

Planetary Atmospheres (Chapter 10)

Based on Chapter 10

- This material will be useful for understanding Chapters 11 and 13 on “Jovian planet systems” and “Extrasolar planets”
- Chapters 4, 5, and 8 on “Momentum, energy, and matter”, “Light”, and “Formation of the solar system” will be useful for understanding this chapter.

Goals for Learning

- What are atmospheres of terrestrial planets like?
- Greenhouse effect
- Winds
- Changes to atmospheres

What is an atmosphere?

- Layer of gas surrounding a world
- All planets and moons have an atmosphere
 - But some, such as Mercury or Moon, have such an insignificant atmosphere that they are effectively “airless”
- Jovian planets are effectively “all atmosphere”
- Atmospheres of terrestrial worlds and satellites of jovian planets are tiny fraction of total mass
- Atmospheres interact with surface and interior

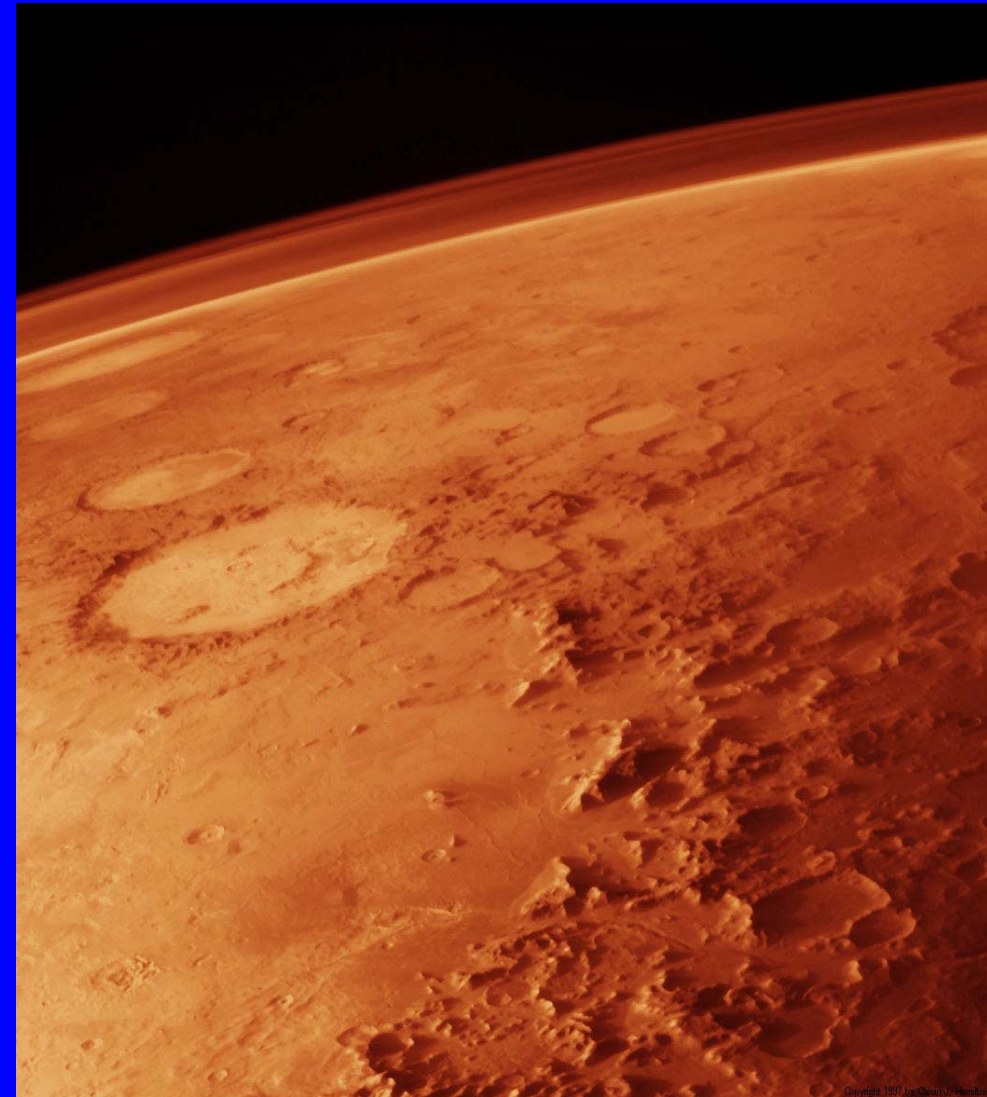
Atmospheres of Moon and Mercury

- Are very, very boring

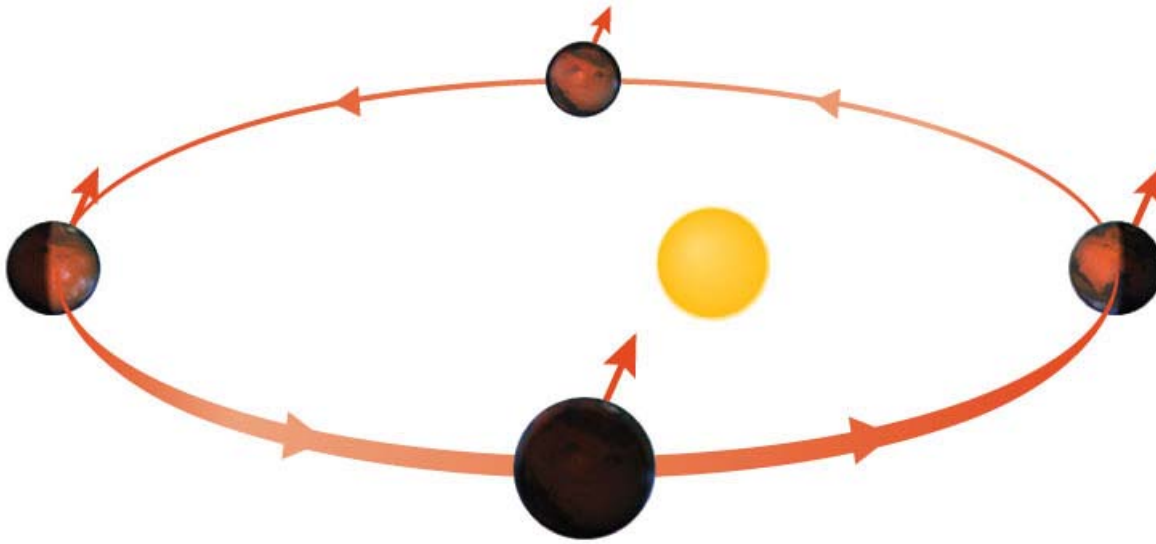
Atmosphere of Mars

- Mostly carbon dioxide (CO₂) – where have you seen CO₂ gas?
- Surface pressure is low
- Colder than Earth

- What causes seasons on Earth?
- What causes seasons on Mars?



Seasons on Mars



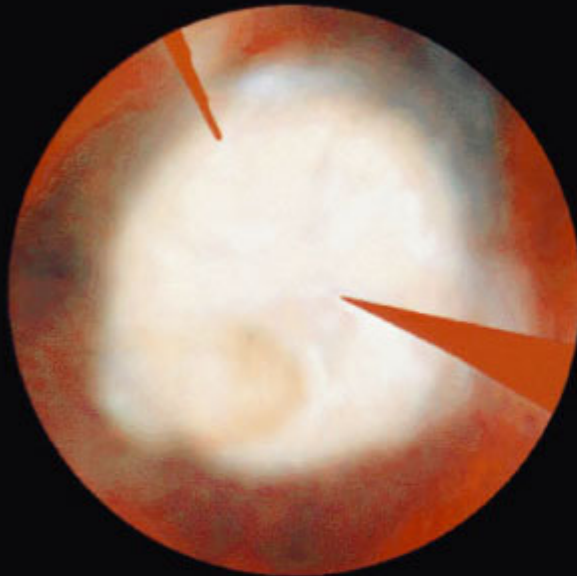
Earth's orbit is almost perfectly circular

