Lecture 13: Class Projects; Atmospheres part 2

Please remind me to take a break at 12:45 pm!

Earth's atmosphere seen from space

Claire Max

May 20, 2014

Astro 18: Planets and Planetary Systems

UC Santa Cruz

Topics for Today

- **Part 1: Class Projects**
- **Part 2: Lecture on Atmospheres, Jovian Planets**

Projects: assignment for today

- Sign up for a project topic. We'll finalize groups today.
- Today: Groups meet in class
- Each group will refine their overall topic, and then pose a more specific sub-question for each person to investigate
- Discuss sub-questions:
  - Does each one still make sense?
  - What makes each question important?
  - How are they related to each other?
- Each group member sign up to address a specific question

By Thursday May 22nd

- **(Group): Together write a 2 page summary of what your project is:**
  1. **what are your sub-questions, and who is responsible for each one?**
  2. **why are they each important (one by one)**
  3. **how are they related to each other**
  4. **what methods can you use to address them:**

     Books? Articles in magazines such as Science or Scientific American? Websites? Journal articles? Be specific.
  5. **What help can I give you**

- **Put "Astro 18" in subject line, send to max@ucolick.org**

By Thursday May 22nd, continued

- From each individual (each of you): email to me
  - A short email giving me feedback on how your group is going: did everyone participate in your brainstorming session, did you feel included or left out, did you enjoy it?
  - Is someone dominating the group too much?
  - Are you finding the work interesting? Here's a place to ask advice about sources, etc.
- Put "Astro 18" in subject line, send to max@ucolick.org

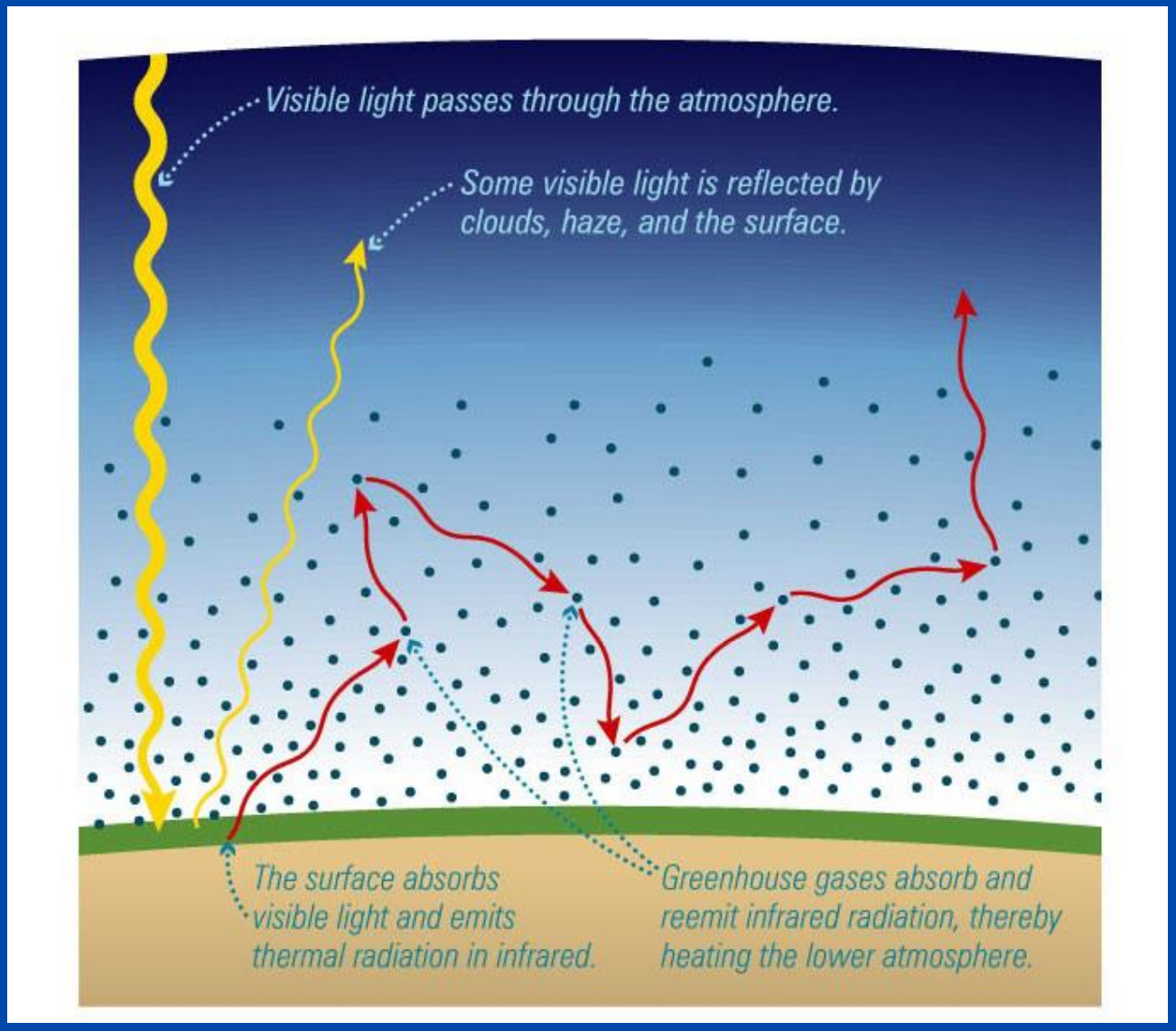
Timetable for Projects

- **Thursday May 22nd: each group write 2-page summary of project plan, each individual send me email about how project is going**
- **Week of May 26th: dig into your topics (read textbooks, other books, articles, reputable websites); meet in person with your group to collaborate; start drafting slides**
- **June 3rd and 6th: present your results in class (PowerPoint or Keynote)**
- **June 6th: final write-up due (one paper from each group)**

Time to split up into your groups

- If you don't yet have a topic or a group, come see me right away
- If your group wants help or advice about choosing sub-questions, let's talk about it
- Take a look at the reference books I've brought in today. Write down which ones could be useful. I will put on reserve in science library.

How does the greenhouse effect warm a planet?



Greenhouse gases

- carbon dioxide CO_2
- water vapor H_20
- methane CH_4
- others too (NO_2, ...)
- More greenhouse gases in atmosphere can lead to higher surface temperatures

Concept Question

What would happen to Earth's temperature if Earth's surface were less reflective?

a) It would go up.
b) It would go down.
c) It wouldn't change

Concept Question

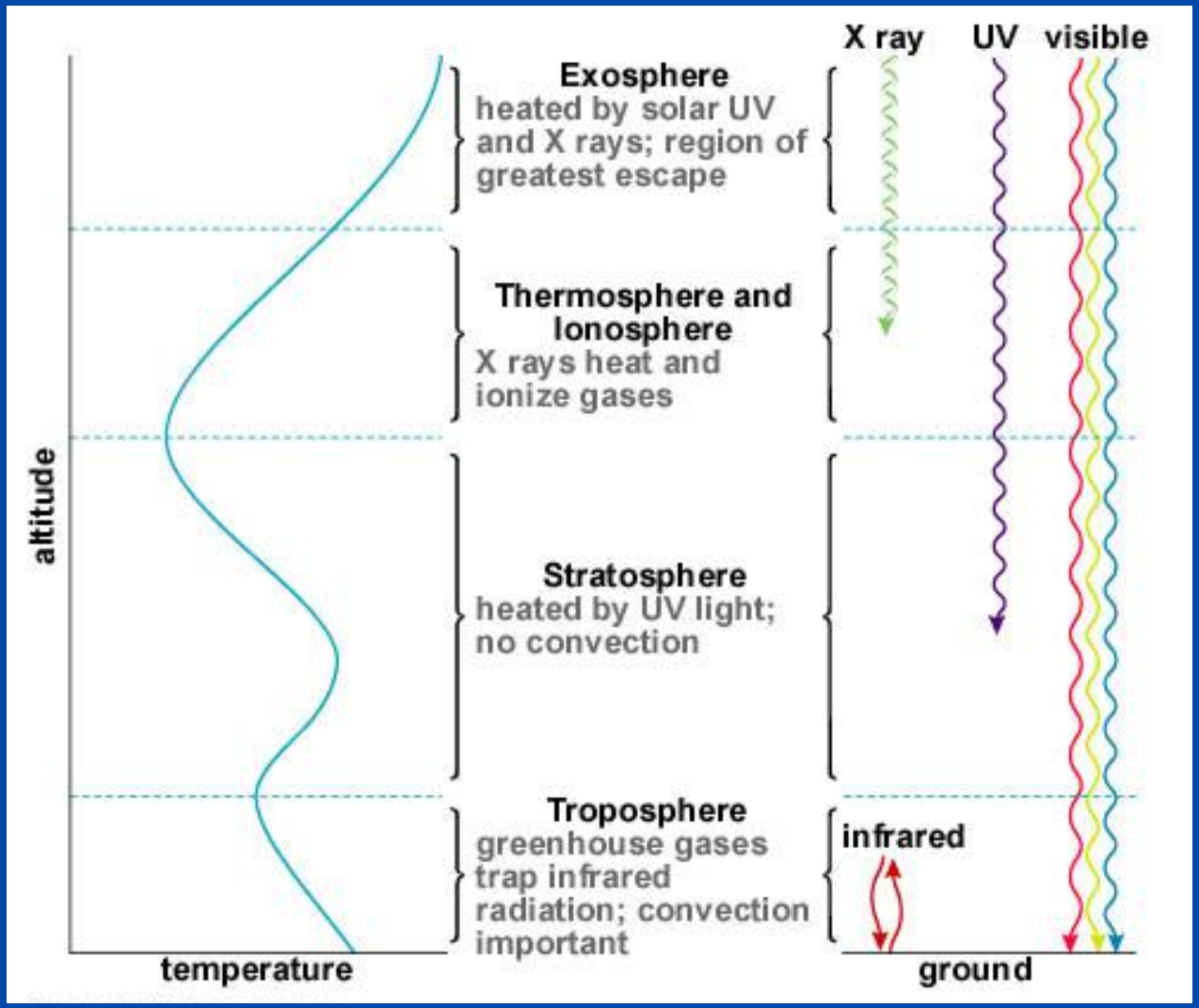
- What would happen to Earth's temperature if Earth's surface were less reflective?

  a) It would go up.
  b) It would go down.
  c) It wouldn't change

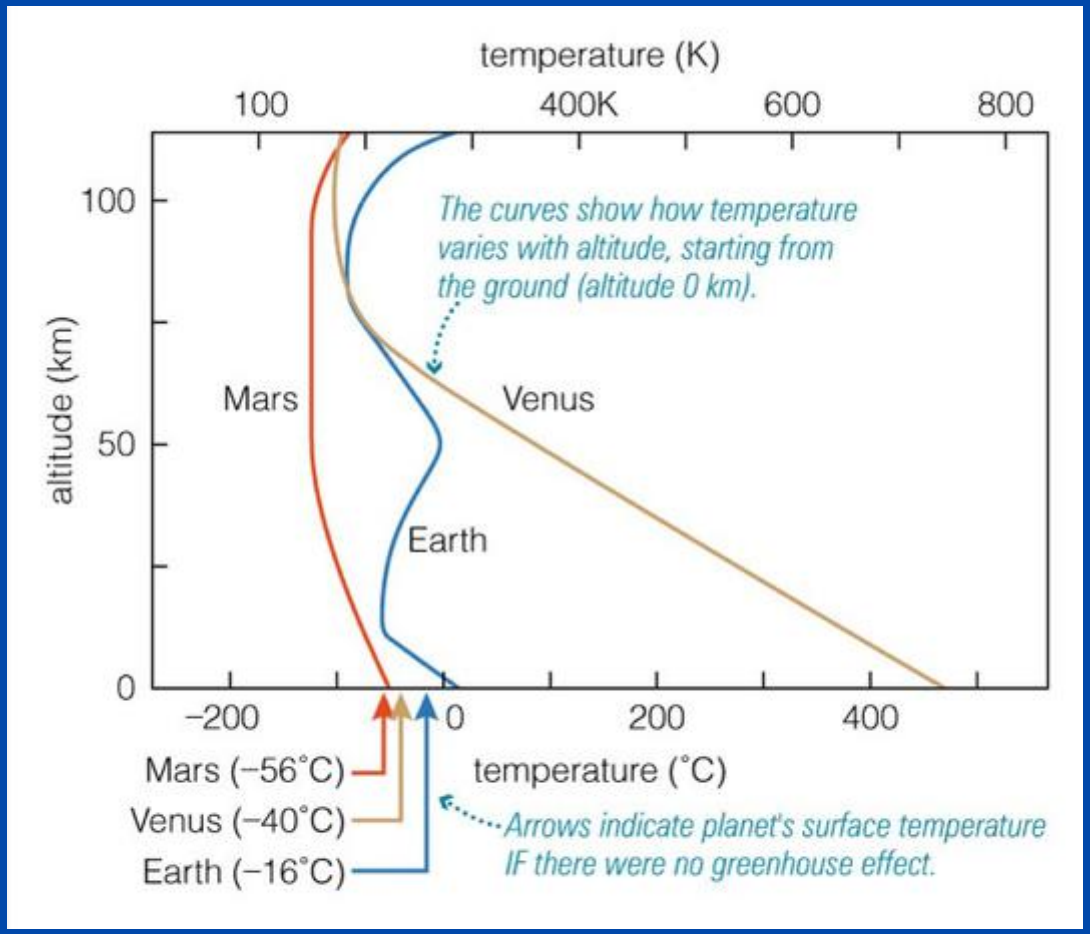
Melting sea ice lowers reflectivity, so Earth heats up more

- This is one of the factors exacerbating global warming.
- As more arctic ice melts in summer, arctic ocean absorbs more light, temperature rises

