Indian Institute of Technology, Kanpur
Department of Earth Sciences

ES0213A: Fundamentals of Earth Sciences

Lecture 07. Earth's Energy

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Experimental Rock Deformation Laboratory

Aims of this lecture

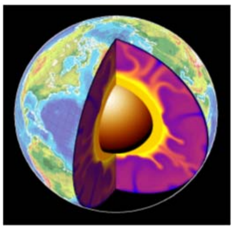
- Earth's resources of energy
- Atmospheric effect on Energy radiation
- Greenhouse effect
- Earth's Energy balance

Global energy Sources

Internal Heat

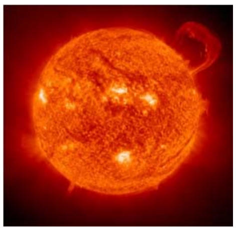
- Earth's matter gravity differentiation by density. It results in Earth's stratification into the high-density iron-oxide core, the residual silicate mantle, the light aluminosilicate crust, and the hydrosphere with the atmosphere.
- Decay of radioactive elements causing the release of heat energy

We will have a dedicated class on this…

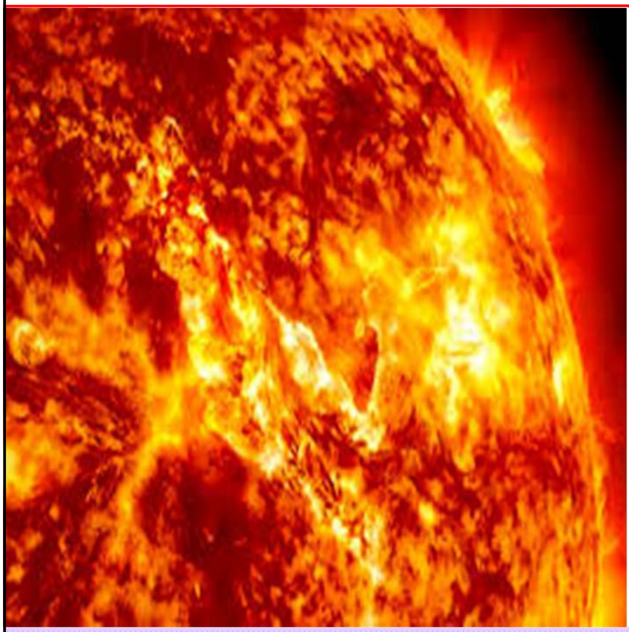


External Heat

- From Sun
- From impact

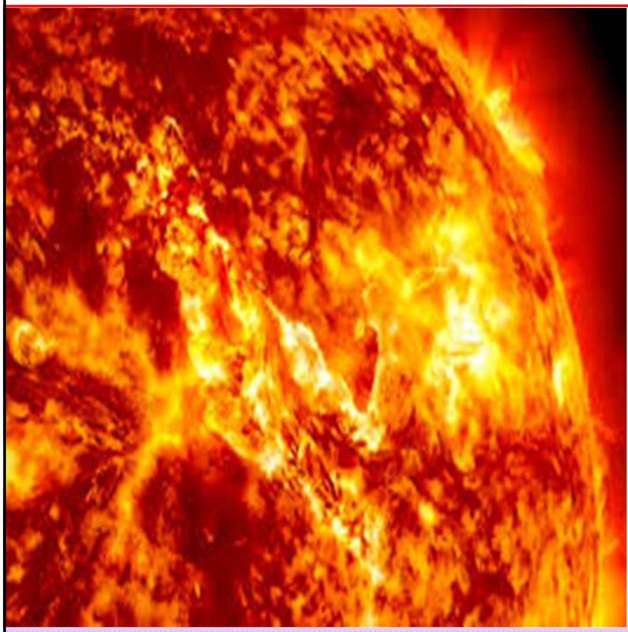


SUN – our star, the furnace



- The sun is a furnace that produces heat energy when H nuclei undergo fusion to He.
- The sun consists of unburned H and He residue
- Sun is considered to be a BLACK BODY as it absorbs all light shined upon it and it emits a spectrum of light (a function of temperature).
- Luminosity (power output): 3.865 x 10^{26} Watts. Since its birth, it has lost about 30% of its luminosity.
- It still has a life about 3-4 billion years from now, till its H reservoir runs out

