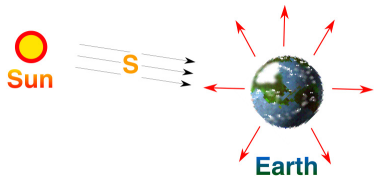


Climate Forcing, Sensitivity and Feedback Processes

Earth's Climate System

What have we learned?

- Earth is a planet
- Planetary temperature is determined by
 - Brightness of our star
 - Earth-sun distance
 - Albedo of the planet
 - Composition of Earth's atmosphere



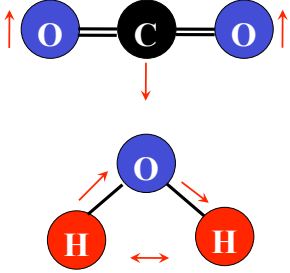
Energy In = Energy Out
 $S(1 - \alpha)\pi R^2 = 4\pi R^2\sigma T^4$

So how can climate ever change?

Earth's Climate System

What have we learned?

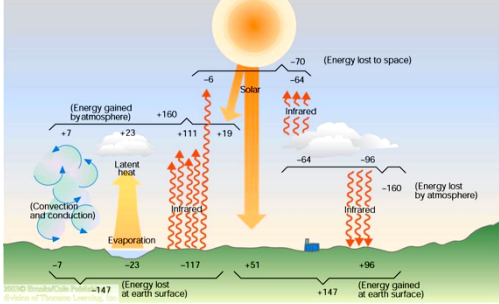
- Earth's overall temperature is determined by **sunshine and albedo (-18 C)**
- Temperature varies dramatically with height because of **greenhouse effect!**
- Surface temperature is **much warmer (+15 C)** than planetary radiation temp



Molecules that have many ways to wiggle are called "Greenhouse" molecules

Earth's Energy Budget

What have we learned?

