

Today

- Jovian planets
- but first - a little more Climate change

Weather and Climate

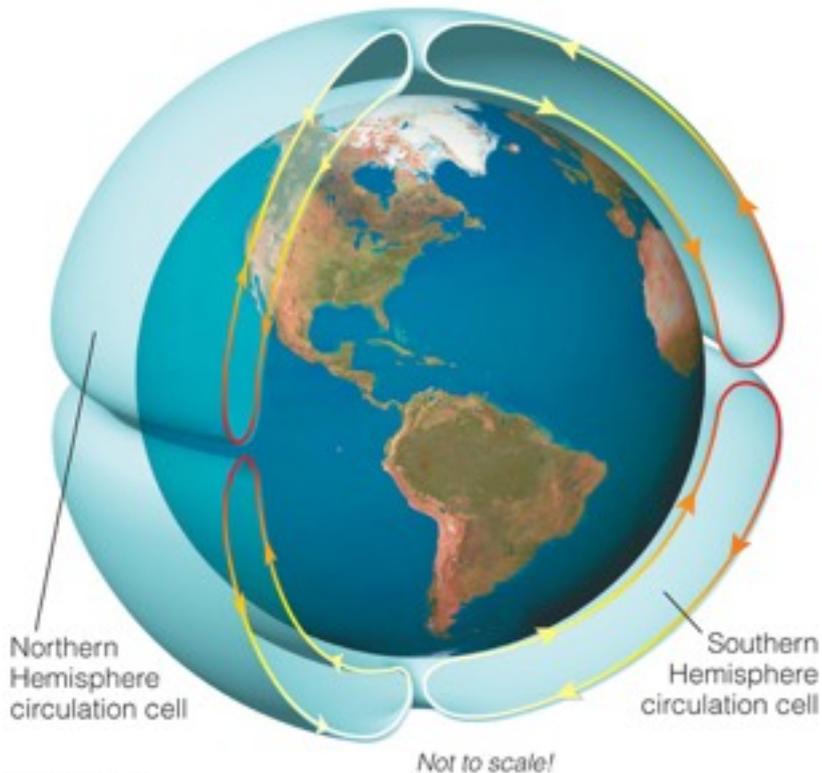
- **Weather** is the ever-varying combination of wind, clouds, temperature, and pressure.
 - Local complexity of weather makes it difficult to predict.
- **Climate** is the long-term average of weather.
 - generally more predictable than weather
 - Stability of climate depends on global conditions
 -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

Global Wind Patterns



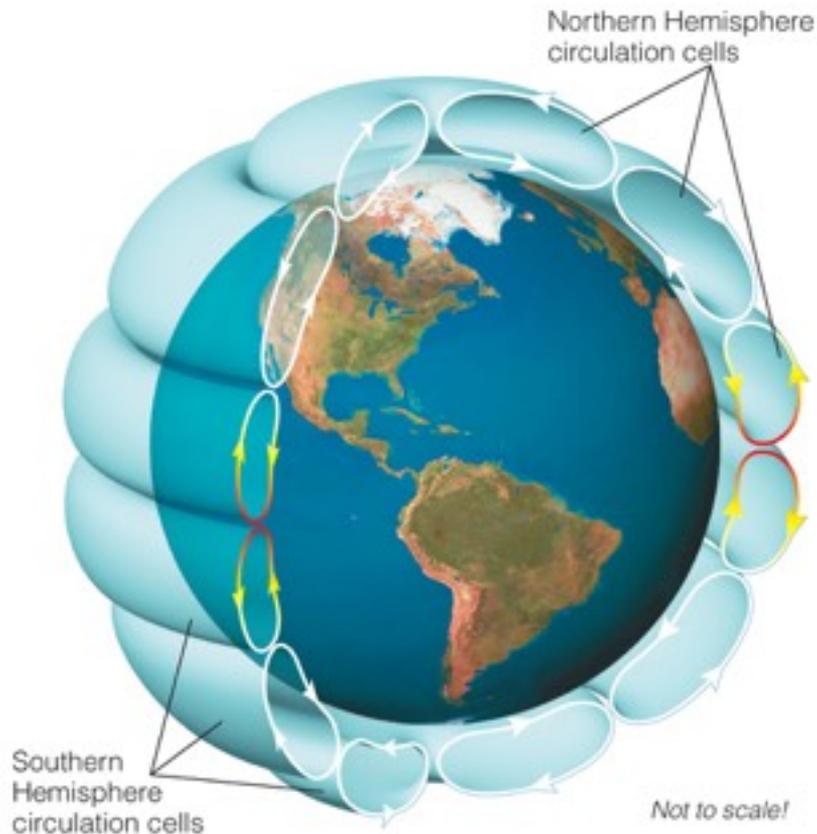
- Heat transport
- Global winds blow in distinctive patterns:
 - Equatorial: E to W
 - Mid-latitudes: W to E
 - High latitudes: E to W

Circulation Cells: No Rotation



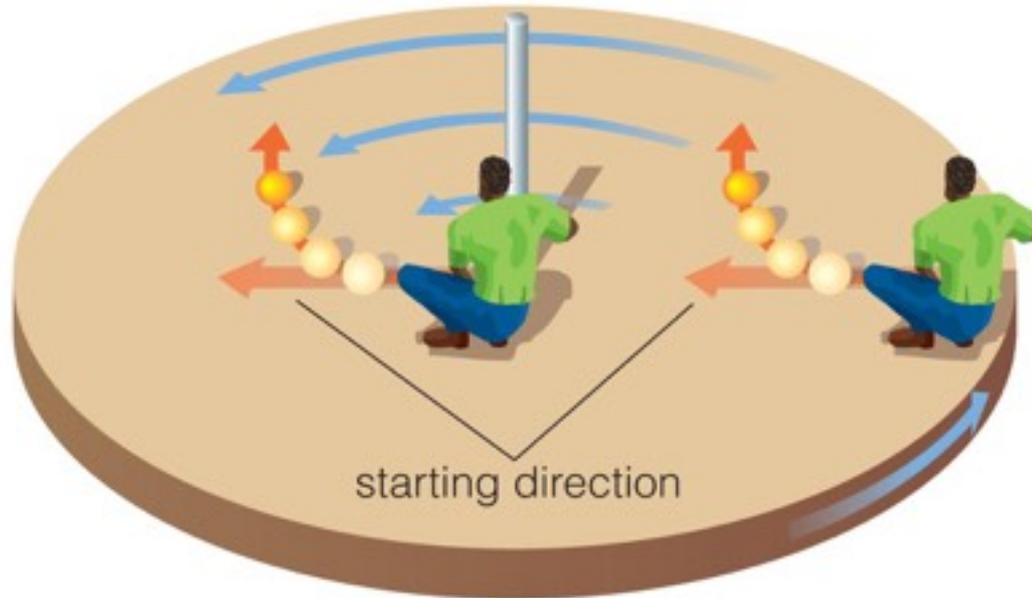
- Heated air rises at equator.
- Cooler air descends at poles.
- Without rotation, these motions would produce two large circulation cells.

Circulation Cells with Rotation



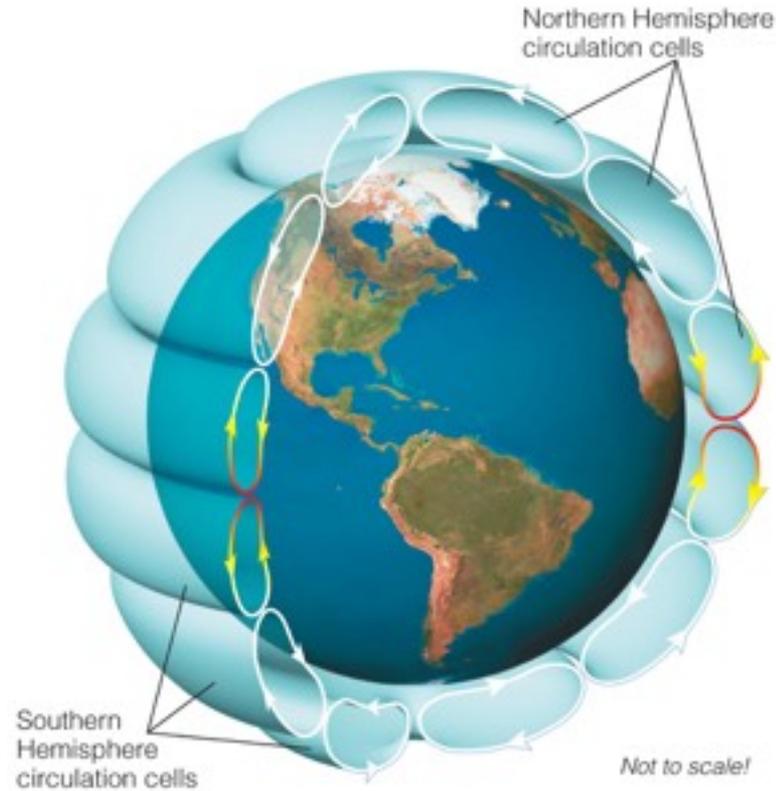
- Coriolis effect deflects north-south winds into east-west winds.
- Deflection breaks each of the two large "no-rotation" cells into three smaller cells in each hemisphere.
 - Tropical
 - Mid-latitude
 - Polar

Coriolis Effect



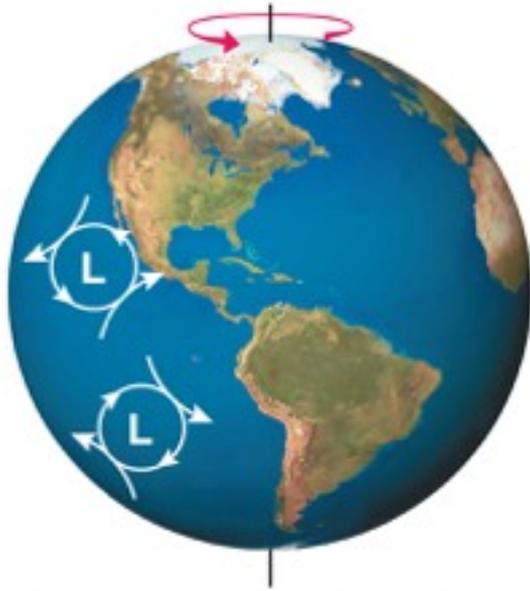
- Conservation of angular momentum causes a ball's apparent path on a spinning platform to change direction.

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.

