[17] Magnetic Fields, and long-term changes in climate (10/26/17)

Upcoming Items

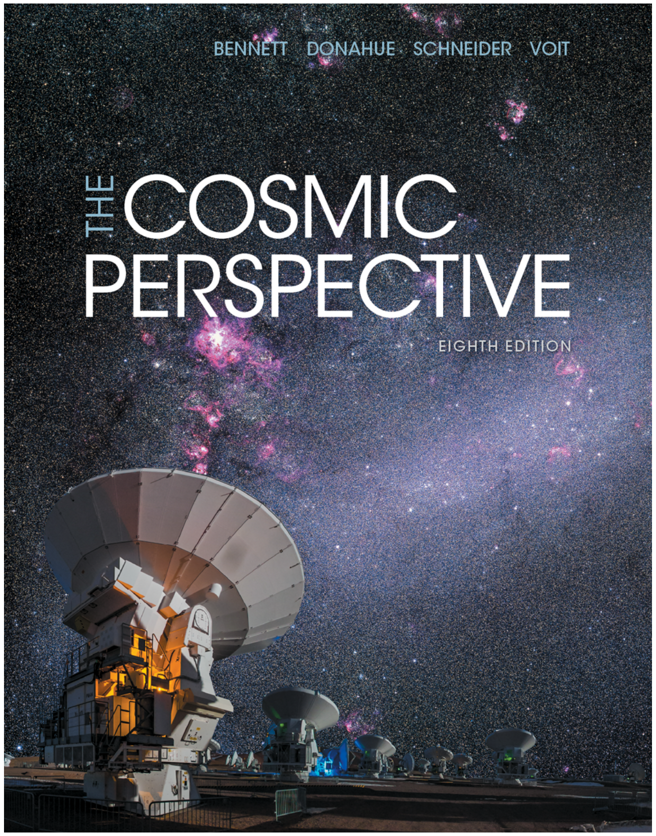
1. Read Chapter 11, do the self-study quizzes
2. Midterm #2 on Tuesday, November 7
   On classes from Oct 5 through Oct 31 inclusive; note that some of that assumes you haven't forgotten previous work ☺

LEARNING GOALS

Chapters 9.1–9.2

For this class, you should be able to…

- … *understand the causes and effects of planetary magnetic fields;*
- … *understand some of the issues related to very long-term climate change, and the human influence*



Any astro questions?

In-class Quiz

1. How do magnetic fields protect atmospheres?
   (a) They divert high-energy charged particles.
   (b) They cool the atmosphere, reducing its scale height.
   (c) The atmosphere is held in by magnetic fields.
   (d) They deflect meteorites to the magnetic poles.

2. Carbon dioxide is a major greenhouse gas. Where is most of the carbon dioxide on Earth?
   (a) In the atmosphere.
   (b) In carbonate rocks.
   (c) In the oceans.
   (d) In the terrestrial biosphere.

Of Possible Interest

- Today 4-5 PM, PSC 1136
- Dr. Erin Kara (one of our Astronomy postdocs) “will be leading an interactive workshop based on some things that she learned recently at an Alan Alda Science Communication Workshop at the Space Telescope Science Institute, such as on techniques for communicating with other scientists, reporters and the public.”
- You’re welcome to come by!

Debate Next Time

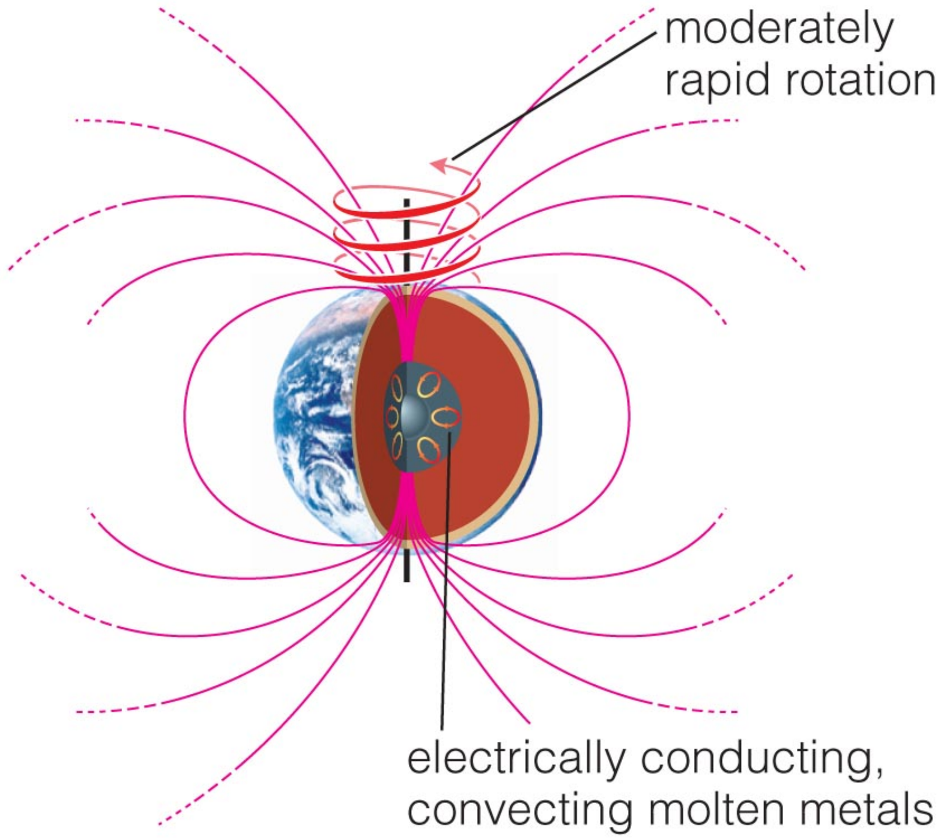
- In honor of Tuesday's date, candy should be provided ☺
- Debate topic:

  Which is more likely to host current life: Mars or Europa?

Magnetic Fields

- We have not yet had an opportunity to discuss magnetic fields, but they are fundamental to many aspects of astronomy
- Magnetic fields are produced by electrical currents (look up Maxwell's Equations!)
  This is easiest if there is actual motion (like in an electromagnet), but can also come from magnetic "domains" (like in the iron in a permanent magnet; this is called ferromagnetism, because ferro- means iron)
- Thus their relation to geological motion, and atmospheres, makes this a good time to treat magnetic fields
- Note: magnetic fields do not require net electric charge; that's why they can be important even if charge isn't (electrons going one way have the same effect as protons going the other)

Planetary Magnetic Fields



- Moving charged particles create magnetic fields.
- So can a planet's interior, if the core is *electrically conducting*, *convecting*, and *rotating*, i.e., hot!