Generic atmospheric structure



Compare Earth, Venus, Mars

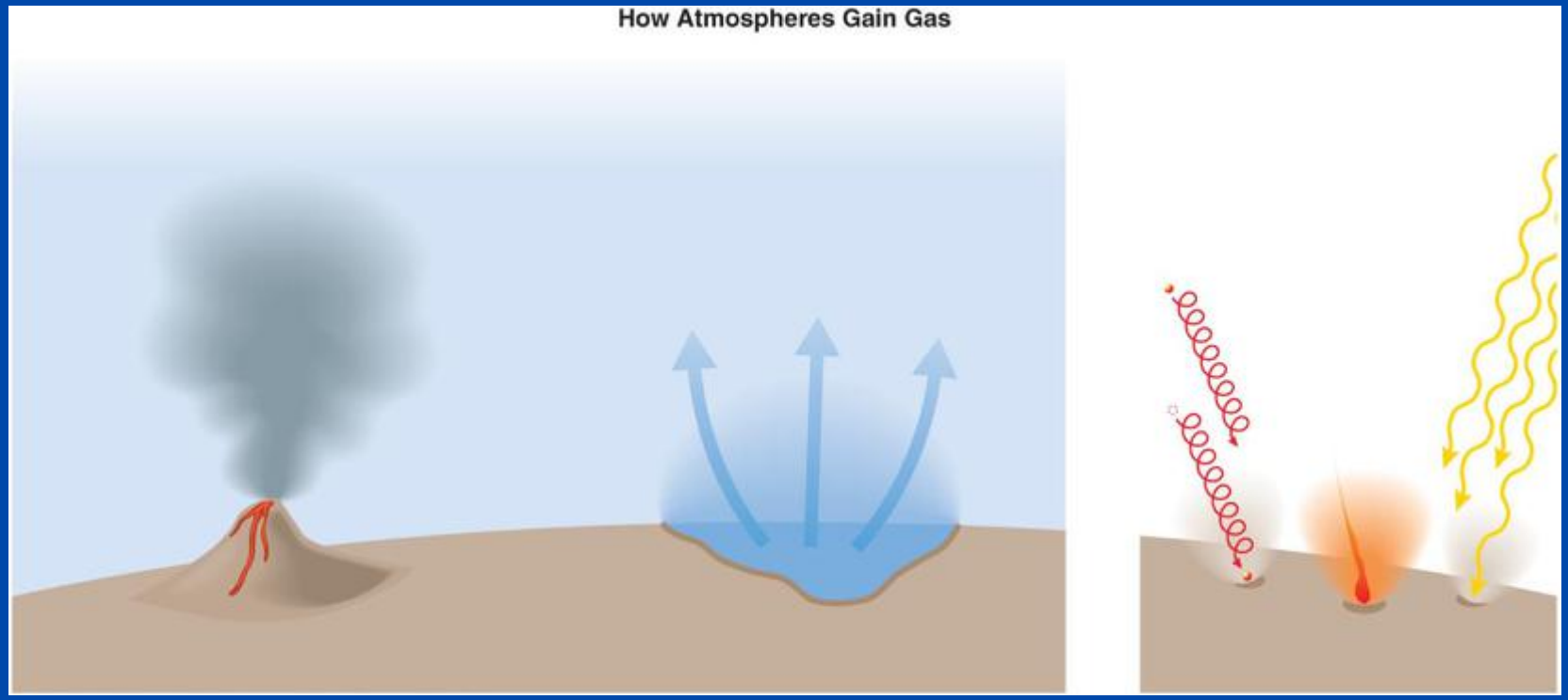


- Earth is only planet with a stratosphere because of UV-absorbing ozone molecules (O_3).
- Those same molecules protect us from Sun's UV light.

History of atmospheres on Venus, Earth, Mars

- **Huge changes took place over the 4.6 billion years since planets formed!**
  - **Both Venus and Mars had more temperate atmospheres in the past than today**
  - **Venus was cooler, Mars was warmer**
- **Question: why are atmospheres of Venus, Earth, Mars so different?**

Sources of atmospheric gases



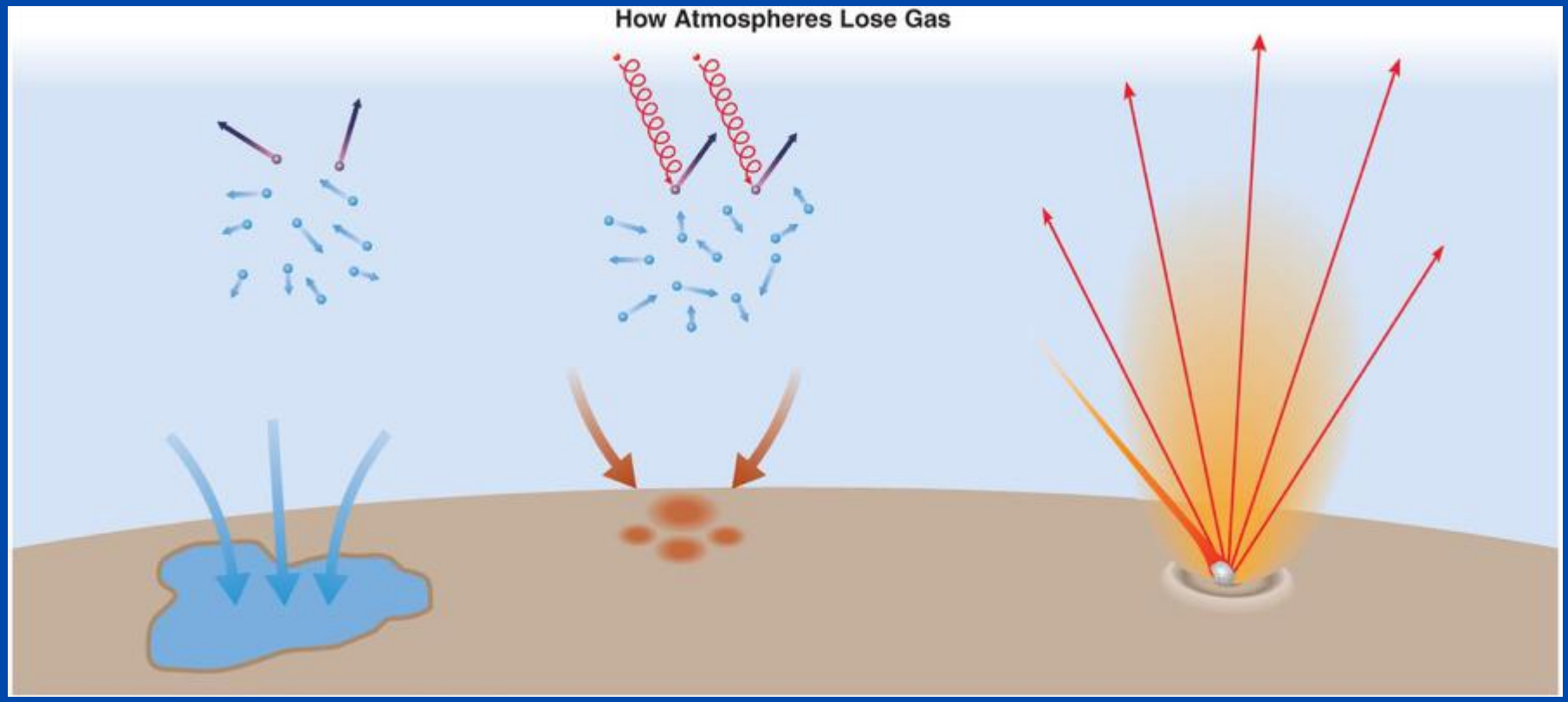
Outgassing from volcanoes

Evaporation of surface liquid; sublimation of surface ice

Impacts of particles and photons eject small amounts

Volcanic outgassing in action

Losses of Atmospheric Gases

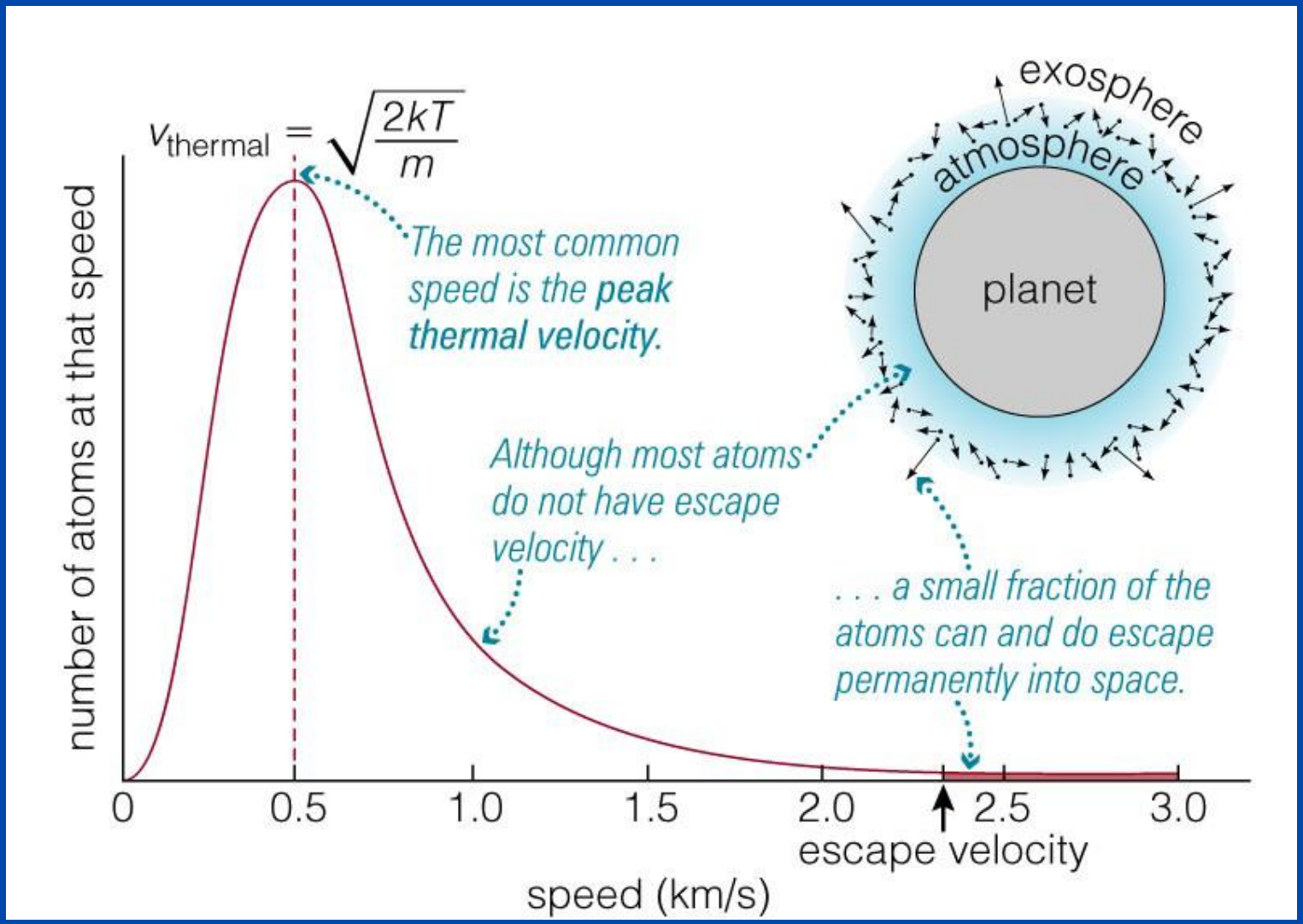


Condensation onto surface

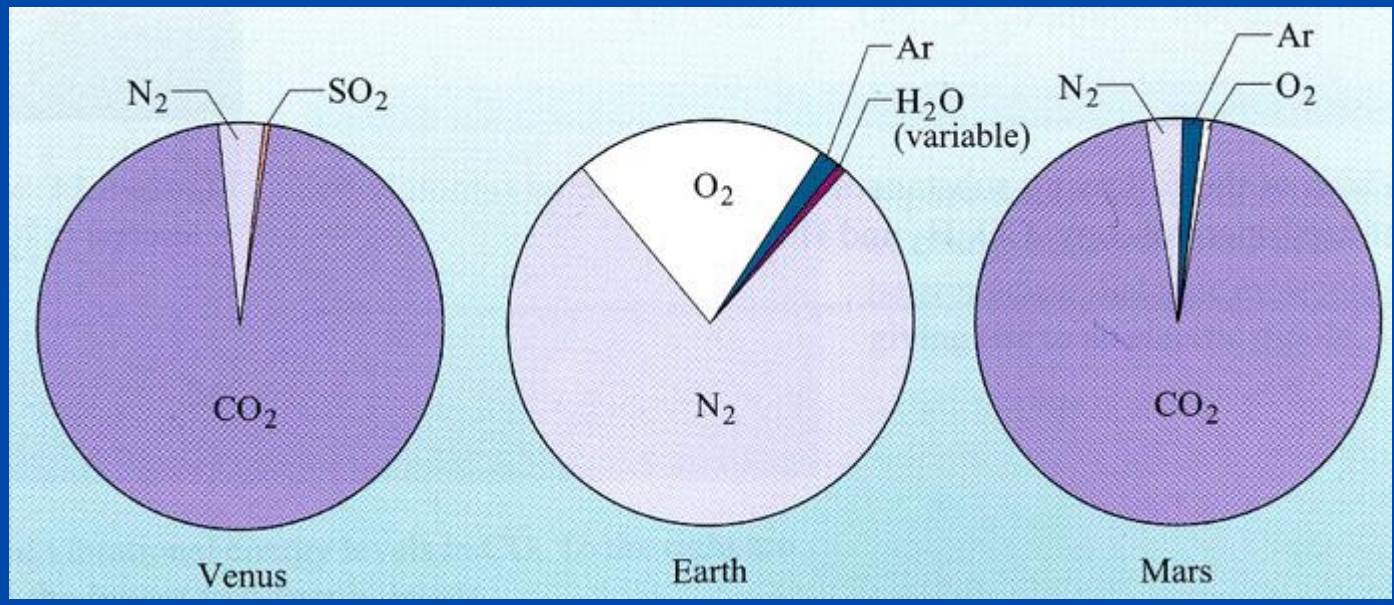
Chemical reactions with surface

Large impacts blast gas into space

Thermal Escape of atmospheric gases



Components of atmospheres on Venus, Earth, Mars



- Why are they so different?
- Were they always this different from each other?