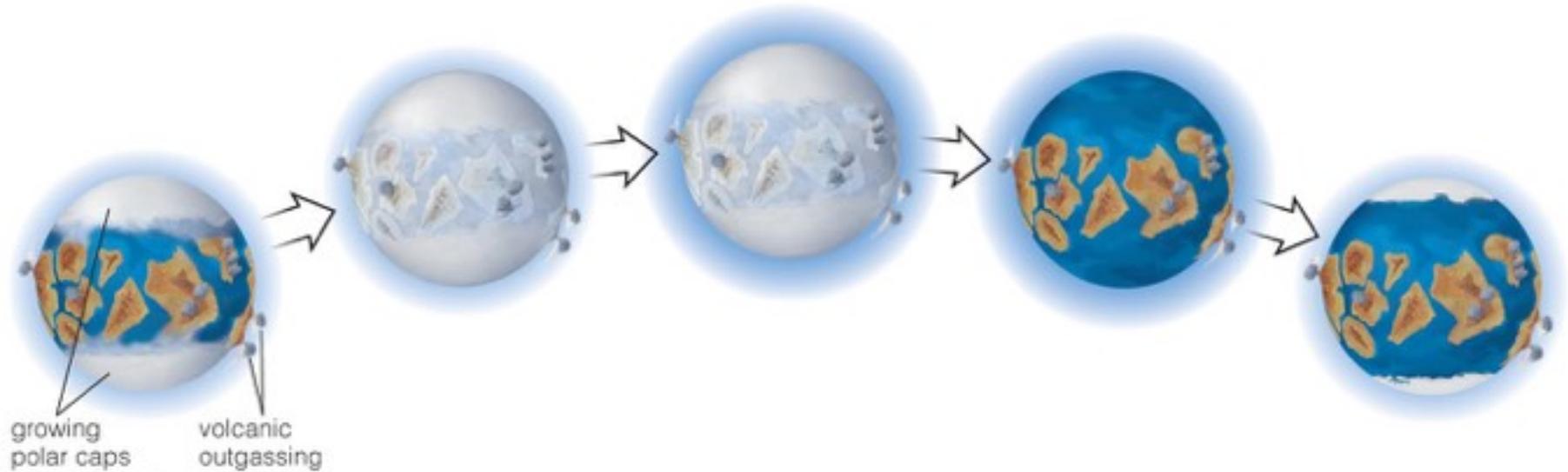
Coriolis Effect on Earth

- 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.

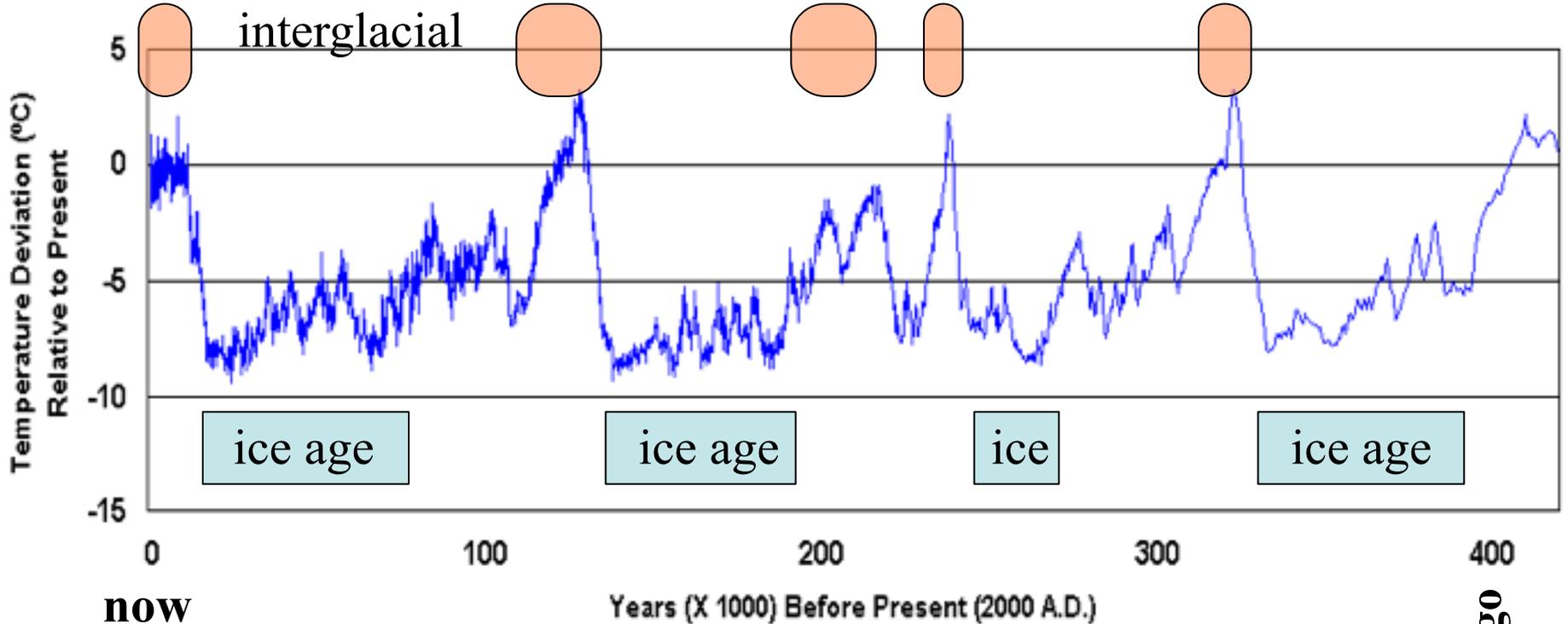
Long-Term Climate Change



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

Temperature of Lower Atmosphere Last 400,000 Years

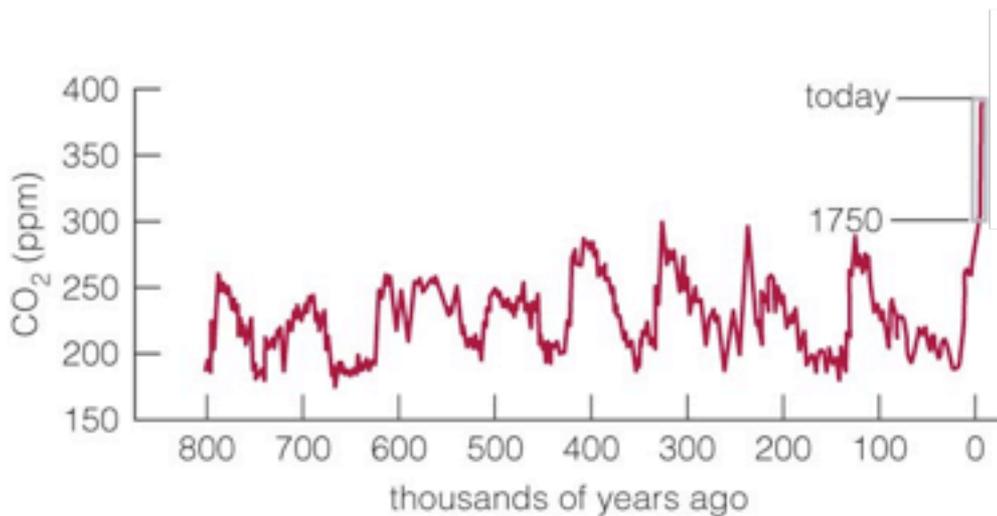
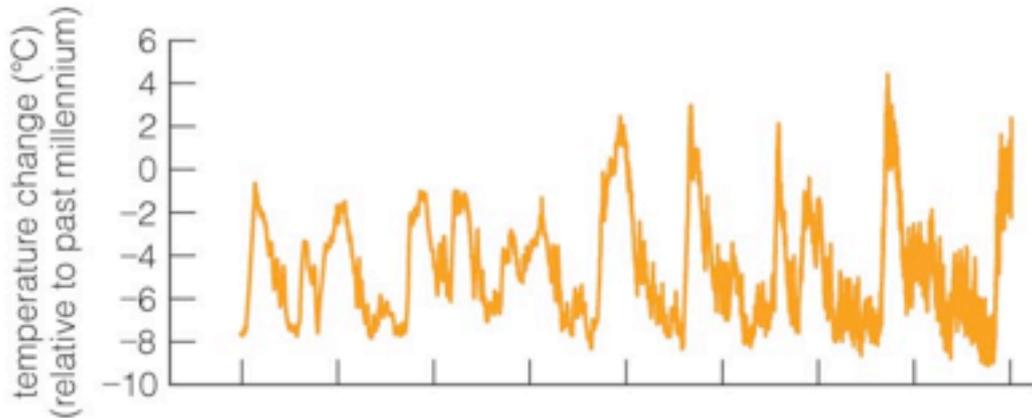
From Antarctica ice and air data



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.

