MONDAY: energy in and energy out on a global scale

Atmospheric Greenhouse Effect

- Why we would freeze to death without it
- Earth-atmosphere energy balance

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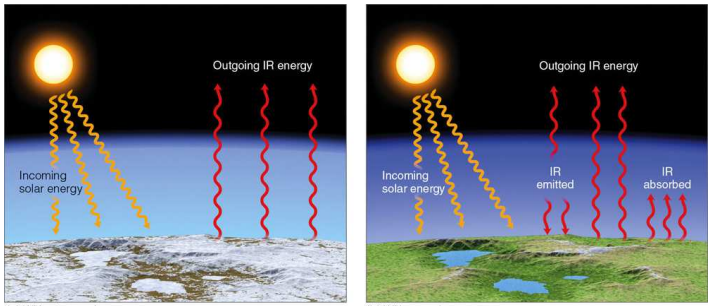
Atmospheric Greenhouse Effect



(a) Without greenhouse gases (b) With greenhouse gases

- If earth's atmosphere didn't contain greenhouse gases the surface temperature would be a lot colder than is observed
- Greenhouse gases absorb part of the outgoing infrared radiation and re-emit that back to the earth's surface, causing an extra warming

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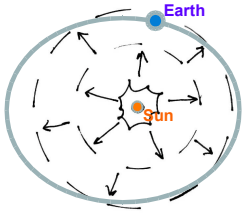
Solar Radiation

- Energy is radiated by the sun at a rate of $6 \cdot 10^7$ Watts per square meter, corresponding to a total rate of $4 \cdot 10^{26}$ Watts (light bulb ~ 60 W)



- As sun's radiation spreads out and reaches earth's orbit, it's intensity drops to 1368 W / m^2
- This quantity S = 1368 W / m^2 is called the solar constant (even though it does fluctuate slightly over time)

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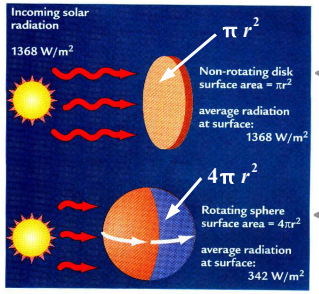
Solar (Ir)radiation

- As sun's radiation spreads out and reaches earth's orbit, it's intensity drops to 1368 W / m^2



Amount of incident (but not necessarily absorbed) sunlight onto earth can be determined by a disk with earth's radius

Averaged over the earth's surface this incoming radiation amounts to 342 W / m^2

342 W / m^2 impinges on average on the top of the earth's atmosphere

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Reflection and Albedo

- Albedo: the ratio of reflected radiation to incoming/incident radiation ($\alpha = E_r/E_i$)
- Surface albedo varies spatially and temporarily
- (thick) Clouds are highly reflective, i.e. have large albedo →

TABLE 2.3 Typical Albedo of Various Surfaces

SURFACE	ALBEDO (PERCENT)
Fresh snow	75 to 95
Clouds (thick)	60 to 90
Clouds (thin)	30 to 50
Venus	78
Ice	30 to 40
Sand	15 to 45
Earth and atmosphere	30
Mars	17
	10 to 30
	5 to 20
	10*
	3 to 10
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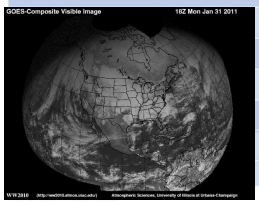
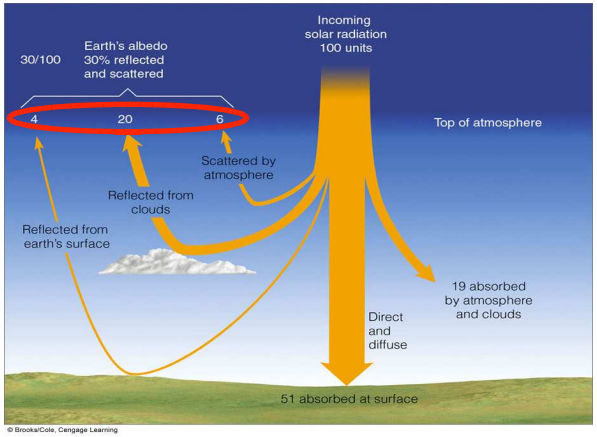


'No Greenhouse' Scenario: albedo due to earth's surface, atmosphere, clouds (30%) → **239 W/m² = 70% of the 342 W/m² incoming radiation stays in earth's climate system.**



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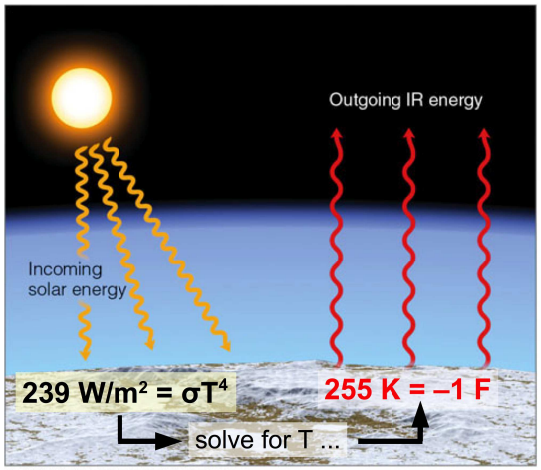

Earth Radiation Balance

- If the earth radiates energy constantly – why doesn't it cool down?
- **The earth system is in a state of radiative equilibrium!** *(incoming solar radiation is balanced by outgoing terrestrial radiation)*
- Equilibrium temperature = 255 K (–1 F)
- **Radiative equilibrium** based on the above **predicts a surface temperature of –1 F**
- **BUT: observed surface temperature = 59 F**
- Where do the extra 60 F come from?

