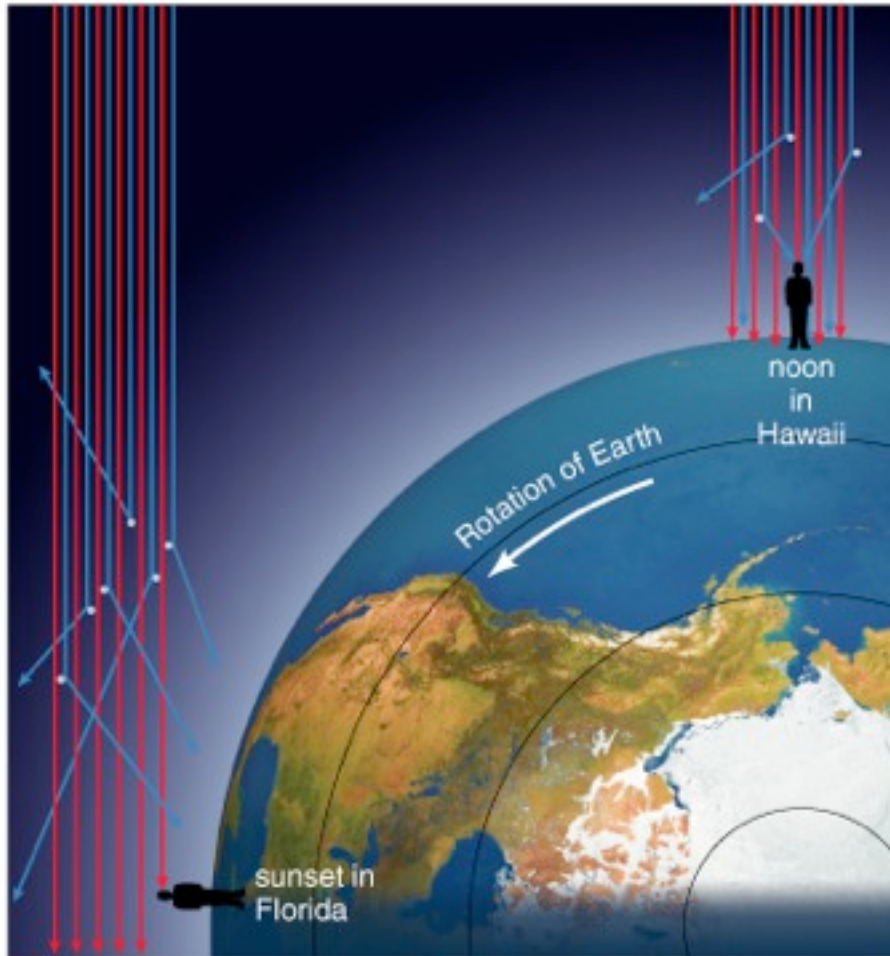


Today

- Terrestrial Planets
 - Earth, Venus, Mars
- Atmospheres
- Climate
 - Greenhouse effect from planetary perspective
- Factors affecting atmospheres

EXAM NEXT TIME

Why the sky is blue

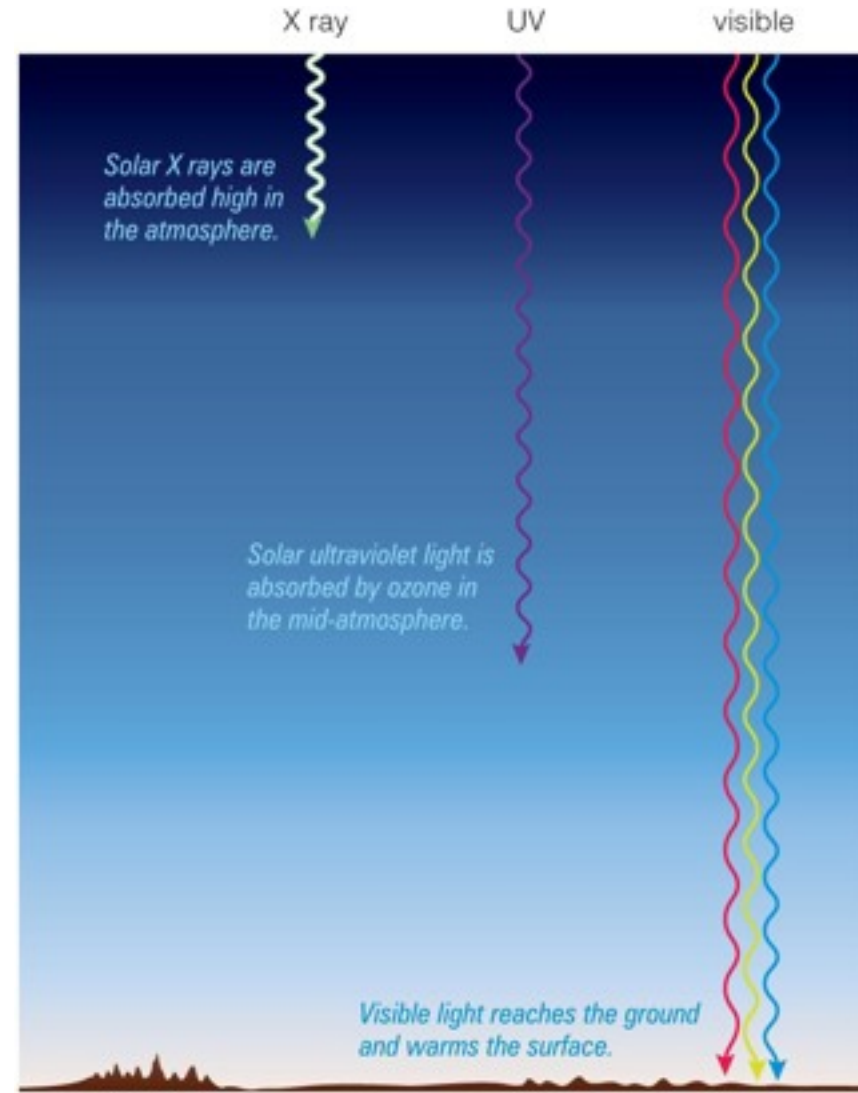


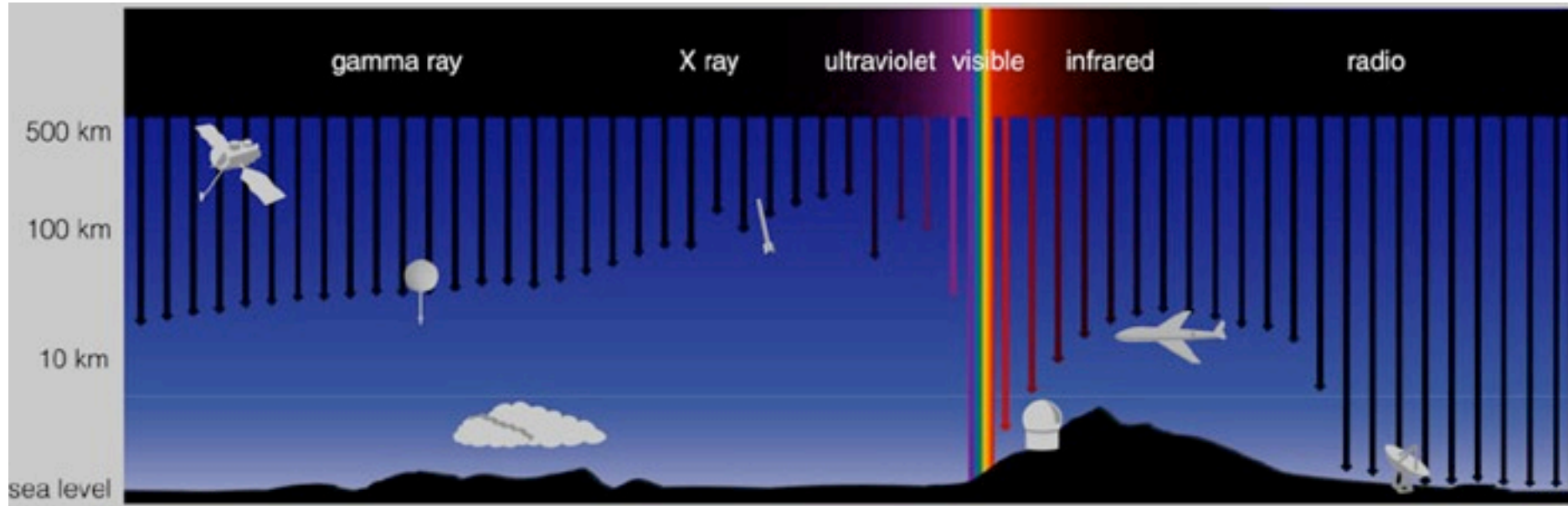
- Atmosphere scatters blue light from the Sun, making it appear to come from different directions.
- Sunsets are red because less of the red light from the Sun is scattered.

Radiation Protection

- All X-ray light is absorbed very high in the atmosphere.
- Ultraviolet light is absorbed by ozone (O_3).