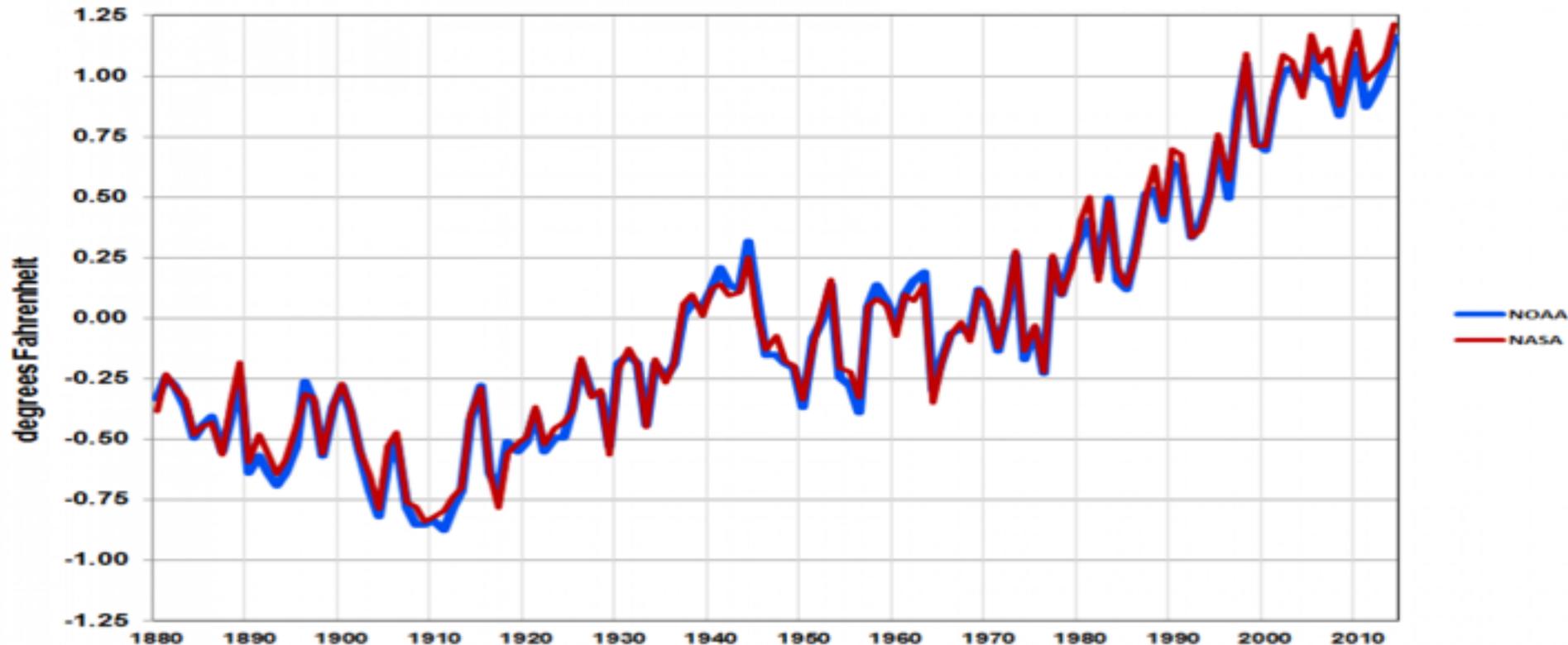
The anthropogenic greenhouse effect (Global Warming and human activity)

What is real information?

What is misleading?

Should we be worried?

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



2014

- Did we have a colder than average winter?

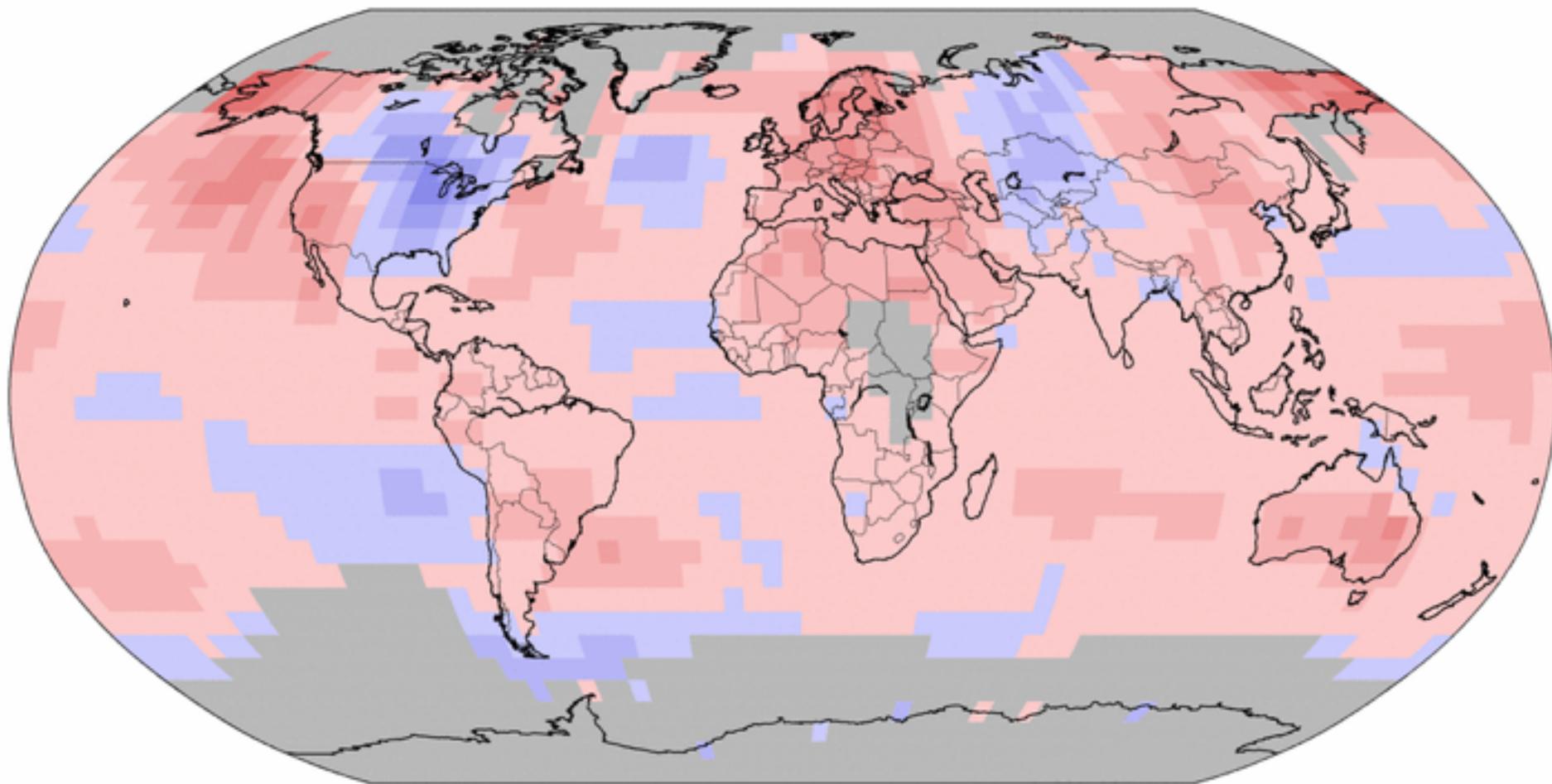
Yes - winter in Ohio was colder than average.

- 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)

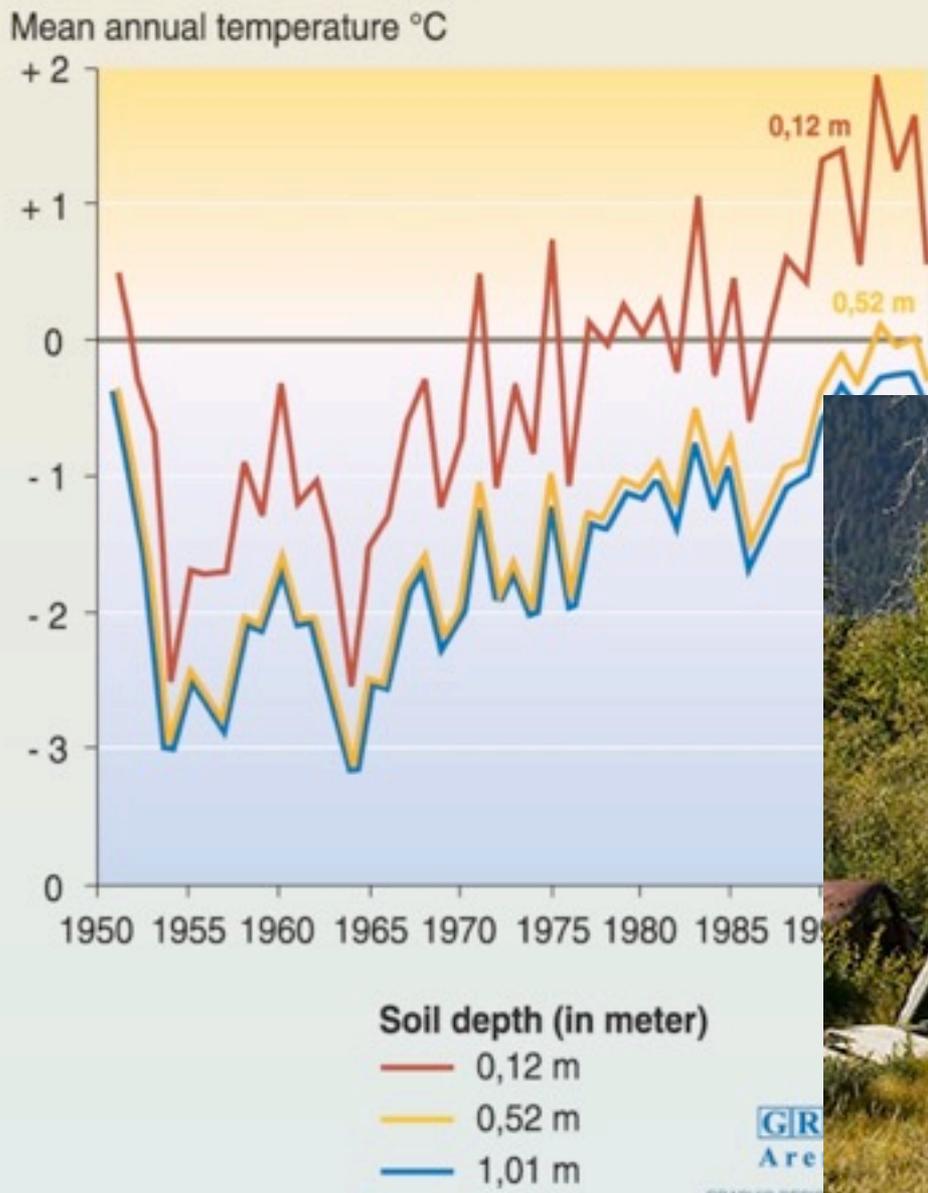
Data Source: GHCN–M version 3.2.2 & ERSST version 3b