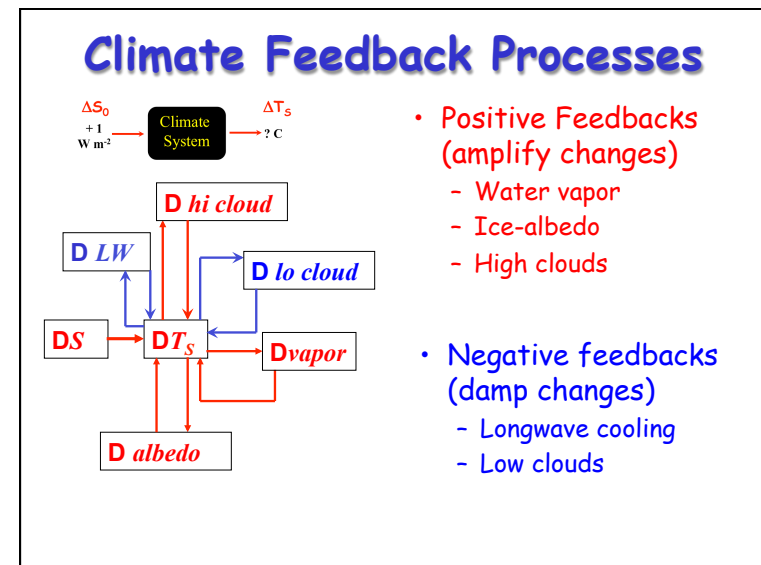
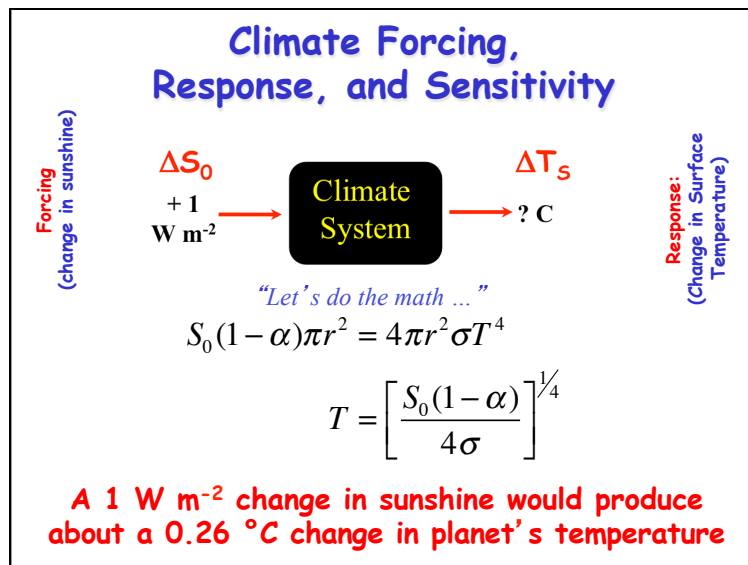
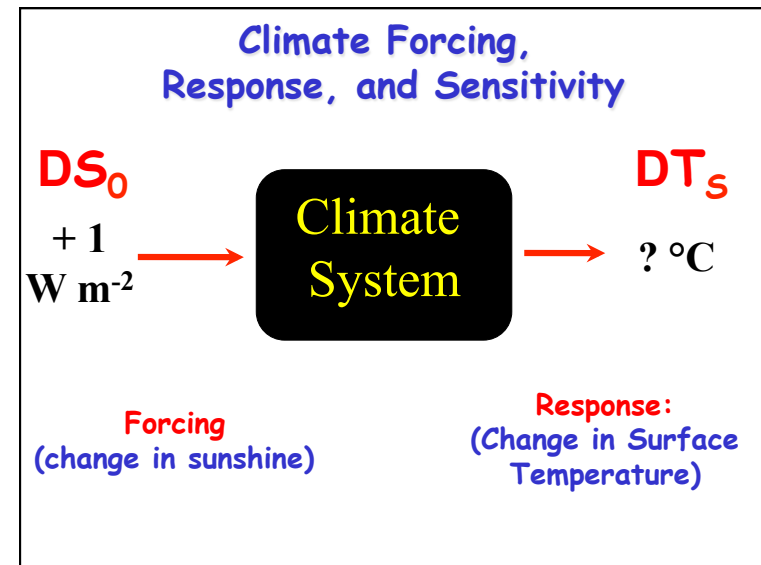
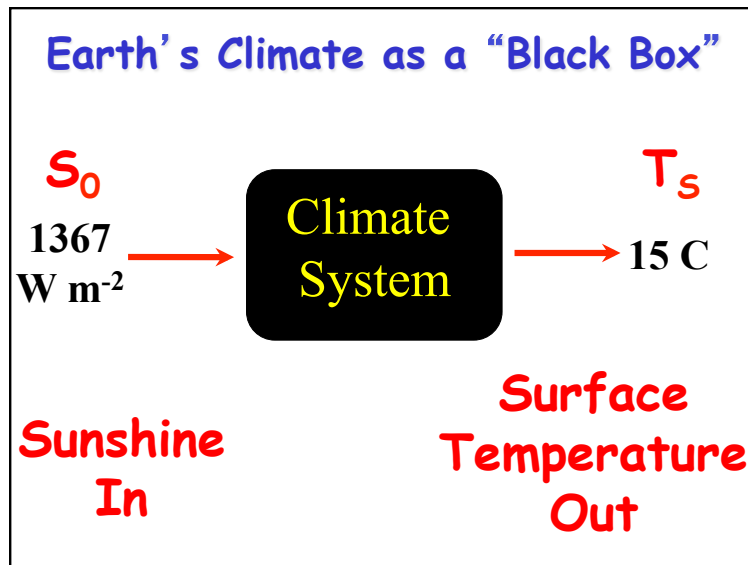


