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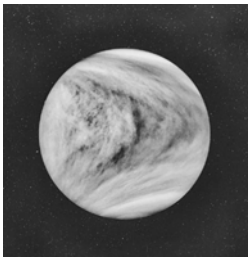
Lecture #18: Venus atmosphere and climate

- Properties of the atmosphere.
- Greenhouse Effect.
- Climate Implications.
- Readings:
  - –Chapters 9.5, 9.6, 10.5, 10.6.



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The Main Point

Venus has a thick carbon dioxide atmosphere that creates an extreme greenhouse effect. Earth and Venus have had divergent evolutionary histories despite similar sizes and compositions.

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Atmospheric Composition

- Composition determined by spectroscopy from ground based telescopes and direct sampling from landers and balloons (!)

The Atmospheres of Venus and Earth

Gas	Venus	Earth
Carbon Dioxide (CO_2)	96.0%	0.03%
Nitrogen (N_2)	3.5	78.1
Argon (Ar)	0.006	0.93
Oxygen (O_2)	0.003	21.0
Neon (Ne)	0.001	0.002

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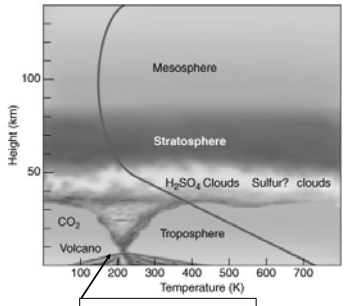
Atmospheric Structure

- Atmosphere divided into layers like Earth's.
- Enormous clear and hot *troposphere.*
- Clouds of sulfuric acid! (not water!)
- CO_2, Sulfur may be volcanic in origin, but we have not yet detected any direct evidence for active volcanism now.
- Surface temp ~ 480°C.
- Surface pressure ~ 90 bars (same pressure as ~1 km under water).



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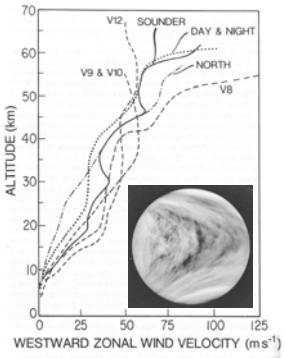
Atmospheric Circulation

- Winds near the surface are only strong enough to move sand grains and dust (10-20 km/hr).
- But the upper layers of the atmosphere move very fast (> 175 km/hr). They circle the planet every four days, a pattern called ***super-rotation***.
- Venus also has atmospheric circulation patterns between the equatorial and polar areas, similar to those on Earth.
- Also: several Venus probes returned data indicating lightning activity in the atmosphere!



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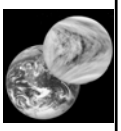
Venus and Earth are very similar…

Property	Earth	Venus
Diameter (km)	12,756	12,104
Mass (kg)	6.0×10^{24}	4.9×10^{24}
Density (g/cm^3)	5.52	5.25



Venus and Earth are assumed to have formed from essentially the same material in the inner solar system. Given their similar sizes and compositions, we expect Venus and Earth to have had similar levels of volcanic outgassing and similar compositions of their atmospheres.

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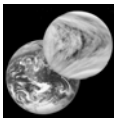
Yet so different…



Property	Earth	Venus
Surface Temperature	~ 15°C	~ 470°C
Surface Pressure (bars)	1	90
Atmospheric Comp.	N_2, O_2, Ar,...	CO_2, N_2 ,...

The atmospheres on Venus and Earth have had wildly divergent evolutionary histories due to different distances from the Sun. Venus suffered a runaway greenhouse effect.

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Equilibrium Temperature

- What is the "no-greenhouse" equilibrium temperature of a planet?
  - Depends on distance from the Sun and reflectivity.
  - Amount of power received per unit area is S_0 / a^2 where S_0 is the solar constant and a is the semi-major axis in AU. The solar constant is $S_0 = 1368$ [W/m^2].
    - Planet "intercepts" an amount = $\pi R_P^2 \cdot S_0 / a^2$, where R_P is the radius of the planet.
    - Some fraction, A, is reflected back into space, while the fraction (1-A) is absorbed.
    - Therefore the total heat input to the planet is $(1-A) \cdot \pi R_P^2 \cdot S_0 / a^2$ [W].
  - Amount of power radiated per unit area at temperature T is σT^4 [W/m^2].
    - Planet radiates from its entire surface $4\pi R_P^2$ [m^2].
    - Therefore the total heat output from the planet is $4\pi R_P^2 \cdot \sigma T^4$ [W].
  - Balance heat input and heat output: $(1-A) \cdot \pi R_P^2 \cdot S_0 / a^2 = 4\pi R_P^2 \cdot \sigma T^4$.
- For Earth with a=1 AU and reflectivity A= 0.29, T = 255 K = -17°C = 0°F.
- For Venus with a=0.7 AU and reflectivity A=0.75, T = 235 K = -40°C = -40°F.