Evidence of global warming

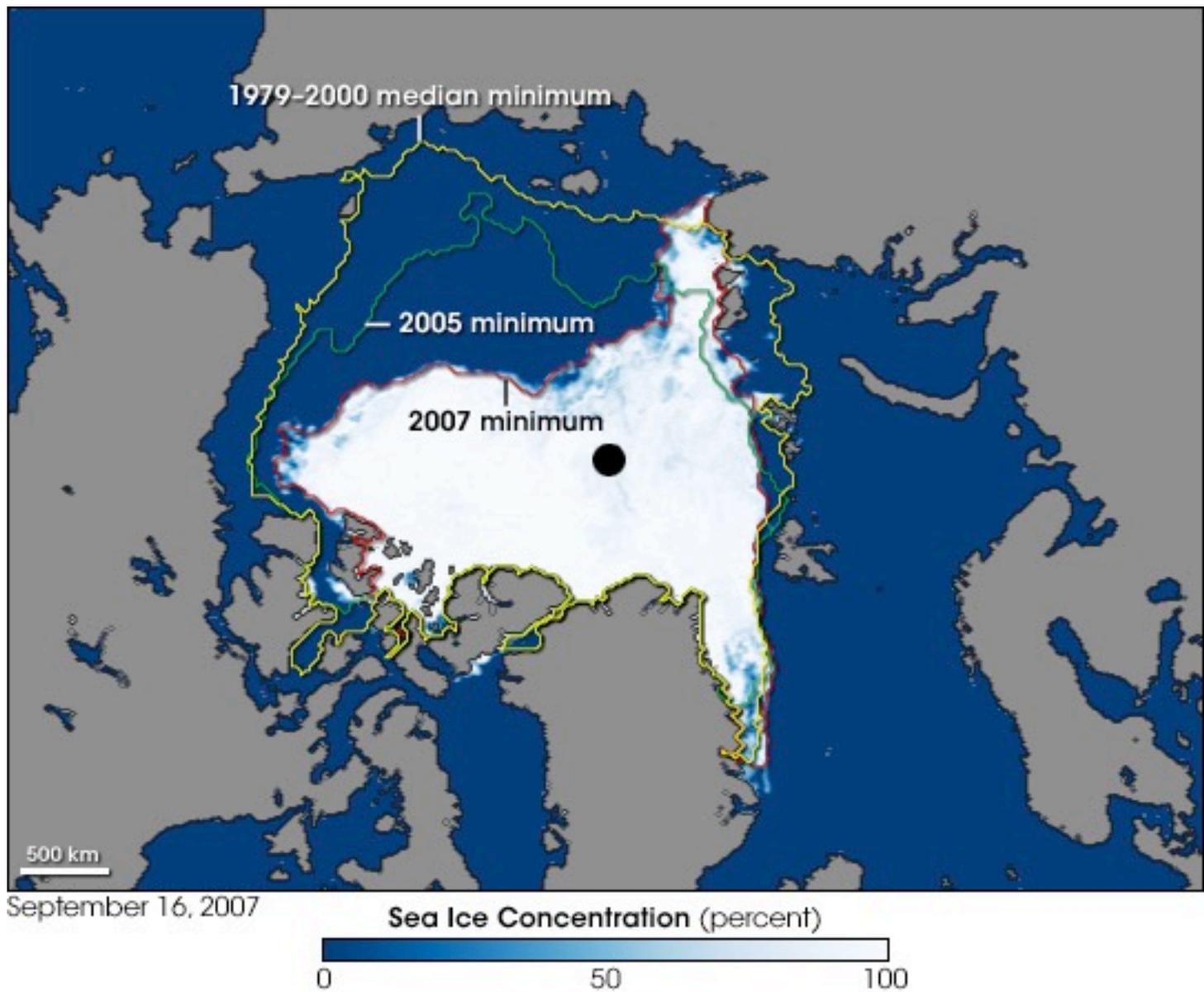
- Increase in greenhouse gas concentrations
- Surface temperature measurements
- Ocean temperature measurements
- Sea level rise (water expands as it warms)
- Melting arctic icecap; retreating glaciers
- Poleward migration of species
- More extreme weather events
 - both warm & cold; hurricanes; snowmageddon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

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

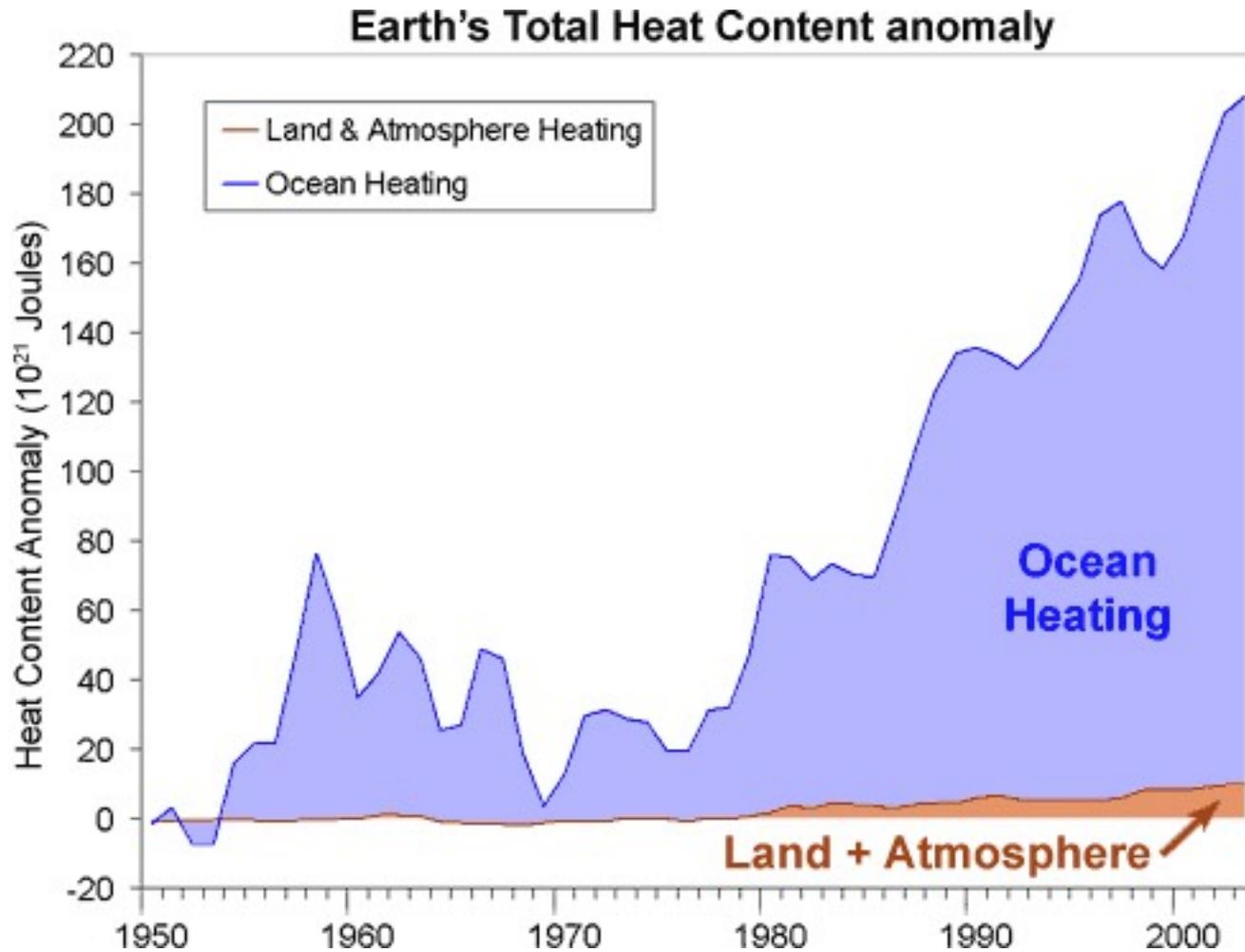


Arctic permafrost is melting





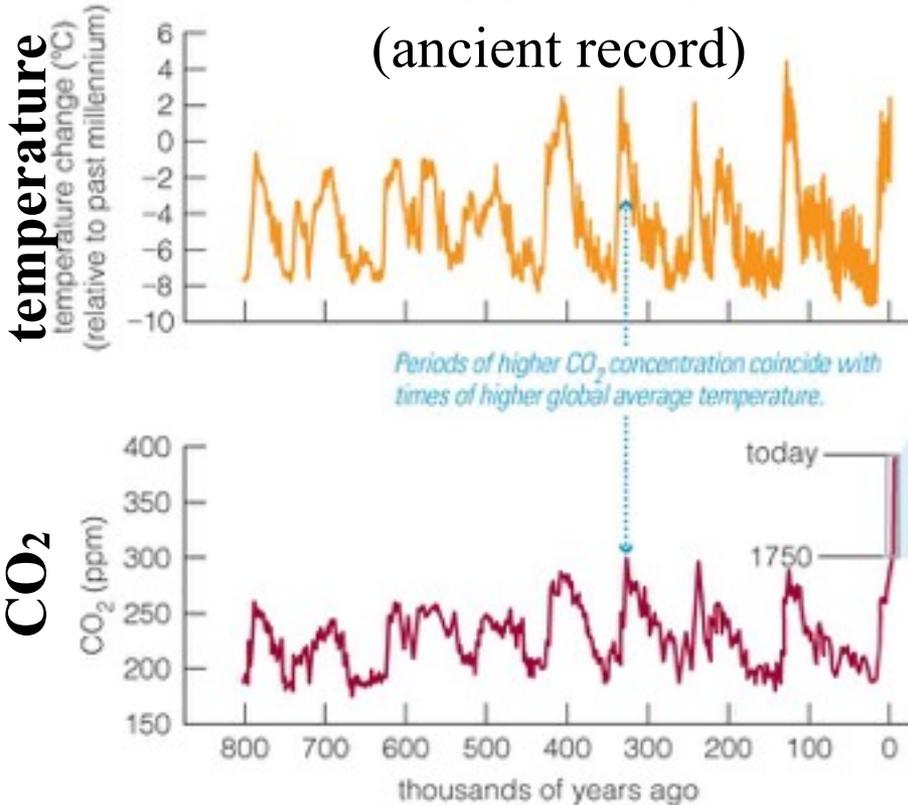
Fabled Northwest passage opened for first time in history in 2007



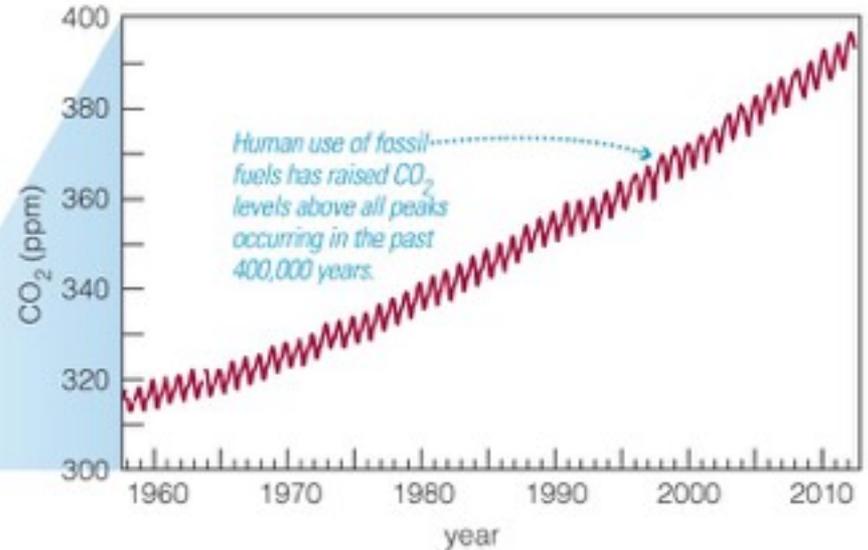
The Earth's climate is out of equilibrium - heat is accumulating in the ocean faster than it is being radiated into space.

