Lecture 12:
Climate Regulation and Climate Change

Astronomy 141 – Winter 2012

This lecture reviews changes in the Earth's climate through geological history.

The Greenhouse Effect helps determine the mean temperature of the Earth.

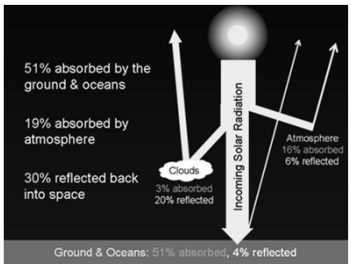
The CO_2 Cycle regulates the amount of CO_2 in the atmosphere, and is driven by plate tectonics

The CO_2 Cycle and Greenhouse Effect acts together like a thermostat to regulate global temperatures.

Ice ages and periods of glaciation appear to be correlated with cycles of variation in the earth's orbit and tilt.

Very deep ice ages, called Snowball Earth, represent an interesting extreme of the climate change cycle.

The Greenhouse Effect makes the present-day Earth about 35°C warmer than with no atmosphere.



Primary "Greenhouse Gases" are

H_2O vapor

CO_2 (carbon dioxide)

CH_4 (methane)

These all strongly absorb infrared photons heating the atmosphere

The CO_2 content of the atmosphere is regulated by the *CO_2 Cycle*.

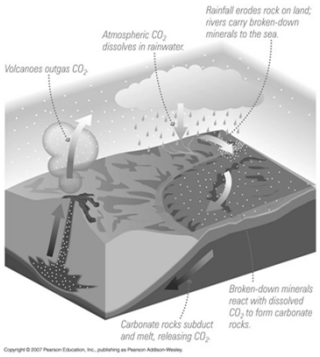
Rain drops dissolve CO_2 and form a mild acid.

Rain erodes rock, washing CO_2-rich sediments into the oceans.

Dissolved CO_2 reacts with Calcium to make carbonate rocks (limestone)

Carbonate rocks subduct into the mantle and melt, releasing CO_2

Volcanoes outgas CO_2



The operation of the CO_2 Cycle depends critically on having liquid water and plate tectonics.

Liquid water (raindrops and oceans) to dissolve atmospheric CO_2

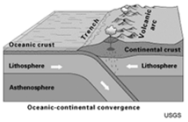
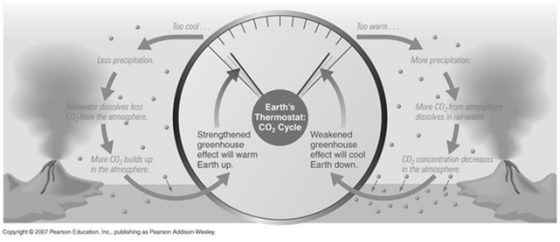


Plate tectonics to subduct carbonate rocks into the mantle where melting releases CO_2

Volcanism to release trapped CO_2 back into the atmosphere.

The CO_2 Cycle and the Greenhouse Effect act like a thermostat to regulate global temperatures.



An example of a classic “negative feedback loop”

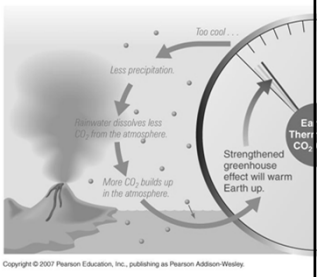
If the global temperature drops, more CO_2 is left in the atmosphere, strengthening greenhouse heating.

Cooler temperatures mean less rainfall.

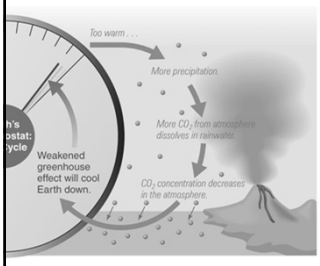
Less CO_2 is scrubbed out of the atmosphere.

Net build-up of CO_2 in the atmosphere increases the greenhouse effect.

Atmosphere warms back up, restoring the balance.



If the global temperature warms, less CO_2 is left in the atmosphere, weakening greenhouse heating.



Warmer temperatures means more rainfall.

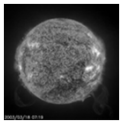
More CO_2 is scrubbed out of the atmosphere.

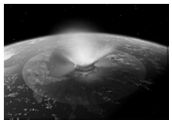
Net deficit of CO_2 in the atmosphere weakens the greenhouse effect.

Atmosphere cools back down, restoring balance.

This balance can be upset by influences acting from outside the regulation cycle.

Changes in the amount of sunlight (Solar Forcing) due to
- Changes in the Sun's Brightness
- Changes in the Earth's orbit or tilt.