Role of Rotation

- Planets with slower rotation have less weather, less erosion, and a weak magnetic field.
- Planets with faster rotation have more weather, more erosion, and a stronger magnetic field.

Magnetic Fields

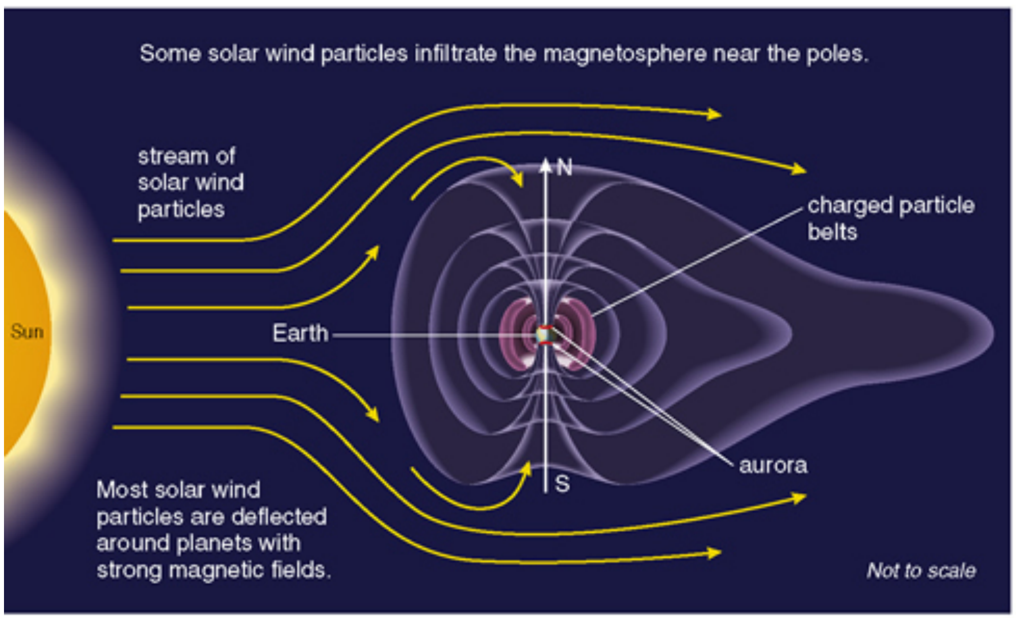
- A planet's magnetic field gives us more information on the interior structure.
- Earth's magnetic field…
  - "Dipole" form (same as bar magnet).
  - Due to currents flowing in the molten interior of the rotating Earth, forms a "dynamo."
  - In general, the presence of a global (dipole) magnetic field signals the presence of electrical currents in a rotating, convecting fluid interior.
  - Magnetic field reverses direction, irregularly, a few times per million years Key evidence for plate tectonics, sea floor spreading!
  - Reversal is much more regular on the Sun; solar cycle

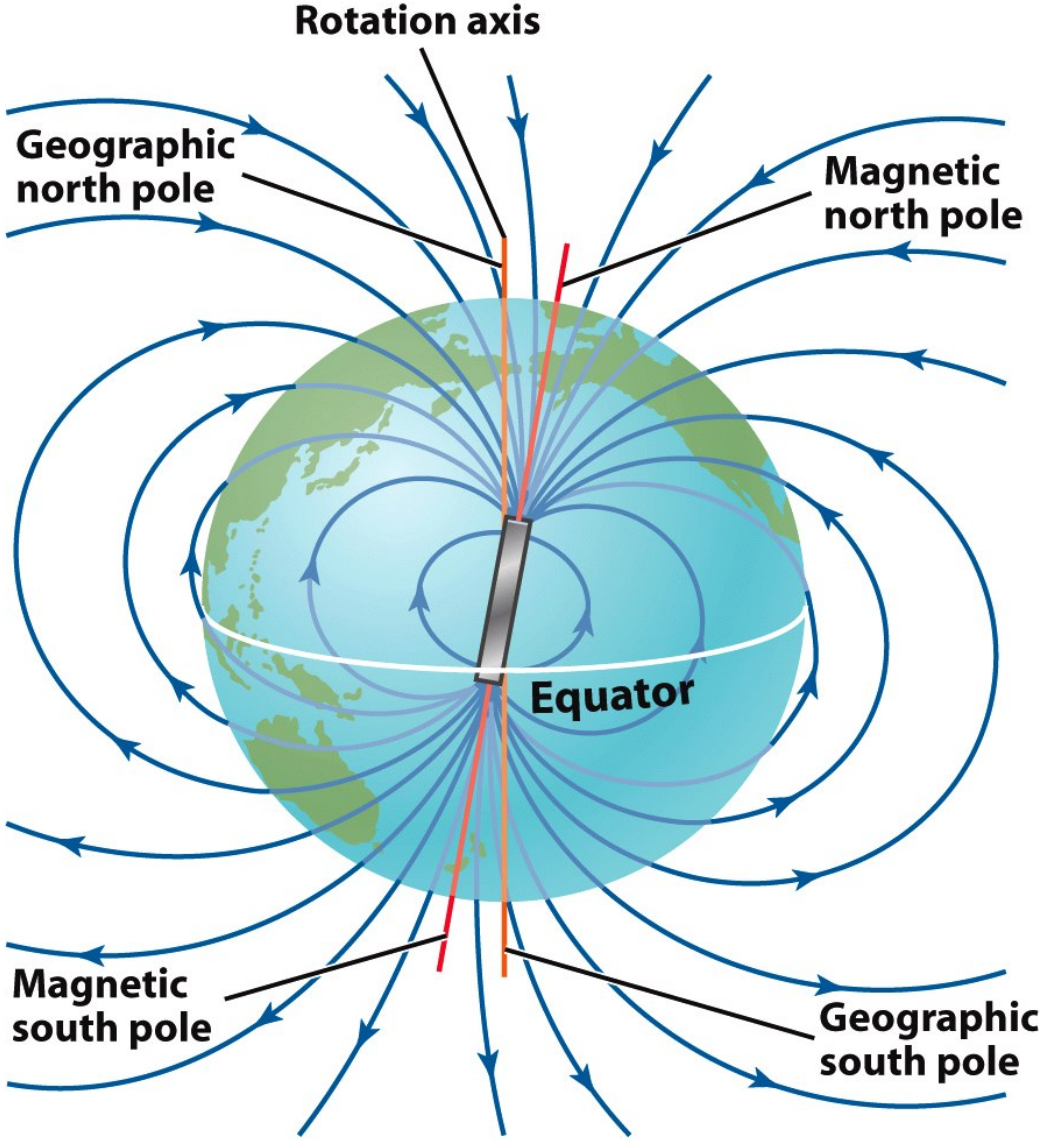
Diversity of Magnetic Properties

- Mercury
  - Weak global field.
  - Tidal effects due to eccentric orbit keep interior fluid, convecting.
- Venus
  - No global field (despite presumed fluid interior!).
  - Slow rotation, and maybe no convection?
- Earth
  - Moderate strength global field (fluid interior).
- Mars
  - No global field (no fluid interior).