CO₂ Concentration

Ice core data
(ancient record)



Mauna Loa Observatory
(modern record)

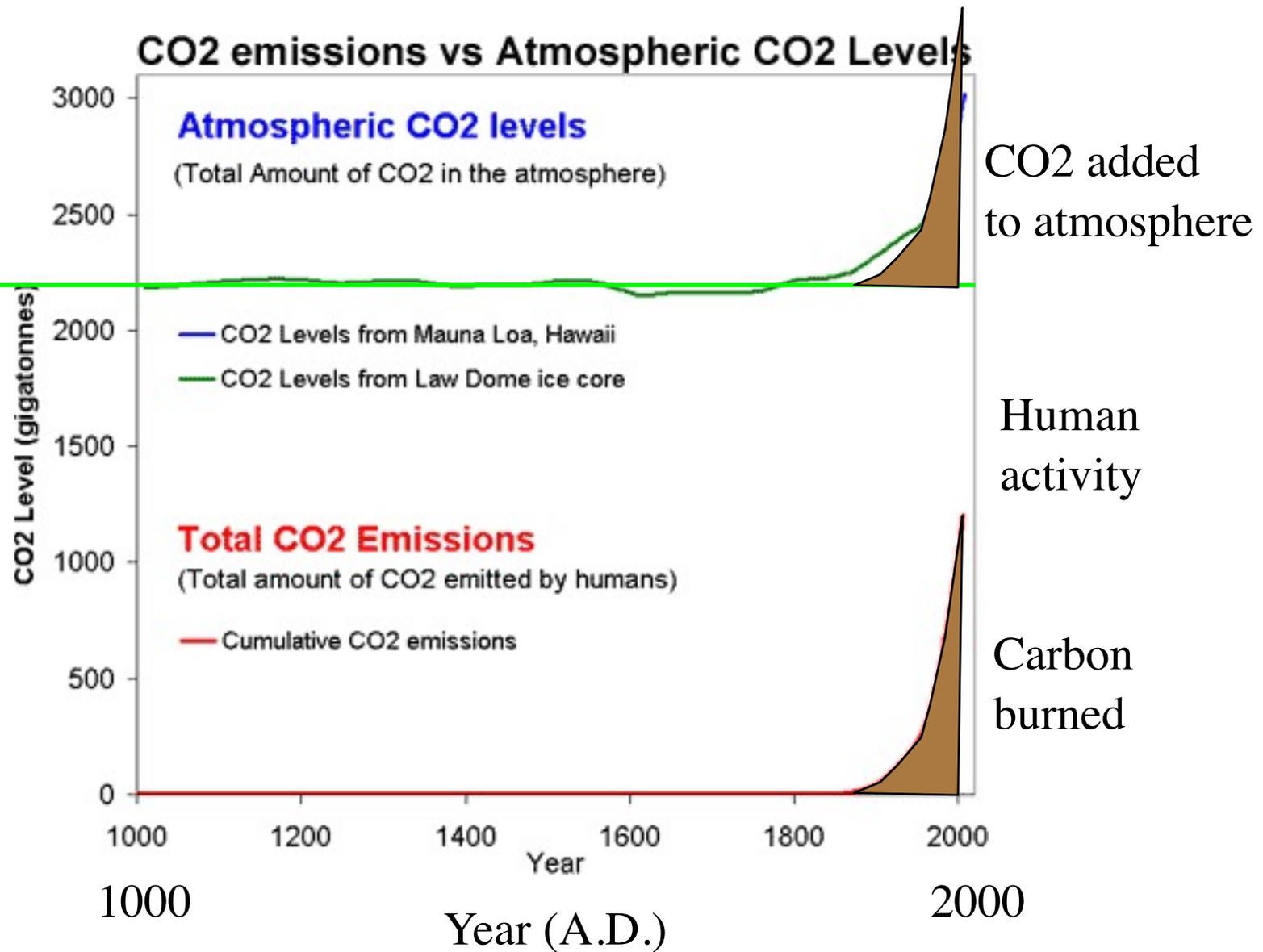


time
(years)

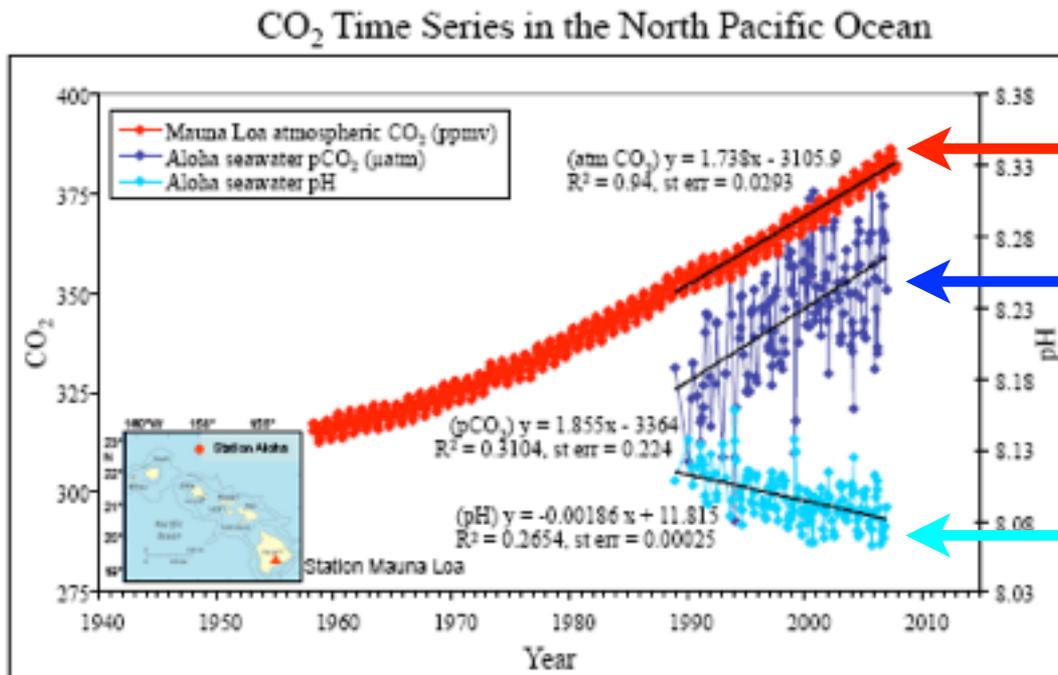
- Most of the CO₂ increase has happened in last 50 years

Pre-industrial CO₂ concentration: 280 ppm. Current level: 400 ppm

Pre-industrial
CO₂ level



- 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



Atmospheric CO₂

Concentration of dissolved CO₂ in seawater

Ocean pH

Basic facts

(non-partisan)

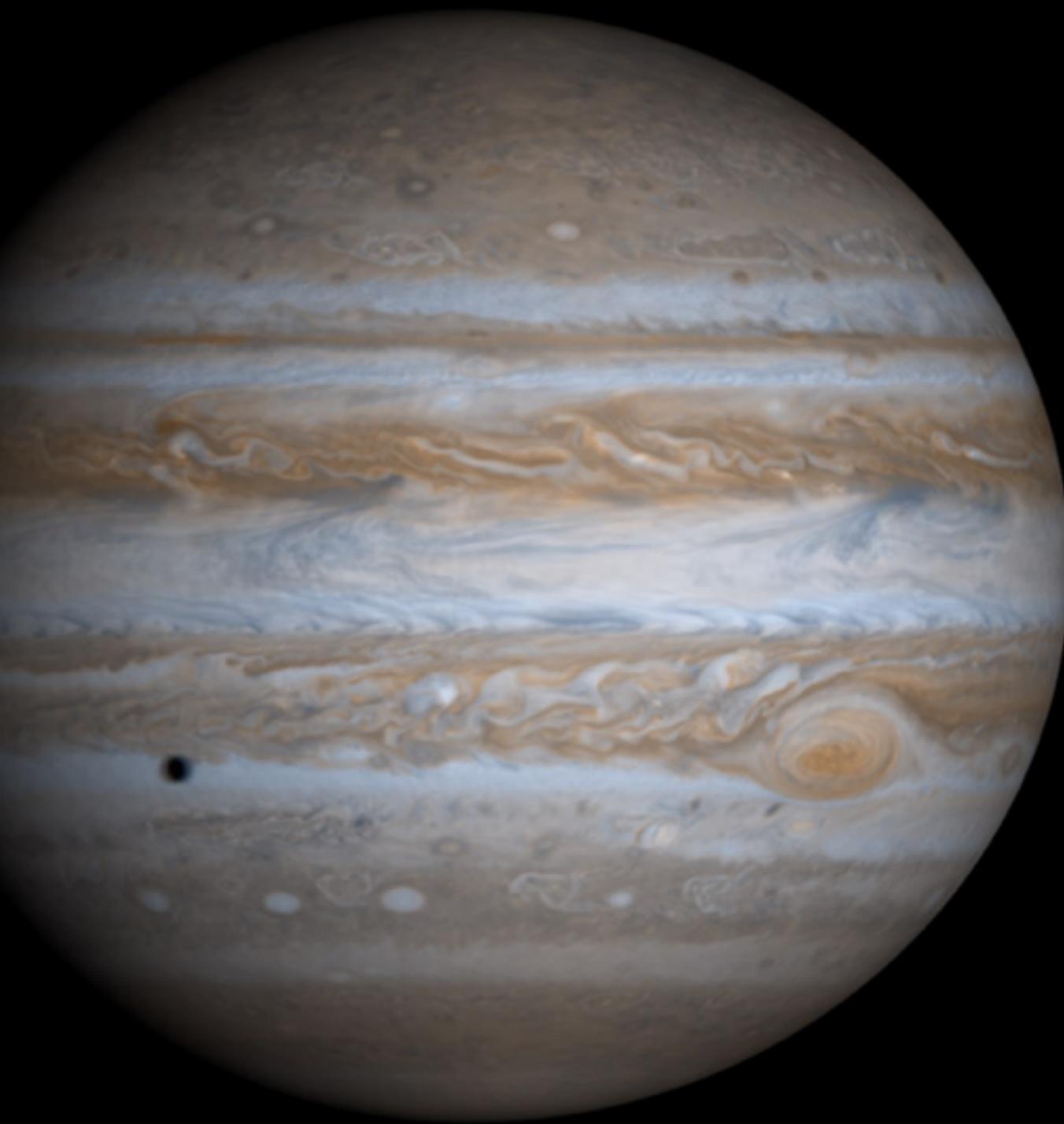
- The globe is warming (measured)
- The concentration of CO₂ in the atmosphere is increasing (measured)
- The measured increase is roughly equal to the amount of fossil fuel we've burned (measured)
- Climate change is the expected result of adding greenhouse gases to the atmosphere (cf. Venus, Mars)