The three atmospheres of Earth: "First Atmosphere"

- **First Atmosphere: Primordial elements**
  - **Composition - Probably H_2, He**
- **Today these gases are relatively rare on Earth compared to other places in the universe.**
- **Were probably lost to space early in Earth's history because**
  - **Earth's gravity is not strong enough to hold lightest gases**
  - **Earth still did not have a differentiated core, which creates Earth's magnetic field. Magnetosphere protects any atmosphere from the solar wind.**
- **Once the core differentiated, gases could be retained.**

"Second atmosphere": produced by volcanic outgassing

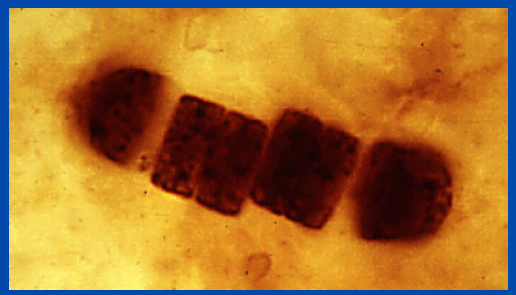
- Gases similar to those from modern volcanoes (H_2O, CO_2, SO_2, CO, S_2, Cl_2, N_2, H_2) and NH_3 (ammonia) and CH_4 (methane)
- No free oxygen (O_2 not found in volcanic gases)
- Ocean Formation - As Earth cooled, H_2O produced by outgassing could exist as liquid
- CO_2 could then dissolve in ocean, be sequestered in marine sediments

"Third atmosphere": Free oxygen, lower CO_2

- **Today, atmosphere is ~21% free oxygen. How did oxygen reach this level?**
- **Oxygen Production**
  - **Photochemical dissociation - breakup of water molecules by ultraviolet light**
    - » **Produced O_2 levels 1-2% current levels**
    - » **At these levels O_3 (Ozone) could form to shield Earth surface from UV**
  - **Photosynthesis: $CO_2 + H_2O$ + sunlight = organic compounds + O_2 - Supplied the rest of O_2 to atmosphere.**
- **Oxygen Consumers**
  - **Chemical Weathering - through oxidation of surface materials (early consumer)**
  - **Respiration of plants and animals (much later)**
  - **Burning of Fossil Fuels (much, much later)**
- **Once rocks at the surface were sufficiently oxidized, more oxygen could remain free in the atmosphere**

Cyanobacteria and stromatolites made early oxygen for atmosphere

- **The first photosynthesis**
  - **Consumes CO_2, release O_2**

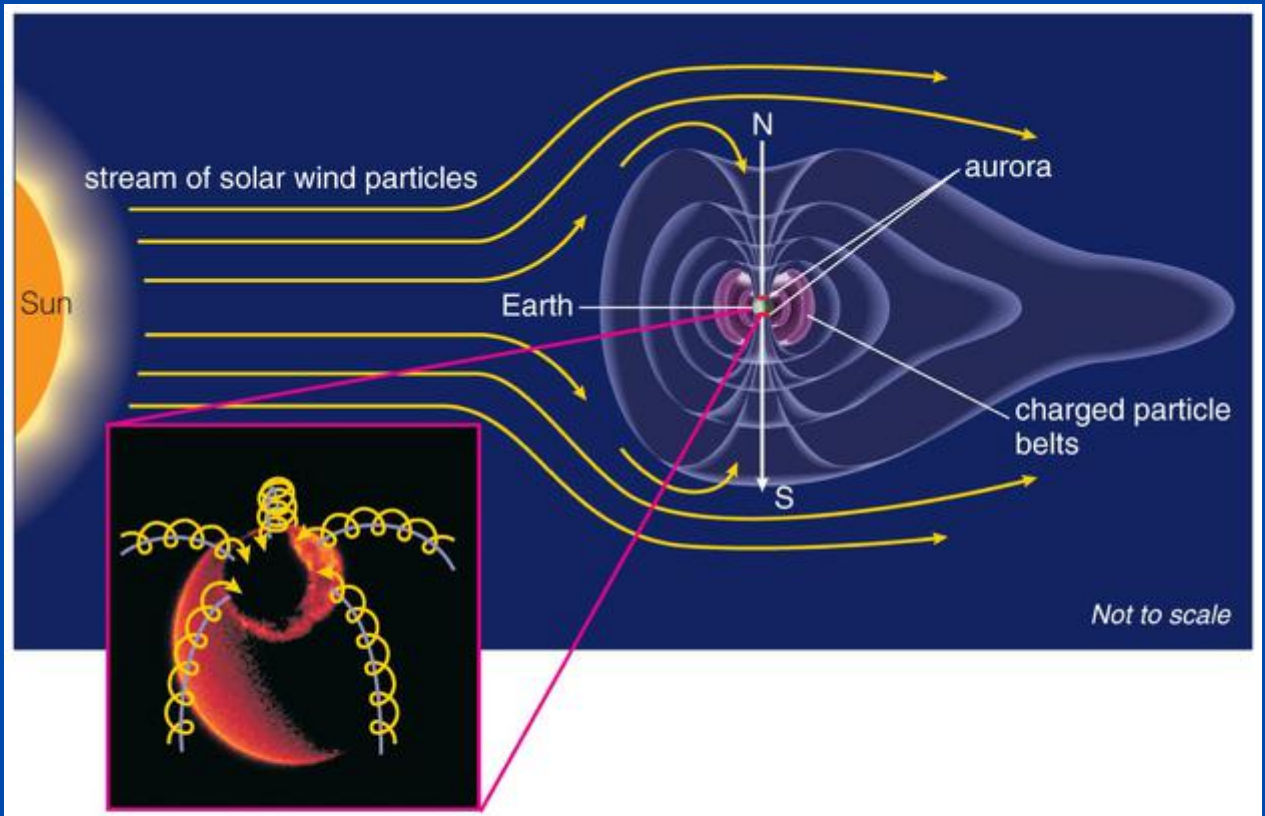


Cyanobacteria: colonies are called stromatolites

Ozone and the Stratosphere

- Ultraviolet light can break up O_2 molecules, allowing ozone (O_3) to form.
- Without plants to release O_2, there would be no ozone in stratosphere to absorb ultraviolet light.

Earth's Magnetosphere

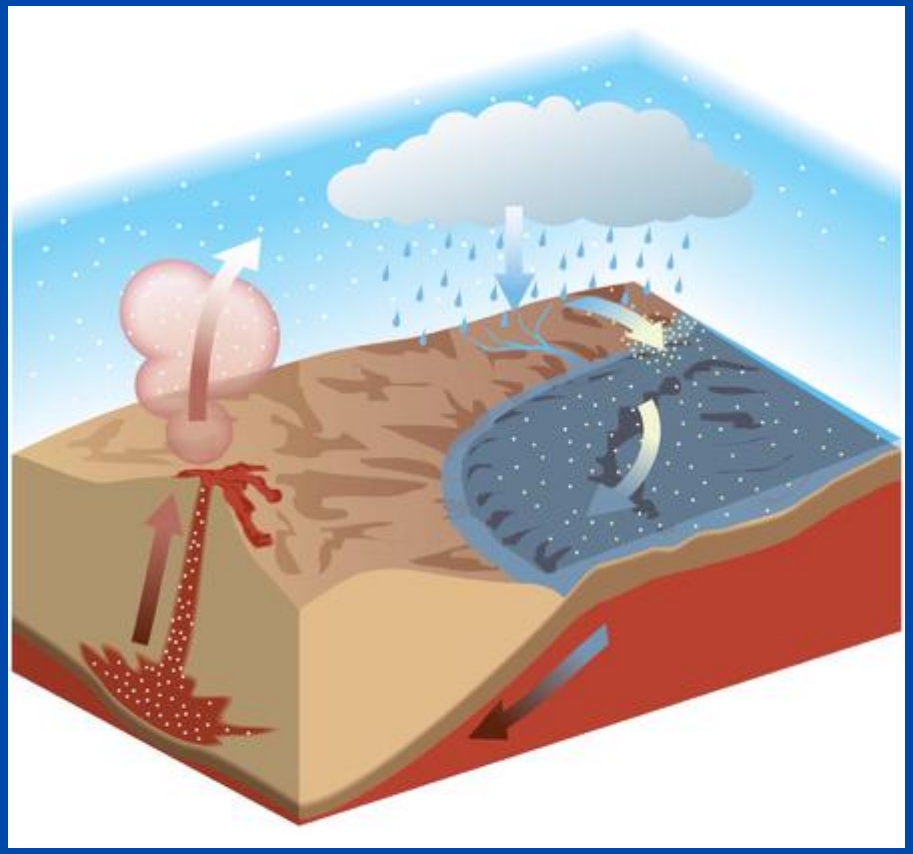


a This diagram shows how Earth's magnetosphere deflects solar wind particles. Some particles accumulate in charged particle belts encircling our planet. The inset is a photo of a ring of auroras around the North Pole; the bright crescent at its left is part of the day side of Earth.

- **Magnetic field of Earth's atmosphere protects us from charged particles streaming from Sun (the solar wind).**

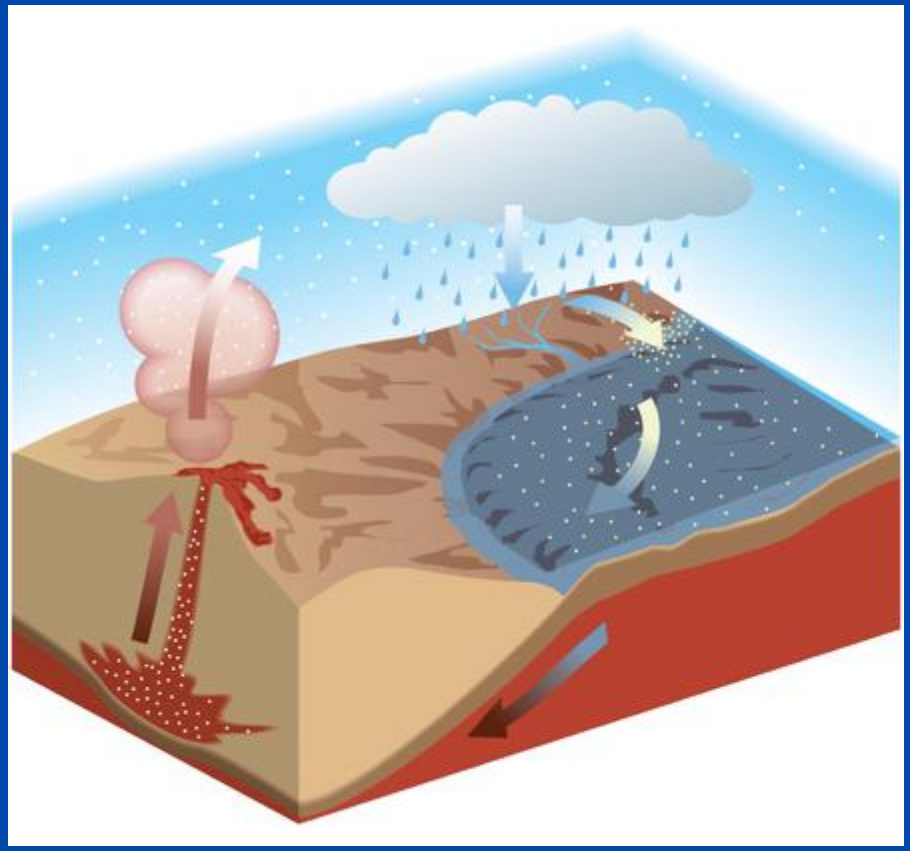
Why does Earth's climate stay relatively stable?

The Carbon Dioxide Cycle



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

Why does Earth's climate stay relatively stable?