There is no hard “line” -
really exponential attenuation





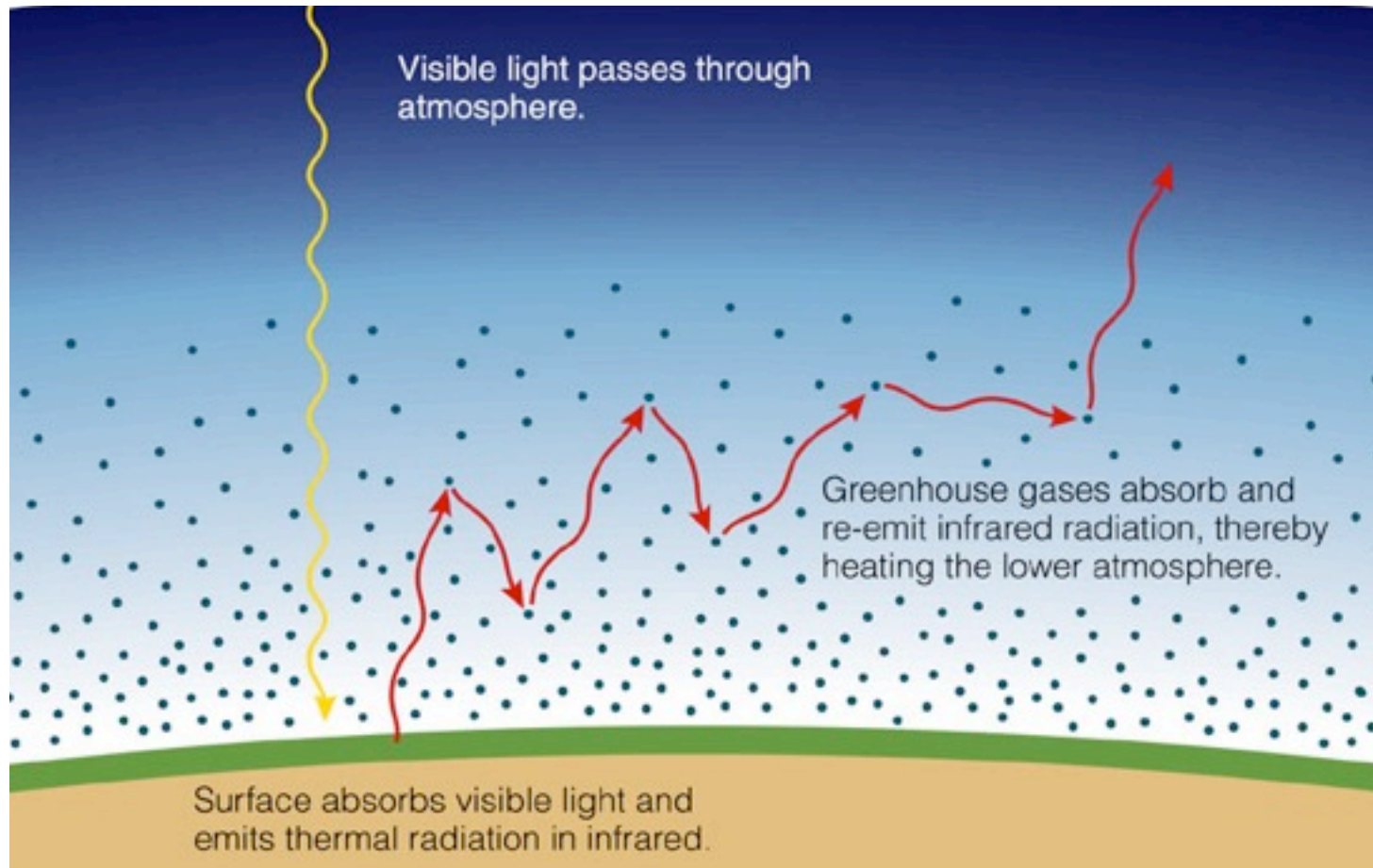
Earth's atmosphere absorbs light at most wavelengths.

The air looks clear to optical light & radio waves;
looks like a brick to X-rays and like a fog to the infrared.

Planetary climates

- Temperature depends on balance between
- Heat input from sun
 - distance dependent
- Heat loss to space
 - atmosphere dependent (natural greenhouse effect)
 - transparent gases (N_2 , O_2) irrelevant
 - greenhouse gases (e.g., H_2O , CO_2) important even if only a small part of the atmosphere

The Greenhouse Effect



Greenhouse Gas

- Any gas that absorbs infrared
- Greenhouse gas: molecules with two different types of elements (CO_2 , H_2O , CH_4)
- Not a greenhouse gas: molecules with one or two atoms of the same element (O_2 , N_2)
 - Though oxygen and nitrogen compose the bulk of the atmosphere, they do not absorb in the infrared so don't contribute to the greenhouse effect

Main greenhouse gases

(on the Earth)

– all are $< 2\%$ of atmosphere, but provide

- Water (H_2O) $\sim 60\%$ of infrared opacity
- Carbon dioxide (CO_2) $\sim 22\%$
- Methane (CH_4) $\sim 7\%$
- Others (ozone, CFCs, nitrous oxide) $\sim 11\%$

Note: water vapor absorbs more IR than CO_2 !

Greenhouse Effect: Bad?

The Earth is much warmer than it would be without an atmosphere because of the greenhouse effect. That's good!

(cf. the moon)

...the same can be said for Venus,
only more so...



Earth's Moon



Why is Venus so hot?

The greenhouse effect on Venus keeps its surface temperature at 470°C (878°F). That's higher than Mercury, even though it is farther from the sun.

The difference is the greenhouse effect.

Why is the greenhouse effect on Venus so much stronger than on Earth?



Atmosphere of Venus



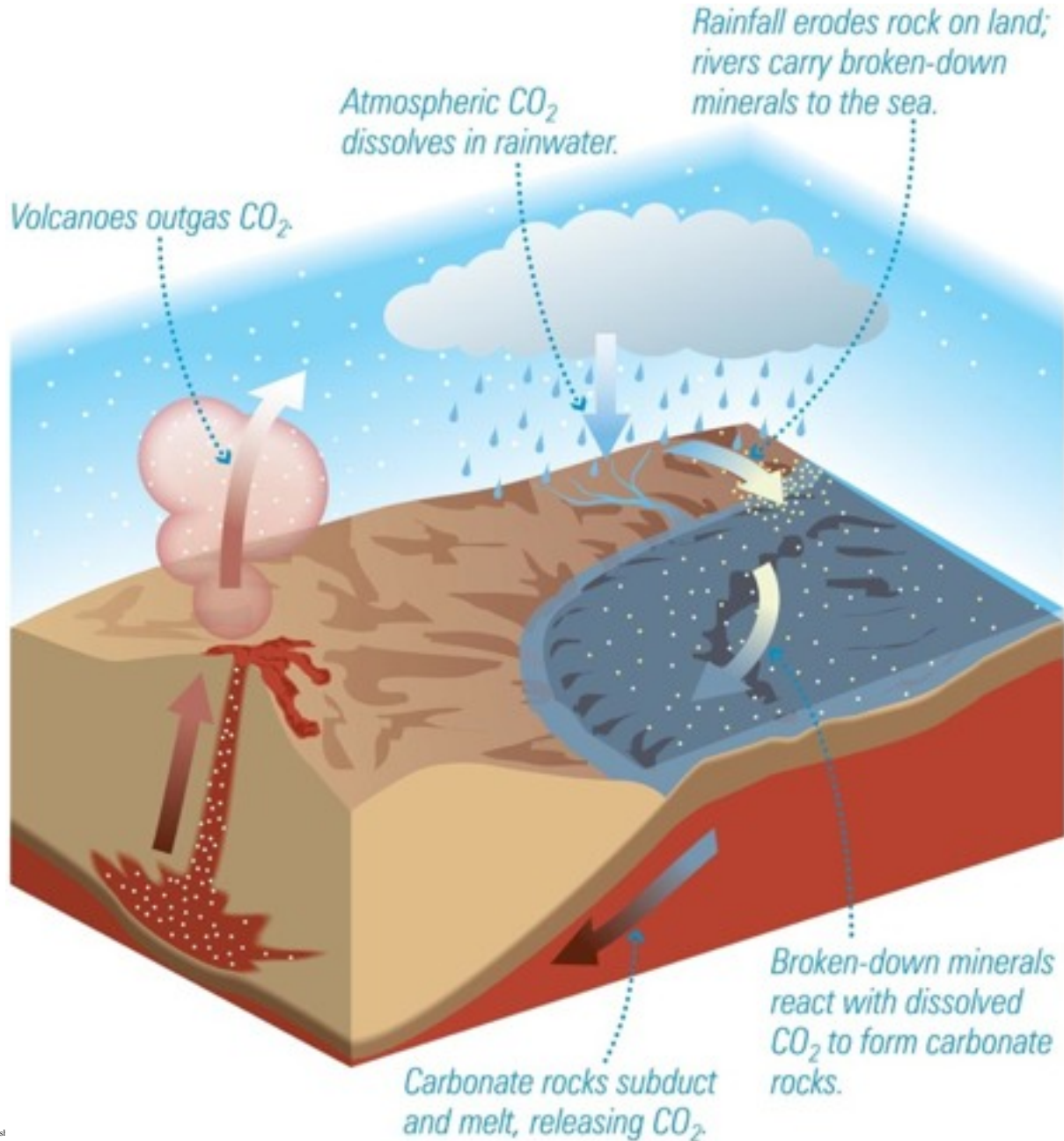
- Venus has a very thick carbon dioxide atmosphere with a surface pressure 90 times that of Earth.
- That's equivalent to nearly a kilometer beneath the surface of the ocean.

Greenhouse Effect on Venus

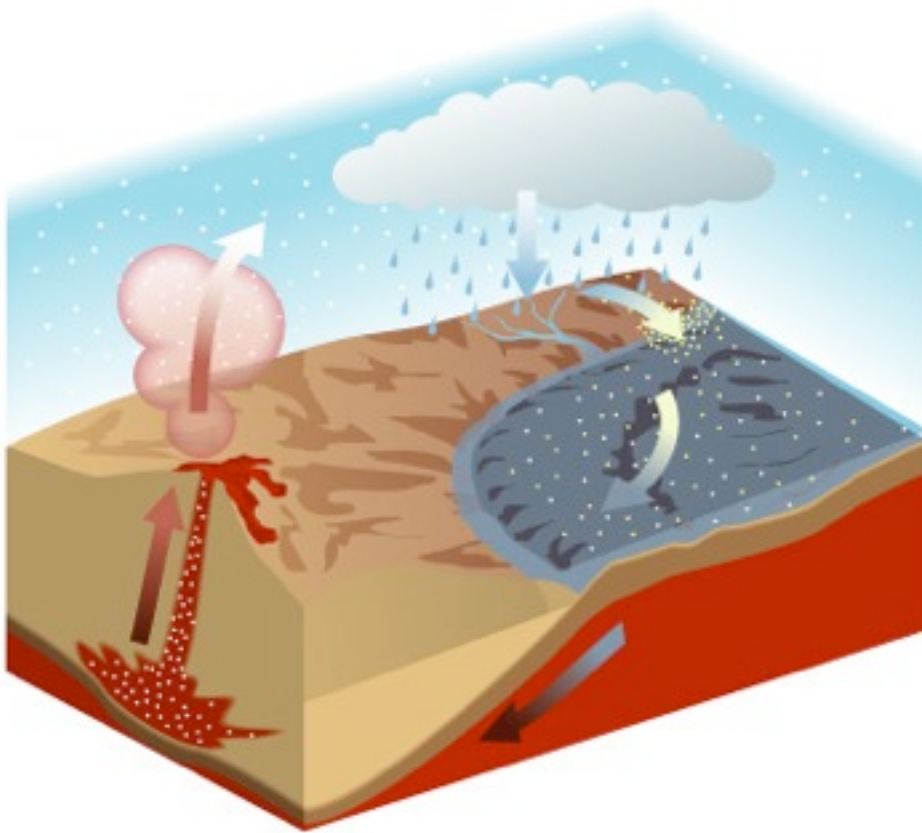


- Thick carbon dioxide atmosphere produces an extremely strong greenhouse effect.
- Earth escapes this fate because most of its carbon and water are in rocks and oceans.

