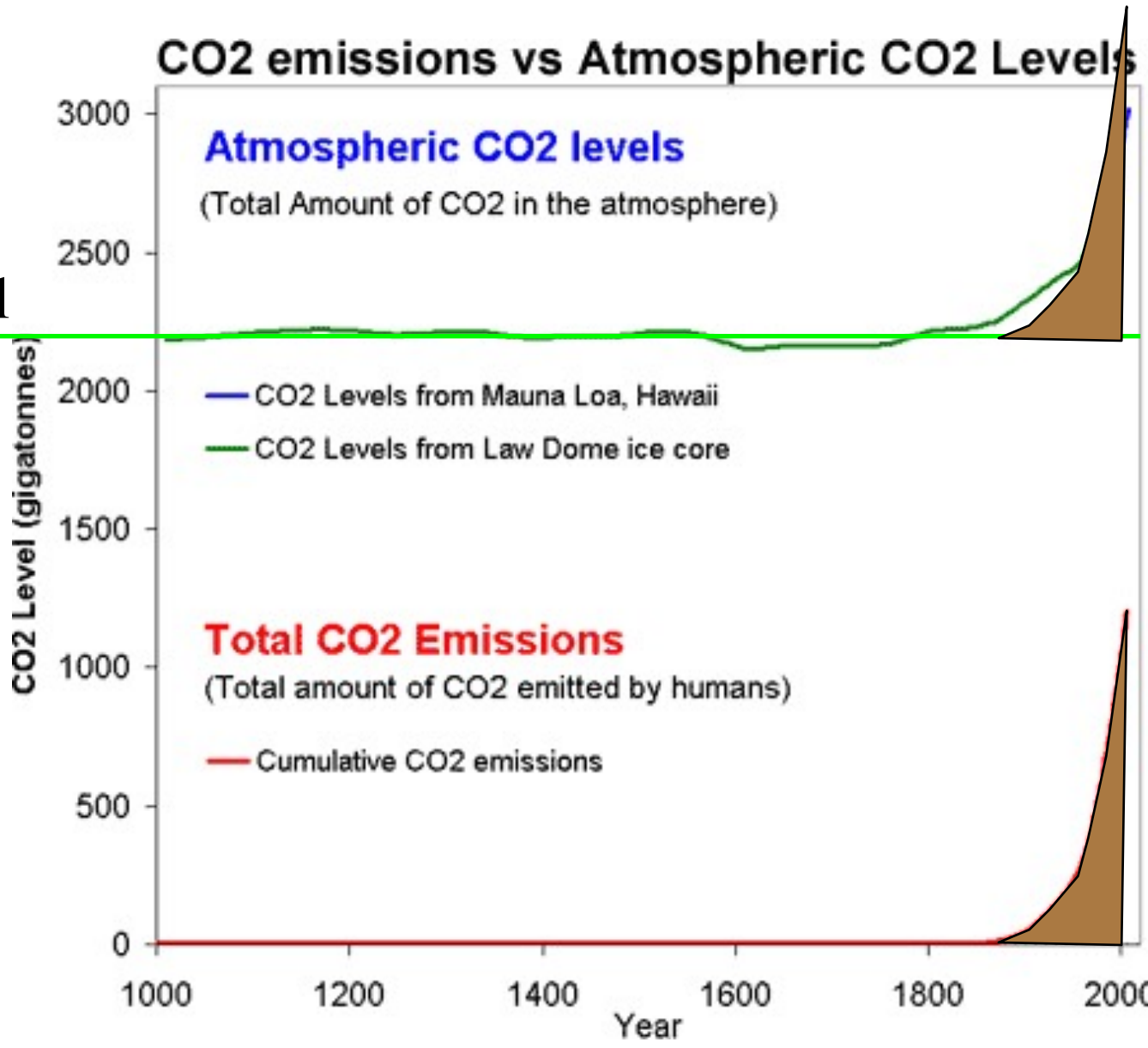
Mauna Loa Observatory
(modern record)



time
(years)

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

Pre-industrial CO_2 concentration: 280 ppm. Current level: 400 ppm



Pre-industrial CO_2 level

CO2 added to atmosphere

Human activity

Carbon burned

1000

Year (A.D.)

2000