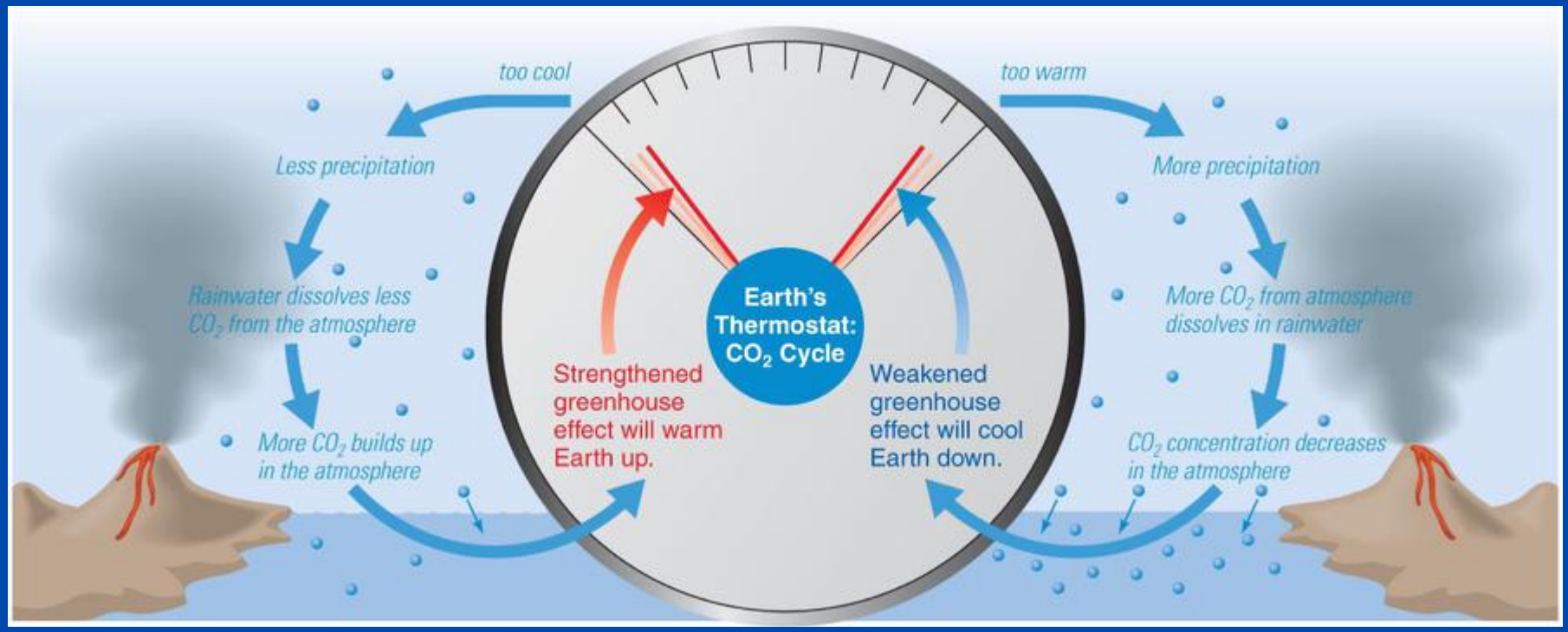


4. Subduction carries carbonate rocks down into mantle

5. Rocks melt in mantle and outgas CO_2 back into atmosphere through volcanoes

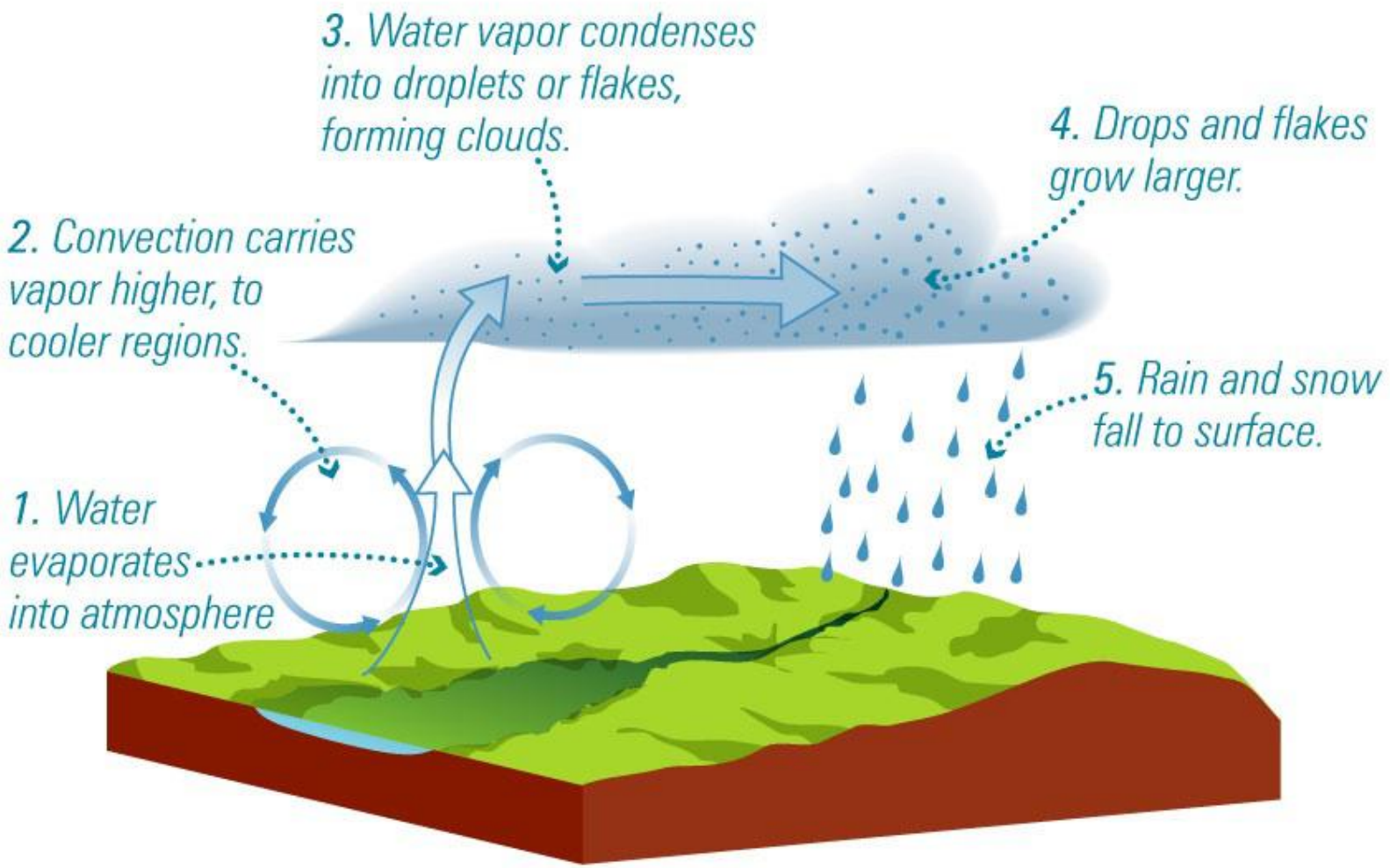
6. Note that Plate Tectonics is essential component of this cycle

Earth's Thermostat



- Cooling allows CO_2 to build up in atmosphere
- Heating causes rain to reduce CO_2 in atmosphere

Earth: hydrological cycle

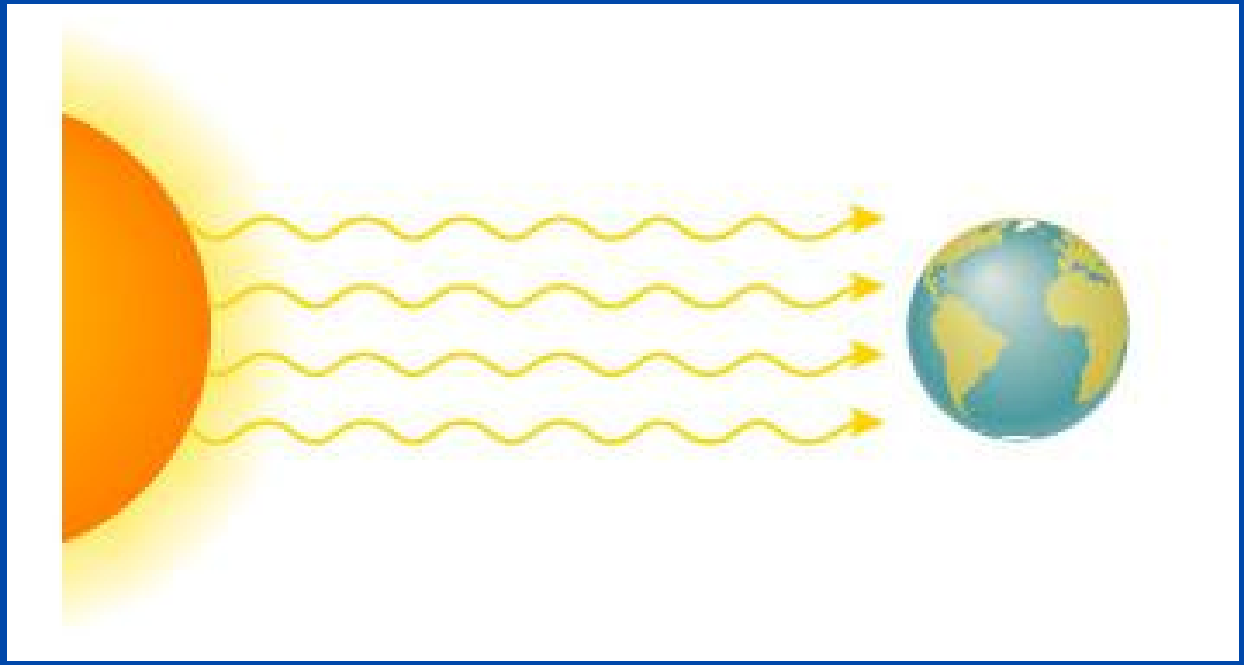


Did Earth get its water from comets?

- Some water from outgassing volcanoes
- Second potential source of the Earth's ocean water is comet-like balls of ice.
- Enter atmosphere at rate of about 20/second.
- Four billion years of such bombardment would give enough water to fill the oceans to their present volume.
- Possible problems: isotope ratios don't match. Under active research.

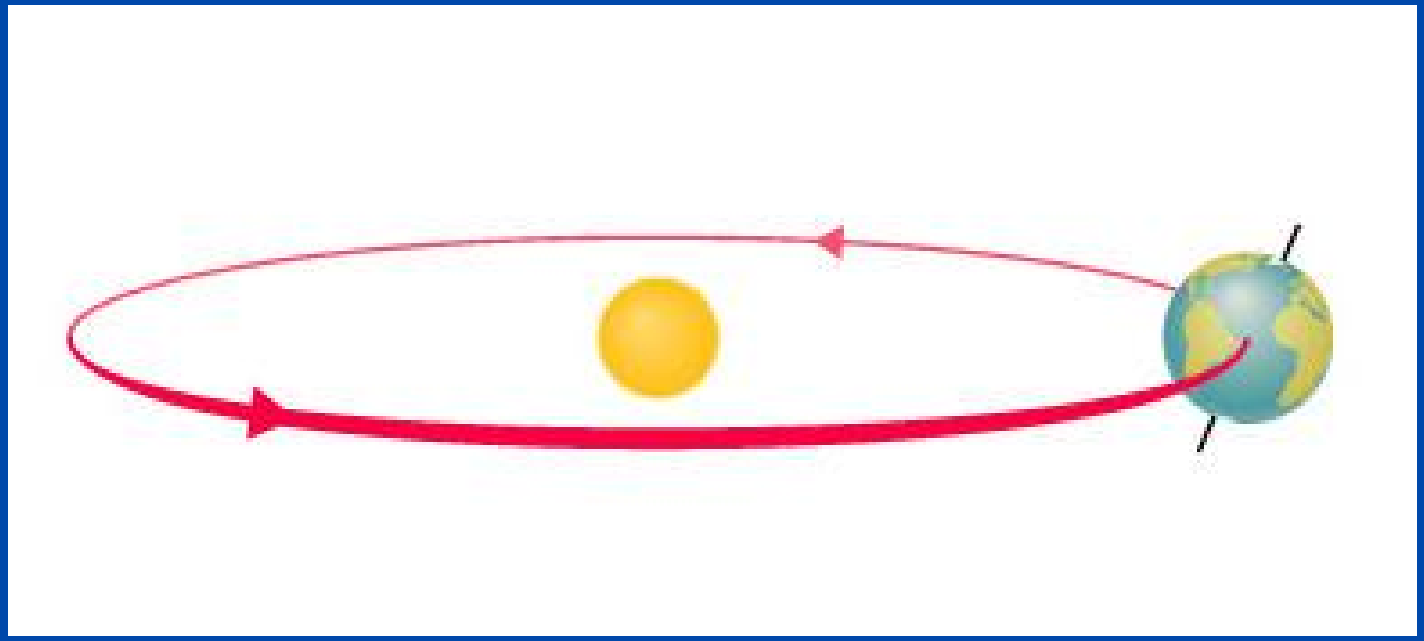
What factors can cause long-term climate change?

Solar Brightening



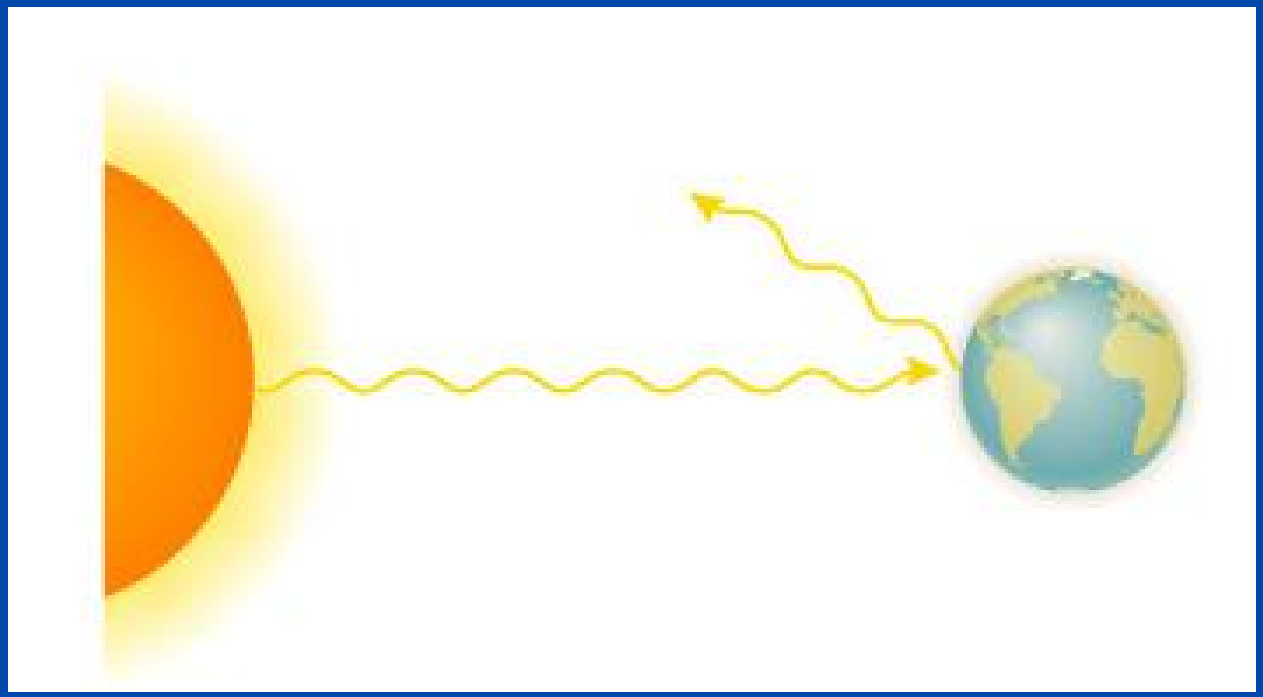
- Sun very gradually grows brighter with time, increasing the amount of sunlight warming planets

Changes in Axis Tilt



- Greater tilt makes more extreme seasons, while smaller tilt keeps polar regions colder

Changes in Reflectivity



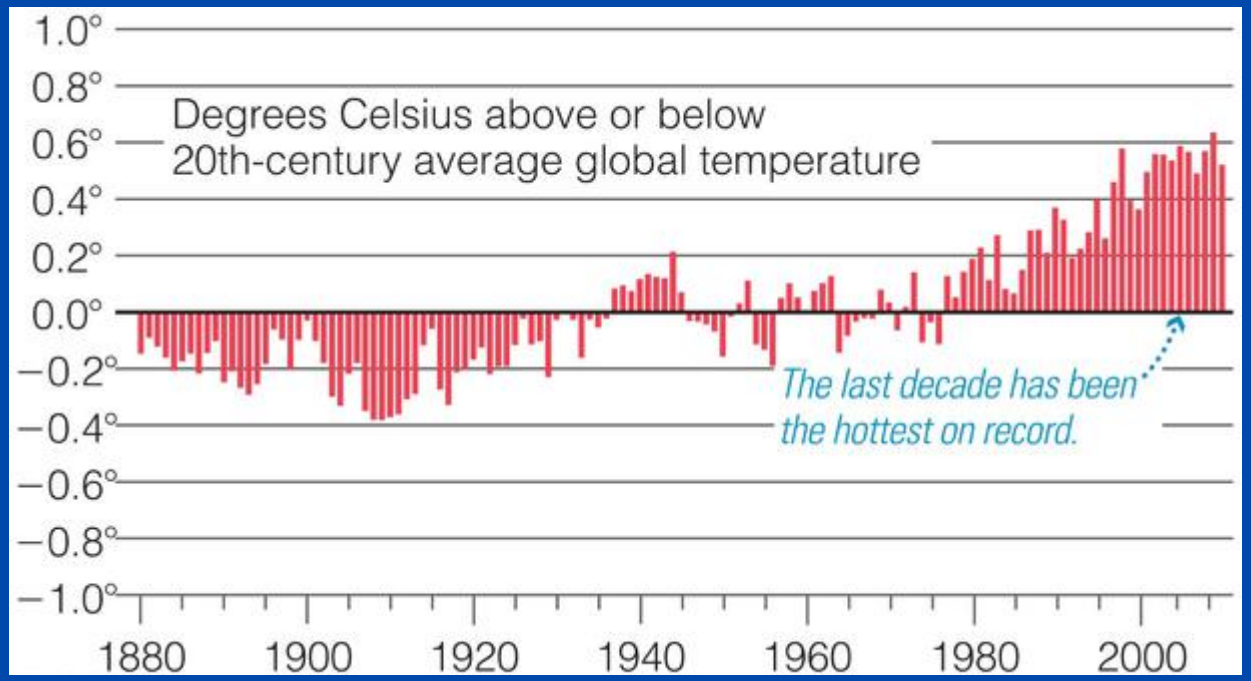
- Higher reflectivity tends to cool a planet, while lower reflectivity leads to warming