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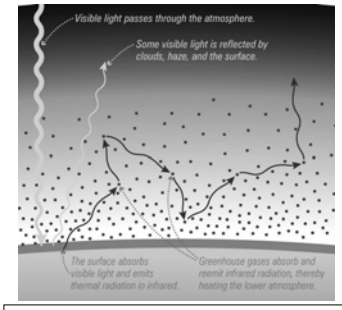
The Greenhouse Effect



Note: Botanical greenhouses trap heat simply by not letting hot air rise, so the term "greenhouse effect" is a bit of a misnomer.

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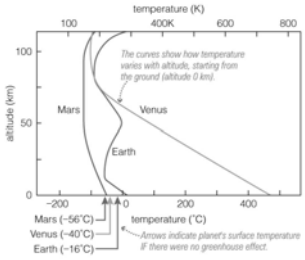
Greenhouse Warming

The amount of warming ΔT due to the greenhouse effect depends on atmospheric composition. Carbon dioxide and water are greenhouse gases.

Mars $\Delta T \sim 5°C$
Earth $\Delta T \sim 30°C$
Venus $\Delta T \sim 500°C$!!



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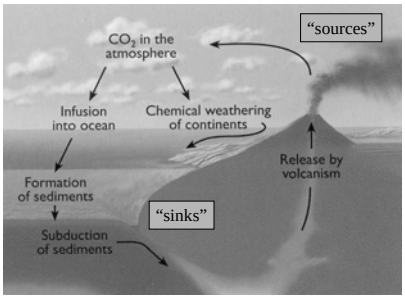
The CO_2 cycle on Earth

- Earth outgassed roughly the same amount of CO_2 as Venus.
- But CO_2 dissolves in rain water and oceans and forms carbonate rocks.
- Plate tectonics recycles CO_2 back to atmosphere.

- Venus was too close to the Sun to allow liquid water. Without oceans or plate tectonics, there is no "sink" for CO_2.



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How Did Venus Get This Way?

- "Runaway Greenhouse" Model:
  - Venus and Earth are assumed to have formed from essentially the same material, with the same initial amounts of H_2O, CO_2, N_2, etc...
  - But *divergent evolution* occurred because:
    - Venus is closer to the Sun, so H_2O can exist only in *vapor* (gas) form.
    - At Earth's distance, *liquid* H_2O could form.
- Model the atmospheres as time progresses...

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Evolution of Atmosphere on Earth

- Volcanic outgassing releases H_2O, CO_2, SO_2, N_2, etc in the atmosphere.
- H_2O forms liquid oceans.
- CO_2 dissolves in the oceans and forms carbonate rocks (*e.g.*, limestone).
  - Equivalent of *~100 bars* of CO_2 stored in rocks!
- Atmosphere ends up being mostly N_2.
- O_2 slowly builds up over time from breakdown of H_2O and (eventually) presence of *life* (Lecture 37)...

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Evolution of Atmosphere on Venus

- Venus outgassing probably similar to Earth's.
  - H_2O, CO_2, SO_2, N_2, etc. build up in the atmosphere.
- But temperature too high for liquid water!
- No ocean to dissolve the CO_2 or SO_2: they build up.
  - 90 bars of CO_2 (close to Earth's equivalent).
- H_2O, other gases *dissociated* by UV light.
  - $2H_2O$ + UV photon --> O_2 + 2 H_2.
  - H_2 (very light) escapes to space.
  - O_2 oxidizes surface rocks (efficient at high T).
  - Venus lost any water it ever had. Loss of an ocean's worth of water supported by high abundance of deuterium (escapes with more difficulty than hydrogen).

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Is Earth headed in the same direction?

- Increase in CO_2 leads to global warming.
- Higher temperatures cause increased evaporation of oceans.
- Higher water vapor content in atmosphere may lead to larger greenhouse effect.
- With higher and higher temperatures, Earth could lose its water as Venus did.
- Such a runaway greenhouse effect is expected in the long-term. Sun's luminosity will increase and the sun will eventually become a red giant. Earth's oceans will evaporate, and CO_2 in rocks will be released (timescale: billions of years).

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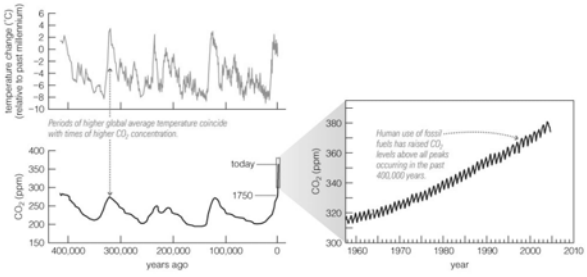
A cautionary tale



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Summary

- Venus and Earth similar in bulk properties, but with very different atmospheres.
- The *Greenhouse Effect* is responsible for the high surface temperature of Venus.
- Earth and Venus have had *divergent* histories:
  - Similar starting compositions.
  - But liquid water on Earth has removed most of the greenhouse gas CO_2 from our atmosphere.
  - With no oceans, CO_2 has built up and caused the greenhouse to run wild on Venus.

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Next Lecture...

- Mars: Overview:
  - •General properties.
  - •Telescopic observations,
  - •Space missions,
- Reading:
  - Chapters 7.1 (Mars), 9.4, 10.4