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, floods, hurricanes...
- Ocean levels rise
 - 8” since 1880 (measured)
 - 3’ forecast by 2100 - mostly thermal expansion *adios, Miami*
- Drought
 - California, southwest dry out (more)
 - due to enhanced evaporation, smaller snowpack

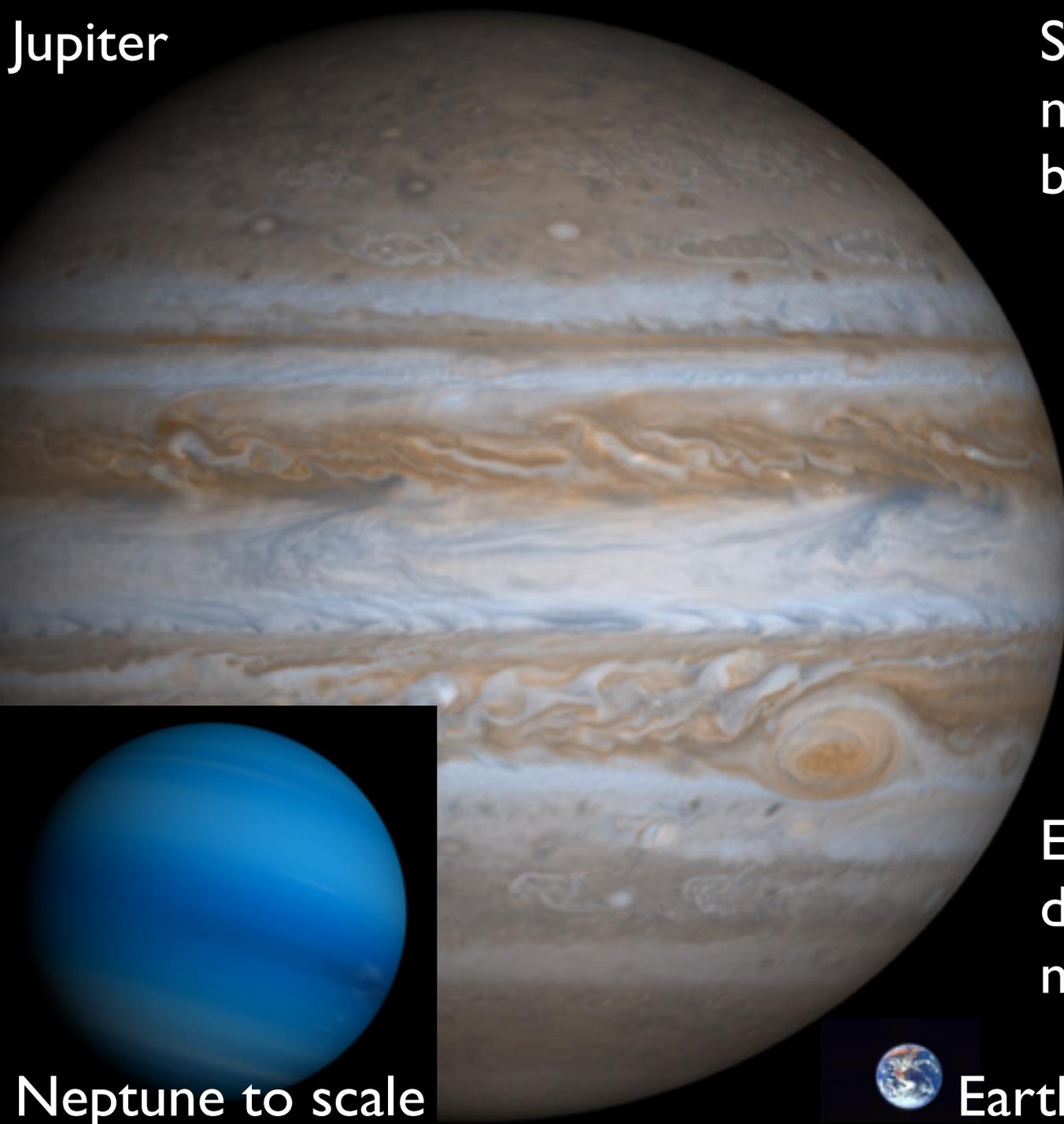
Policy implications

- 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 & the climate we depend on.
- There is finite energy available in non-renewable resources like coal, oil, natural gas...
 - Are we *NOT* going to use these resources?



- Jovian planets

Jupiter



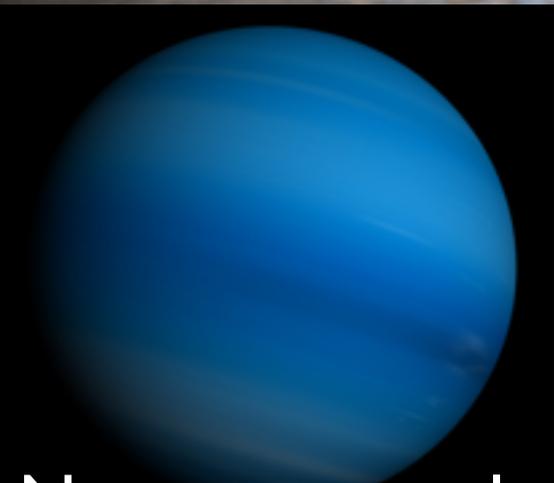
Some astronomers
now distinguish
between

Gas Giants
Jupiter, Saturn

and

Ice Giants
Uranus, Neptune

Expect more
distinctions with
new discoveries

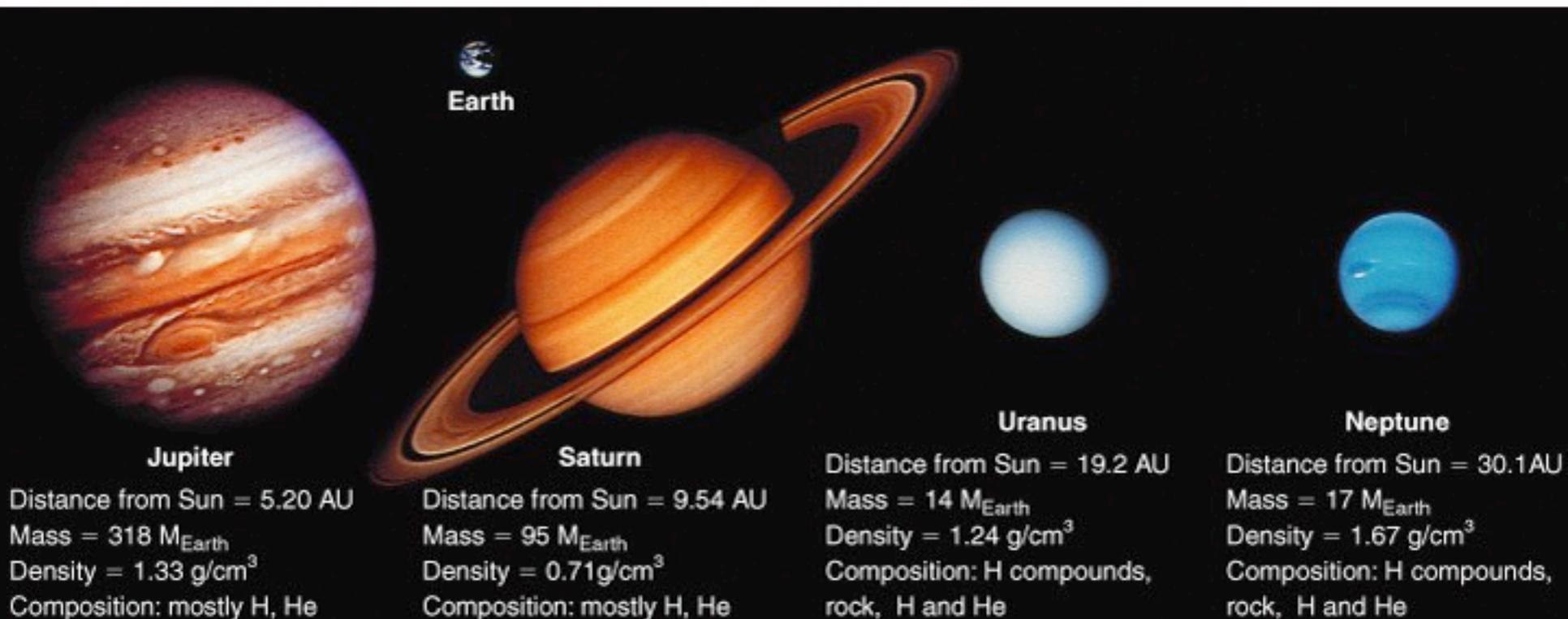


Neptune to scale

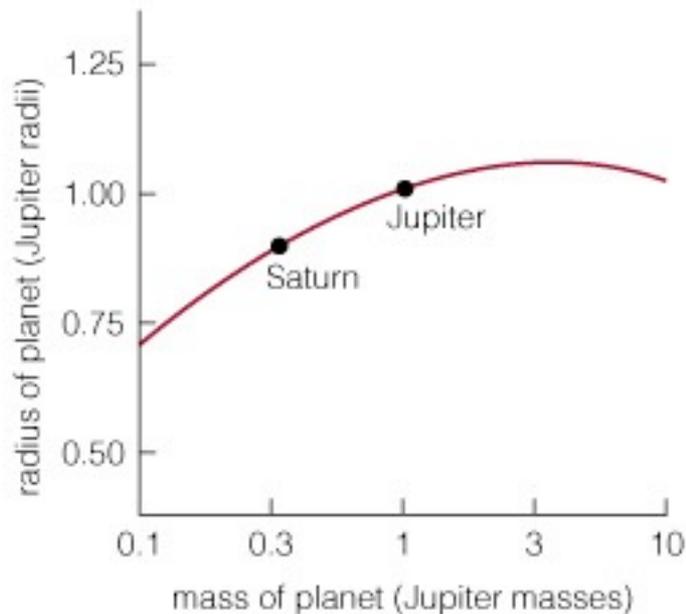


Earth to scale

The Jovian planets are
gas giants -
much larger than Earth in
size and mass, but lower density