Changes in Greenhouse Gases

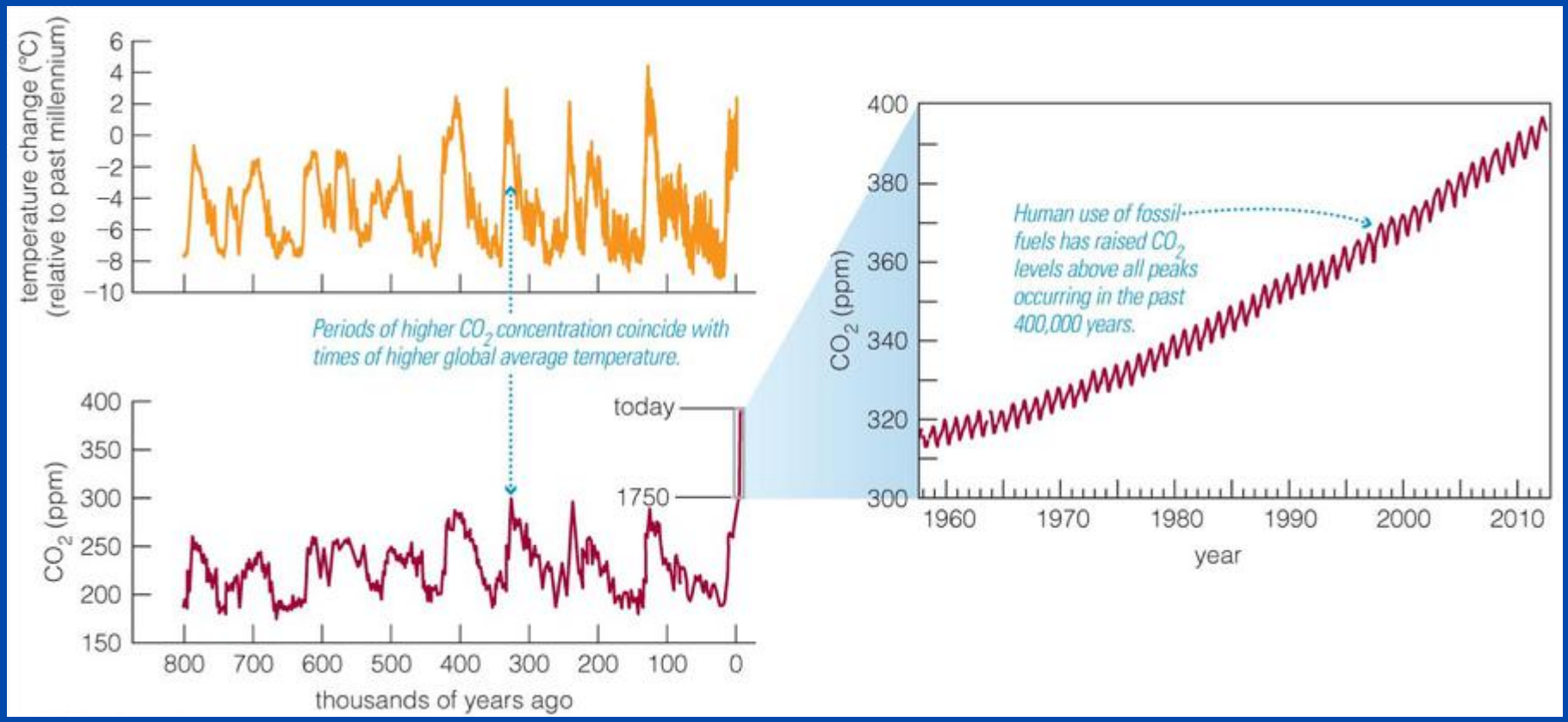
- Increase in greenhouse gases leads to warming, while a decrease leads to cooling

Evidence for Global Warming on Earth

- **Earth's average temperature has increased by 0.5°C in past 50 years.**
- **Most likely contributor to increased temperatures: concentration of CO_2 is rising rapidly.**



Temperature increases as CO_2 concentration goes up



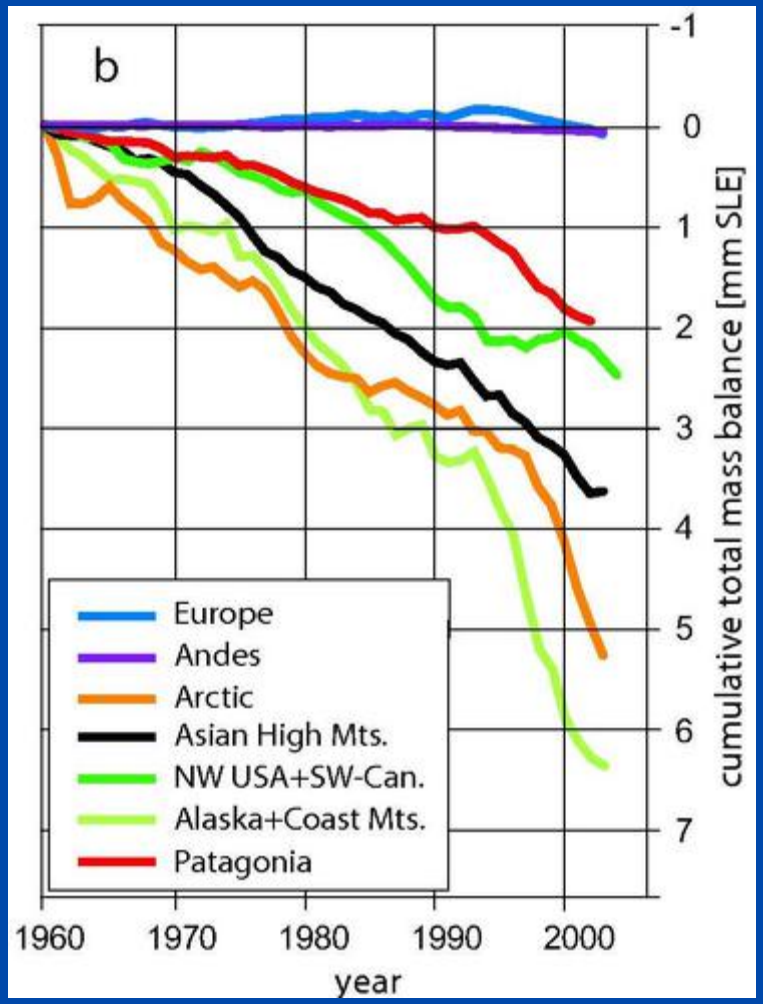
- Most of the CO_2 increase has happened in last 50 years
- Largely due to human endeavors (fossil fuels)

Intergovernmental Panel on Climate Change (IPCC)

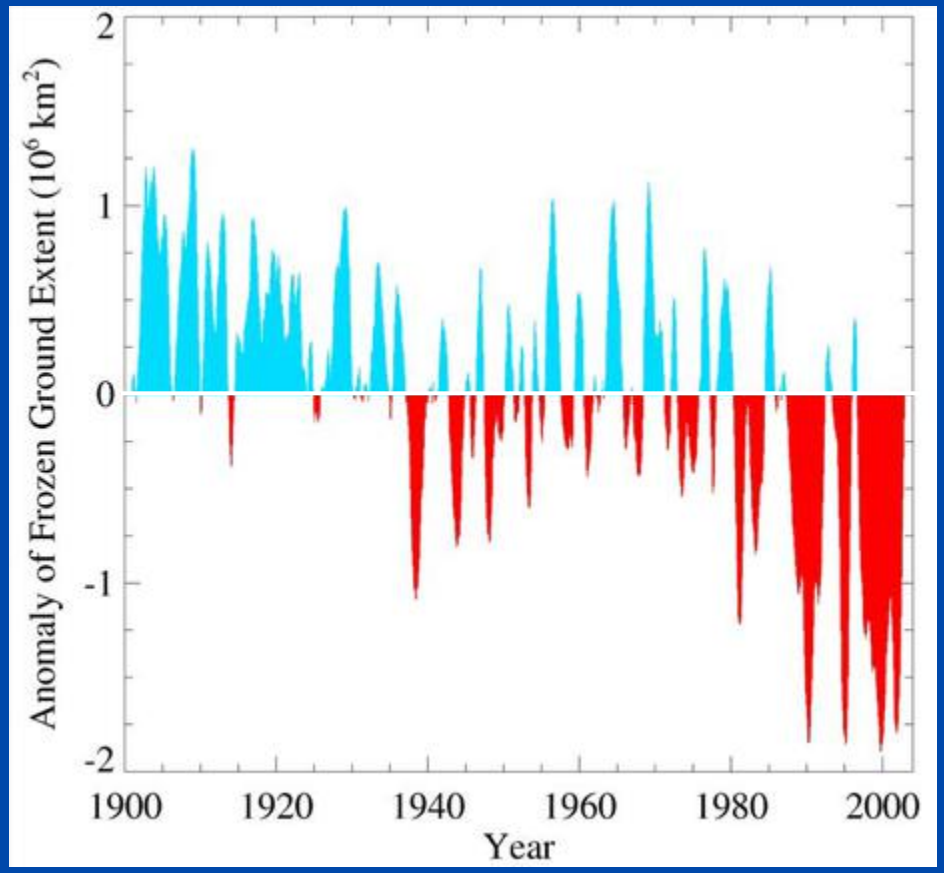
- International scientific consensus
  - The majority of atmospheric scientists agree
  - A few do not agree
- Series of important reports based on scientific method (not infallible, but high quality)
- Nobel Peace Prize
- Look for yourselves: Good website http://www.ipcc.ch/

