Lecture 41

Evolution of the Atmosphere

Heat balance
Albedo
Greenhouse Effect
Venus/ Earth/ Mars

Chemical modification:

• precipitation/evaporation:
  \( \text{H}_2\text{O} \leftrightarrow \) oceans, polar caps
• solution/evolution:
  \( \text{CO}_2 + \text{liquid H}_2\text{O} \leftrightarrow \) carbonate rocks
• "photochemistry"
  solar UV + \( \text{O}_2 \leftrightarrow \text{O}_3 \) (ozone)
• life:
  sunlight + \( \text{CO}_2 + \) photosynthesis \( \rightarrow \) \( \text{O}_2 \)
  (life is only known \( \text{O}_2 \) producer \( \Rightarrow \) good spectroscopic indicator of life!)
• Chemistry with surface
  \( \text{O}_2 + \) most anything \( \rightarrow \) oxides
Heat Balance Feedback Effects

Temperature <-> Atmospheric composition

- Recall equilibrium temperature. Refine this:
- Solar input = Watts/m² (mostly visible wavelengths)
  - Reflected = Watts/m² × Albedo ("Albedo" = fraction of light reflected)
  - Absorbed = Watts/m² × (1 - Albedo)
- Emitted = constant × Temp⁴ (mostly infrared for T -100-800 K)
- Equilibrium: Absorbed (visible) = Emitted (IR)

"Greenhouse" effect

- If atmosphere is transparent to both visible and IR, this gives temperature of solid surface.
- But many gases (especially CO₂) quite opaque to IR while being transparent to visible:
  => Equilibrium temperature applies to upper atmosphere where IR can get out
  => Lower in atmosphere it is much hotter, greenhouse gas supplies IR blanket
Albedo effects

- The albedo affects equilibrium temperature: high albedo => cooler equilibrium temperature:
- Temperature affects precipitation affects albedo
- EG, Ice Age feedback. dropping temp => glaciation => higher albedo => dropping temperature

Atmosphere Comparison: Venus

For all,
- Captured CH₄, NH₃ => H (escapes), C (=> CO₂), N (=> N₂)
- Internal heat -> vulcanism -> CO₂, H₂O (also from comets?)
- Big differences from slight differences in solar input (Venus, Earth), Mass (Earth, Mars)

**Venus:**
- keeps original CO₂, humongous greenhouse effect (+400 K), surface temp 470 K (800 F)
- All CO₂ evaporated from rocks; H₂O remains gaseous
Earth/ Mars Atmospheres

**Earth:**
- H₂O precipitates -> oceans
- CO₂ dissolves -> carbonates
- N₂ not greenhouse => moderate greenhouse effect (+35 K)
- Life (liquid water, CO₂) -> O₂
- O₂ -> O₃ layer, protecting life
- Decreasing greenhouse effect compensates increasing luminosity of sun on the Main Sequence

**Mars:**
- CO₂ escapes, precipitates -> no greenhouse (+5 K)
- H₂O precipitates -> icecaps
- No life? => no O₂, no O₃; surface oxidizes
- Early history: may have been enough of a greenhouse effect to have liquid water. Evidence for fairly recent running water

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Earth’s Heat Budget
Venus Atmosphere Temperature Profile

Earth’s Atmosphere Profile
Mars Early Water

2004 Mars Rover Data

strata – flowing water

Opportunity Rover last week