Earth's Magnetosphere

- Earth's magnetic fields protect us from solar wind (stream of charged particles).
- The charged particles can create aurorae (e.g., the "Northern lights").

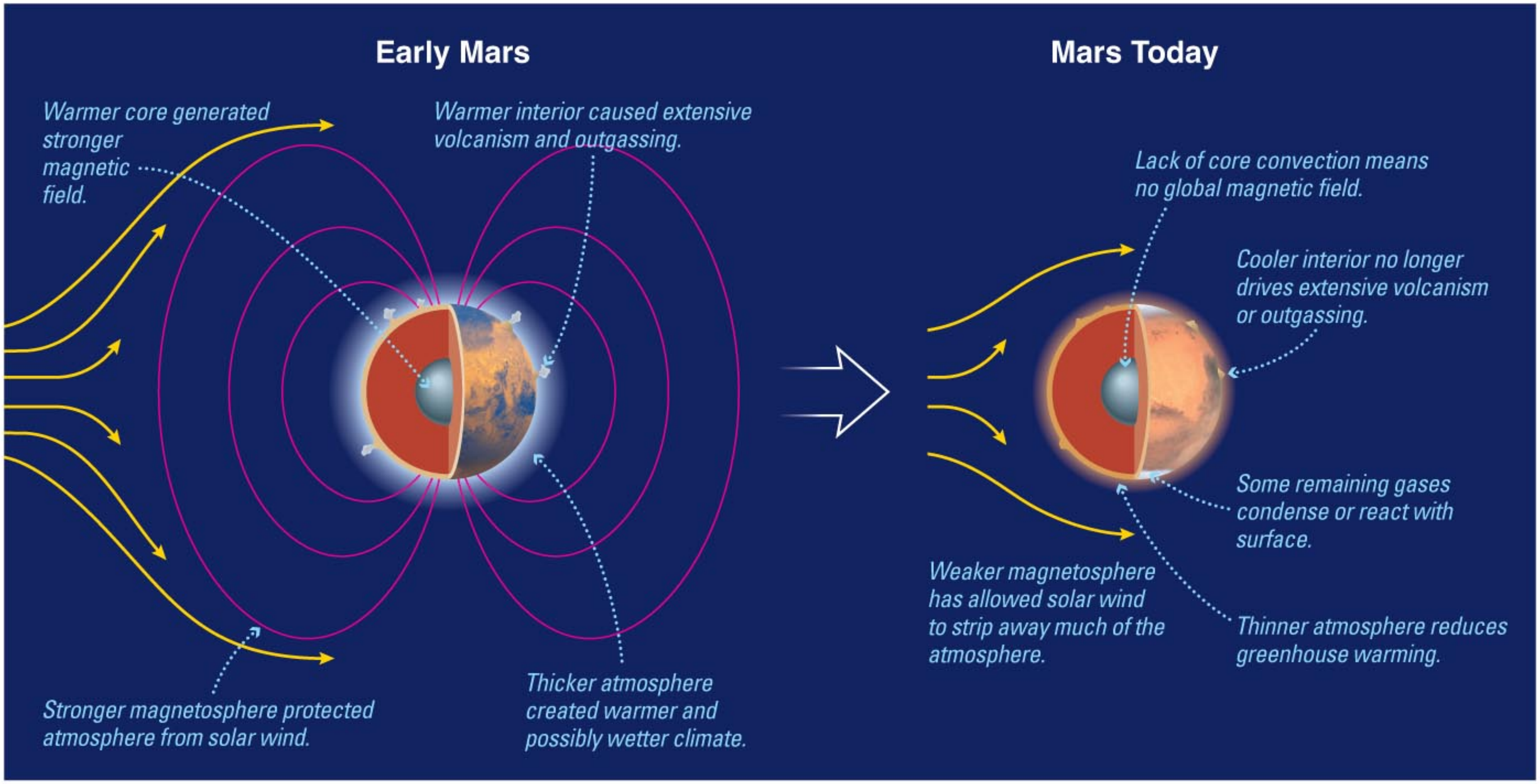



Rotation axis
Geographic north pole
Magnetic north pole
Equator
Magnetic south pole
Geographic south pole

Aurora

b This photograph shows the aurora near Yellowknife, Northwest Territories, Canada. In a video, you would see these lights dancing about in the sky.

- Charged particles from solar wind energize the upper atmosphere near magnetic poles, causing an aurora.
- How many of you have seen an aurora?