IPCC Report 2007

Glaciers and frozen ground are receding

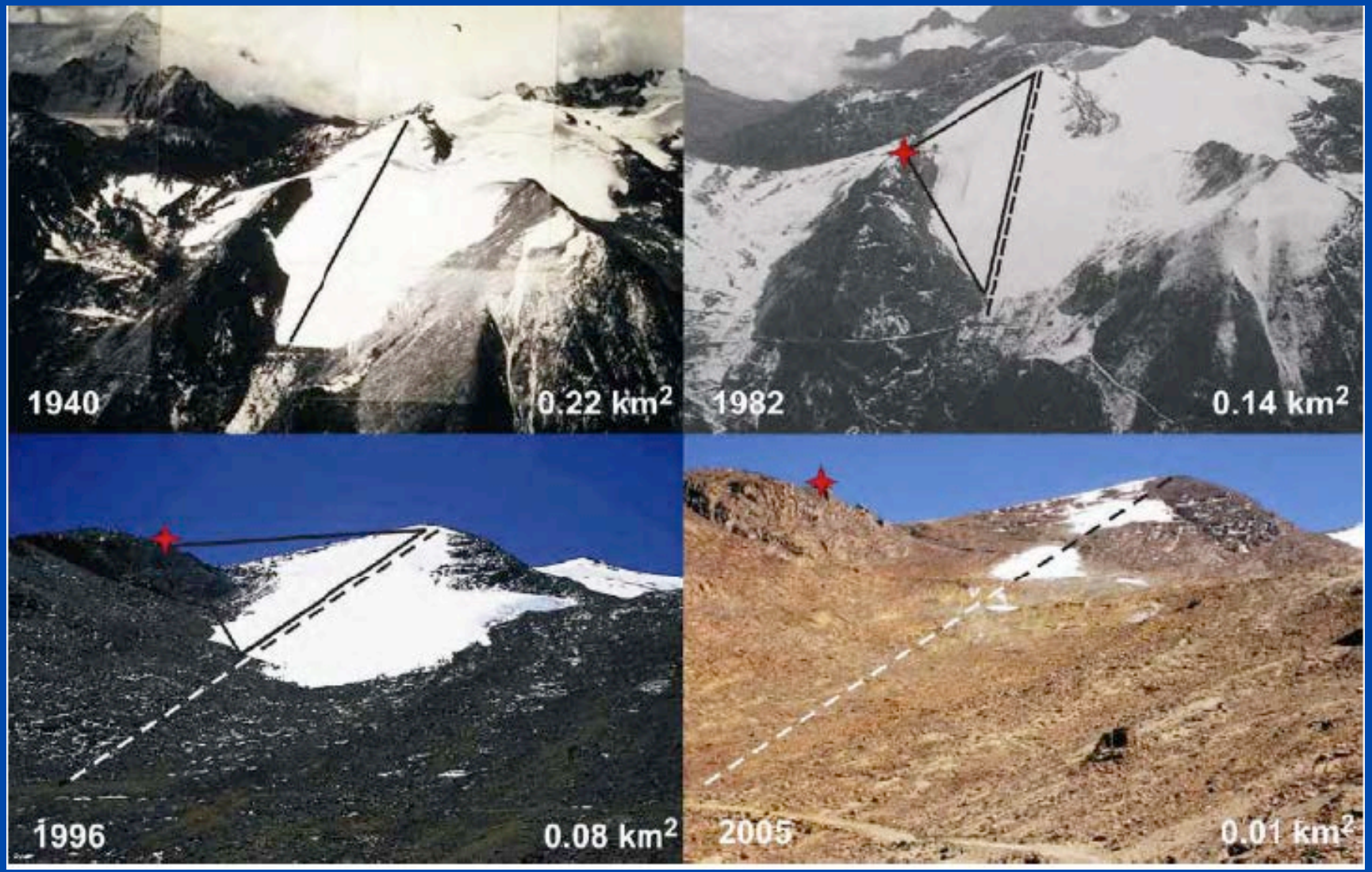


Increased Glacier retreat since the early 1990s

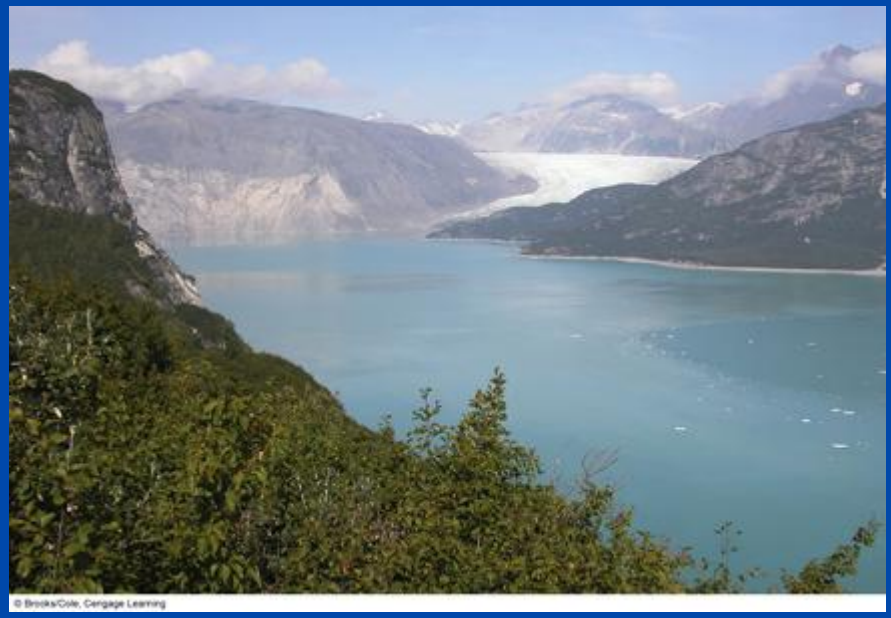


Area of seasonally frozen ground in NH has decreased by 7% from 1901 to 2002

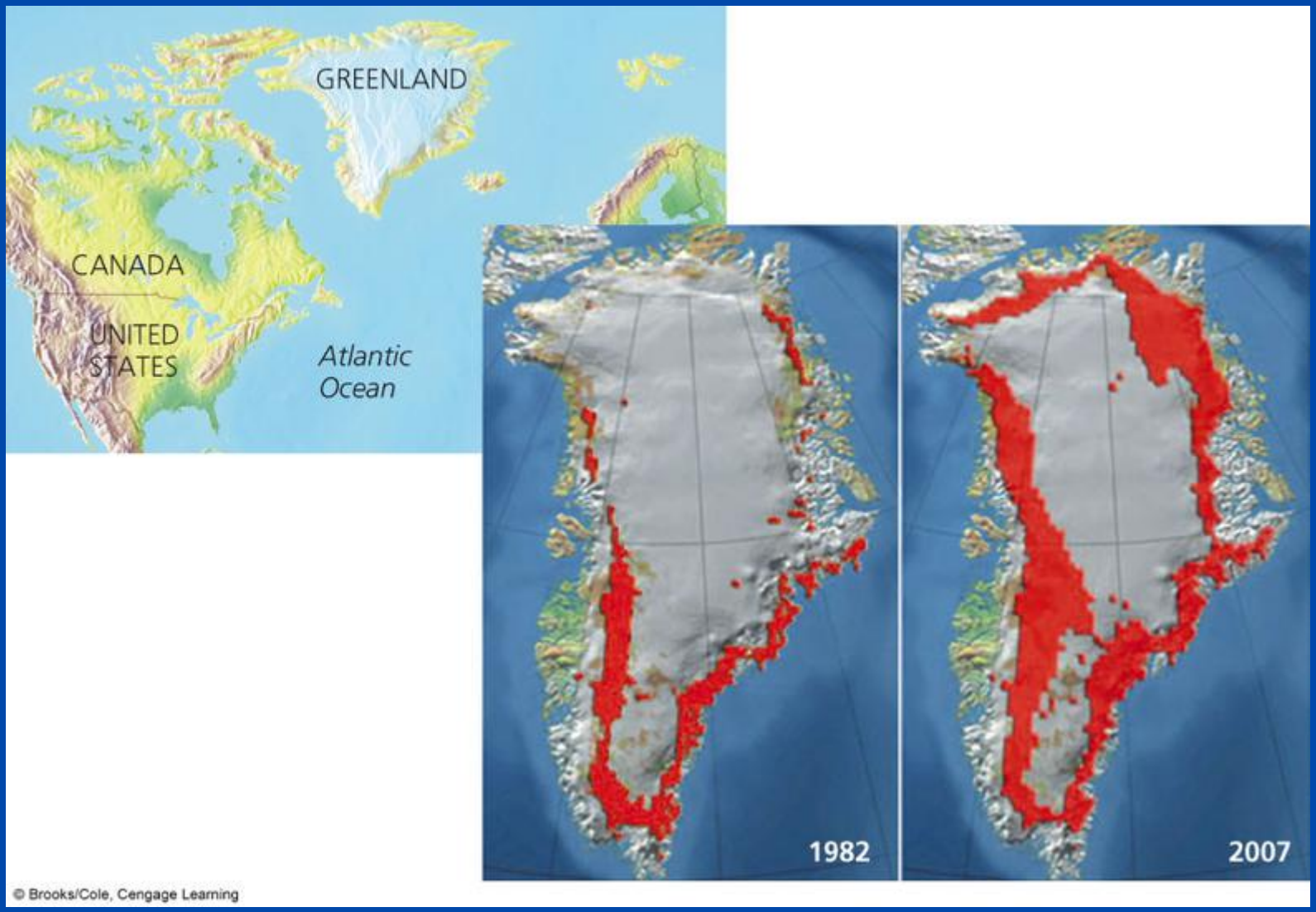
The Chacaltaya Glacier and Ski Lift, Bolivia



Melting of Alaska's Muir Glacier between 1948 and 2004

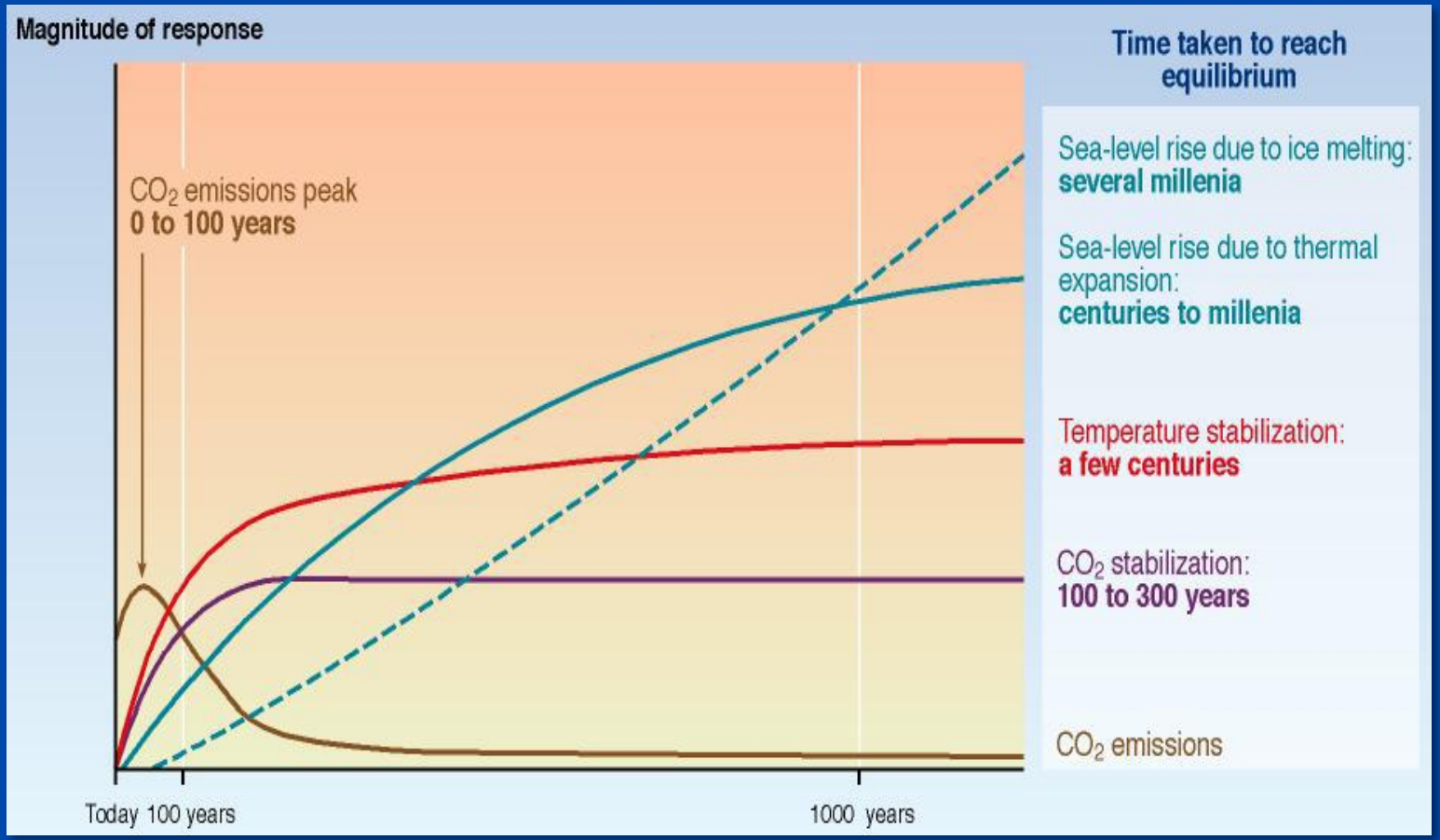


Summer Glacial Ice Melting in Greenland, 1982 - 2007



Global temperature will keep rising even after CO_2 emissions are reduced

IPCC Report 2007



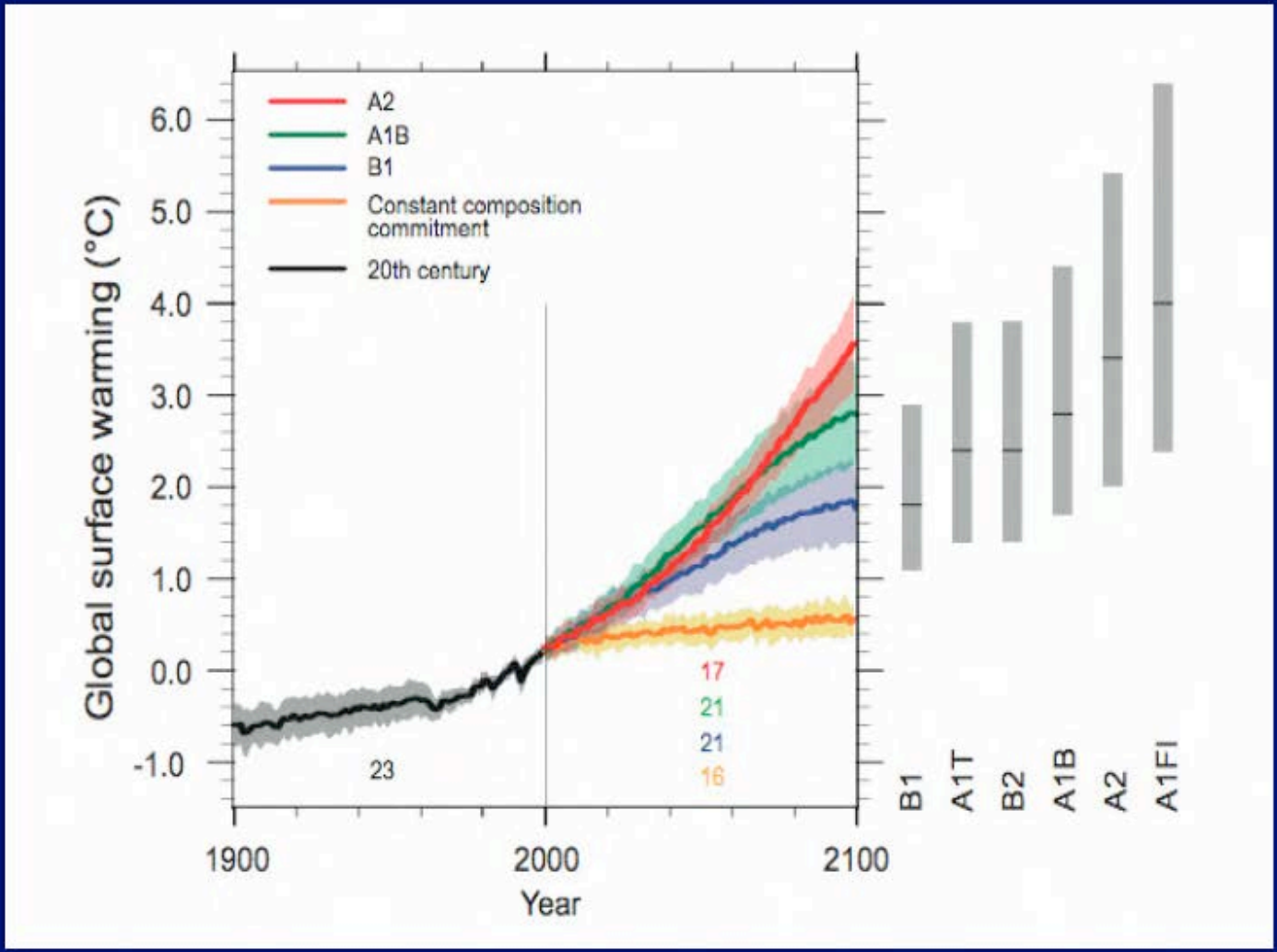
Once CO_2 gets into atmosphere, it stays there for hundreds of years!

Projections of Future Changes in Climate

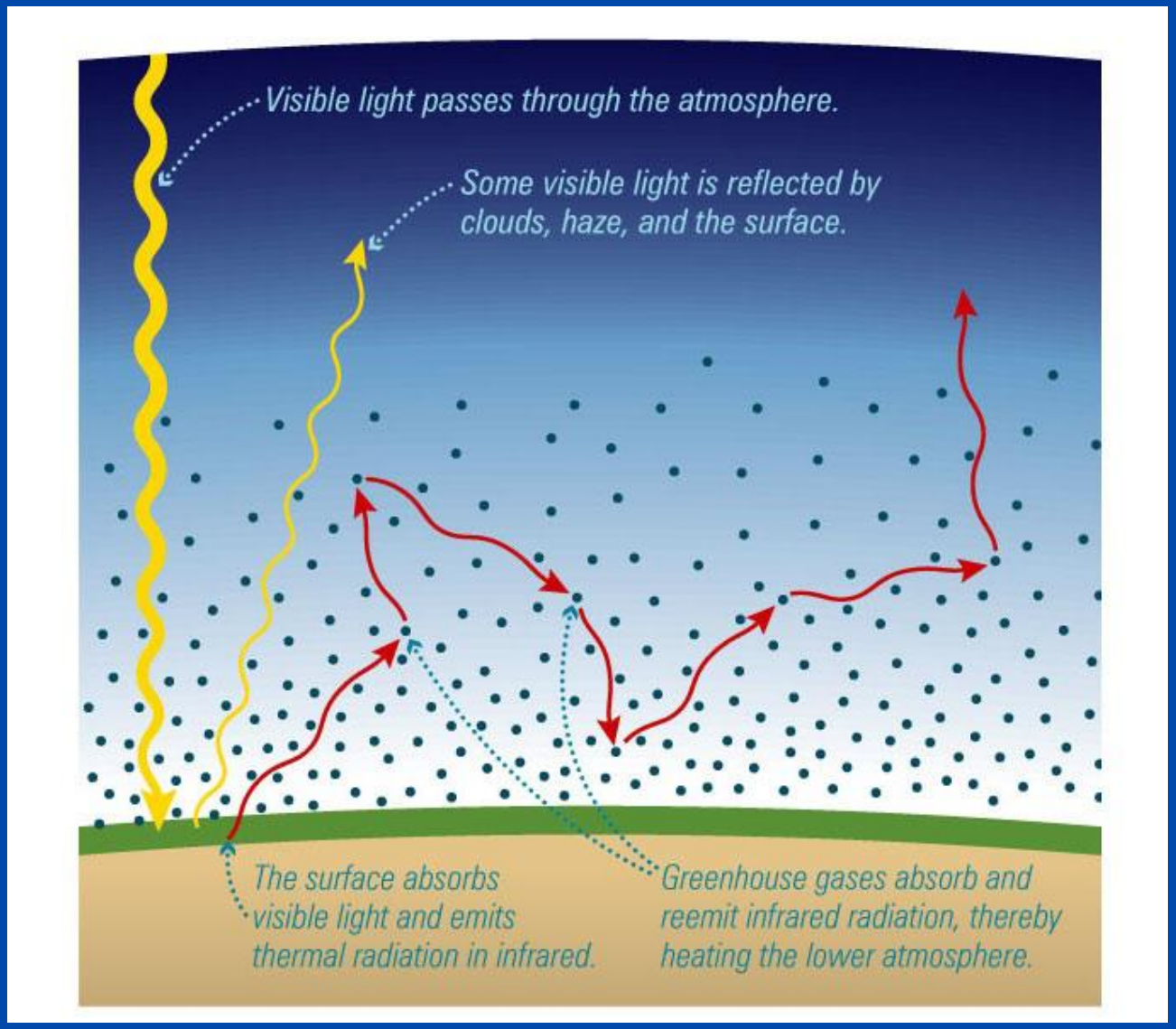
Best estimate for low scenario (B1) is 1.8°C (*likely* range is 1.1°C to 2.9°C),

and

for high scenario (A1FI) is 4.0°C (*likely* range is 2.4°C to 6.4°C).