Mars's orbit is very elliptical

Southern hemisphere summer is different from northern hemisphere summer

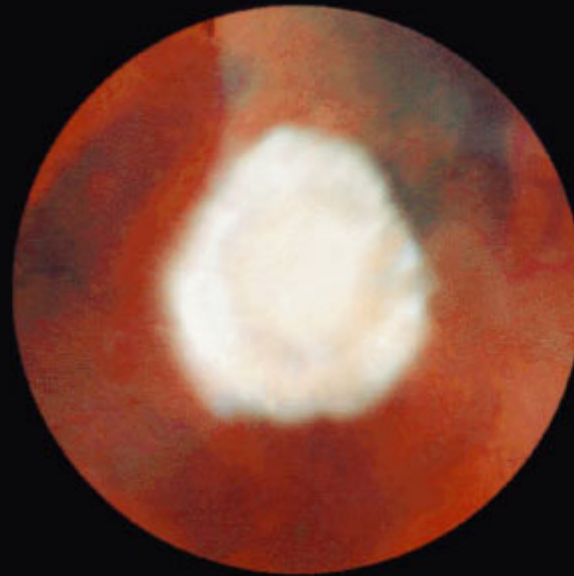
So cold in winter that gas in the atmosphere can freeze and fall as snow

This makes Mars polar caps interesting



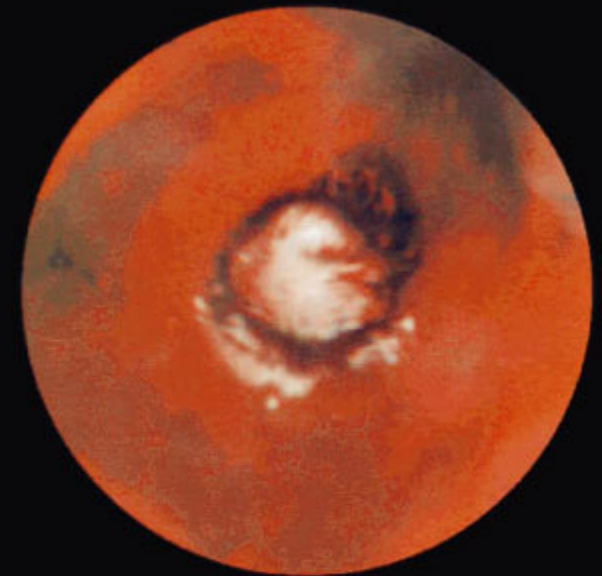
Late winter

Large CO₂ polar cap



Mid-spring

Smaller CO₂ polar cap



Summer

All frozen CO₂ has gone
Frozen H₂O cap remains

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Mars polar caps:

A permanent, small cap of frozen H₂O that exists year-round

A seasonal, large cap of frozen CO₂ during winter that doesn't exist in summer

Which is on top, CO₂ or H₂O cap?

Ancient Mars

- Geology suggests warmer, wetter Mars billions of years ago
- This needs a thicker atmosphere
- Atmospheric gases can escape to space
- Atmospheric gases can react with rocks



Venus

- Surface pressure = 1 km under water on Earth
- Surface temperature = 750 K
- CO₂ atmosphere with clouds of acid
- Does Venus have seasons?



Earth

N_2 and O_2
atmosphere

– which part is
most
important?

Water, water
everywhere

– what phases of
water are
common on
Earth?

Heating Things Up

- Sunlight shines on Earth
- Some is reflected away – does that heat Earth?
- Some is absorbed – does that heat Earth?

- Earth radiates energy to space – what is the name of this process?