Sizes of Jovian Planets



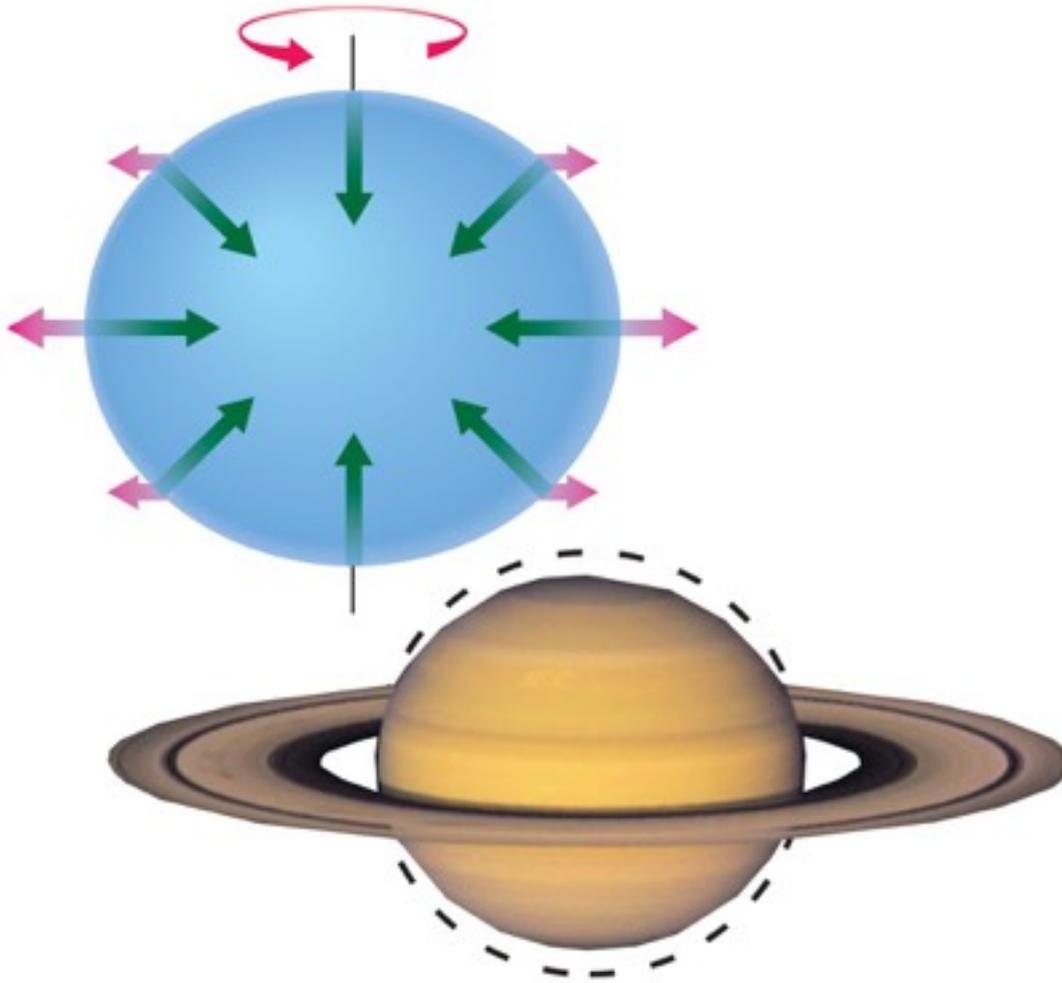
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- Planets get larger as they get more massive
- up to a point...
- Planets more massive than Jupiter are expected to *shrink*.
- There comes a point where gravity wins: adding more mass causes *contraction*.

Jovian Planet Composition

- Jupiter and Saturn
 - Mostly H and He gas
 - *these are the most common elements in the Universe*
 - “Gas Giants”
- Uranus and Neptune
 - Mostly hydrogen compounds: water (H₂O), methane (CH₄), ammonia (NH₃)
 - Some H, He, and rock
 - “Ice Giants”

Rotation and Shape



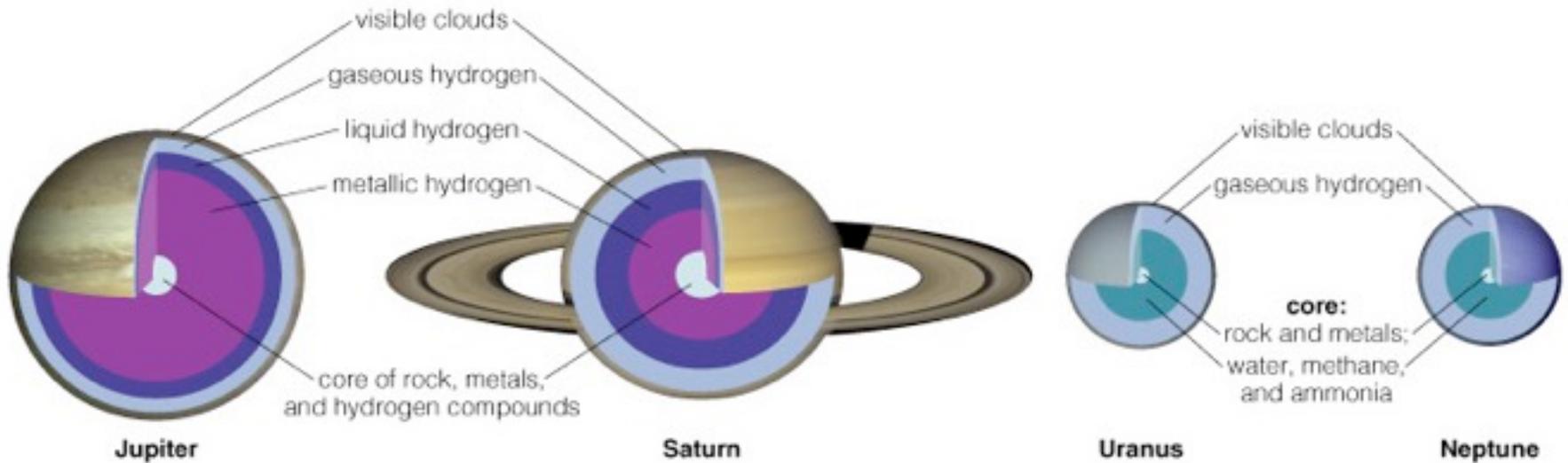
- Jovian planets are not quite spherical because of their rapid rotation.

- “Oblate”