The greenhouse effect: What about Venus and Mars?

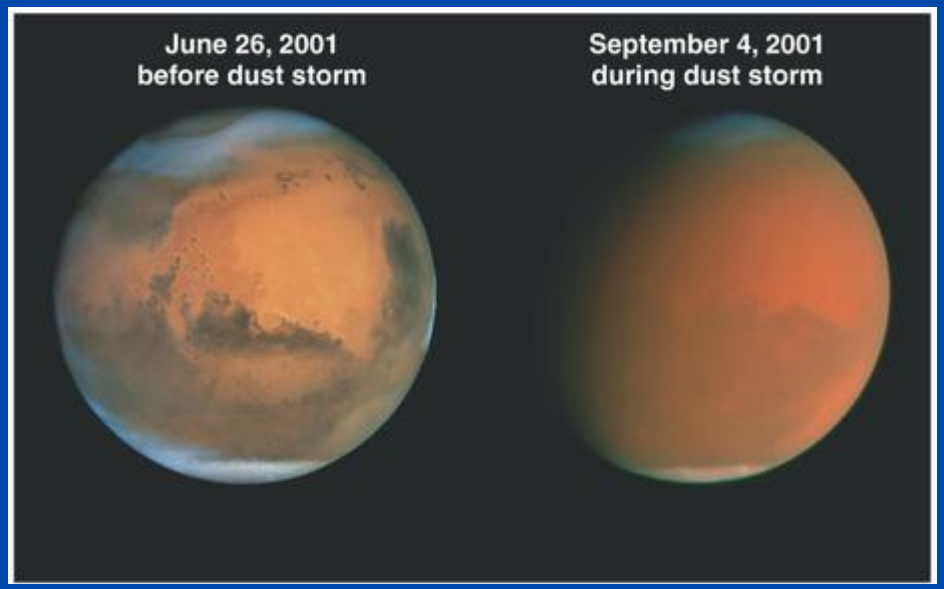


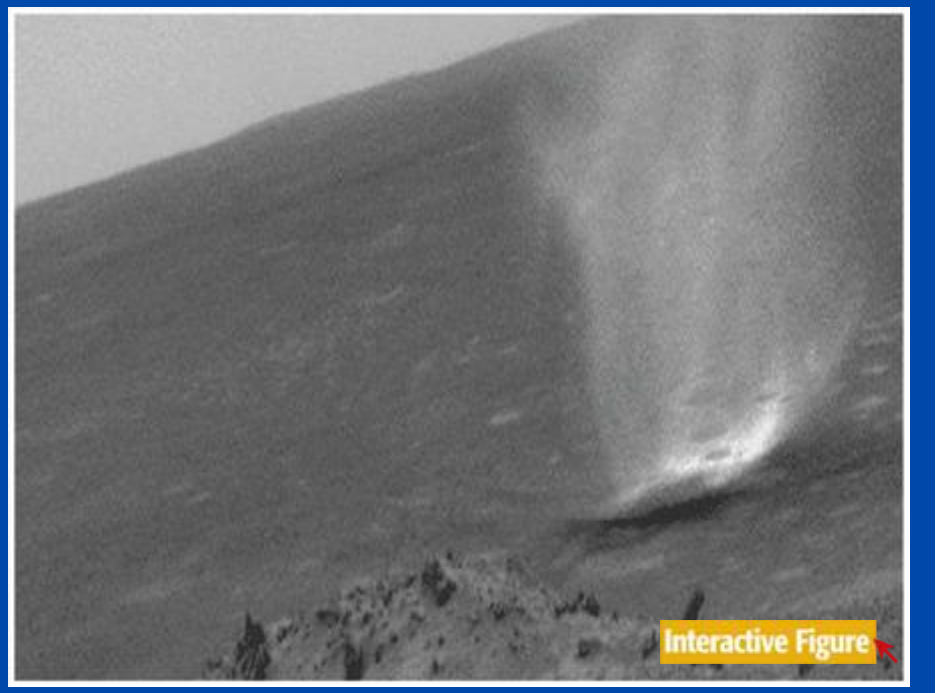
The Atmospheric History of Mars

- **Main questions:**
  - **What is Mars like today?**
  - **Why did Mars change?**

Mars' surface today: dry and barren

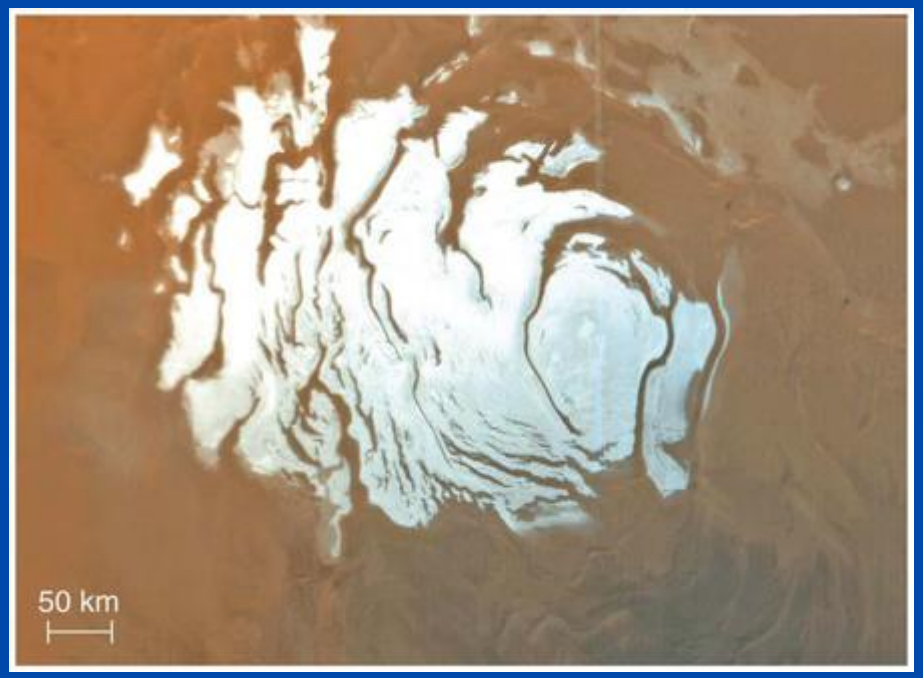
Dust Storms on Mars





- Seasonal winds can drive dust storms on Mars.
- Dust in the atmosphere absorbs blue light, sometimes making the sky look brownish-pink.

Mars today has polar ice caps (though different from Earth's)



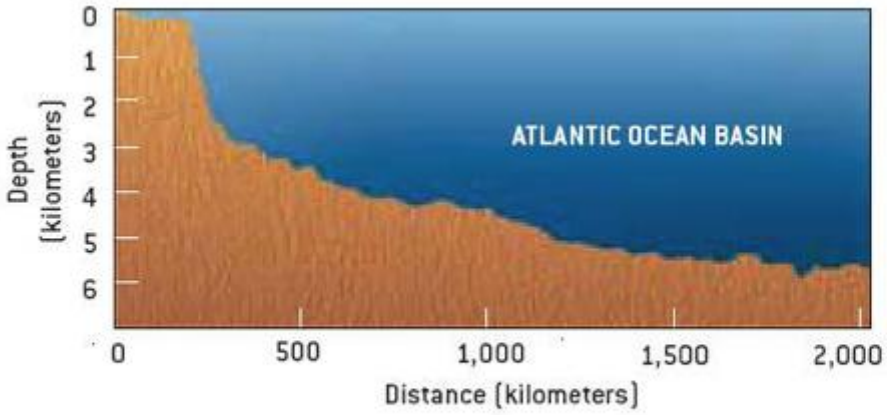
- **Residual ice of the south polar cap remaining during summer is primarily water ice.**
- **Carbon dioxide ice of polar cap sublimates as summer approaches and condenses at opposite pole.**

Why did Mars' climate change?

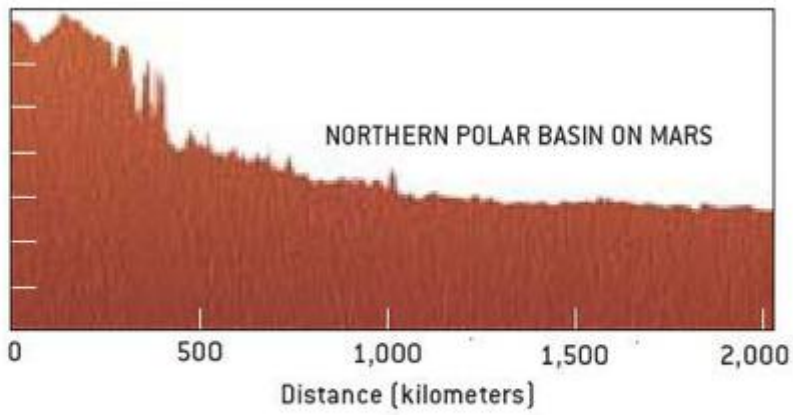
- Evidence of previous era when liquid water was plentiful
- Today: Evidence for ice mixed with soil in top meter of ground

There was once liquid water on Mars

- Geomorphological evidence (*lots* of it)
  - River and flood channels, alluvial fans, slumps, canyons, ...
- One more piece of evidence: shape of ocean basins

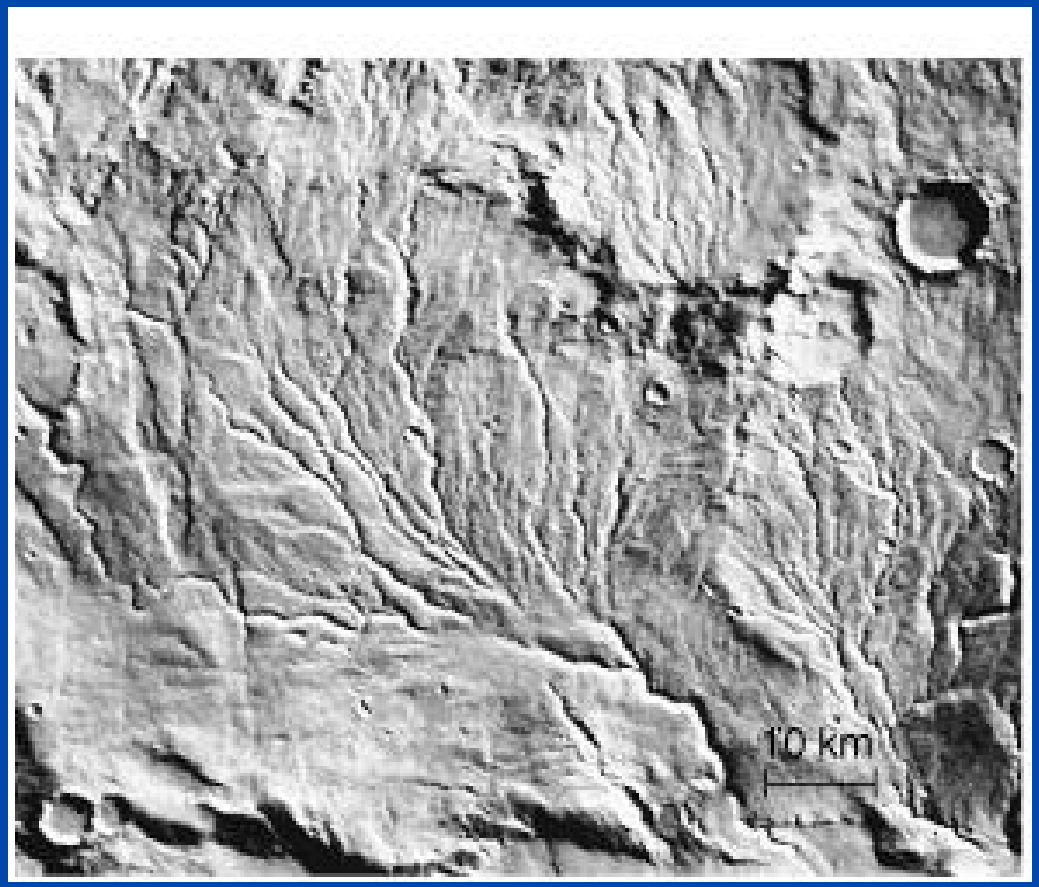


TOPOGRAPHIC MAPPING of Mars has recently revealed remarkable similarities to the ocean basins on Earth. For example, the western



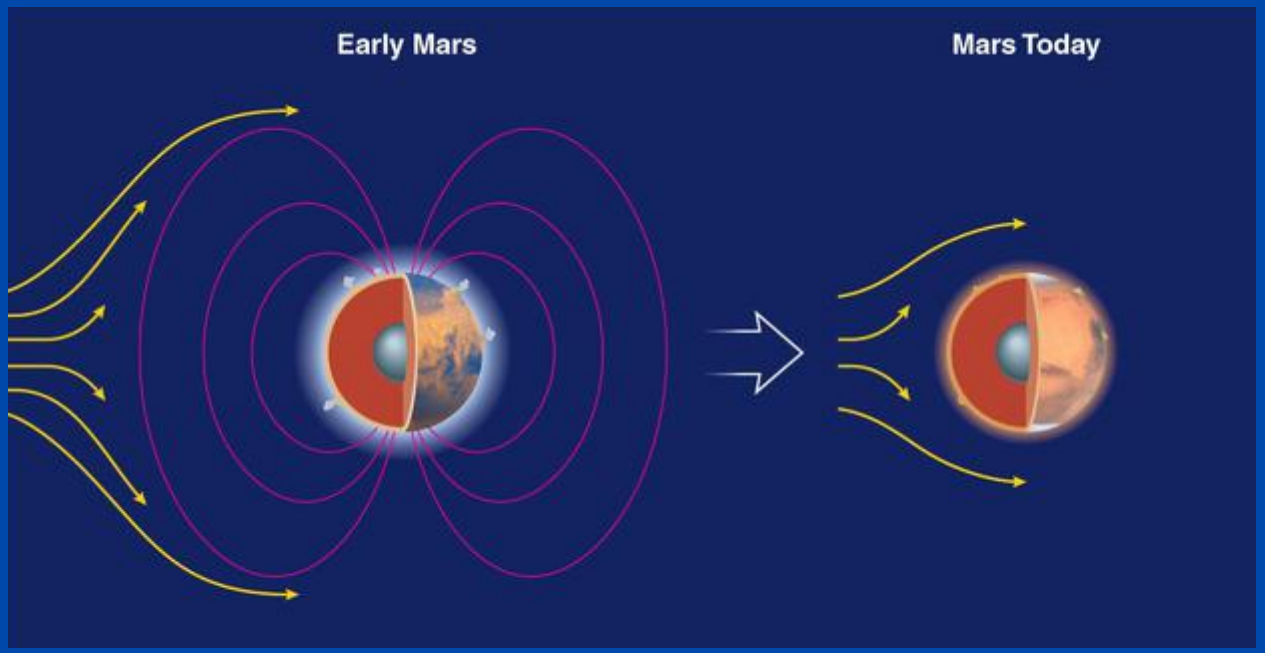
Atlantic near Rio de Janeiro (*left*) presents a similar profile to that of the northern polar basin on Mars (*right*).