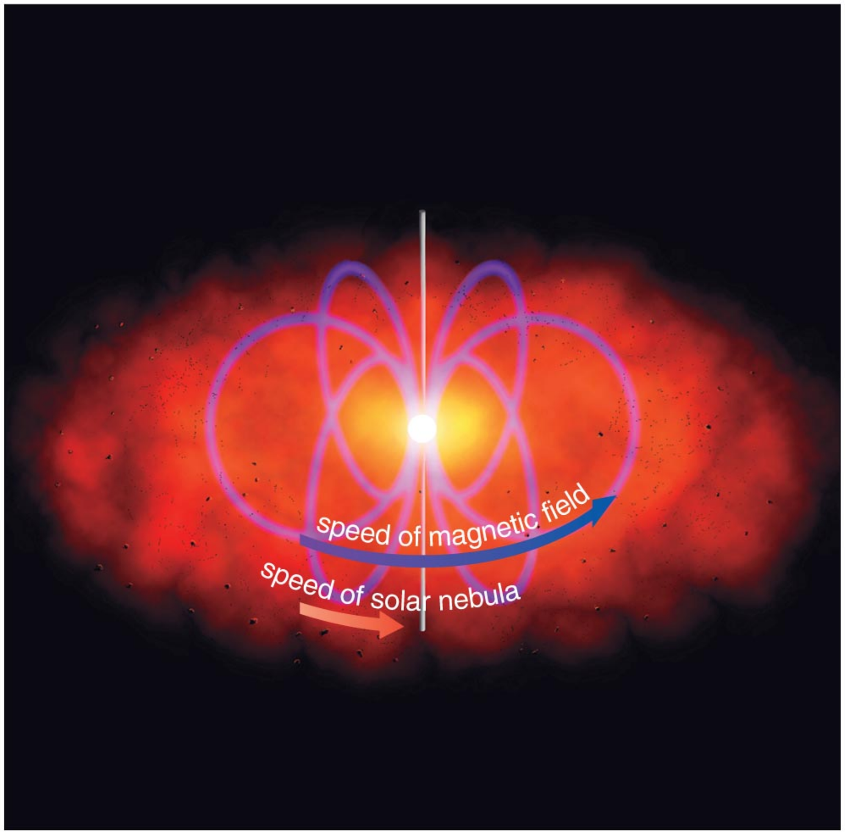


- Magnetic field may have preserved early Martian atmosphere.
- Solar wind may have stripped atmosphere after field decreased because of interior cooling.

Jovian Planet Magnetic Fields

- Jupiter and Saturn
  - Strong global field.
  - Currents generating field are produced in the “metallic hydrogen” in the core. In what sense is it “metallic”? How high a density is needed?
- Uranus and Neptune
  - Moderate global field.
  - Currents generating field are flowing in liquid water containing dissolved ions.

Magnetic Braking



- In nebular theory, young Sun rotated much faster than now (and was much more active as a result).
- Interaction between solar magnetic field and ionized nebula particles slowed the rotation over time.
- Solar wind particles also removed angular momentum from Sun.

Magnetic Braking and the Solar Wind

- Solar wind particles follow the solar magnetic field out to large distances, keeping their initial angular speed.
- When these particles escape the Sun, they carry more angular momentum than they did at the Sun's surface.
  - Angular momentum $L = mrv_{\perp} = m\Omega r^2$ (here Ω is constant).
  - A particle released 10× farther away will carry 100× more angular momentum!

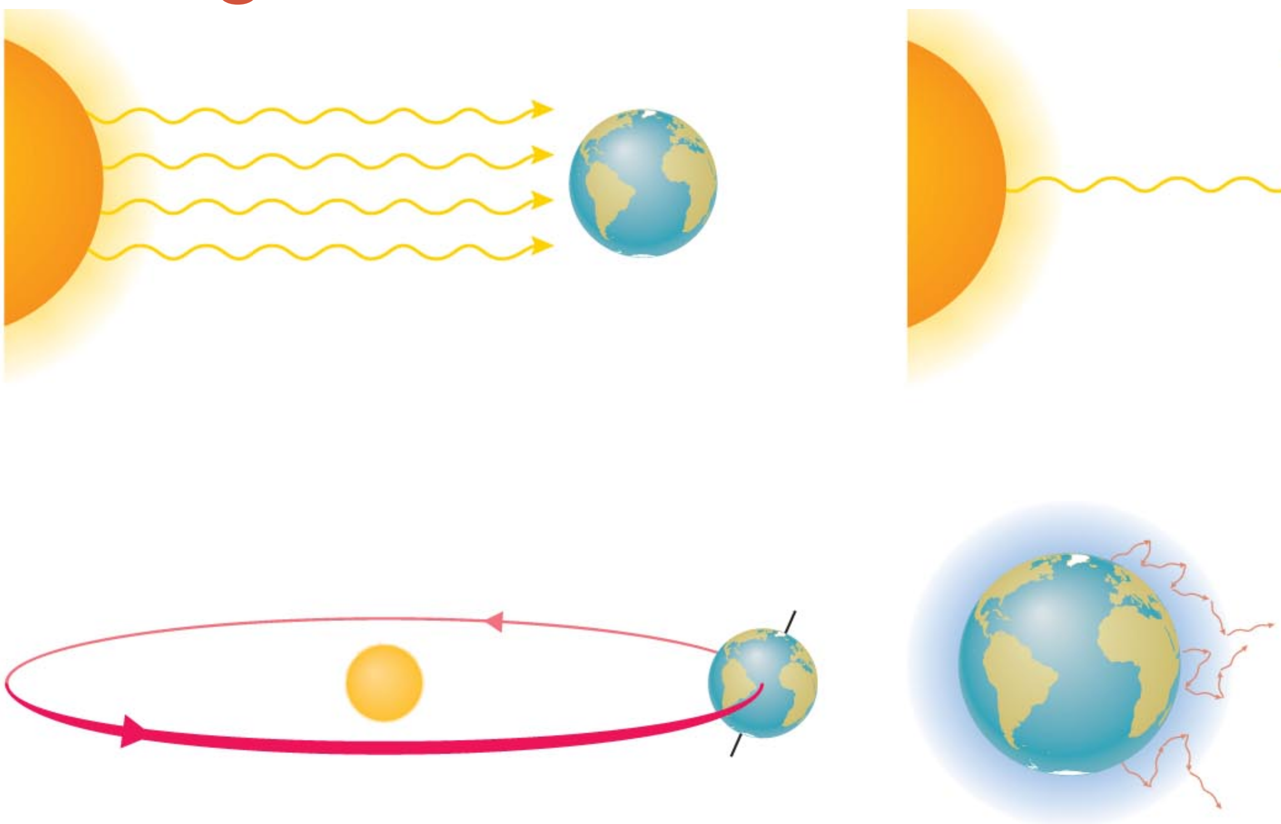
Questions or Comments?

- Any questions or comments about magnetic fields before we move on to issues of climate change?