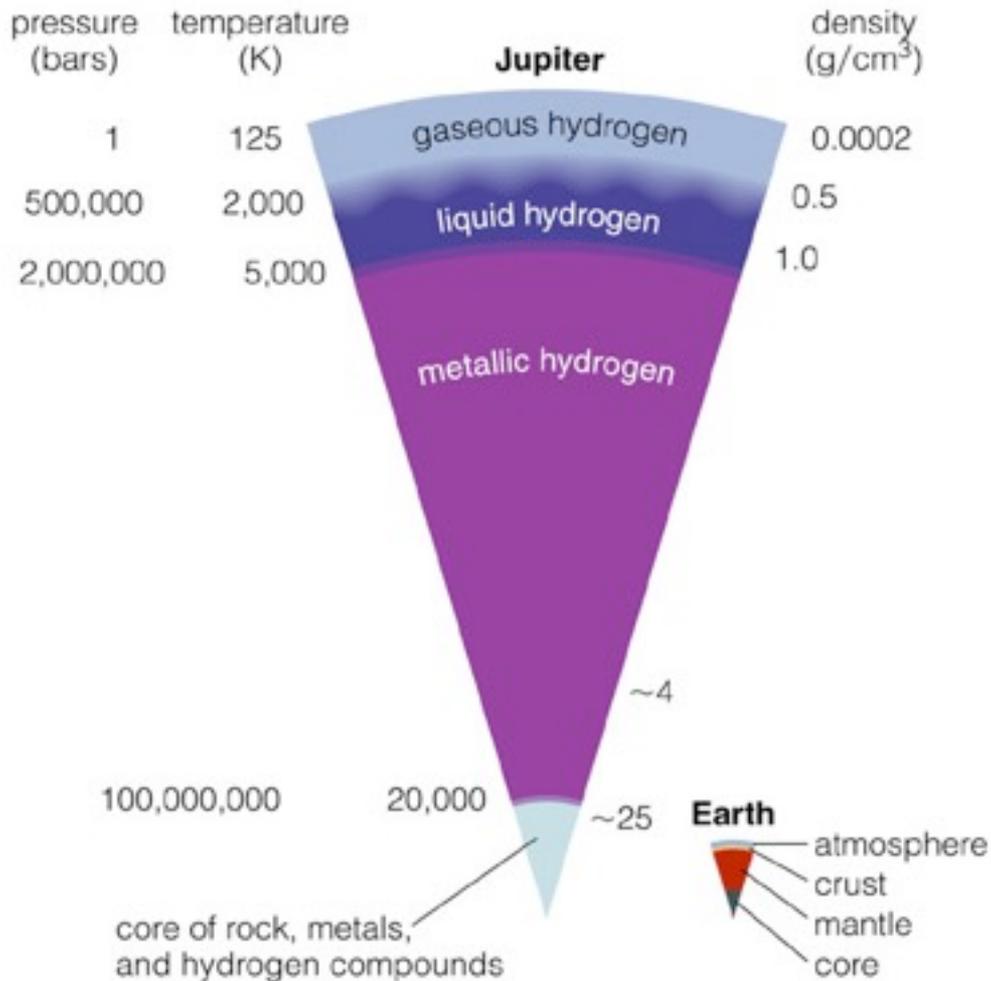
Interactive Figure 

show Jovian Planet shapes

Interiors of Jovian Planets

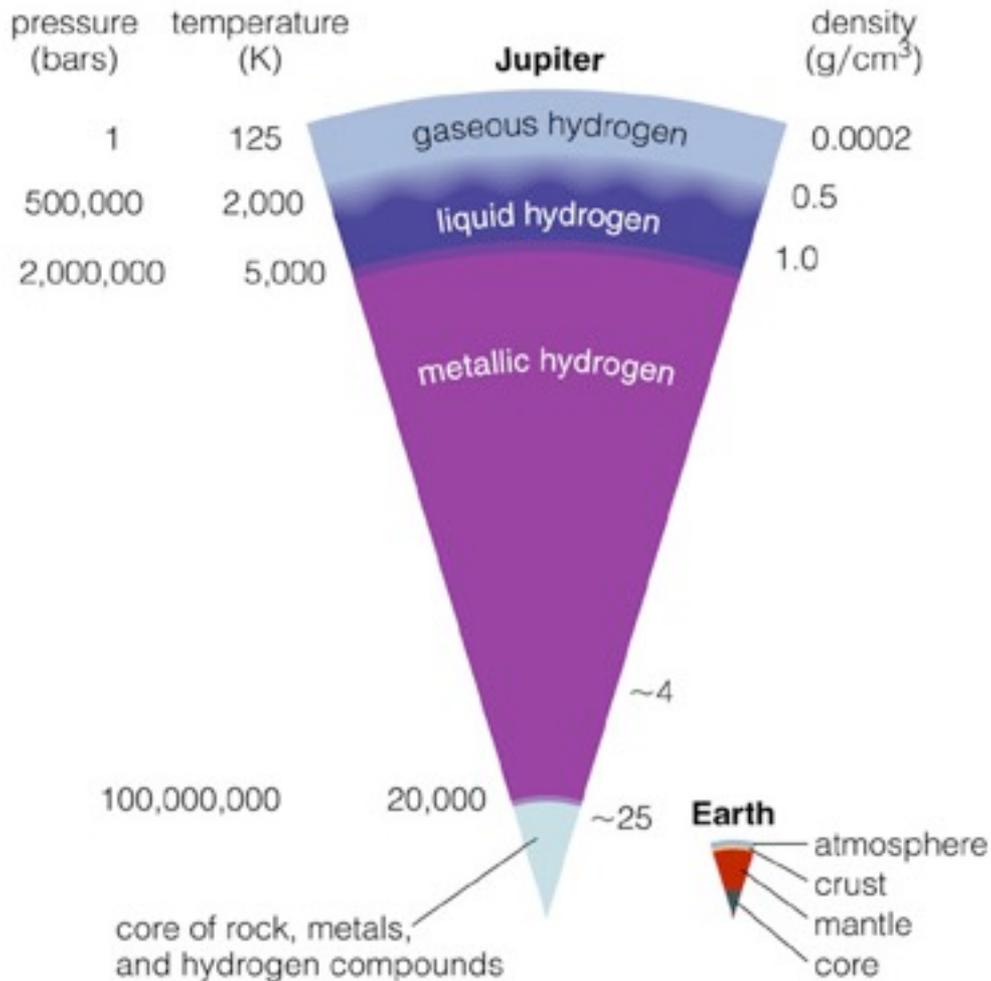


Inside Jupiter



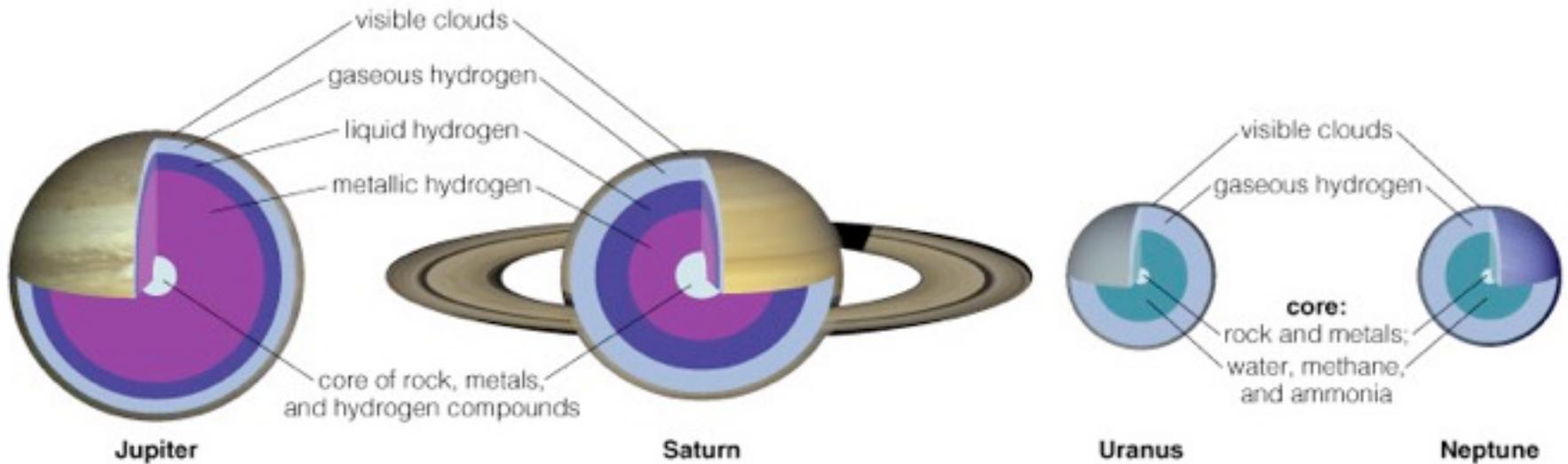
- High pressure inside of Jupiter causes the phase of hydrogen to change with depth.
- Hydrogen acts like a metal at great depths because its electrons move freely.

Inside Jupiter



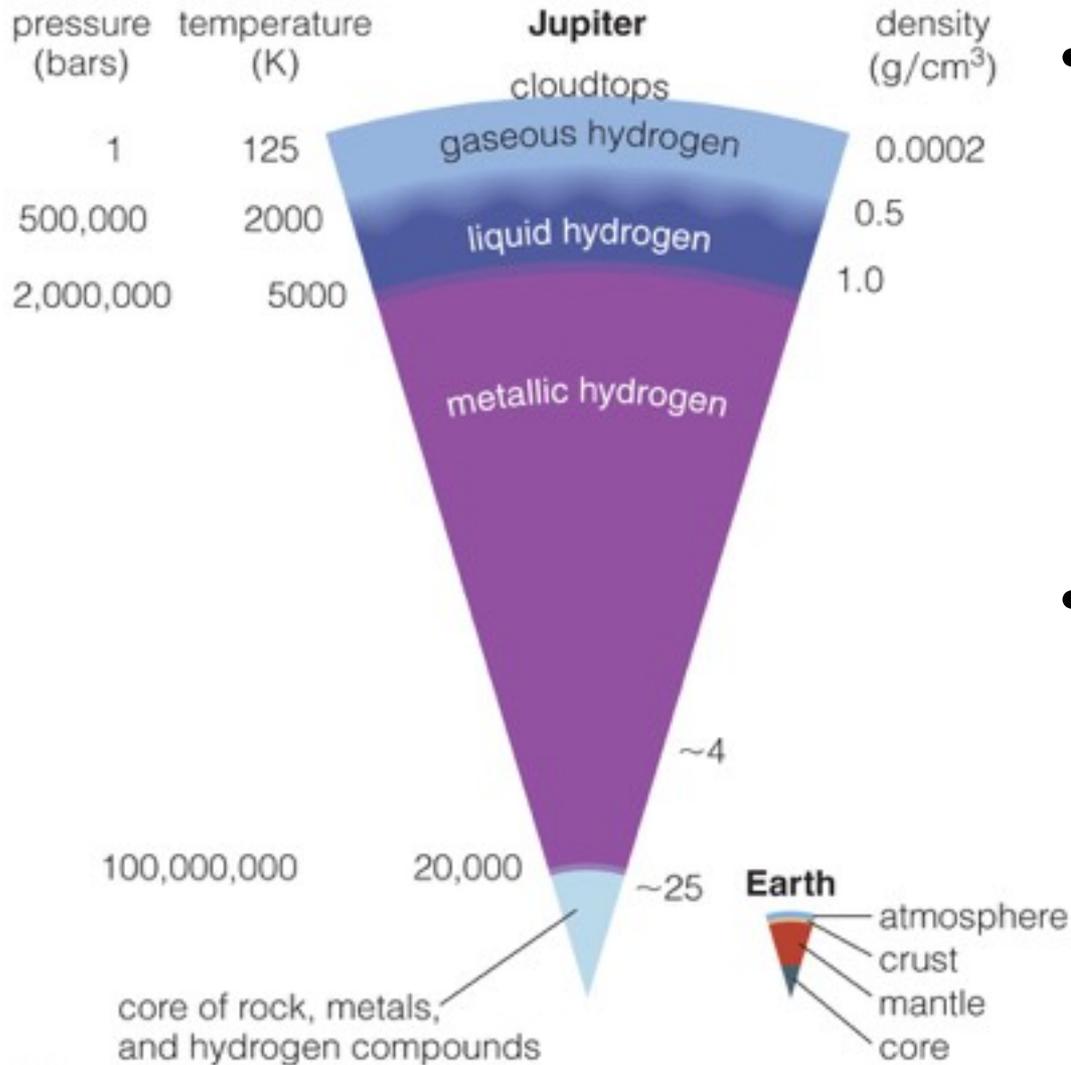
- The core is thought to be made of rock, metals, and hydrogen compounds.
- The core is about the same size as Earth but 10 times as massive.

Comparing Jovian Interiors



- Models suggest that cores of jovian planets have similar composition.
- Lower pressures inside Uranus and Neptune mean no metallic hydrogen.

Jupiter's Internal Heat



- Jupiter radiates twice as much energy as it receives from the Sun.
- Energy comes from the gradual gravitational contraction of the interior (releasing potential energy).

Internal Heat of Other Planets

- **Saturn** also radiates twice as much energy as it receives from the Sun.
 - Energy probably comes from differentiation (helium rain).
- **Neptune** emits nearly twice as much energy as it receives
 - also driven by gravitational contraction, but precise mechanism unclear.
- **Uranus** does not radiate more than it receives.
 - no notable internal heat source
 - lower mass & lower density than Neptune