Climate Change on Mars



- Mars has not had widespread surface water for 3 billion years
- Greenhouse effect probably kept surface warmer before that
- Somehow Mars lost most of its atmosphere (no more Greenhouse)

Climate Change on Mars: Role of magnetic field



- Magnetic field may have helped protect early Martian atmosphere from solar wind.
- Solar wind could have stripped atmosphere after field decreased because of interior cooling.

Mars' atmosphere affected by both volcanoes and B fields?

- Shortly after Mars formed, its surface temperature was ~ equal to its equilibrium blackbody temperature (around -55 C).
- As volcanoes dumped CO_2 and H_2O vapor into atmosphere, greenhouse effect increased temperature above 0 C (freezing) so liquid water could exist.
- Two competing effects determined amount of CO_2 in atmosphere: volcanoes adding CO_2, and rocks absorbing CO_2. Result: moderate level of CO_2 .
- Greenhouse effect could keep surface T > 0 C, as long as volcanoes kept erupting.
- Eventually Mars' core cooled and solidified (Mars is small). Volcanic activity subsided. Magnetic field went away, solar wind particles eroded atmosphere.
- Once rate of eruptions tapered off, CO_2 in the atmosphere started to fall.
- As the atmosphere thinned out, the greenhouse effect weakened. Eventually the average surface temperature dropped, and surface water froze.

Atmosphere of Venus Today

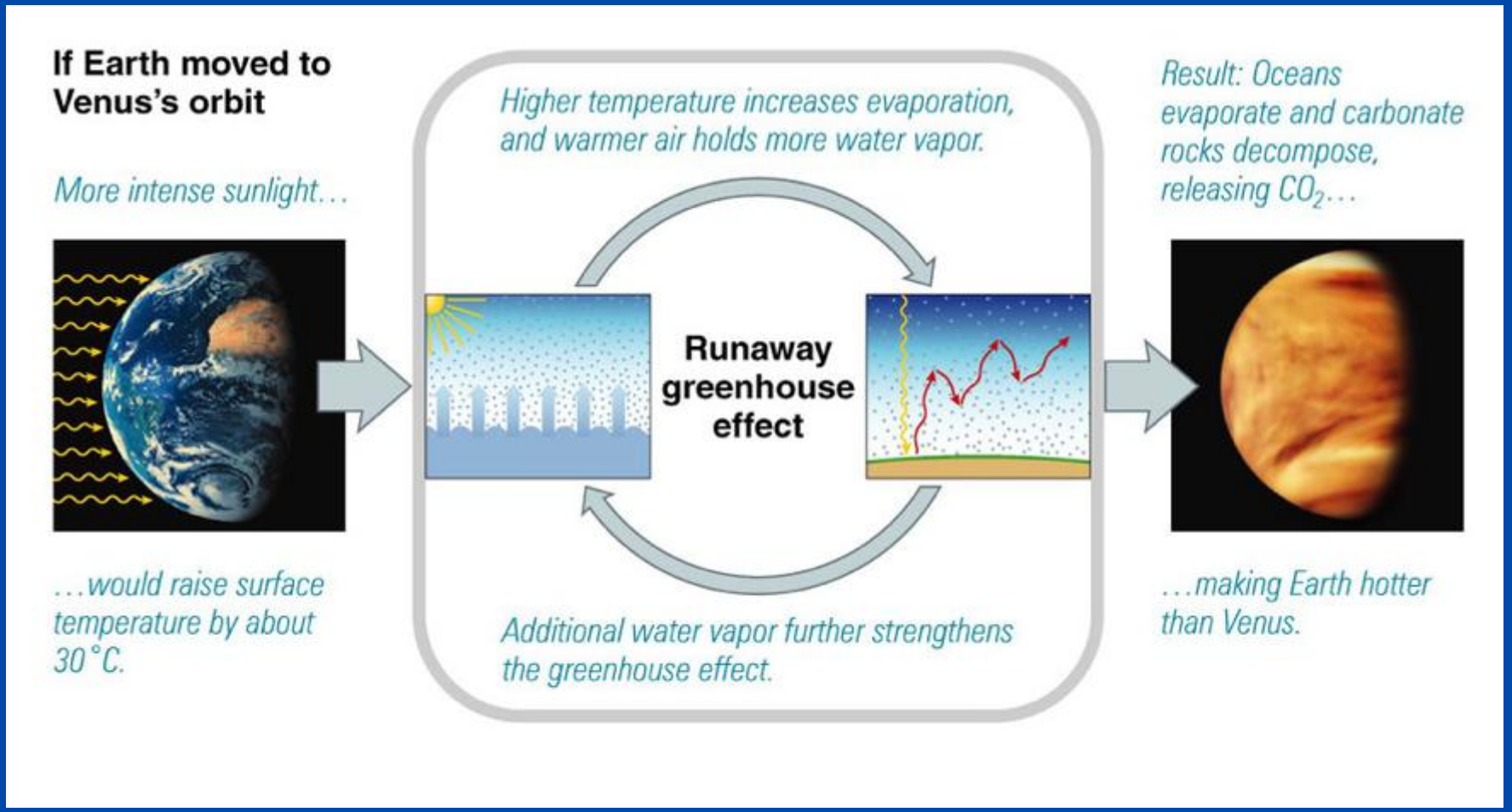
- Venus has a very thick carbon dioxide atmosphere with a surface pressure 90 times that of Earth.
- Surface temperature very high.
- Slow rotation produces little weather.

Visible wavelength image of day side (red-orange); infrared image of night side (blue)

Greenhouse Effect on Venus

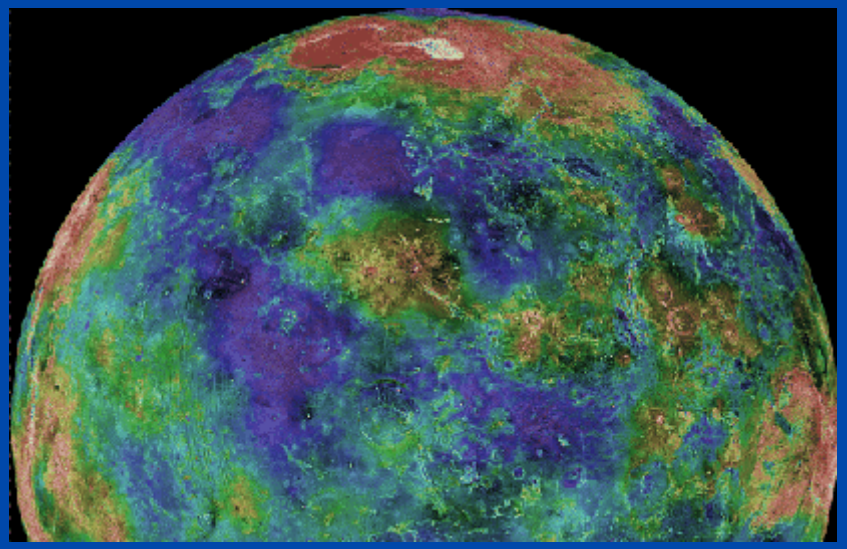
- **Thick carbon dioxide atmosphere produces an extremely strong greenhouse effect.**
- **Earth escapes this fate because most of its carbon and water is in rocks and oceans.**

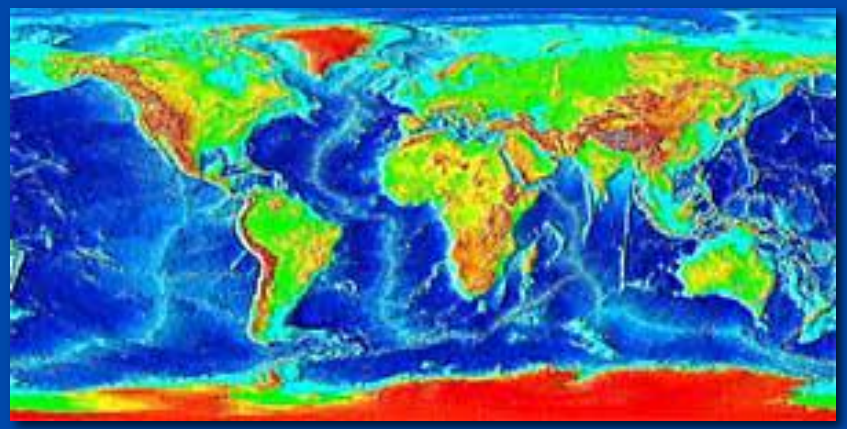
Venus Climate Today: Due to runaway greenhouse effect



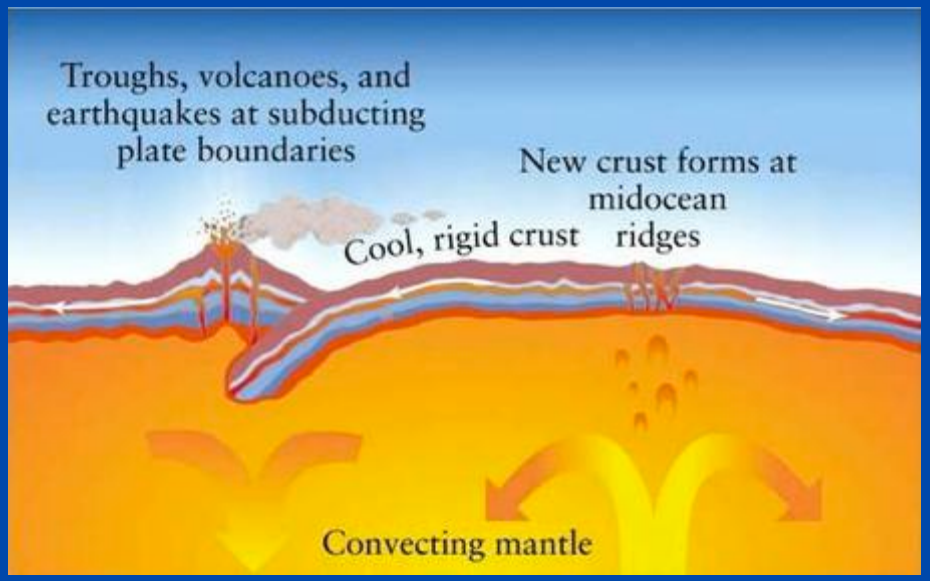
Venus plate tectonics?

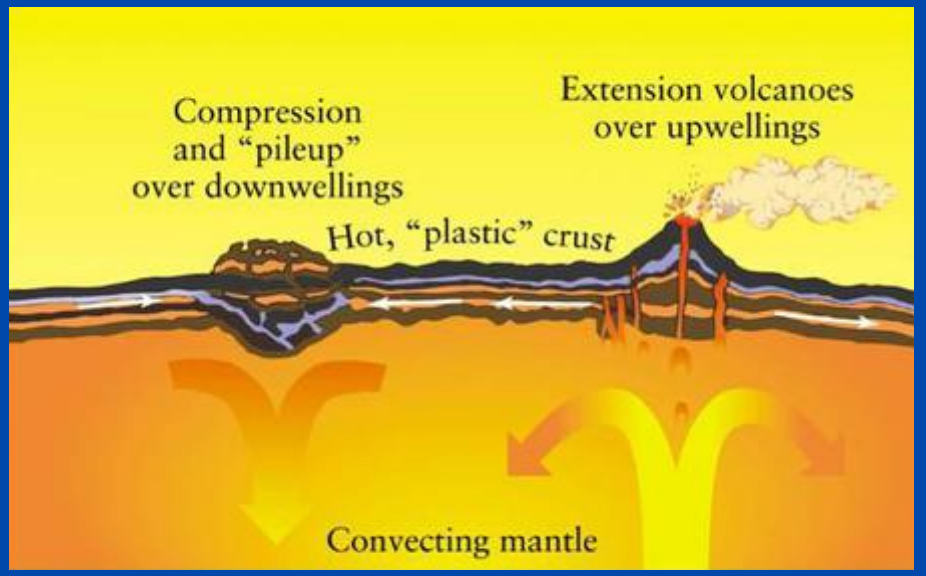
- No evidence for plate tectonics on Venus
  - No mid-ocean rifts
  - No subduction trenches
- Volcanos spread evenly across surface instead of at plate boundaries, as on Earth.
- Lithosphere not broken into plates; probably because heat at surface slightly softens the lithosphere.





Subduction of Earth's crust takes carbon out of atmosphere





Credit: The New Solar System, Sky Publishing Corporation

- **Carbonates on rock surfaces and from shells of sea life are subducted along with crust on Earth**
- **Takes Carbon out of atmosphere, so it can't form CO_2**
- **Doesn't happen on Venus (any more …)**

Resurfacing on Venus

- Venus has far fewer impact craters than Moon & Mercury
  - Dense atmosphere protects it
  - Volcanic resurfacing has erased most small craters
- Surface age is < a billion years.
  - Venus was "resurfaced" by lava flows during relatively short period
- This differs profoundly from Earth's crustal history. What is it telling us?
  - Could Venus' present crust only have formed that recently?
  - Could there have been a growing crust before 1 billion years ago that "turned over" as heat built up underneath, to lead to a new era of major lava flows?
- Is this event correlated with the end of plate tectonics due to “bake-out” of water from surface rocks?

The Main Points

- **Atmospheres of terrestrial planets are very different now from the way they were born**
  - **Formation: volcanoes, comets**
  - **Destruction: escape, incorporation into rocks, oceans**
  - **Huge changes over a billion years or less**
- **Prospect of human-induced global warming on Earth needs to be taken seriously**