Carbon cycle on Earth

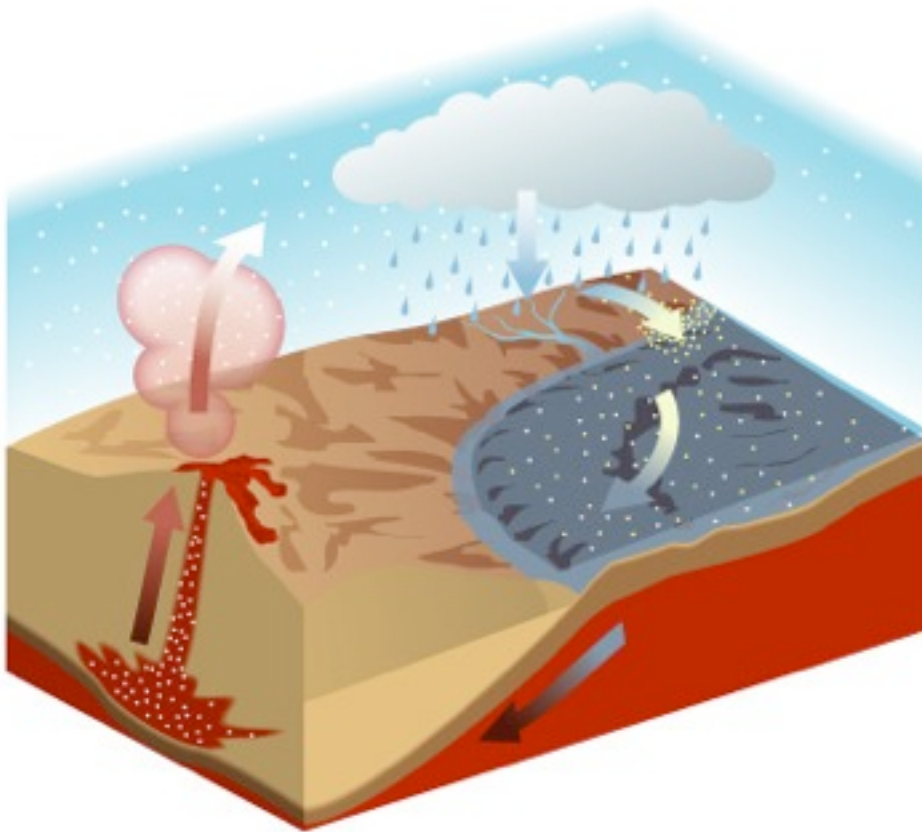


Carbon Dioxide Cycle



1. Atmospheric CO_2 dissolves in rainwater.
2. Rain erodes minerals that flow into the ocean.
3. Minerals combine with carbon to make rocks on ocean floor.

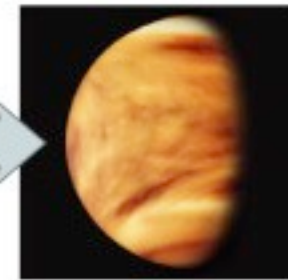
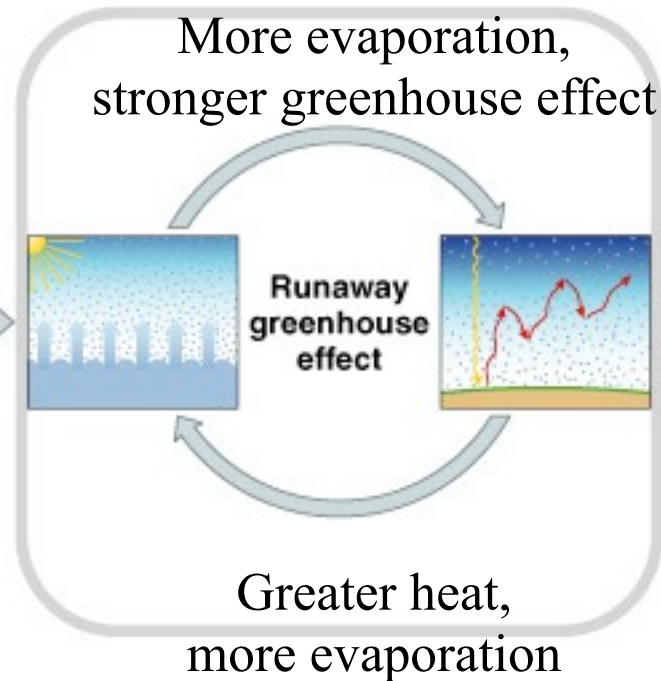
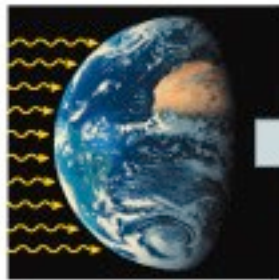
Carbon Dioxide Cycle



4. Subduction carries carbonate rocks down into the mantle.
5. Rock melts in mantle and outgases CO_2 back into atmosphere through volcanoes.

Runaway Greenhouse Effect

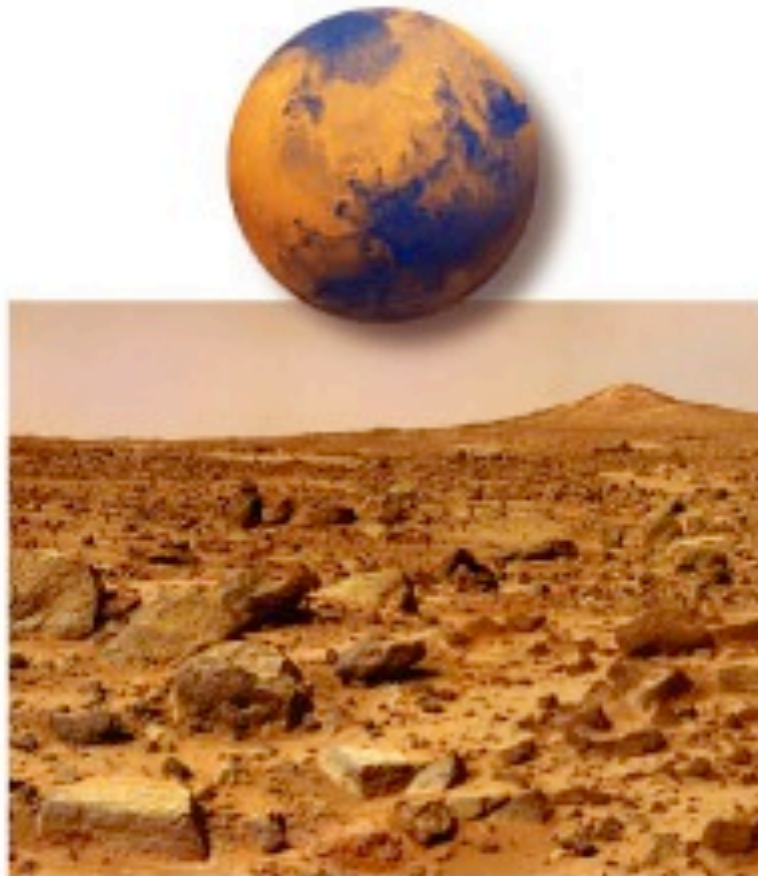
If Earth moved to
Venus's orbit



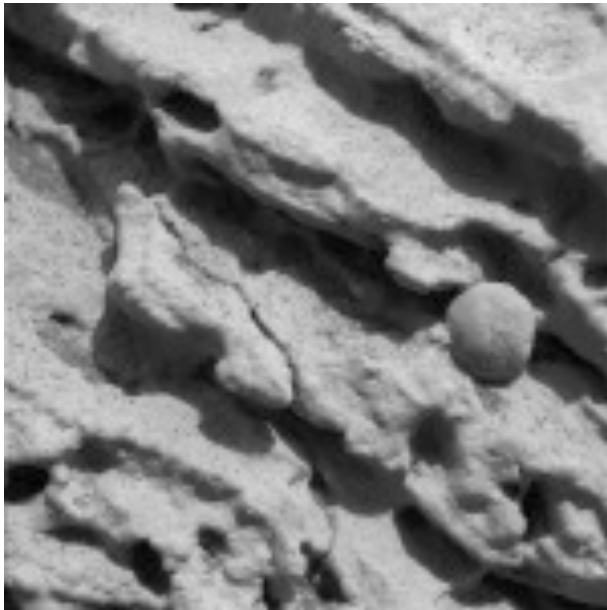
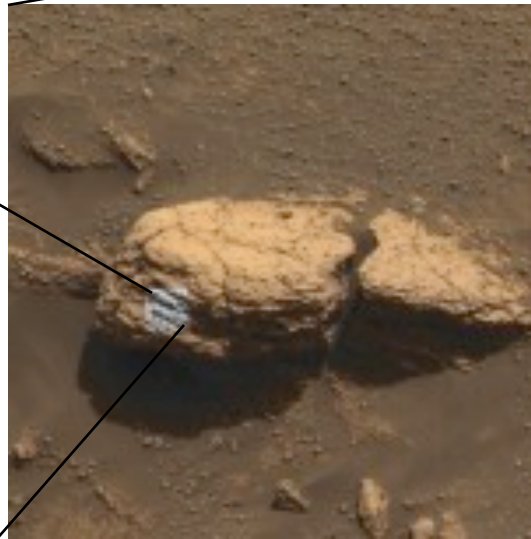
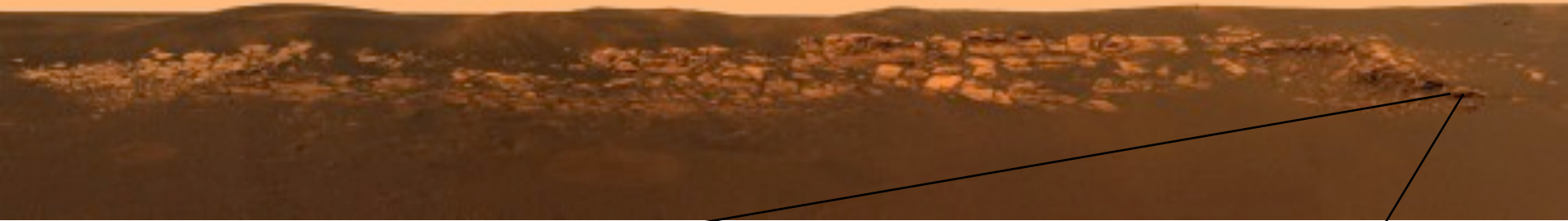
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- Oceans evaporate; no longer absorb CO₂.
 - CO₂ builds up in atmosphere unchecked
 - “runaway greenhouse”