SUN – our star, the furnace

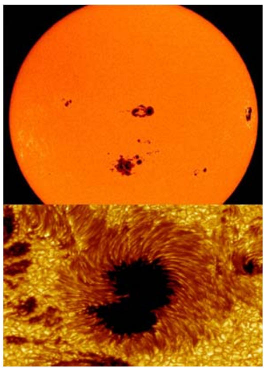


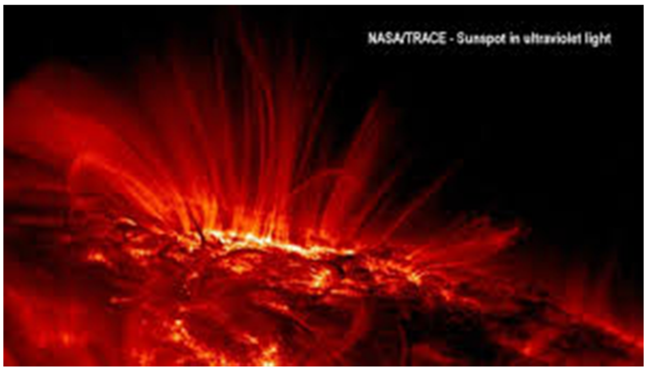
- In context to our Earth's energy, the SUN delivers two "products" we are concern about -

PLASMA RADIATION

PLASMA

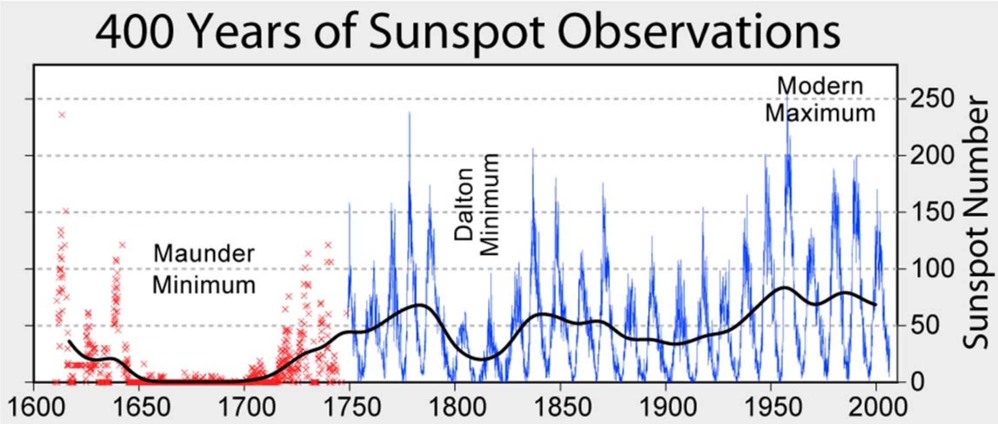
- In the Sun's core, T = 15.6 million K and the pressure is 300 billions times that of Earth's. T on sun's surface is 6000 K
- These extreme conditions break the Sun's H and He atoms into a swirling mass of charged particles - PLASMA
- These plasma particles are always in motion due to sun's strong magnetic field. A burst of such magnetism produces a SUNSPOT. Cooler than average ~ 4500 K.





PLASMA

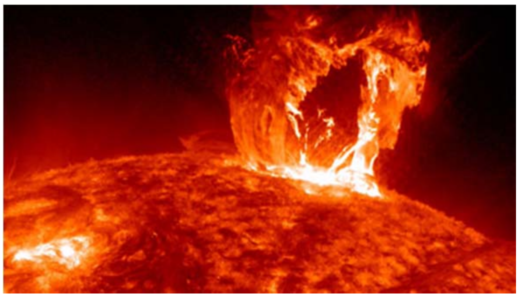
- On short term, sunspots on 11 year cycle cause a small change in global temperature (~ 0.1 K change)

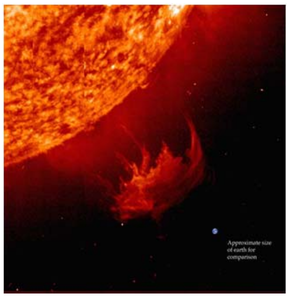


Remember, butterfly effect !