- Energy in per day = energy out per day
 - but Earth's surface is hotter than we expect

Draw stuff on board

- Without an atmosphere
- With an atmosphere

- Visible radiation
- Infrared radiation

Greenhouse Effect

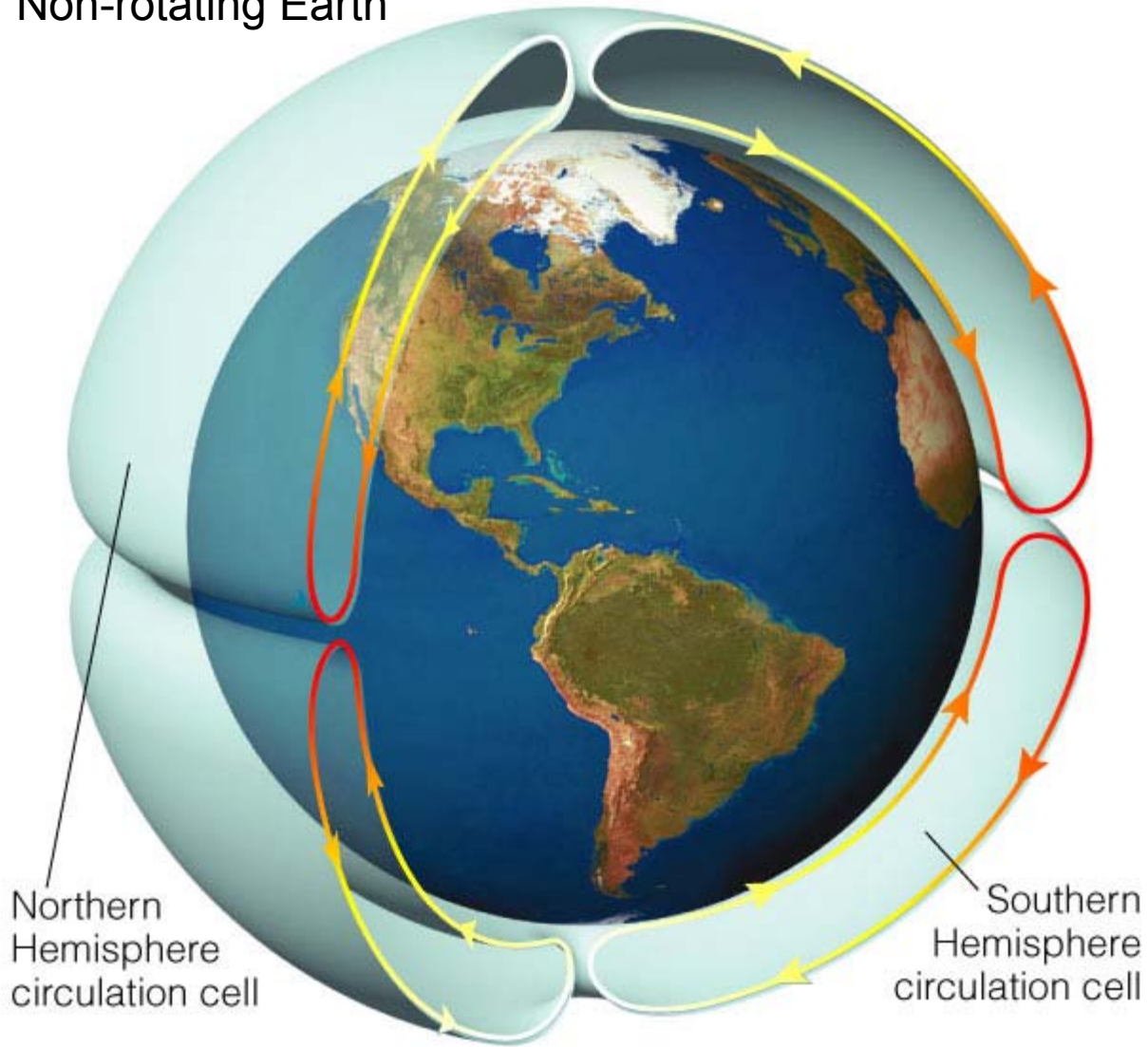
- Atmosphere makes planet's surface hotter
- Atmosphere transmits visible light, but absorbs infrared light
- Water (H₂O), Carbon Dioxide (CO₂), and Methane (CH₄) are effective greenhouse gases
- Which planets have no, some, or lots of greenhouse warming?
 - Moon, Mercury, Mars, Venus, Earth