Mars: the opposite extreme

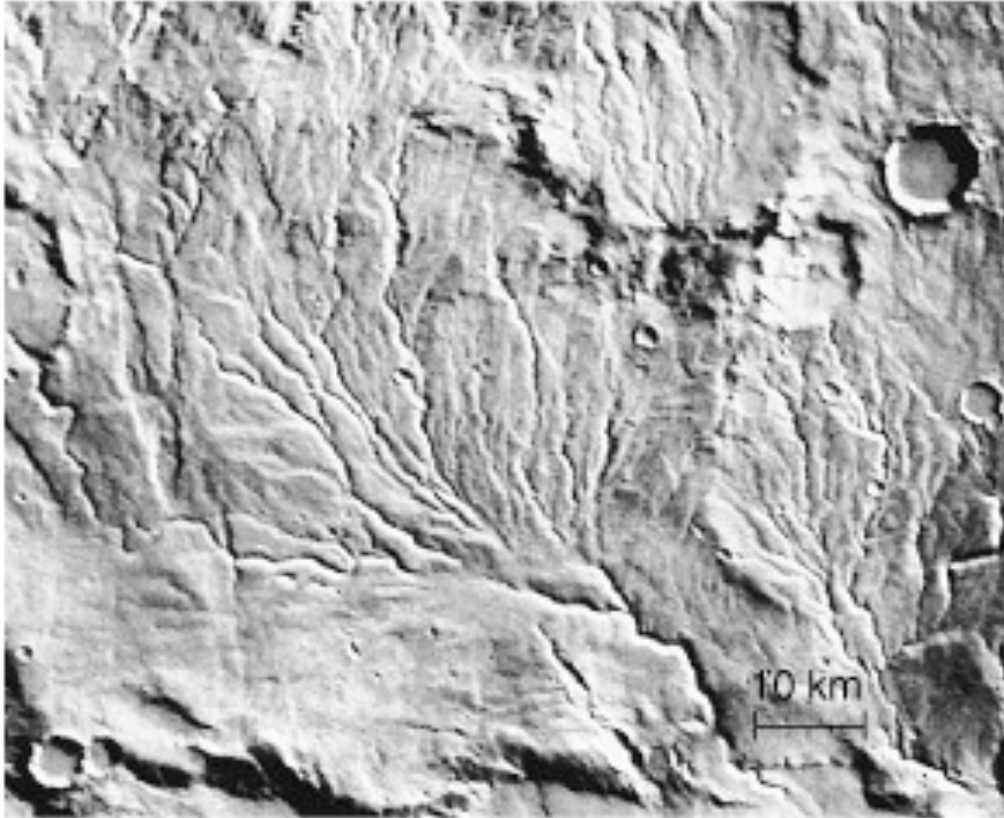


- Low gravity and a thinning atmosphere led to a runaway icehouse.
- Mars atmosphere currently $\sim 1\%$ as thick as Earth's



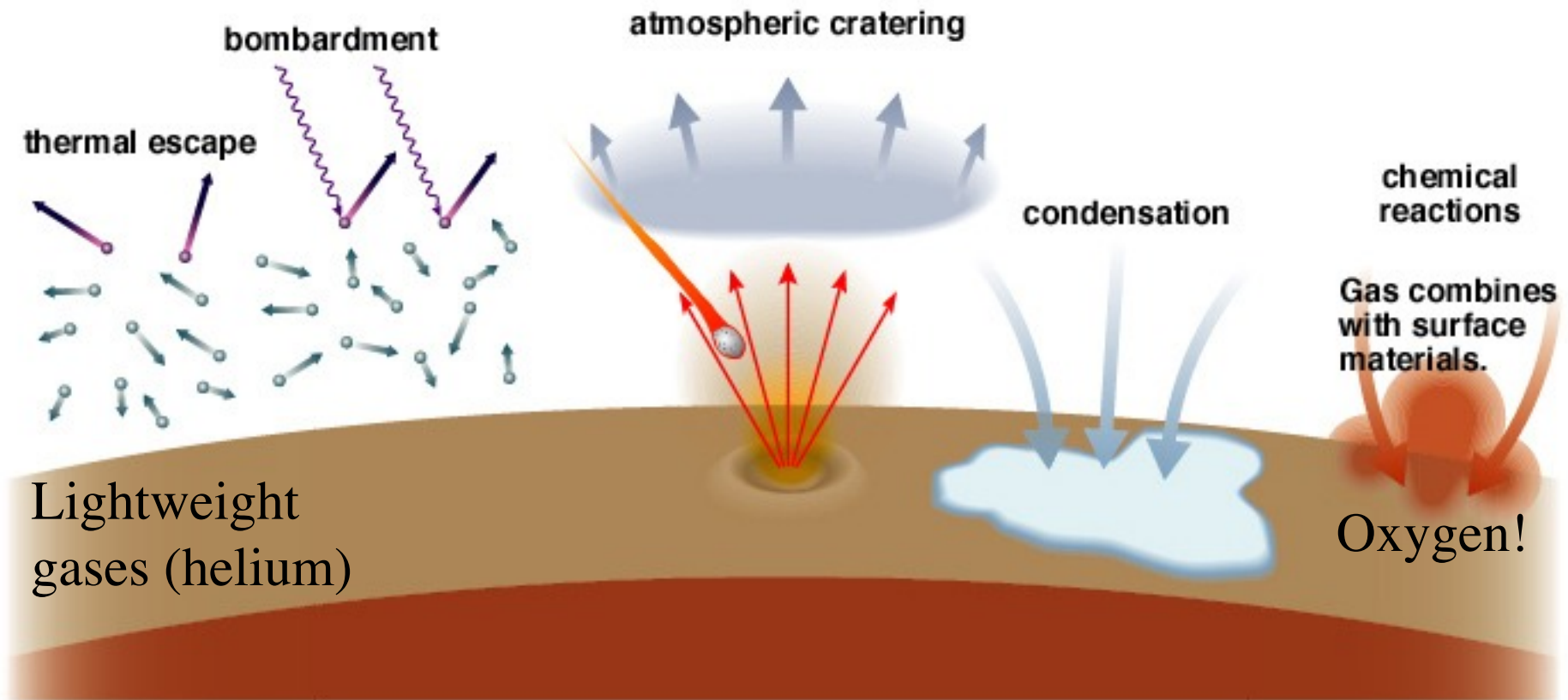
- 2004 *Opportunity* Rover provided strong evidence for abundant liquid water on Mars in the distant past.
- How could Mars have been warmer and wetter in the past?