PLASMA

- A sufficiently strong magnetic irregularity may cause plasma to arc off the sun's surface as a SOLAR FLARE.
- The solar flare can also leave the Sun's strong gravitational field as CORONAL MASS EJECTION (CME).

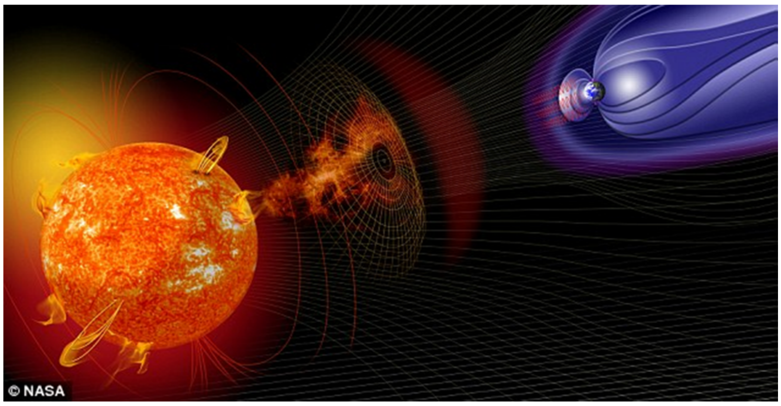




- Eventually the CMEs hit earth. Why aren't we roasted, baked and boiled?

PLASMA

- It is our own magnetic field (the protective magnetic shield) that saves us… and 1) produces auroras (borealis and australis), which forms when particles enter earths atmosphere near the poles.



- Field Electronics – satellite communications, electrical outages (Quebec 1989).

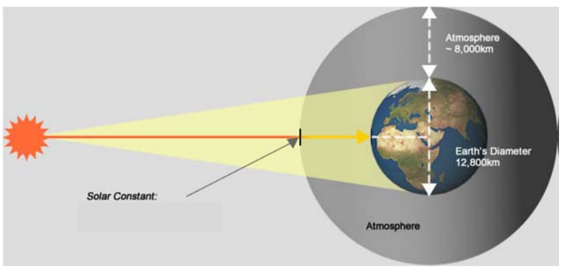
PLASMA

- How much time it requires for CMEs (velocity ~ 3 million km/hr) to reach earth?

$$time_{CME} = (\text{distance from Sun/ CME velocity}) = 50 \text{ hours}$$

- How much energy (solar constant, $\mathbf{S_o}$) we receive from sun?

  [solar constant, $\mathbf{S_o}$ = Luminosity / Area of the coverage sphere]



Radiation

- The sun continuously emits radiant energy, aka RADIATION
- What is radiation?
  - Transfer of energy that occurs when energized waves travel
  - Does it require a medium? In vacuum?
  - What is the speed of radiation? Constant or variable?
  - Who / what can emit radiation?

Radiation

- **Stefan-Boltzmann Law - I**: Warmer objects emit radiation more intensely than coo objects do.

$$E = \sigma T^4$$

E : Radiation in Watts/m^2
σ : Stefan-Boltsmann constant = 5.67 x 10^{-8} Wm^{-2} K^{-4}
T : Temperature (in Kelvin)

- **Wien's law**: Warmer objects emit shorter wavelengths; cooler objects emits larger wavelengths