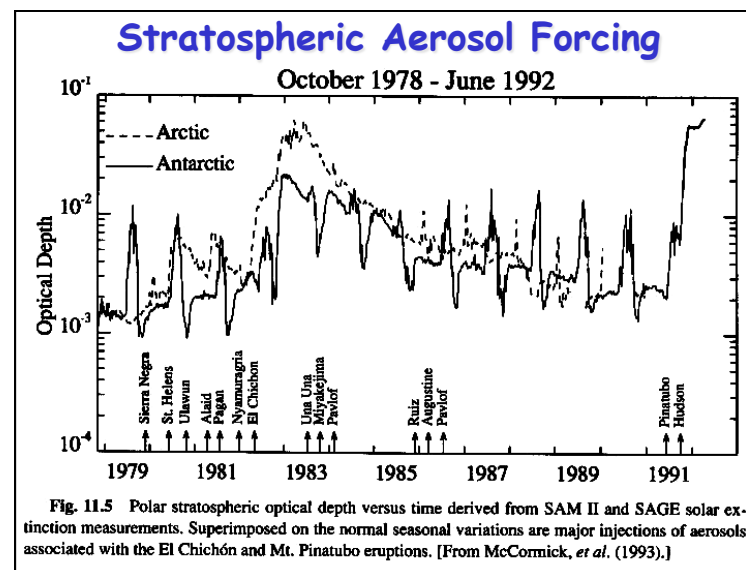
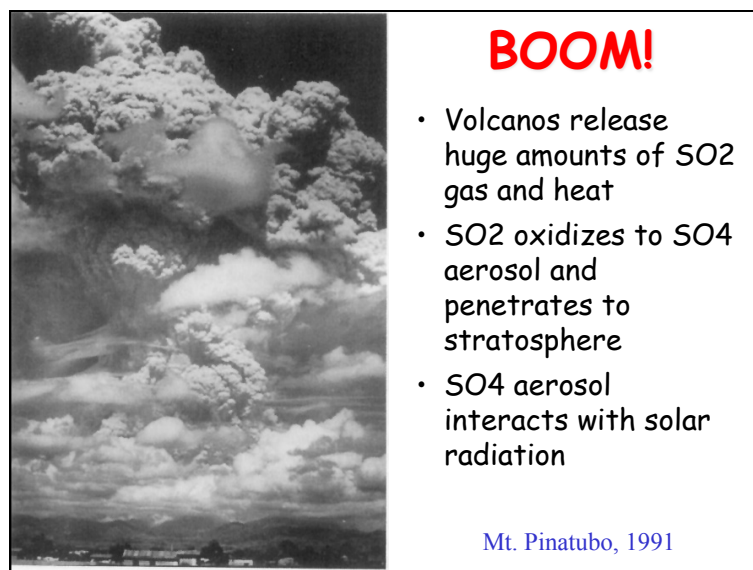
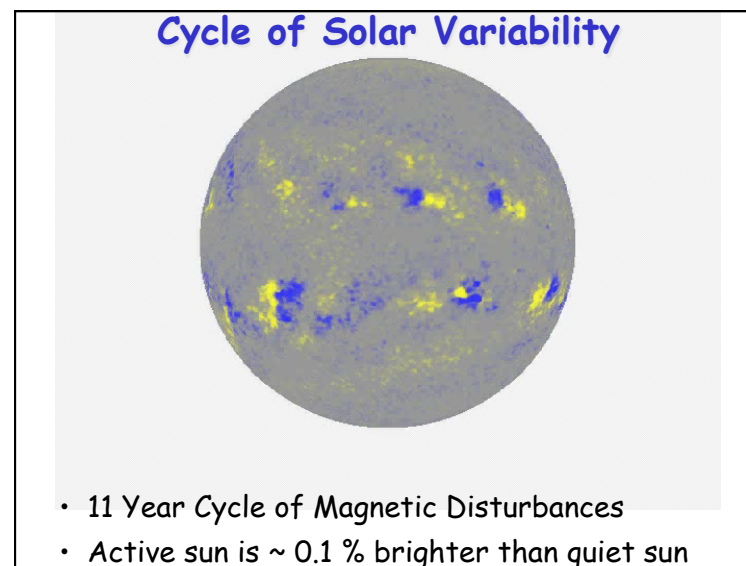
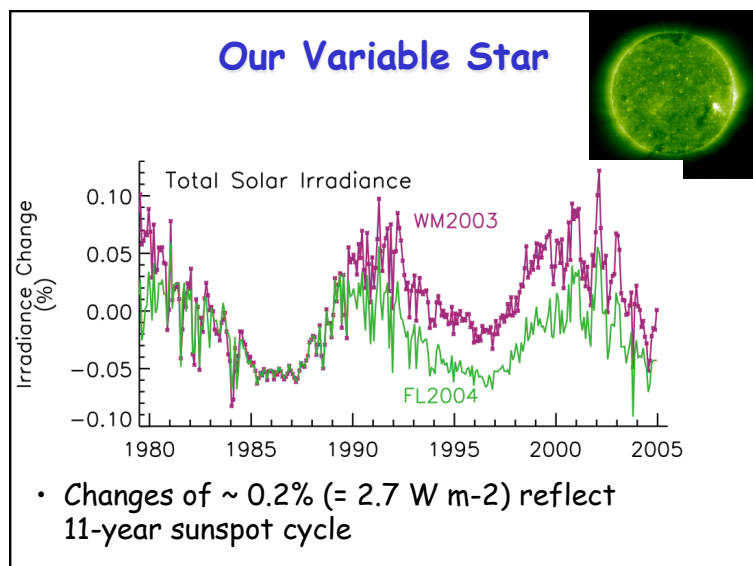
Surface climate depends on heating