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

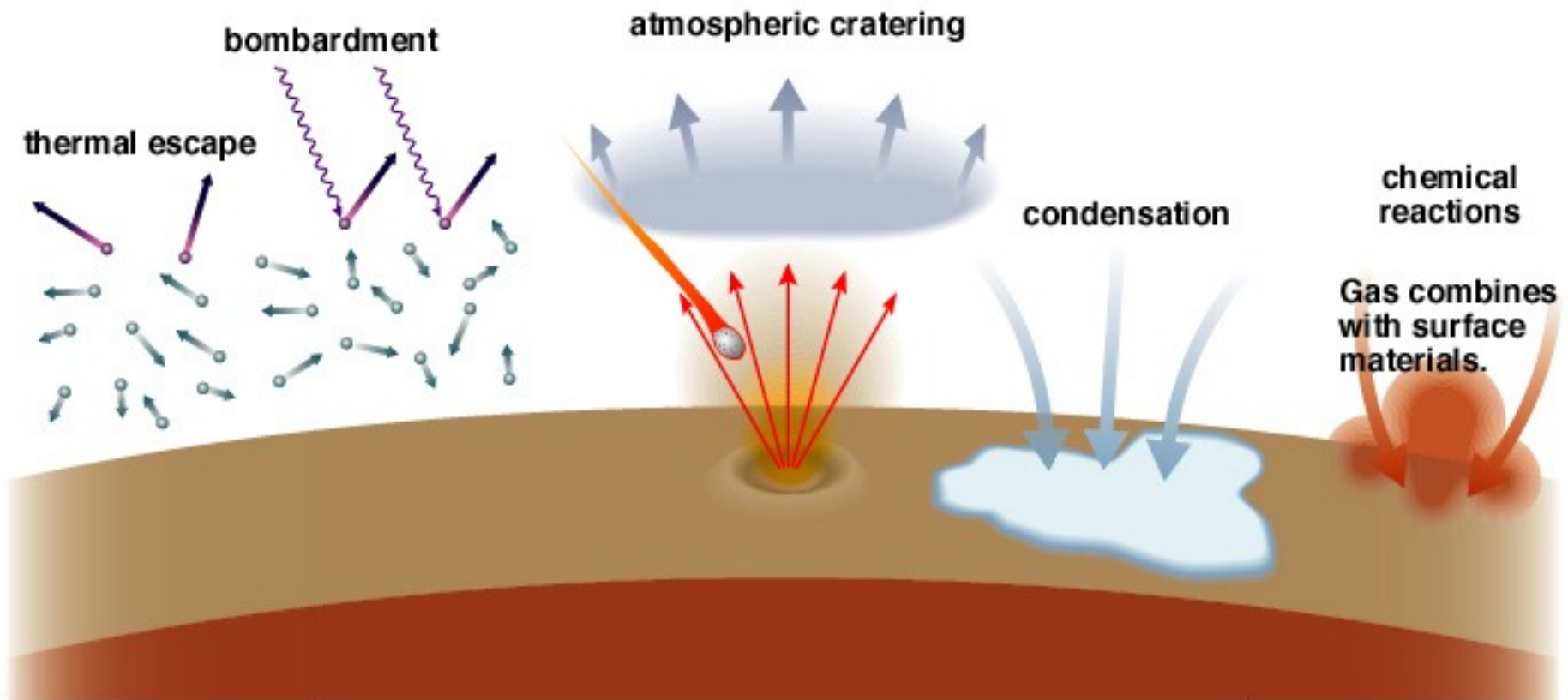


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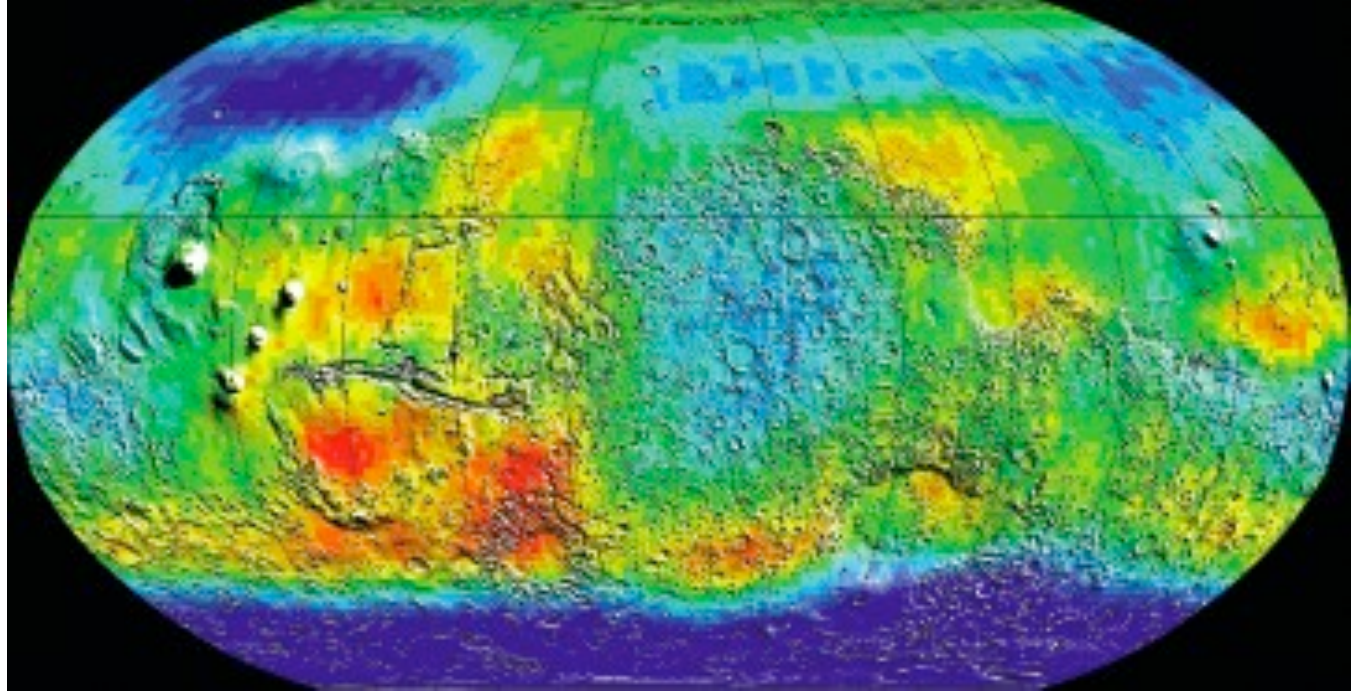
Can break up
water vapor;
hydrogen escapes

Water can
freeze out

- 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 Martian water lies frozen underground (blue regions)



Some scientists believe accumulated snowpack melts carve gullies even today.



Planetary climates

close to sun

- Mercury (no atmosphere)
 - Hot on day side, cold on night side
- Venus (thick atmosphere)
 - Hot all the time (hotter than Mercury!)
- Earth (“nice” atmosphere)
 - “just right”
- Moon (no atmosphere)
 - Hot on day side, cold on night side
- Mars (thin atmosphere)
 - colder now than in past

same distance
from sun

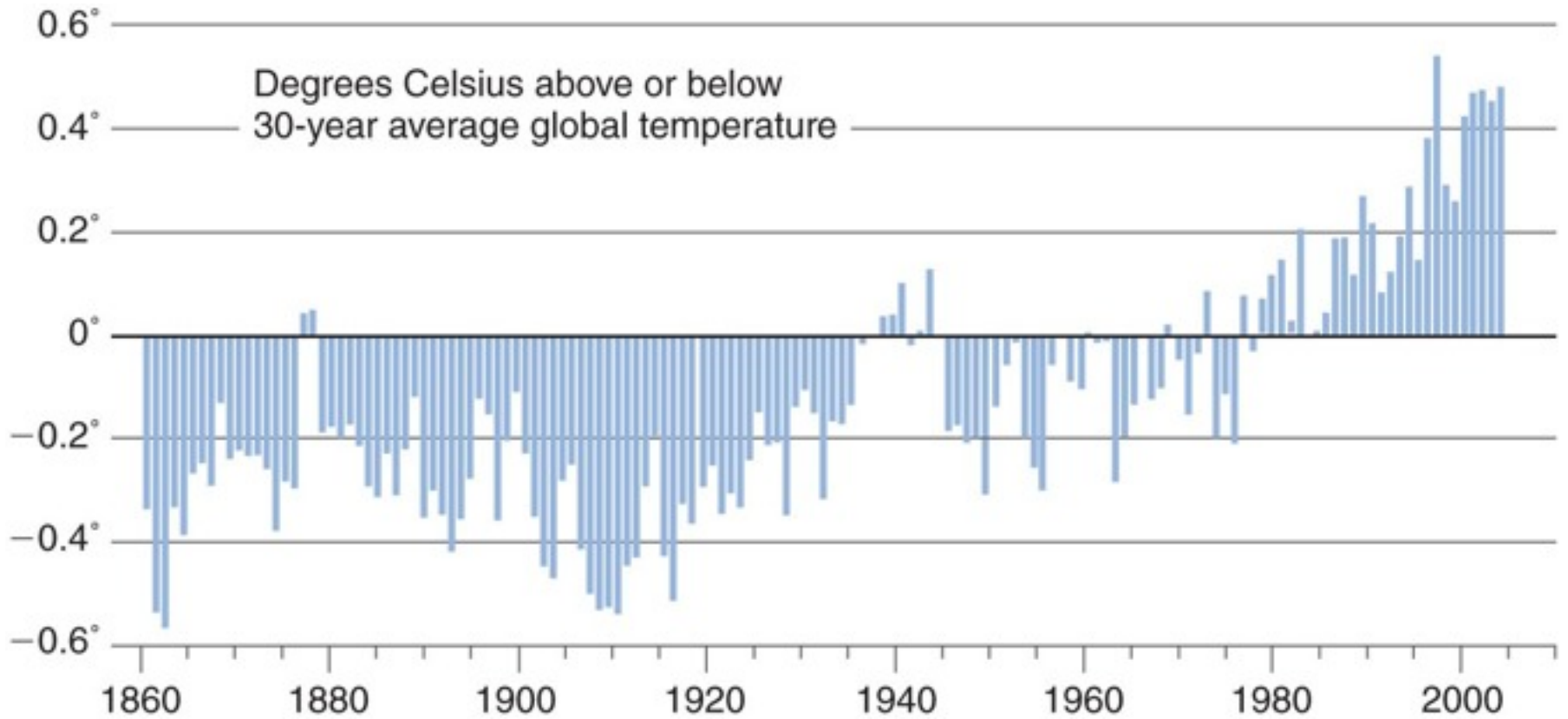
far from sun

The anthropogenic greenhouse effect (Global Warming and human activity)

What is real information?

What is misleading?

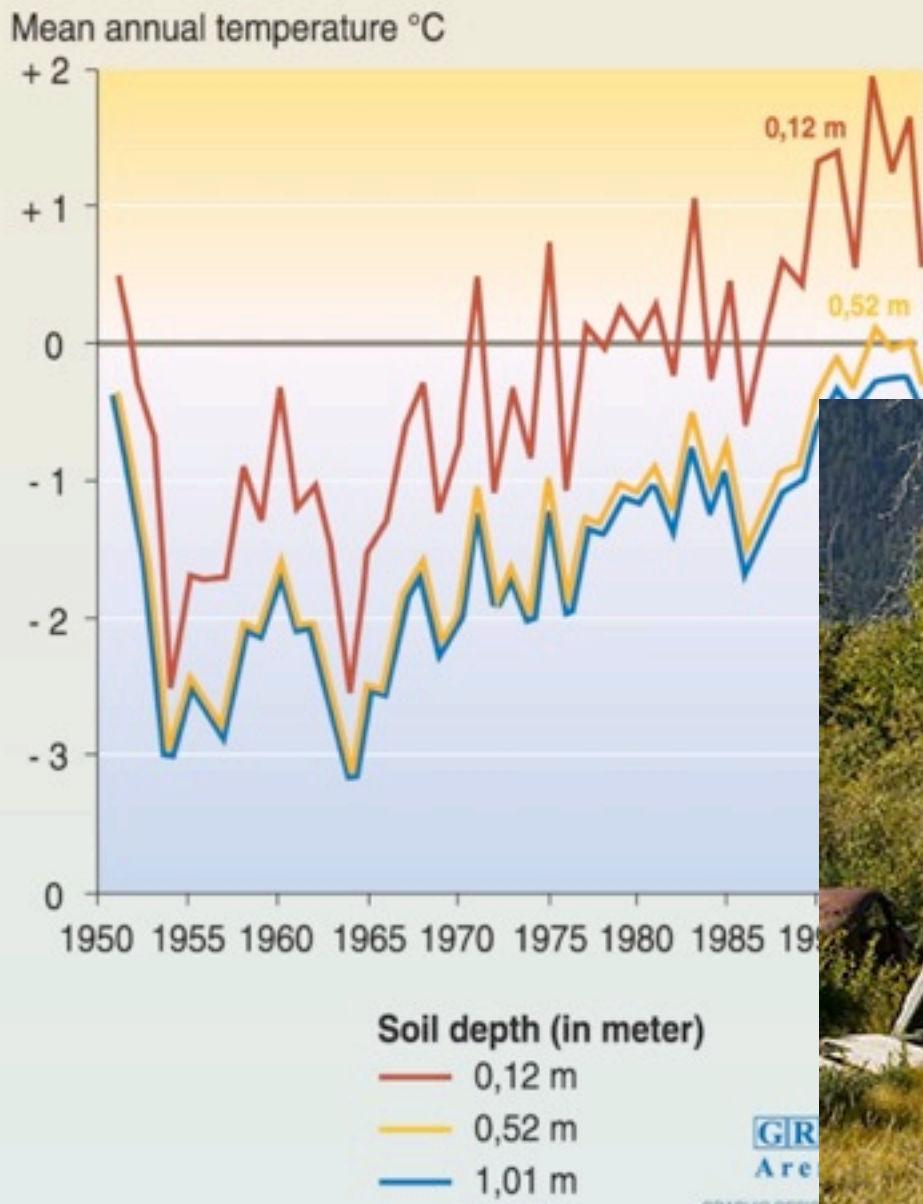
Should we be worried?