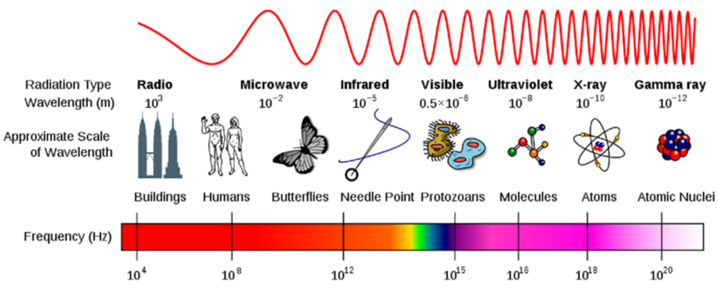
$$\lambda_{max} = \frac{C}{T}$$

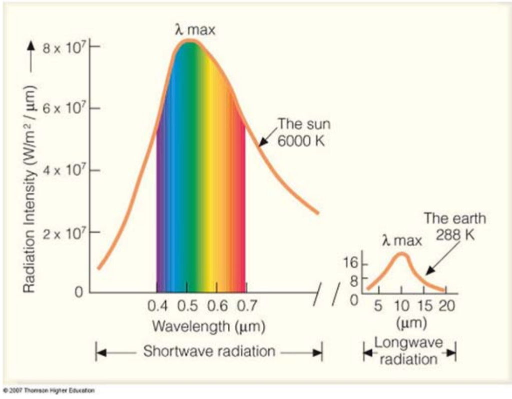
L : wavelength (μm)
C : constant = 3000 μm K
T : Temperature (in Kelvin)

Warmer objects: Large intensity and shorter wavelengths
Cooler objects: Less intensity and higher wavelengths

Radiation

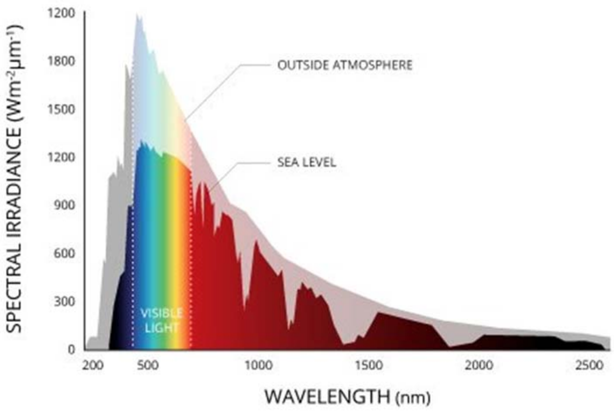
- λ_{max} *(SUN) = 0.5 μm*
- λ_{max} *(EARTH) = ~10 μm*





Radiation from Sun and Earth

- **INSOLATION** - **Incoming Solar Radiation:** Intensity of incoming solar radiation on an object (Flux / Unit Area)



Heat Balance

- **Stefan-Boltzmann law - II**: Each planet must balance net incoming solar radiation with outgoing radiation, determined by its temperature.

$$(1 - \alpha)\, \pi R^2 S_o \quad = \quad 4\pi R^2 \sigma T^4$$

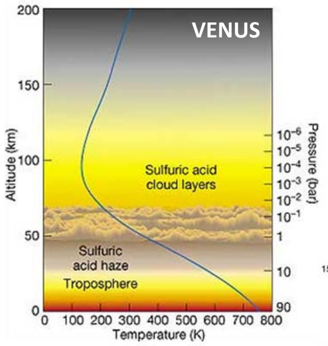
α : Earth's albedo (30%)
R :Radius of Earth (6371 km)
S_0 : Solar Constant for Earth (1367 Wm^{-2})
σ : Sterfan-Boltzman Constant (5.67 x 10^{-8} Wm^{-2} K^{-4})
T : Temperature in Kelvin

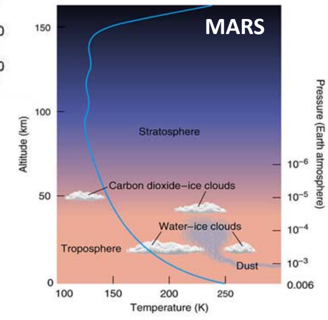
Temperatures of inner planets

	Albedo (α)	Equilibrium T (°C)	Actual surface T (°C)	
Mercury	0.1	162	180	Just about agrees
Venus	0.59	-10	453	Disagrees badly
Earth	0.31	-18	15	Disagrees
Mars	0.15	-55	-43	Nearly agrees