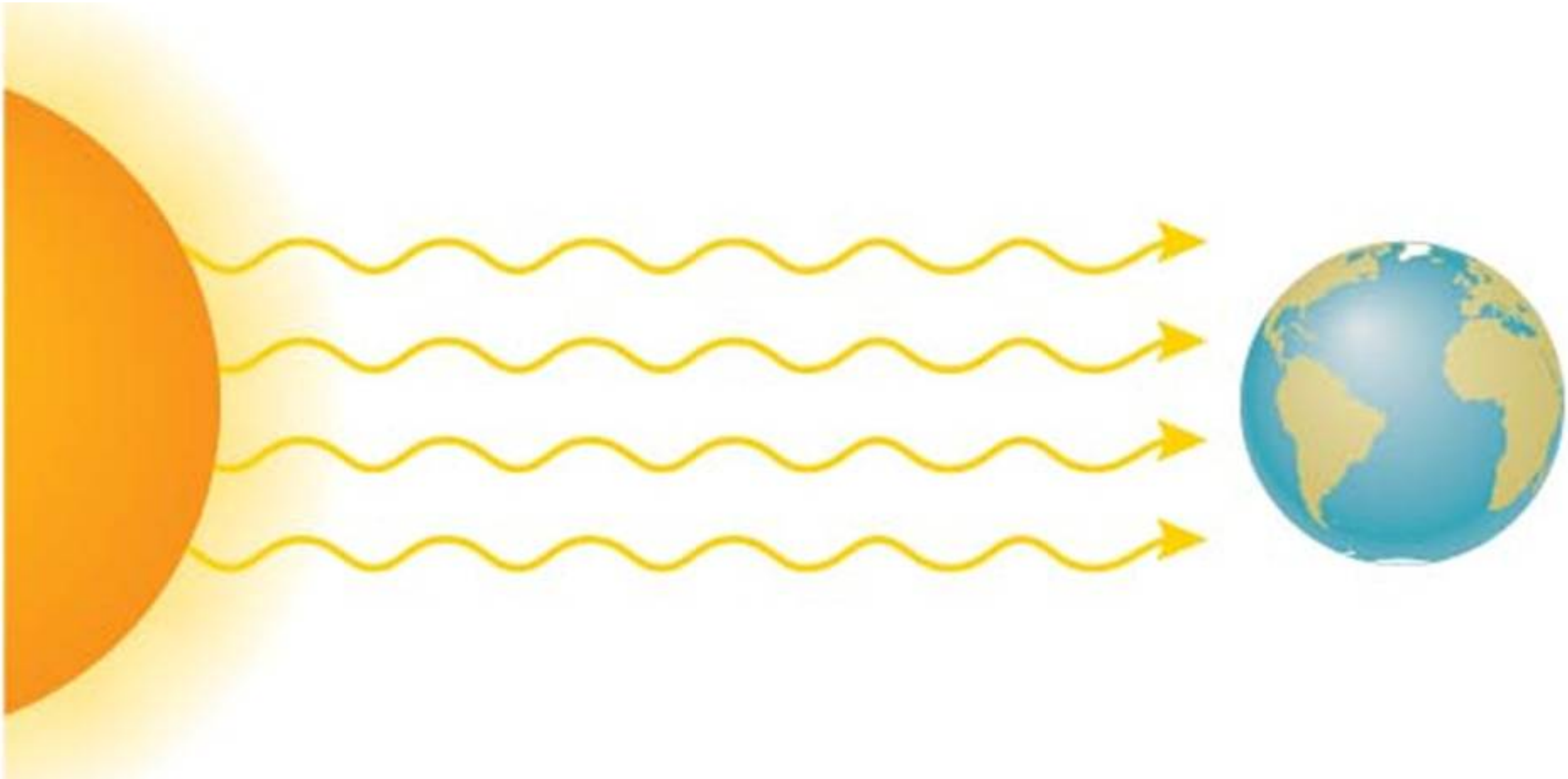
Group Question

- What are some factors that can contribute to *long-term* climate change?

What factors can cause long-term climate change?

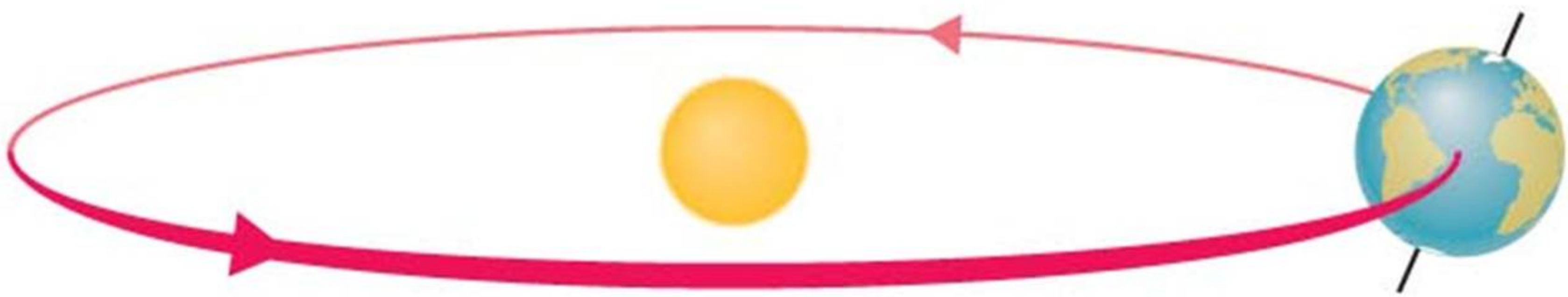


Solar Brightening



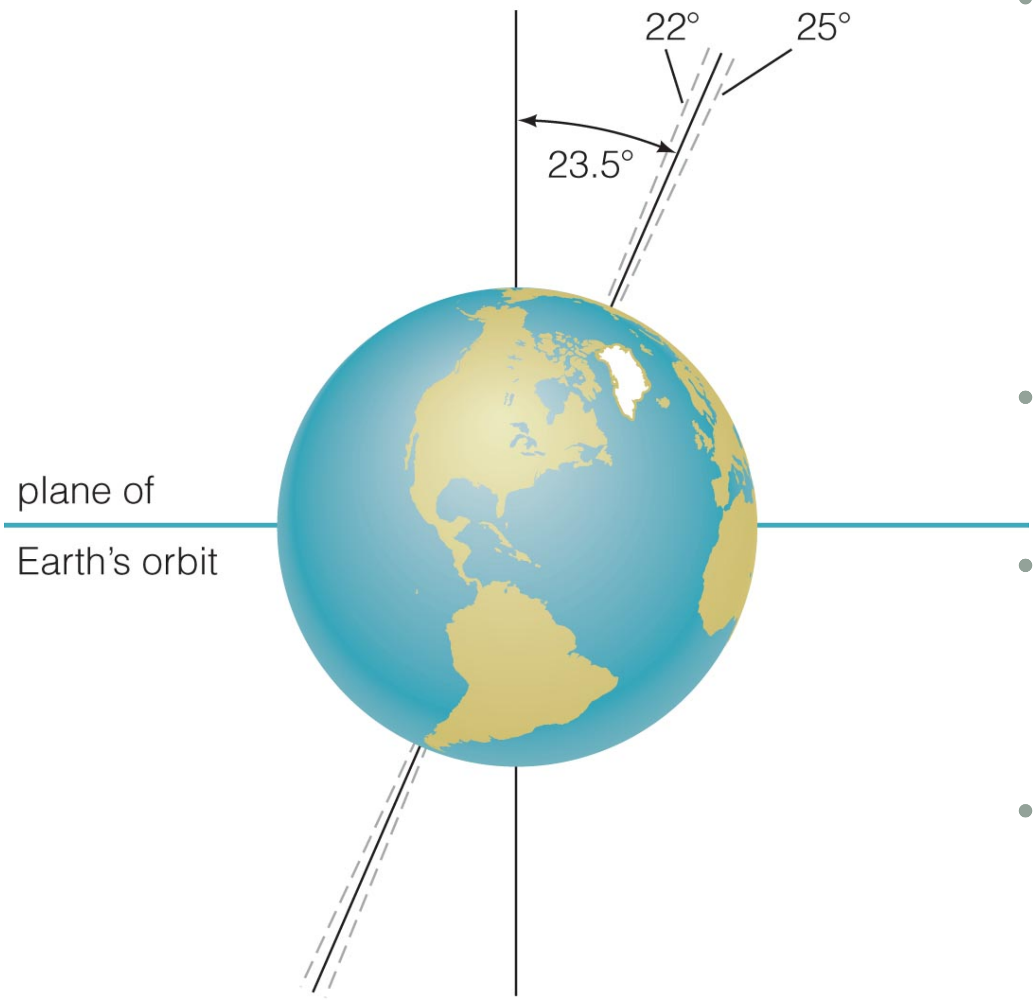
- The Sun very gradually grows brighter with time, increasing the amount of sunlight warming the planets.