Evidence of global warming

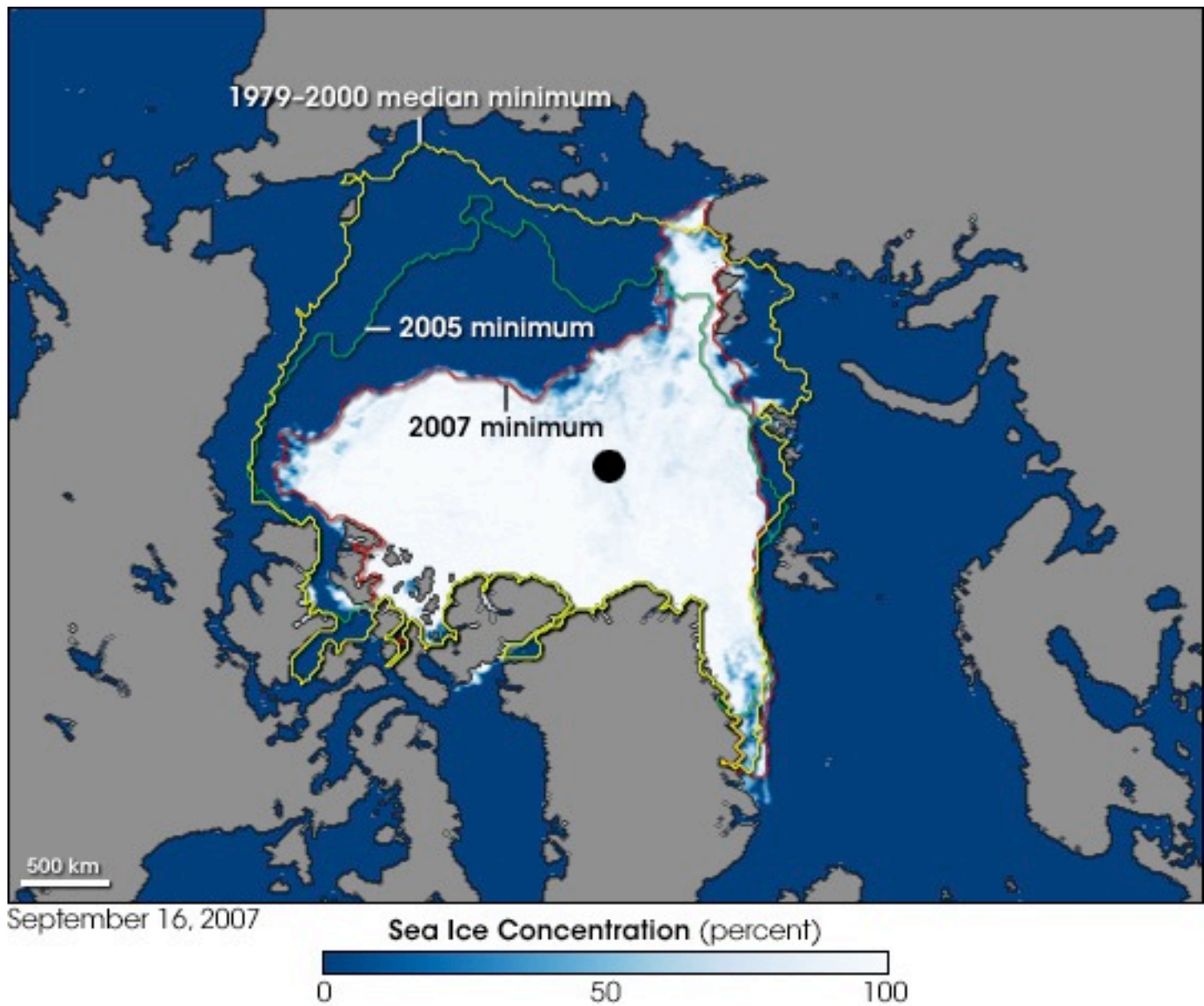
- Increase in greenhouse gas concentrations
- Surface temperature measurements
- Ocean temperature measurements
- Sea level rise (water expands as it warms)
- Melting arctic icecap; retreating glaciers
- Poleward migration of species
- More extreme weather events
 - both warm & cold; hurricanes; snowmageddon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

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

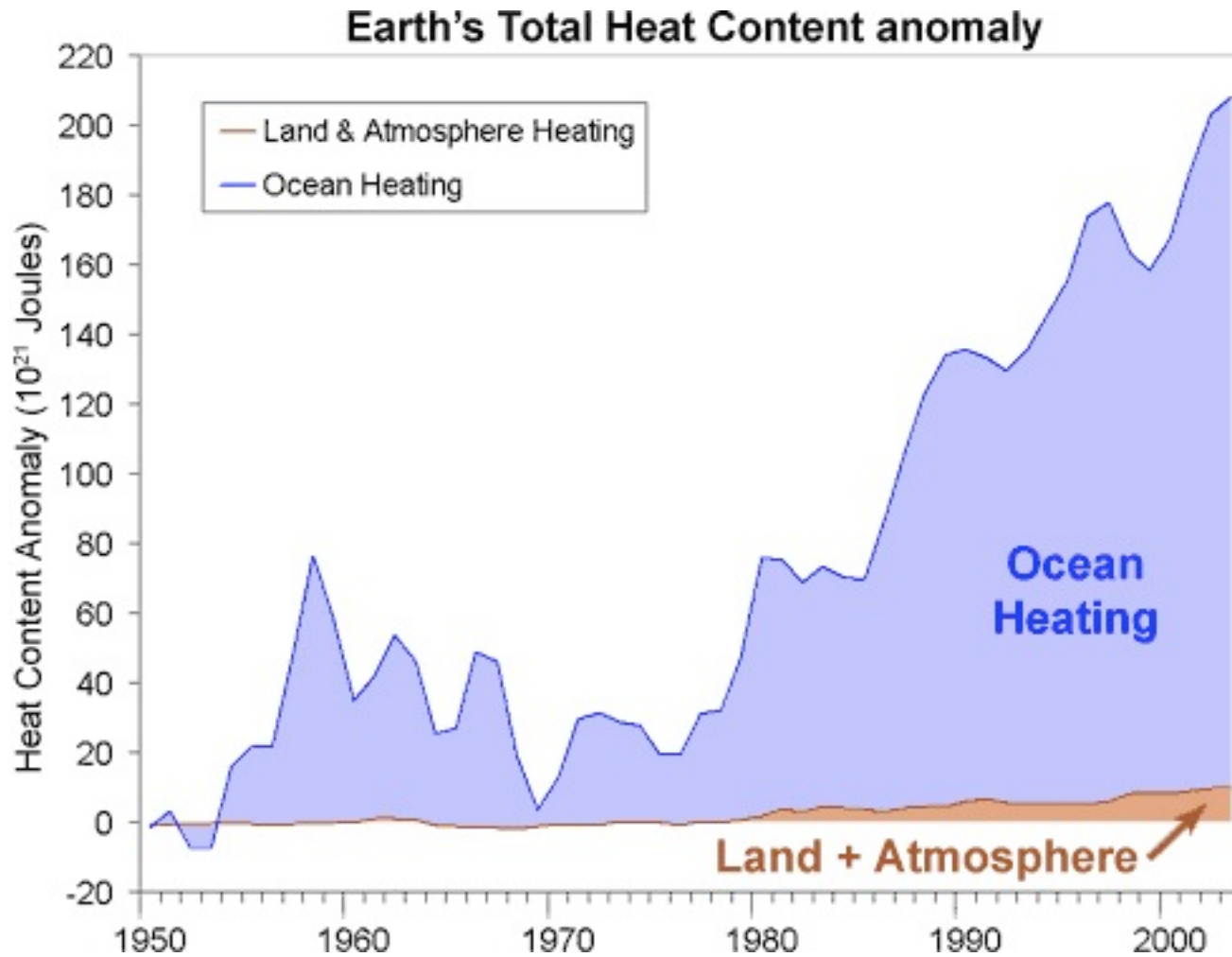


Arctic permafrost is melting



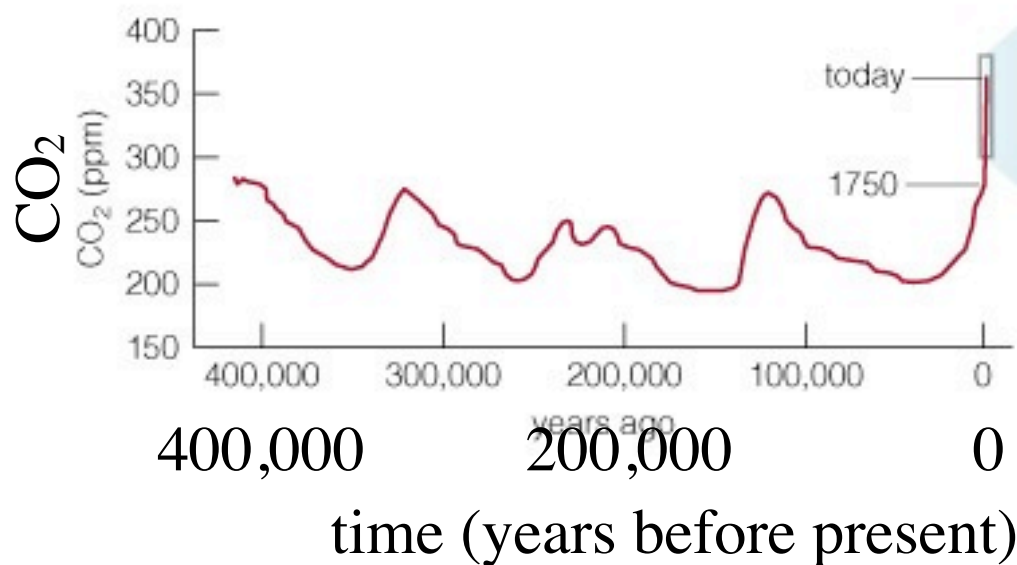
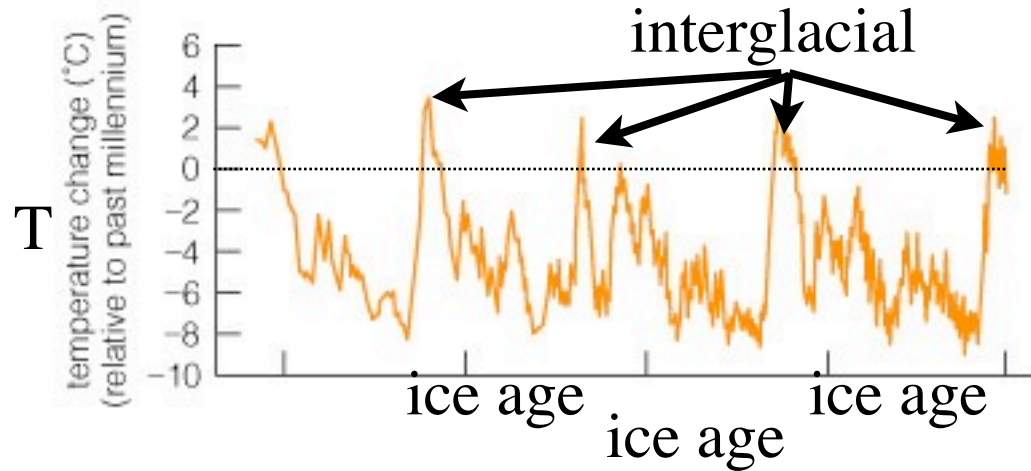