Temperatures of inner planets

- Radiative equilibrium works well for Mercury (no atmosphere) and just about for Mars (thin atmosphere).. But not for Earth and Venus.
- The disagreement for Venus and the Earth is because these two planets have atmospheres containing certain gases which modify their surface temperatures.
- This is the 'Greenhouse Effect' in action:
  - Earth's surface is 34°C warmer than if there were no atmosphere
  - Venus has a 'runaway' Greenhouse effect, and is over 400°C warmer
  - Mars atmosphere slightly warms its surface, by about 10°C
- The existence of the Greenhouse Effect is universally accepted (it is not controversial), and it links the composition of a planet's atmosphere to its surface temperature.

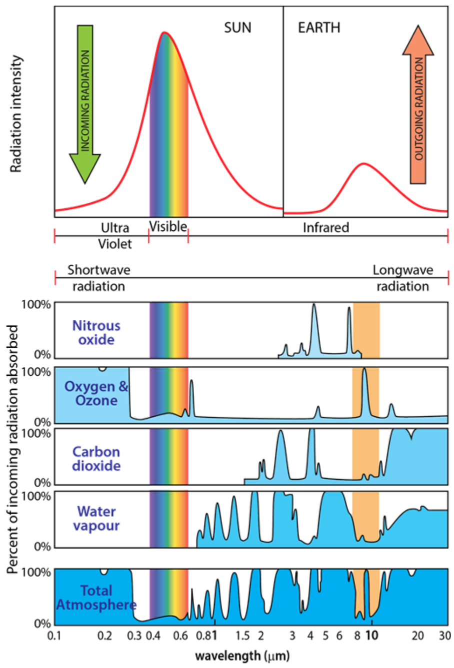




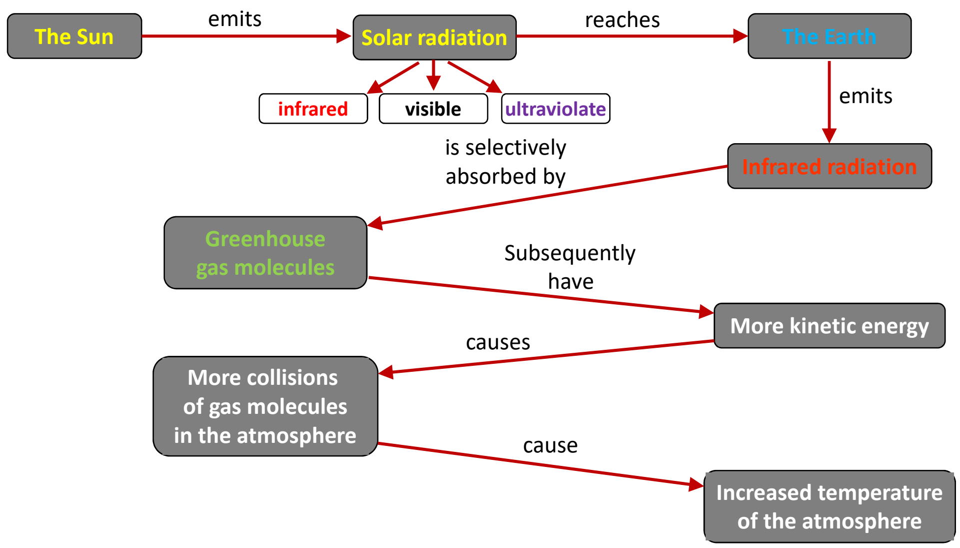
The greenhouse effect

- Sun's peak output is visible light
- Earth's Atmosphere transmits visible light (radiation). This radiation reaches the surface, absorbed and warms the surface (Insolation).
- Earth's surface is, however, much colder than that of the sun. Earth's peak output is longer wavelength infrared radiation.
- The greenhouse gases in the atmosphere absorb infrared and warm the atmosphere.