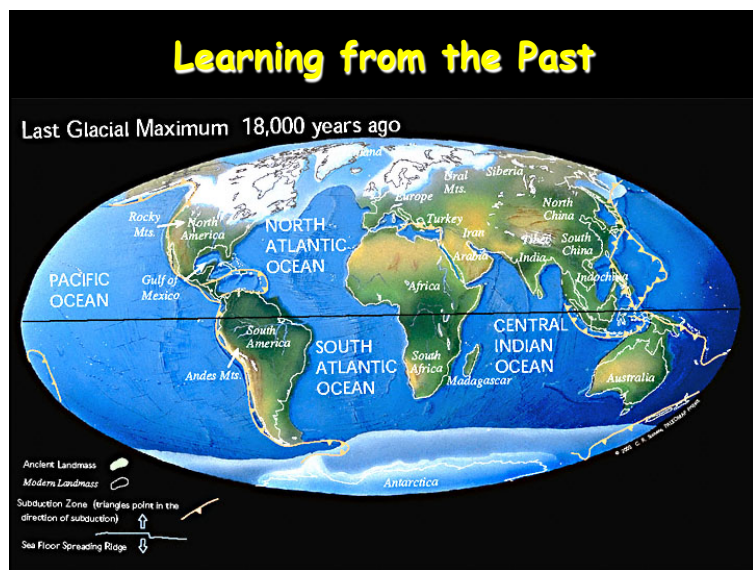
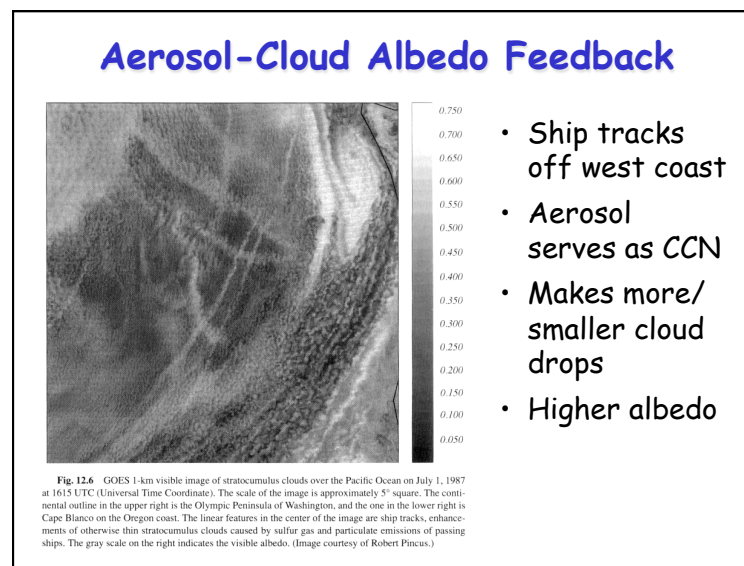
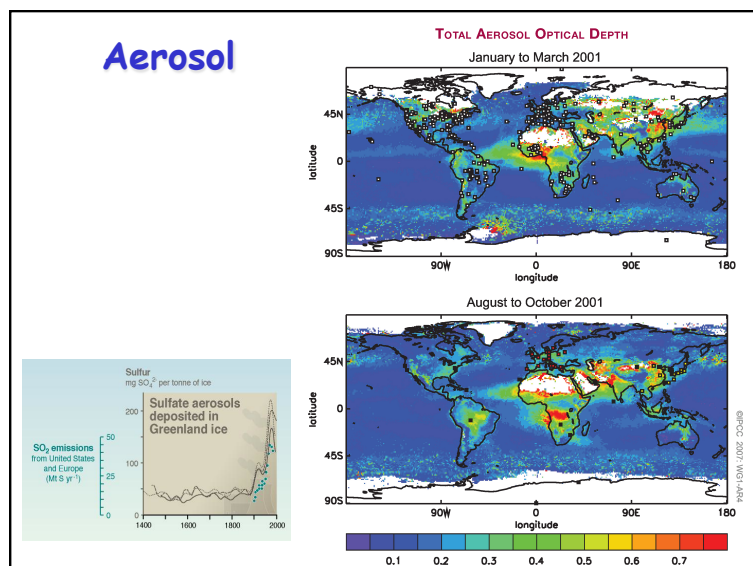
- 51 units of absorbed solar
- 96 units of downward infrared (almost 2x sunshine)!

Surface climate depends on cooling

- 117 units of upward infrared
- 23 units of evaporation, 7 units of rising thermals







Estimating Total Climate Sensitivity

- At the **Last Glacial Maximum** (~ 18k years ago) surface temp ~ 5 K colder
- CO₂ was ~ 180 ppm (weaker greenhouse, 3.7 W m⁻² more OLR)
- Brighter surface due to snow and ice, estimate 3.4 W m⁻² more reflected solar

$$\lambda = \frac{\Delta T_s}{\Delta F} = \frac{T_s(\text{now}) - T_s(\text{then})}{F(\text{now}) - F(\text{then})}$$

$$= \frac{5\text{K}}{(3.7 + 3.4)\text{Wm}^{-2}} = 0.70 \frac{\text{K}}{\text{Wm}^{-2}}$$

Almost 3x as sensitive as suggested by Stefan-Boltzmann alone ... Other feedbacks must be going on as well