Fabled Northwest passage opened for first time in history



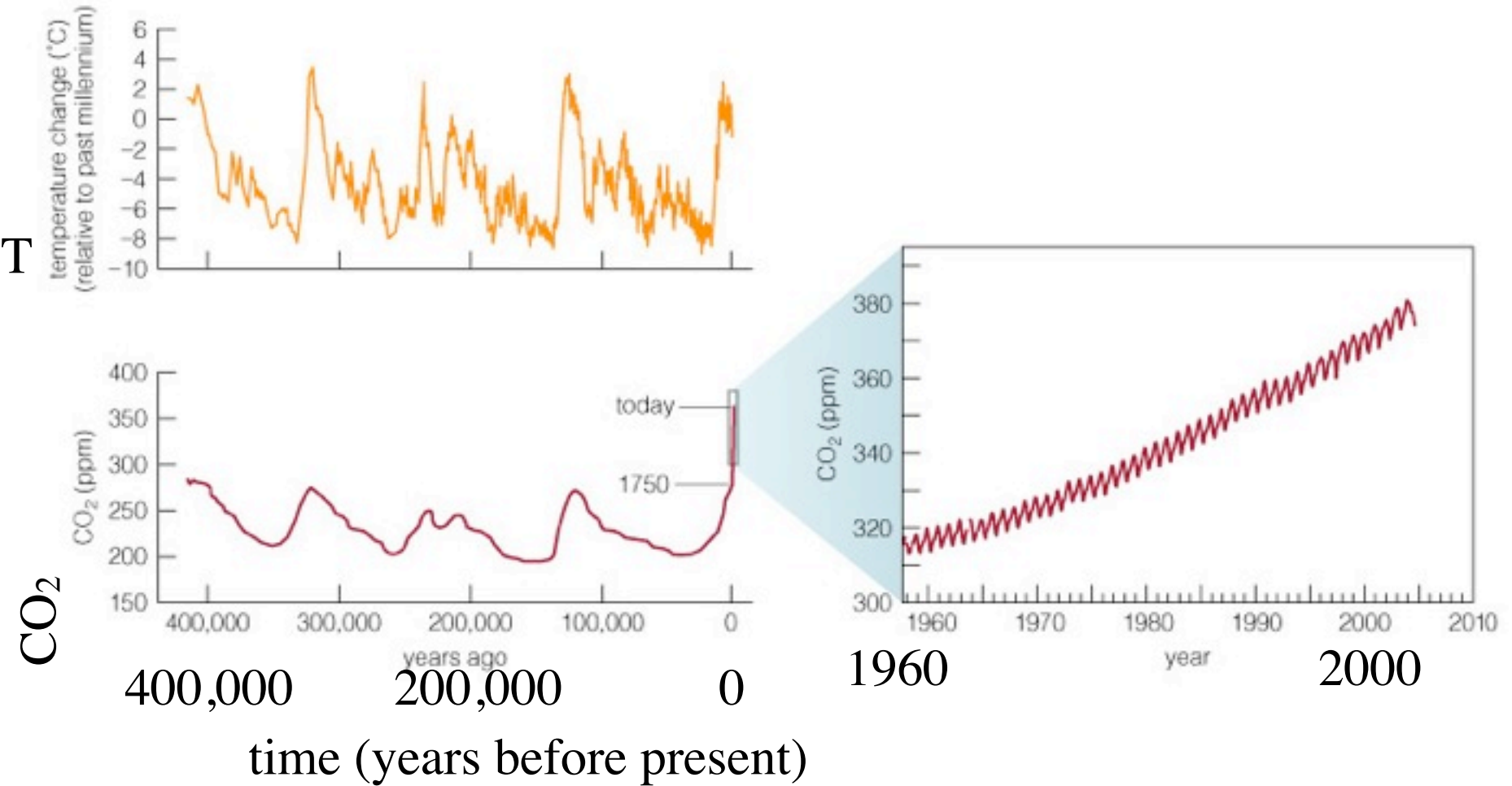
The Earth's climate is out of equilibrium - heat is accumulating in the ocean faster than it is being radiated into space.

CO₂ Concentration



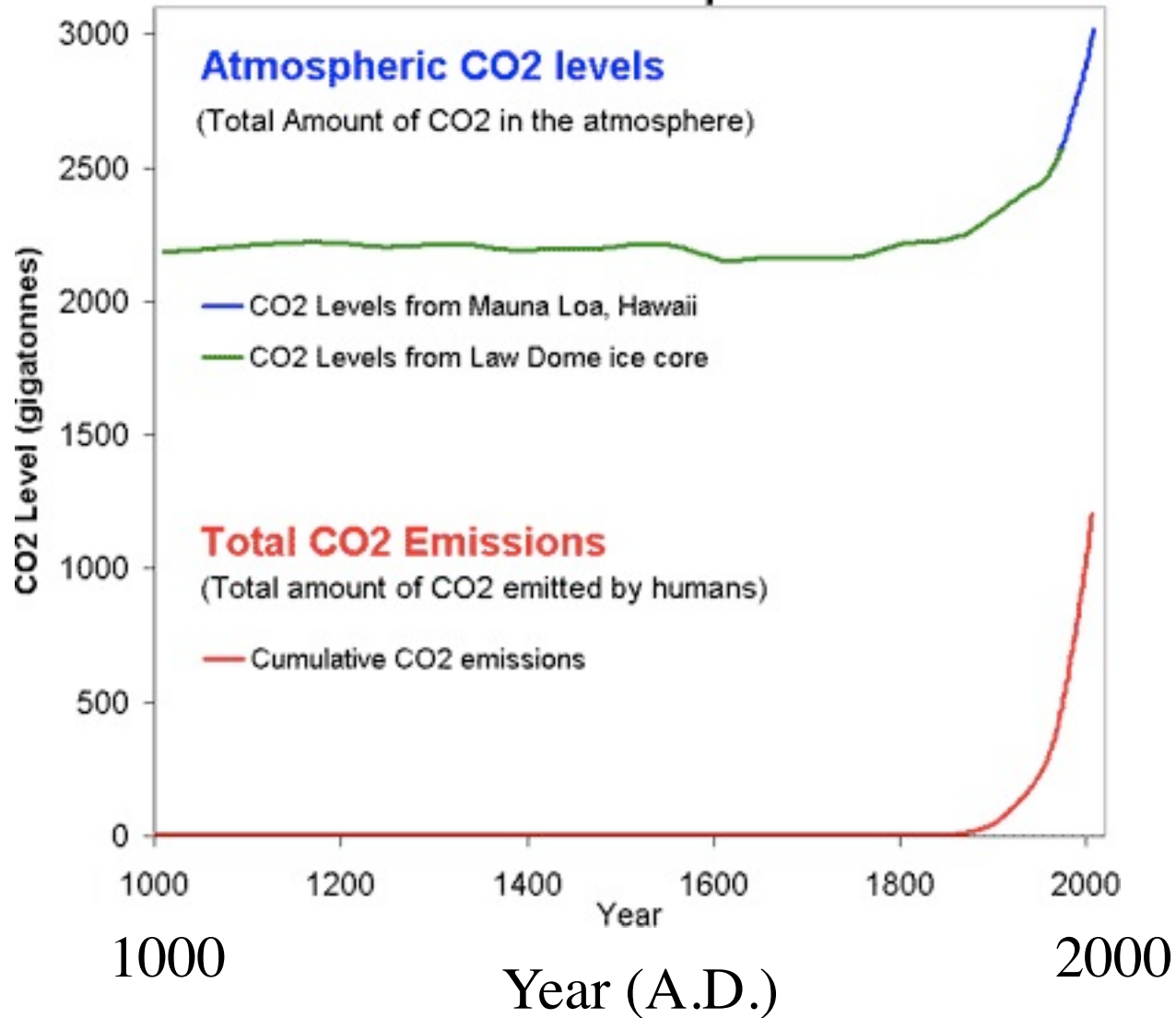
- Global temperatures have tracked CO₂ concentration for the last 500,000 years.
- Antarctic air bubbles indicate the current CO₂ concentration is at its highest level in at least 500,000 years.