Weather and Climate

- Climate is what you expect
- Weather is what you get

- Think about air just above Earth's surface
- How is it heating up? cooling down?
- Are things the same at all latitudes?
 - Draw globe on board to show circulation cells

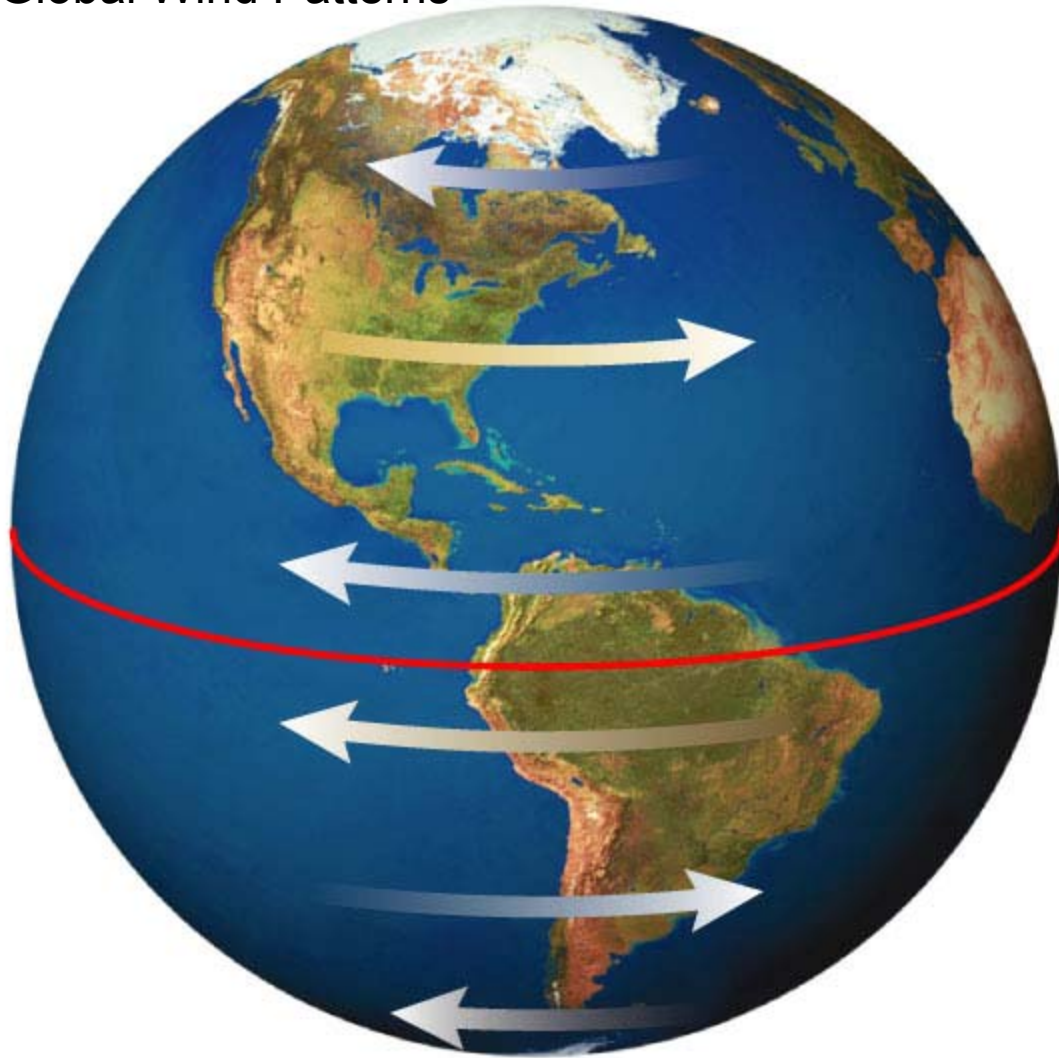
Non-rotating Earth



Not to scale!