Is GREENHOUSE EFFECT good or bad for us?

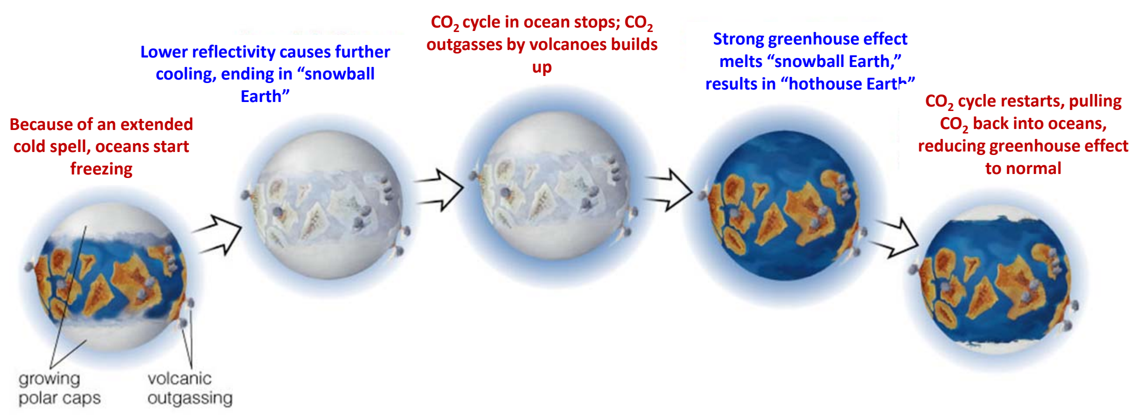


The greenhouse effect – flow chart



The snowball Earth

- We know that a cold earth makes a colder Earth (remember positive feedback loop!)
- We also know that there were few ice-ages, when the surface of the Earth was covered by snow and ice. The last one happened about 635 million years ago. Oceans froze to a depth of 1 km and stayed about 12 million years.
- How did the Earth manage to melt all the ice and snow to make itself again habitable?



Global warming – a quick poll

- Is global warming real?
  - Yes
  - No
- How much has the average temperature of the Earth risen in the last 100 years?
  - ~ 0.5°C
  - ~ 5.0°C
  - ~ 10.0°C
  - ~ 1.0°C
- This is the highest temperature ever recorded in Earth's history.
  - Yes
  - No
- Who is responsible for Global Warming?
  - Human Activities
  - Natural causes
  - ET
  - Hard to tell
- Which gas in the atmosphere is to blame?
  - Ozone
  - CO_2
  - H_2O
  - O_2

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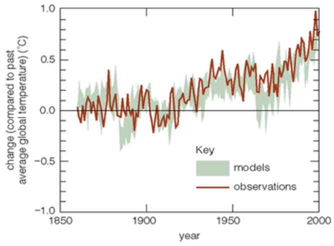
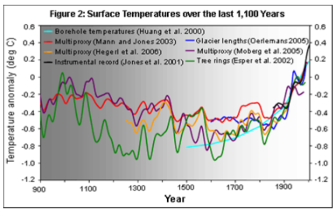
Global warming – the scenario



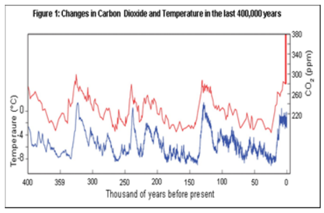
There is a gradual increase in the average temperature of the Earth's atmosphere in the last 100 years…It has risen about 1°C since 1900…

- *Are human activities causing global warming?*
- *What other (non-human) factors can cause global warming?*
- *How does global warming affect our life?*



Reconstructions of surface temperature variations from six research teams. Each curve illustrates a somewhat different history of temperature changes, with a range of uncertainties that tend to increase backward in time (as indicated by the shading).

NRC, 2006. National Academy of Sciences, Courtesy of the National Academies Press. Washington, D.C.