Changes in Axis Tilt



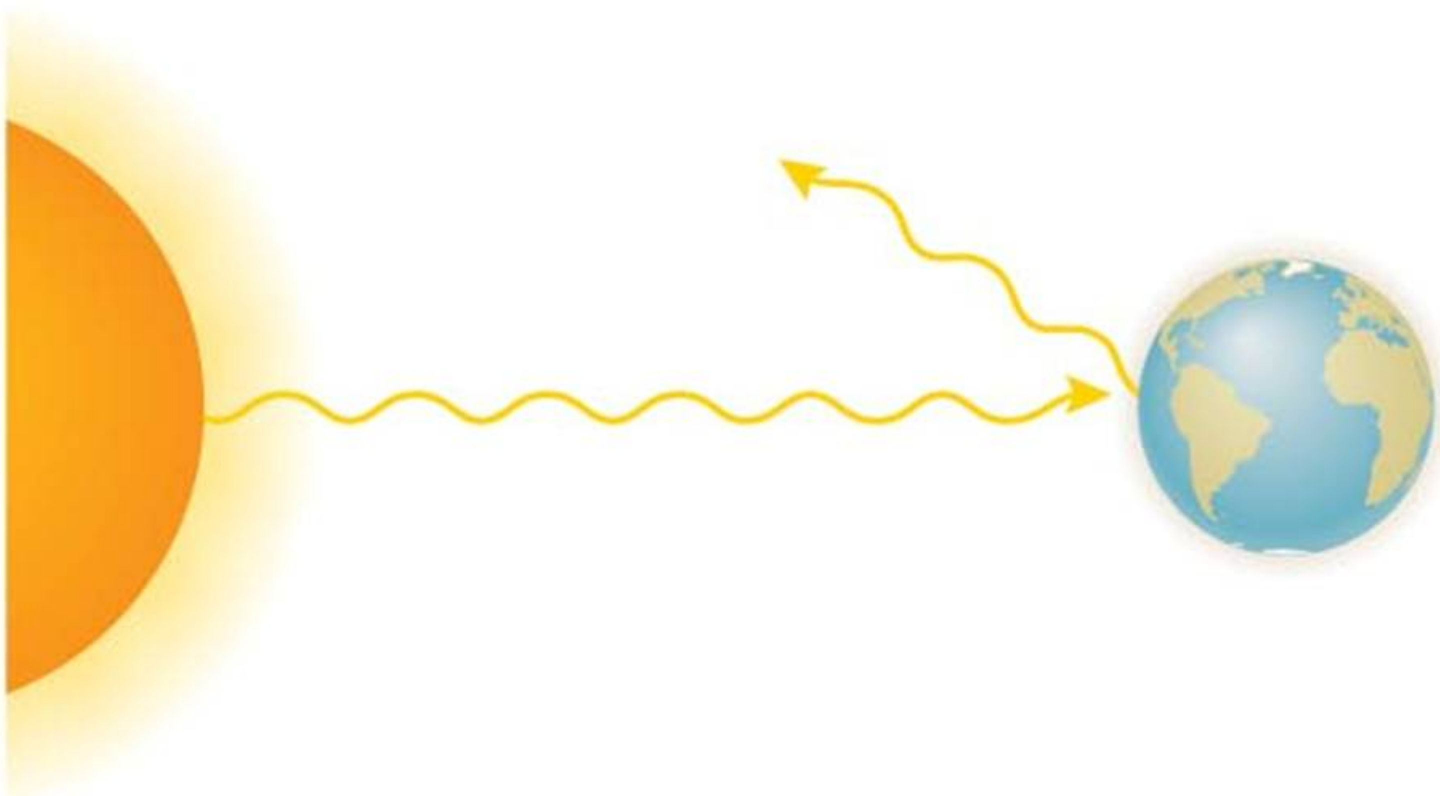
- Greater tilt creates more extreme seasons, while smaller tilt keeps polar regions colder.

Changes in Axis Tilt



- Small gravitational tugs from other bodies in the solar system cause Earth's axis tilt to vary between 22° & 25°.
- Mars varies from 10 to 50 degrees, chaotically!
- Our large Moon may save us from this huge range of tilts.
- Good or bad for life on Earth?