Circulation cells are a few km high

Global Wind Patterns



Surface winds

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Earth's rotation complicates our simple picture

In Boston, storms and other weather systems tend to arrive from the east

What two factors control atmospheric circulation (winds)?

What winds do you expect Mars and Venus to have?

Where do atmospheres and oceans come from?

- Terrestrial planets formed from metal and rock. Where did Earth's water come from?
- How does planetary size affect this?
- Important gases are: N_2 nitrogen, CO_2 carbon dioxide, H_2O water
- O_2 oxygen is special

Where do atmospheres and oceans go to?

- Suggest some ways that gases can be removed from an atmosphere
- Suggest some ways that liquids can be removed from an ocean

Where do atmospheres and oceans go to?

- Suggest some ways that gases can be removed from an atmosphere
 - Escape to space (permanent)
 - Condensation/precipitation (temporary)
 - Chemical reactions with rocks
 - Form snow/ice, then bury that beneath rock
- Suggest some ways that liquids can be removed from an ocean
 - Evaporation (if hot)
 - Chemical reactions with rocks

Atmospheric Histories: Mars, Venus, Earth

- Follow histories of H_2O (water), N_2 (nitrogen), CO_2 (carbon dioxide) and O_2 (oxygen)
- When they were young, did each planet have none/some/lots of each of these molecules in atmosphere or oceans?

Early Atmospheres

- Venus and Earth had lots of H_2O , CO_2 , and N_2 due to their large size
- Mars had smaller amounts of H_2O , CO_2 , and N_2
- None of them had much O_2 in their atmospheres

Mars

- Young Mars had 400x as much CO₂ as it does today, plus enough water to have 100 m deep oceans, and lots of N₂
- Mars magnetic field dies early (why?) and solar wind starts ripping atmosphere away
- Lack of an ozone layer allows solar UV photons to break apart H₂O molecules into atoms

Mars

- H atoms easily escape to space (why is size important here?), but O atoms do not escape easily
- Water molecules cannot reform without H
- Oceans vanish
- Combination of solar wind and weak gravity make it easy for N_2 , CO_2 to escape as well

Venus and Earth

- Young Venus had enough water to fill Earth's oceans
- Early Earth had as much CO₂ as Venus's thick atmosphere does today
- Earth today has N₂ in atmosphere, H₂O in oceans (safe from solar UV photons), CO₂ in carbonate rocks (eg limestone)

Venus and Earth

- What would happen to Earth's temperature if we moved it closer to the Sun?
- Would more or less water end up in the atmosphere?
- Would greenhouse effect strengthen or weaken?
- Where would H₂O and CO₂ molecules be at the end of this?

Runaway Greenhouse Effect

- Oceans evaporate, H₂O in atmosphere
- Carbon dioxide is released from carbonate rocks into the atmosphere
- Solar UV photons break H₂O into H and O
- H escapes to space – never to return
- End with thick CO₂ atmosphere

