Extraterrestrial Life: Lecture #7

Next homework: Thursday

To first approximation: **distance** from star and **luminosity** of star determine the surface temperature and possibility for liquid water on surface

Atmosphere (`greenhouse effect') also plays an important role - warms Earth by ~20 degrees Celsius

- water vapor
- carbon dioxide
- methane

increased concentration warms the planet

Particulate matter (dust from volcanoes) cools

Is the climate stable over geological time?

Feedback: if the surface temperature rises, does the concentration of greenhouse gases in the atmosphere:

- increase, possibly raising the temperature further?
  Positive feedback
- decrease, offsetting the rise?
  Negative feedback

Empirically, expect negative feedback to prevail on the Earth - but may be different for other planets…

Short term feedback processes

Short term feedbacks are mostly positive - destabilizing

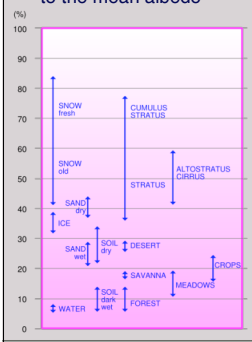
e.g. water vapor: increased temperature leads to more evaporation from the oceans, increasing the atmospheric concentration of water vapor

Water is a greenhouse gas, so this is positive feedback

Role of clouds?

Timescale: essentially instantaneous

Extent of ice cover also affects the climate via changes to the mean albedo



If increased temperature leads to less snow and ice, fraction of Solar energy that will be absorbed increases

Positive feedback

Timescale: 1000s of years

Long term feedback processes

On longer timescales, geological processes dominate

Tiny fraction of the Earth's total CO_2 reservoir is in the atmosphere

- atmosphere: CO_2 ~381 parts per million

  8×10^{11} tonnes: 800 GigaTonnes

- ocean:

  4×10^{13} tonnes: 38,000 GigaTonnes

- rocks

  5×10^{16} tonnes

Volcanic activity can liberate CO_2 from rocks and release it into the atmosphere

Mt Pinatubo

Magma can be few % by mass water

Large eruptions release km^3 to ~1000 km^3 of rock

Estimate for the current volcanoes to atmospheric CO_2:

1.3×10^8 tonnes / year = 0.13 GigaTonnes / yr

Timescale for significant changes to the atmosphere:

$$\tau \approx \frac{8 \times 10^{11} \text{ tonnes}}{1.3 \times 10^{8} \text{ tonnes / yr}} = 6000 \text{ yr}$$

Expect volcanic activity to be important on timescales of the order of 10^4 years

Carbon sinks

In the atmosphere:

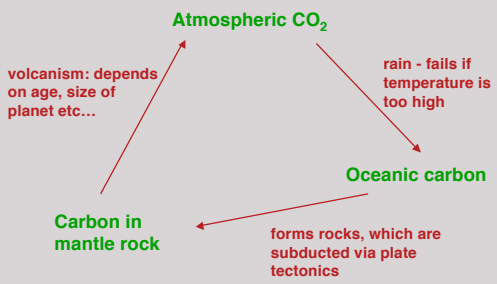
water + CO_2 -> carbonic acid (H_2CO_3)

Weak acid in rain weathers silicate rocks:

- yields bicarbonate
- becomes locked up in calcium carbonate (shells) from biological activity in the oceans
- carbonates becomes locked up in the crust

Same process can occur without biological activity

Carbonate-silicate cycle



This is a **negative** (stabilizing) feedback loop:

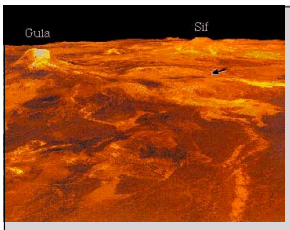
- warmer temperatures: more moisture in the atmosphere, more rain, greater rate of removal of CO_2 from the atmosphere
- cooler temperatures: less rain, longer residence time for CO_2 in the atmosphere

Very long term changes in climate are driven by:

- Sun's changing luminosity
- cyclical changes in the Earth's orbit / rotation
- different arrangements of the continents
- changes in volcanism
- life…

Despite these variations, appears that the natural carbonate-silicate cycle has been sufficient to roughly stabilize the Earth's surface temperature for several billion years (but, ice ages, `snowball Earth' episodes…)

What are the limits to this stabilizing influence?



Magellan radar image of Venus

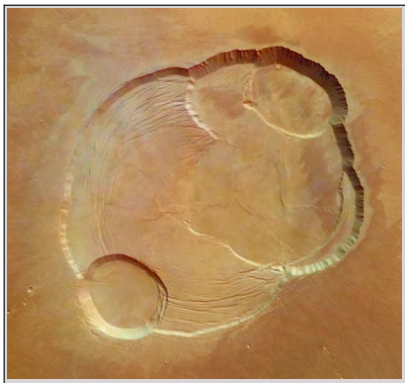
Other planets?

Volcanoes on surface of Venus - probably still volcanically active planet

But, water has all been evaporated by high surface temperature and lost into space

Weathering aspect of the carbonate-silicate cycle does not operate - large concentration of CO_2 in the atmosphere

Venus' surface temperature is 464 Celsius



Mars certainly had active volcanism during the planet's history

Olympus Mons: 27km high

Summit of Olympus Mons on Mars: Mars Express

Mars: active volcanism and plate tectonics appears to have ceased in distant past

Small size of planet (10% mass of Earth) has allowed Mars to cool and plate tectonics has ceased

Volcanic outgassing aspect of the cycle has been broken

<u>Implications for extrasolar habitable worlds?</u>

Small planets, without long term plate tectonics, may not be able to maintain a habitable climate - `habitable zone' for such planets may be much smaller / non-existent

What is the typical mass of terrestrial planets?

- probably depends upon the mass of solid material: less favors more, smaller planets
- Solar System have two `Earth-mass' planets
- around lower mass stars may be quite different