Changes in Reflectivity

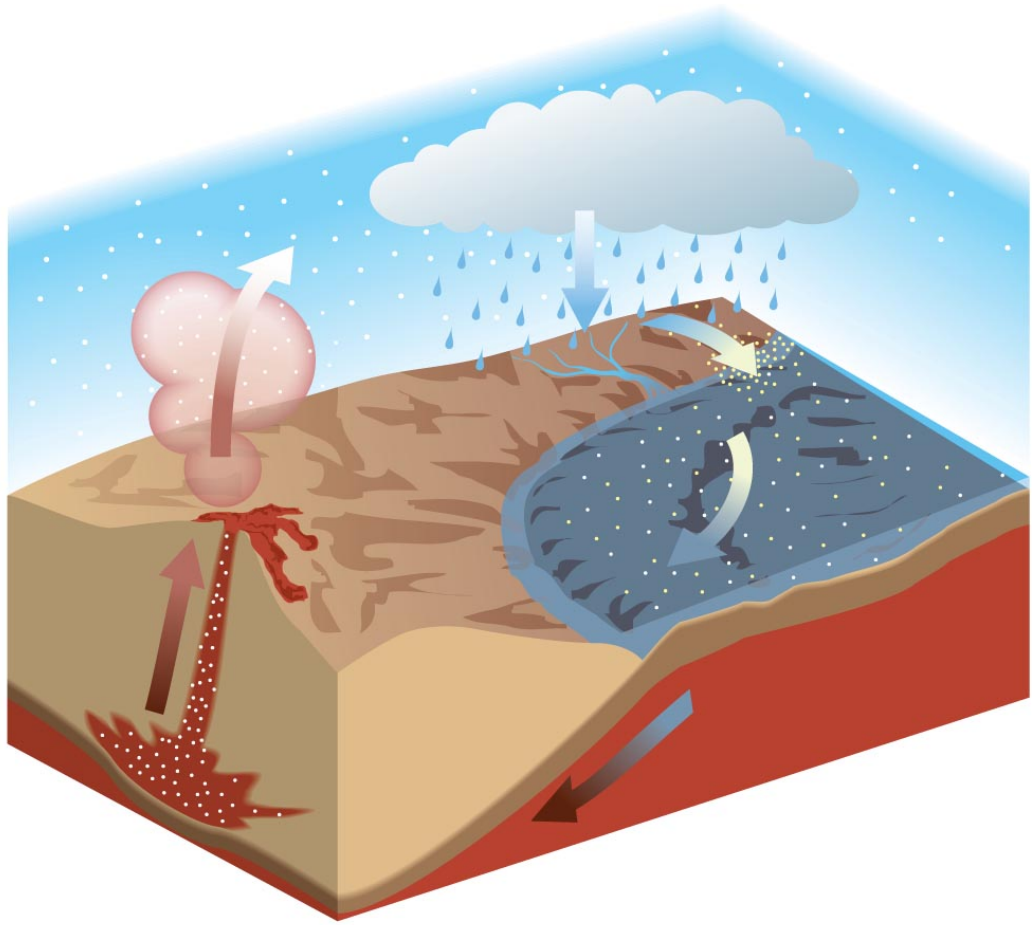


- Higher reflectivity tends to cool a planet, while lower reflectivity leads to warming. Snowball Earth!

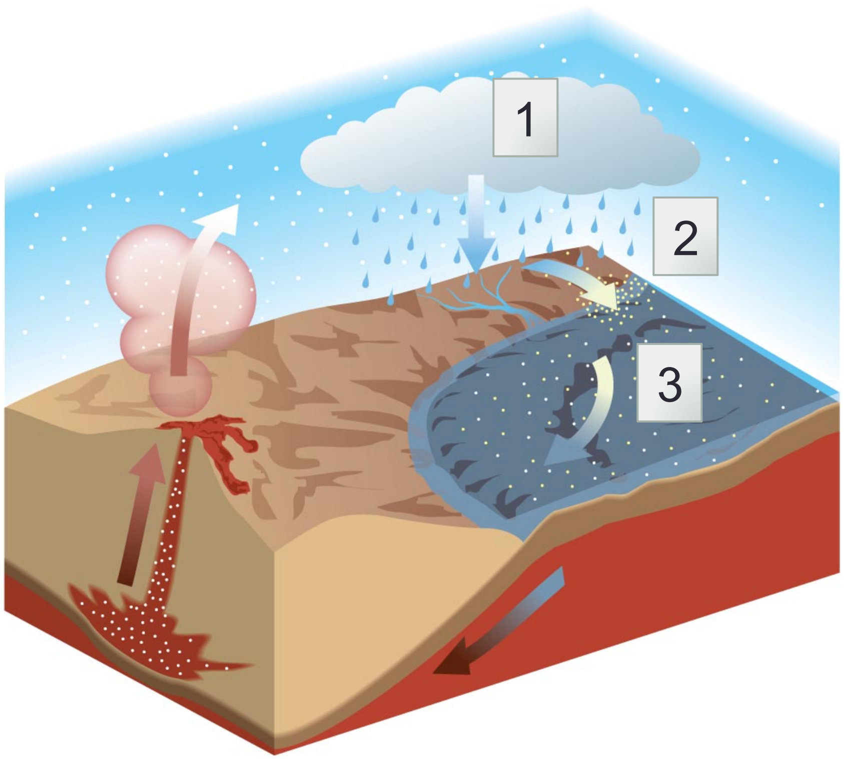
Changes in Greenhouse Gases

- An increase in greenhouse gases leads to warming, while a decrease leads to cooling. Cause of Permian Extinction?

Why does Earth's climate stay relatively stable?