Oxygen

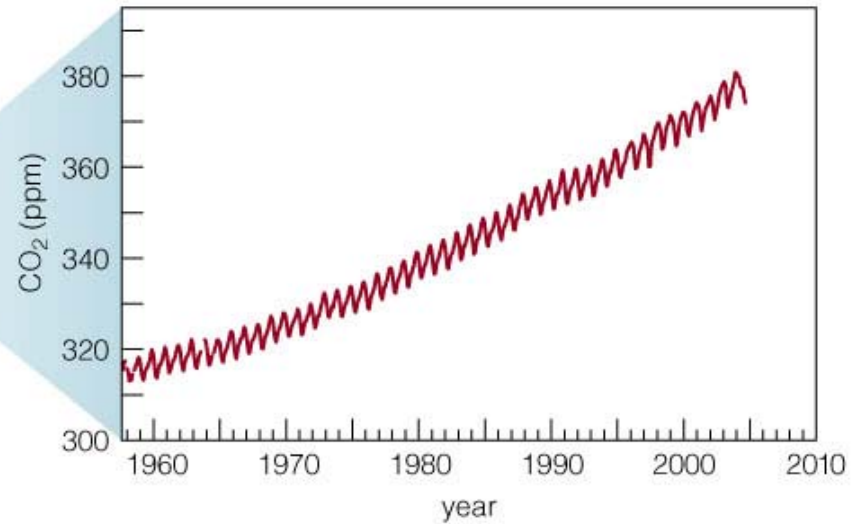
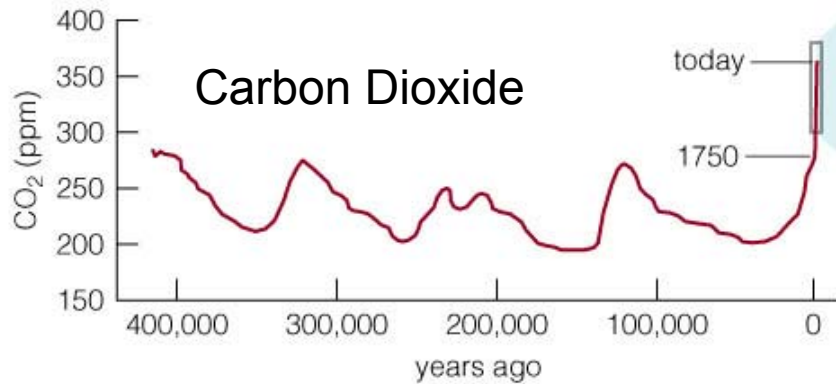
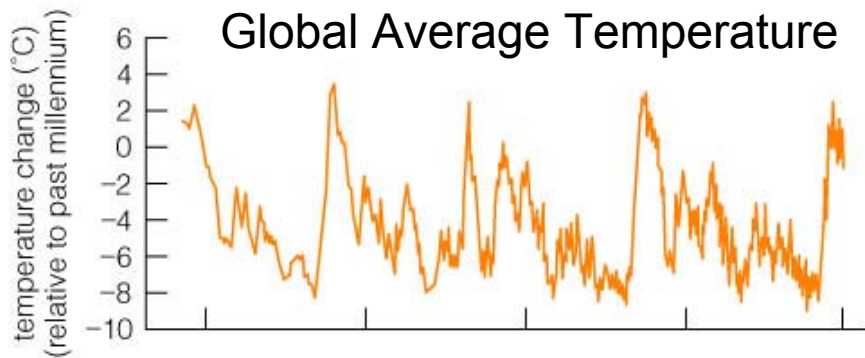
- Life creates oxygen. Life needs oxygen
- O_2 is very reactive, is only present in atmosphere because life continually produces it
- Ozone (O_3) is formed from O_2
- Ozone in stratosphere stops solar UV from reaching surface and fragmenting H_2O molecules

Climate Change

- What can cause climate change on planets?