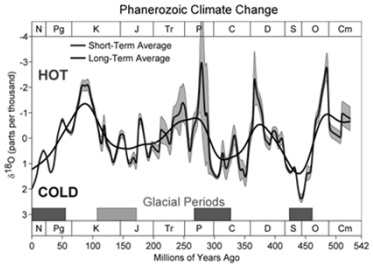




Asteroid impact kicks up dust cooling the atmosphere

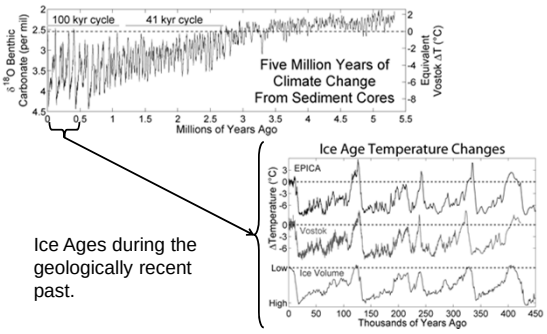
Human activity injecting massive amounts of CO_2 outside the CO_2 cycle)

We see evidence in the geological record for long periods of very cold weather or “ice ages”



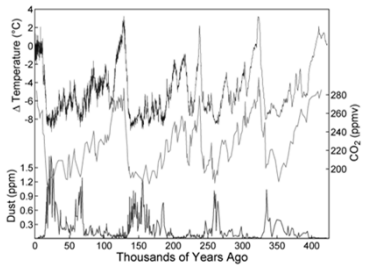
Long-term trends may be related to changes in the Sun’s brightness and the arrangement of continents and oceans.

Recent ice ages have occurred in regular, repeating patterns of roughly 40,000 to 100,000 years.



Ice Ages during the geologically recent past.

Ice ages are seen to correlate with changes in the CO_2 content of the atmosphere.



Ice core data from Vostok, Antarctica

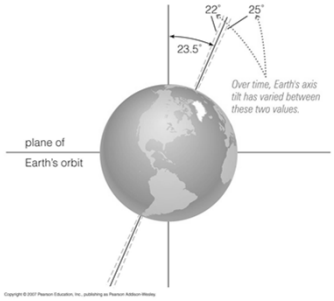
Recent ice ages appear to correlate with periodic changes in the Earth's orbit and tilt.

Earth's axis tilt gives us the cause of the seasons.

Tilt varies on a 41,000 cycle.

Less tilt = milder seasonal variation

More tilt = bigger seasonal variation



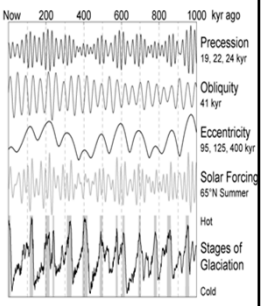
Milankovitch Cycles are the collective effect of variations in the earth's tilt and orbital parameters.

Three main cycles:

Changes in Earth's axial tilt (depth of seasons) every 41 kyrs

Changes in ellipticity of Earth's orbit (length of seasons), three cycles of 95, 125, and 413 kyrs

Precession (wobble) of Earth's rotation axis (timing of seasons) every 26 kyrs



Not perfect, but strongly suggestive…

In the distant past, very long, deep ice ages have occurred that caused the oceans to freeze.

Two episodes:

Late Proterozoic 750 - 580 Myr ago

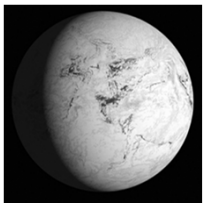
Early Proterozoic 2.4 - 2.2 Gyr ago

Very deep freezes:

–50°C average temperatures

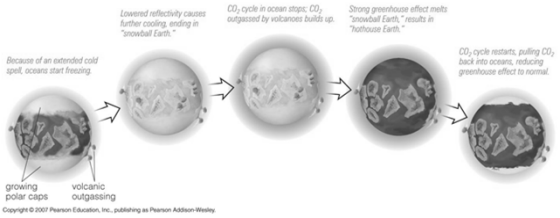
Oceans frozen to a depth of 1 km!

Oceans freezing temporarily shuts down the CO_2 Cycle.



Snowball Earth

Snowball Earth is caused by runaway cooling in polar-ocean ice caps (positive feedback).



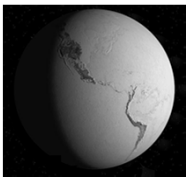
Frozen oceans stop CO_2 cycle, but volcanic outgassing continues, and CO_2 builds up to ~1000x current levels.

Subsequent strong CO_2 greenhouse effect melts the ice.

The Earth has experienced repeated changes in its climate over its long history.

Negative and Positive feedback cycles at work

Interplay between plate tectonics, atmospheric composition and astronomical effects.



Has numerous implications for understanding the history of life, and the habitability of the Earth.