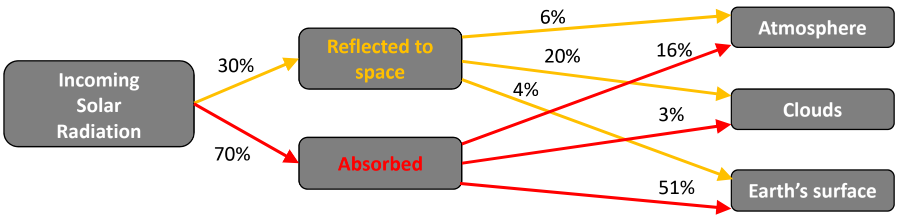
Fluctuations in temperature (blue) and in the atmospheric concentration of carbon dioxide (red) over the past 400,000 years as inferred from Antarctic ice-core records. The vertical red bar is the increase in atmospheric carbon dioxide levels over the past two centuries and before 2006.

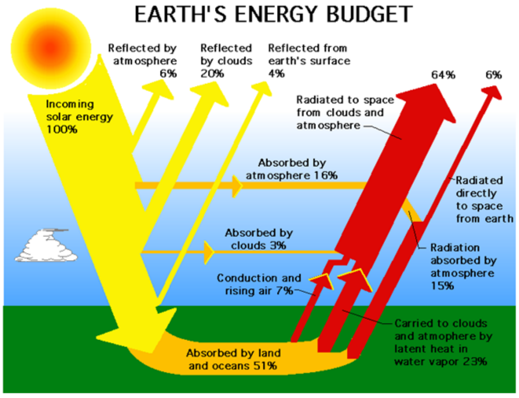
A. V. Fedorov et al. *Science* 312, 1485 (2006).

What's the big deal if CO_2 causes 1°C temperature increase?

- An increase in atmospheric temperature (human or natural origin) will lead to the increase in the water vapor content of the **troposphere.**
- Because water vapor is a strong greenhouse gas, the increase in H_2O vapor in turn causes enhanced greenhouse effect, raising the temperature more.
- Higher atmospheric temperature will cause more evaporation of water
- Which leads to even higher temperature… POSITIVE FEEDBACK LOOP… and effectively culminate to Runaway Greenhouse Effect.

Earth’s Energy Balance



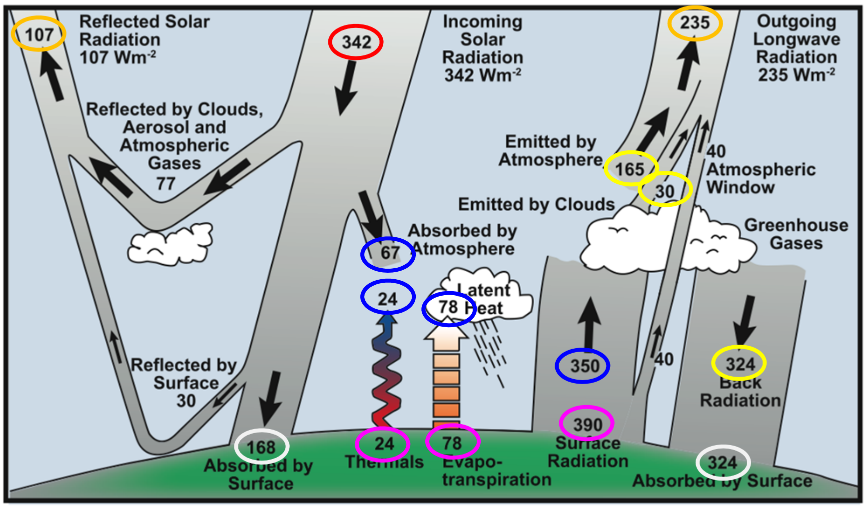


Earth’s Energy Balance

342 Energy entering top of atmosphere = Energy leaving top of atmosphere 107+235

67+350+78+24 Energy gained by atmosphere = Energy lost by atmosphere 165+324+30

168+324 Energy entering Earth’s surface = Energy leaving Earth’s surface 24+78+390



Next Lecture

Concept of Plate Tectonics