CO₂ Concentration

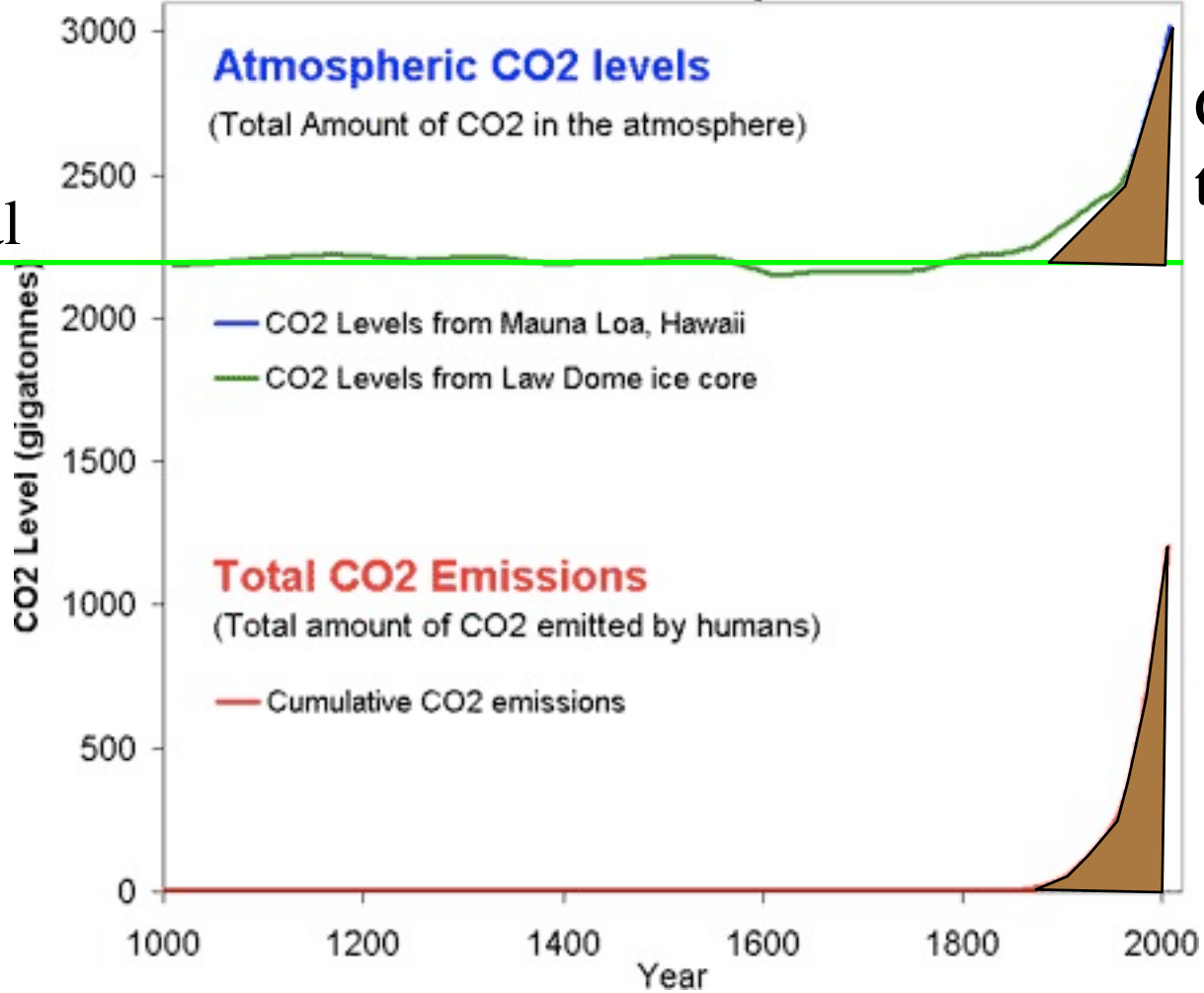


- There has been a sharp increase in CO₂ over the last 50 years. Amount consistent with the fuel burned.

CO2 emissions vs Atmospheric CO2 Levels



CO2 emissions vs Atmospheric CO2 Levels



CO2 added to atmosphere

Human activity

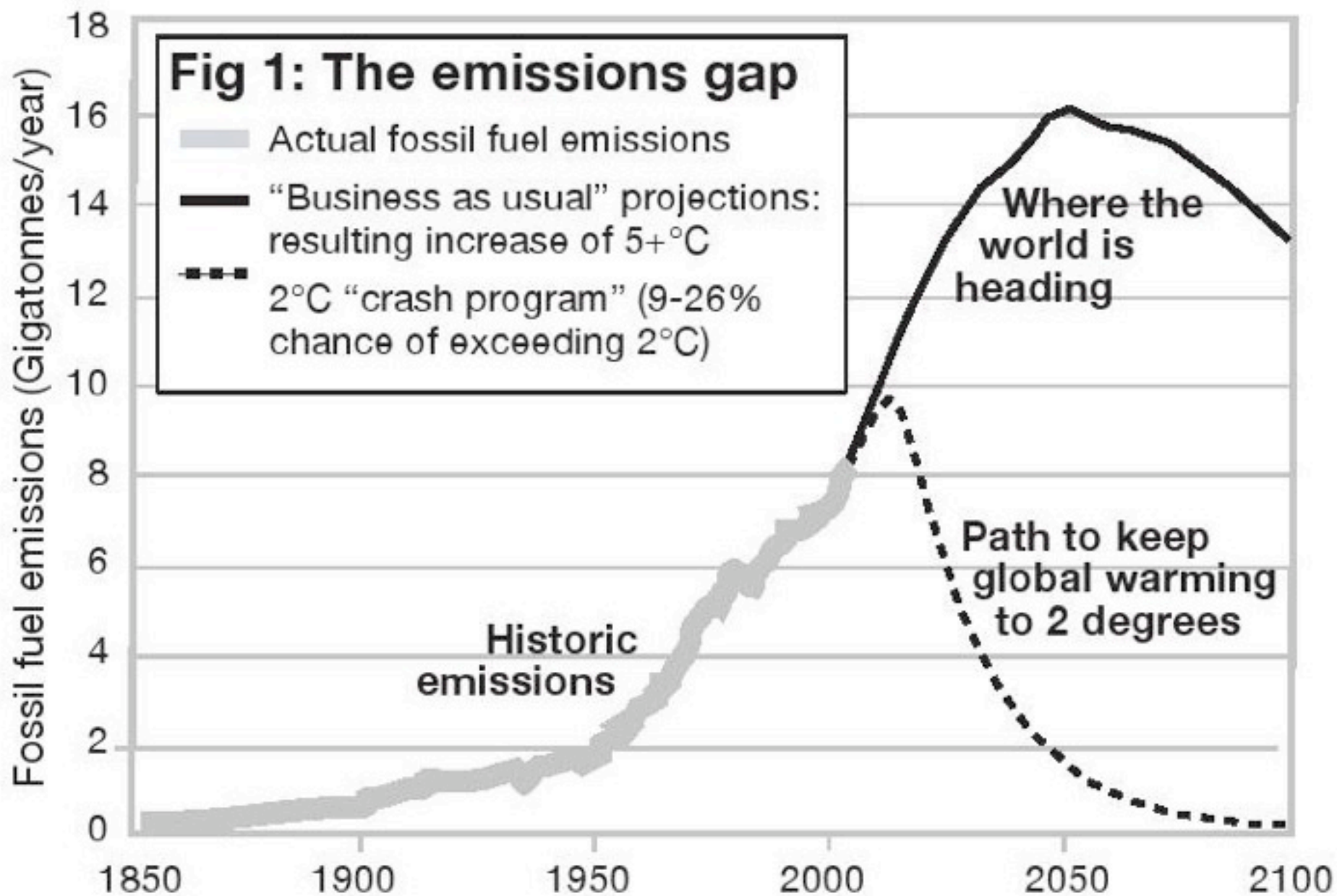
Carbon burned

Pre-industrial CO₂ level

1000

Year (A.D.)

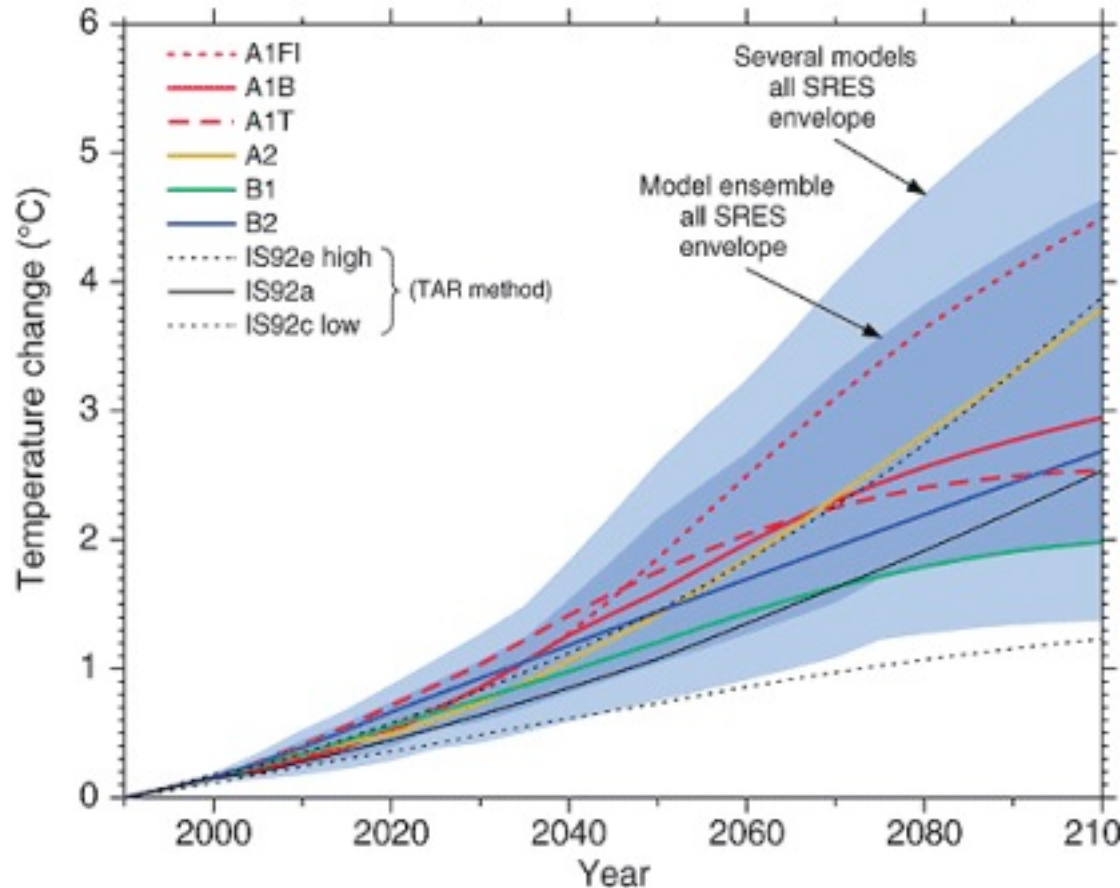
2000



Source: *Historic emissions/BAU path:* GCP Report No 5/2006 www.globalcarbonproject.org.
BAU based on 2001 IPCC report scenario. 2°C “crash program” path: Athanasiou, T, S Kartha, P Baer. 2006 “Greenhouse Development Rights”. EcoEquity/Christian Aid (www.ecoequity.org)

Climate Change Forecasts

- The recent temperature increase is consistent with human production of greenhouse gases.
- Basic physics simple; detailed predictions hard.
- We are changing the composition of the atmosphere we rely on.



Policy implications

- Basic trend clear but detailed long range forecast challenging.
 - Probably some winners as well as losers
- Probably a bad idea 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?