Climate Change

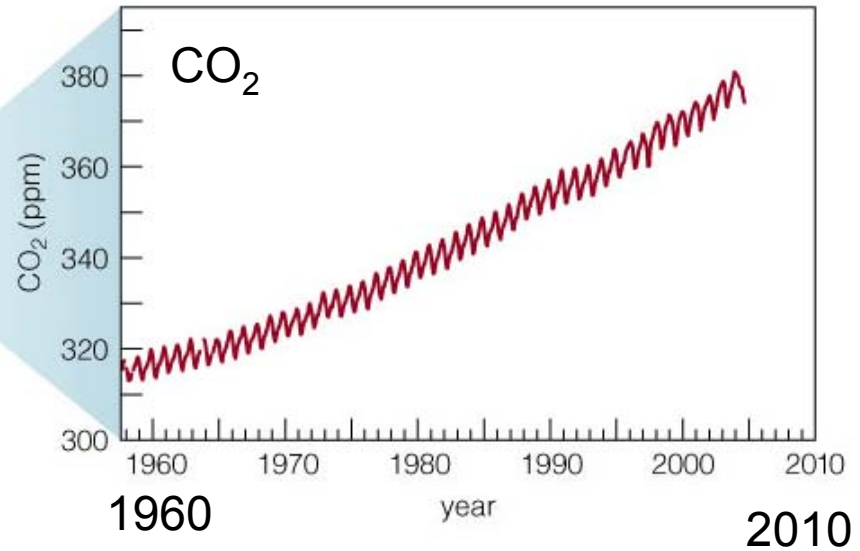
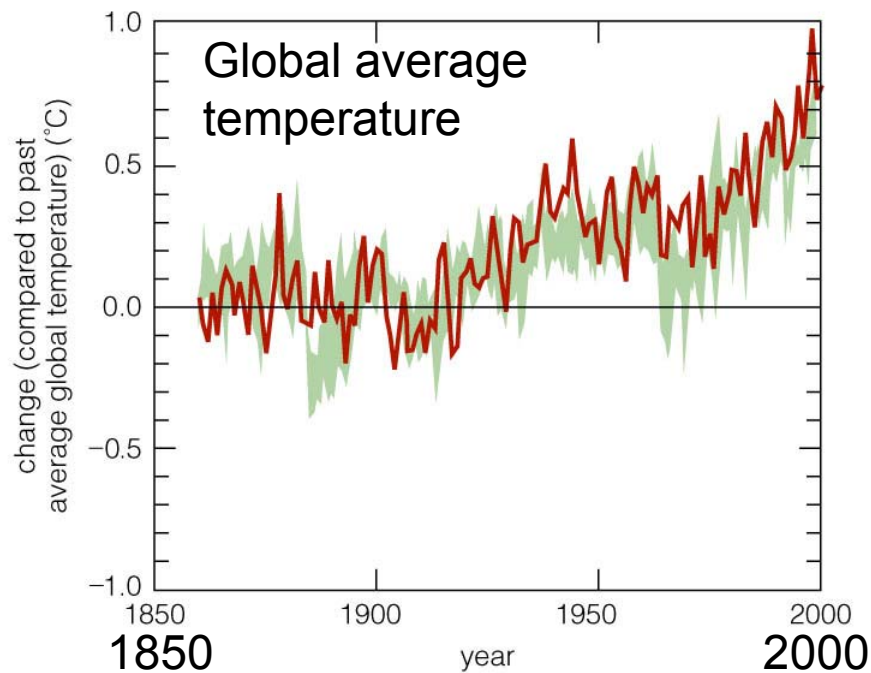
- Sun has become 30% brighter since solar system formation
- Higher reflectivity (icy or cloudy) means less sunlight absorbed, less heating
- Greater axis tilt means more extreme seasons. Less axis tilt means annual sunshine at poles is less, get ice ages
- Greenhouse gases in atmosphere



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Global average temperature increases when carbon dioxide content increases

Global average temperature decreases when carbon dioxide content decreases



Carbon dioxide content is higher now than at any time in the past 400,000 years. Cause is burning of fossil fuels

Global average temperatures have increased by 0.5K in the past 50 years

Goals for Learning

- What are atmospheres of terrestrial planets like?
- Greenhouse effect
- Winds
- Changes to atmospheres

Goals for Learning

- What are atmospheres of terrestrial planets like?
- Mercury/Moon = boring
- Mars: Low pressure, cold, CO₂, polar caps, different in the past
- Venus: High pressure, hot, CO₂, no seasons
- Earth: N₂ and O₂, plus oceans of water

Goals for Learning

- Greenhouse effect
- Atmospheric gases are transparent to Sun's visible radiation, but absorb planet's infrared radiation
- Planet's surface gets hotter as a result
- Occurs on Venus, Earth, and Mars
- Venus has very strong greenhouse effect,

Goals for Learning

- Winds
- Affected by heating/cooling of atmosphere
 - Winds try to blow from hot to cold regions
- Affected by rotation of planet

Goals for Learning

- Changes to atmospheres
- Start with CO_2 , H_2O , N_2
- Escape to space, reactions with rocks alter atmosphere
- Mars, Venus, and Earth have very different histories for their atmospheres