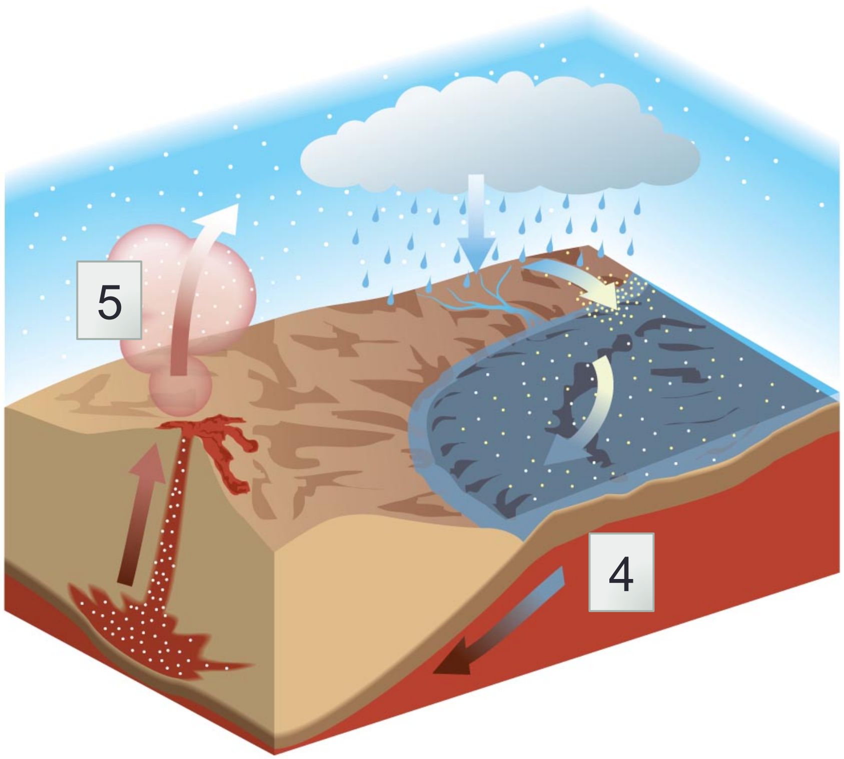


Carbon Dioxide Cycle



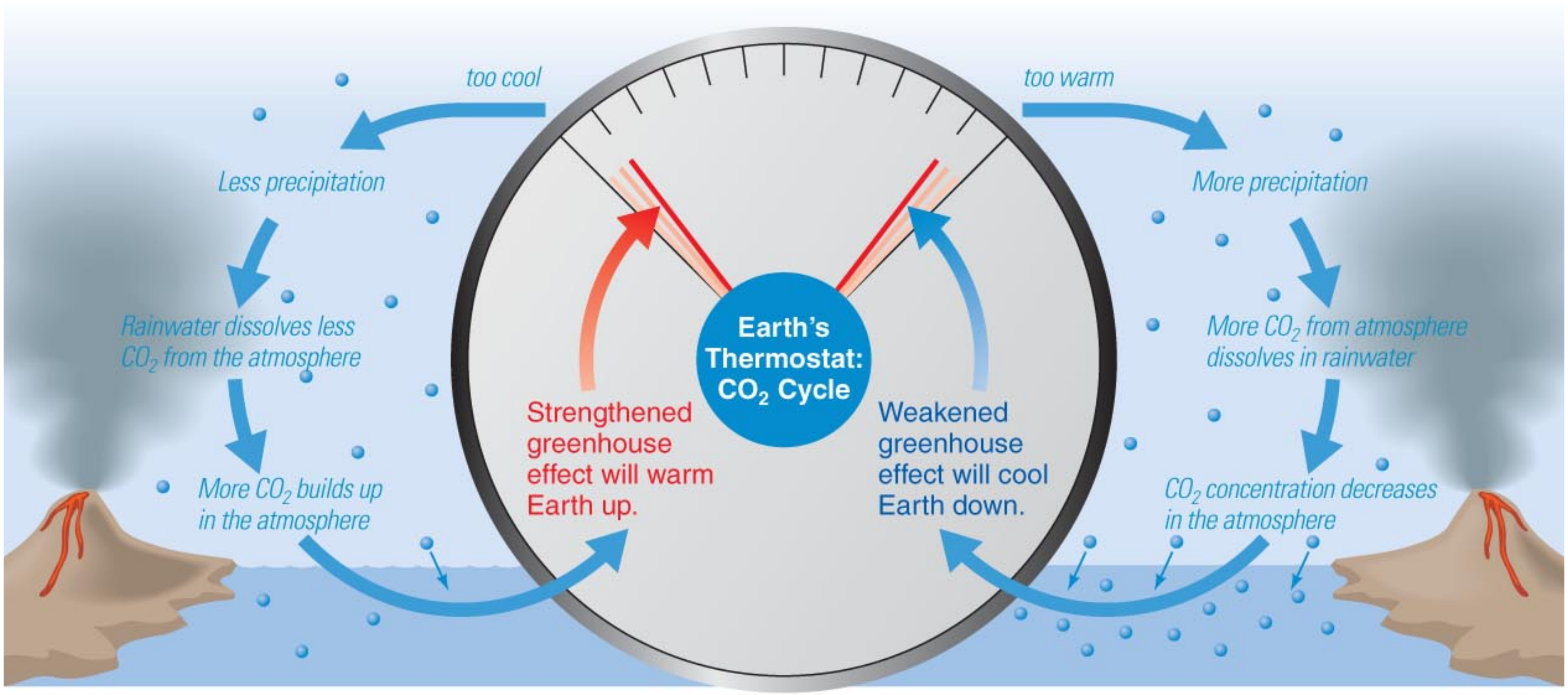
1. Atmospheric CO_2 dissolves in rainwater.
2. Rain erodes minerals that flow into the ocean.
3. Minerals combine with carbon to make rocks on the ocean floor.

Carbon Dioxide Cycle



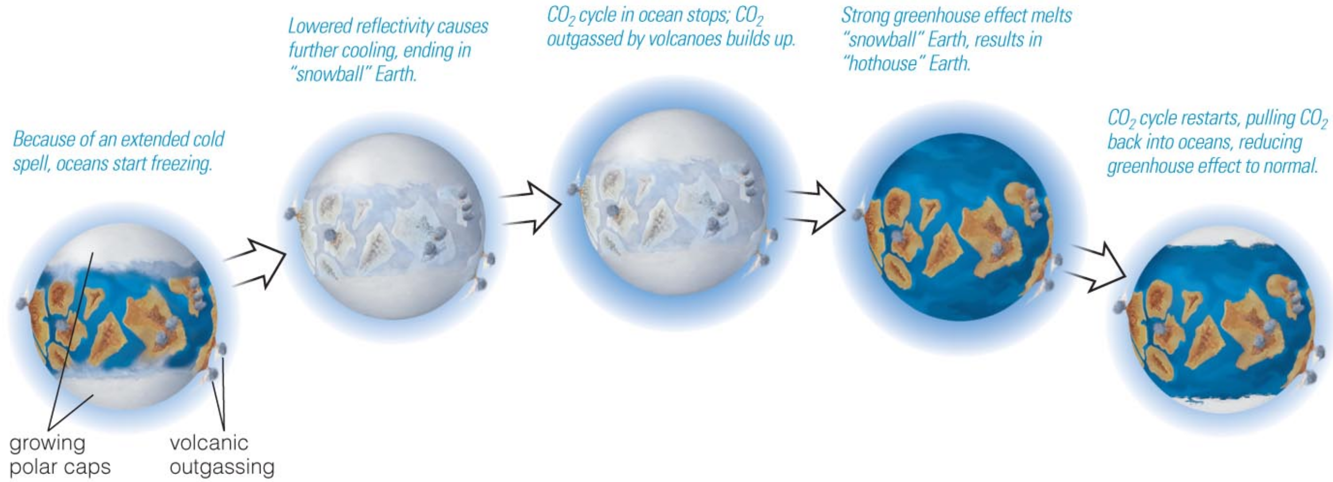
4. Subduction carries carbonate rock down into the mantle.
5. Rock melts in the mantle and CO_2 is outgassed back into the atmosphere through volcanoes.

Earth's Thermostat



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

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.

How is human activity changing our planet?