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Earth Radiation Balance

'Black Body' Atmosphere (Heuristic 'Greenhouse')

Albedo = 0.3, black body atmosphere means all radiation absorbed by the atmosphere from below is re-emitted and received by earth's surface, i.e. another 239 W/m²:

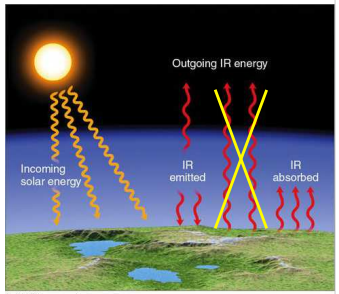
$2 \cdot 239\ W/m^2 = \sigma T^4$

solve for T ...

→ in this case, globally averaged surface temperature of the earth would be:

T = 303 K = 30 C = 86 F!

(observed: 288 K = 15 C = 59 F)



(b) With greenhouse gases

The Role of the Atmosphere: Selective Absorption

- A number of gases in our atmosphere are selective absorbers: they selectively absorb (and emit) radiation at certain wavelengths
- **Therefore, they are not blackbody radiators!**
- Most gases let the short wave (solar) radiation pass through and only absorb the longer (infrared) wave radiation
- This gives rise to the **Greenhouse Effect**!
- Greenhouse gases: H_2O, CO_2, CH_4(methane), N_2O (nitrous oxide), O_3, CFCs, ...

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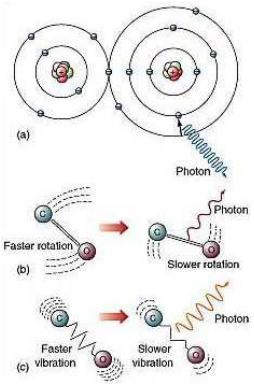
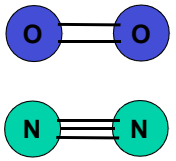
Atoms, Molecules, and Photons



- Atmospheric gases are made of molecules
- Molecules are groups of atoms that share electrons (bonds)
- Photons can interact with molecules
- Transitions between one state and another involve specific amounts of energy

Dancing Molecules and Heat Rays!

- Nearly all of the air is made of oxygen (O_2) and nitrogen (N_2) in which two atoms of the same element share electrons

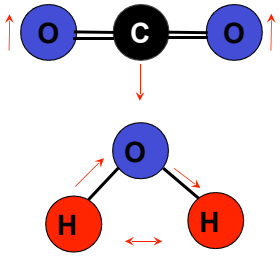


- Infrared (heat) energy radiated up from the surface can be absorbed by these molecules, but not very well

Diatomic molecules can vibrate back and forth like balls on a spring, but the ends are identical

Dancing Molecules and Heat Rays!

- Carbon dioxide (CO_2) and water vapor (H_2O) are both different!
- They have many more ways to vibrate and rotate, so they are very good at absorbing and emitting infrared (heat) radiation

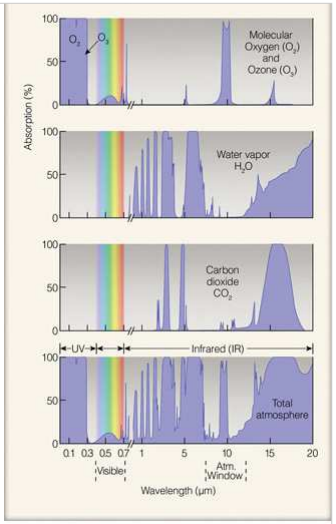


Molecules that have many ways to wiggle are called "Greenhouse" molecules

Absorption spectrum of CO2 was measured by John Tyndall in 1863!

Selective Absorption by Variable Gases

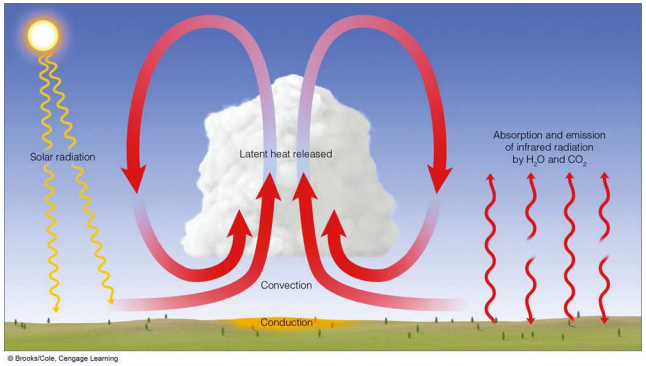
- Atmospheric variable gases let most of Sun's radiation (shortwave) pass through
- Atmospheric variable gases absorb much of radiation emitted upward from the earth (terrestrial radiation)
- "Atmospheric Window" between 8–11 μm lets most terrestrial radiation pass through (earth emits at 288 K (59 F) which corresponds to ~ 10 μm)
- Clouds can close this window!



Earth Radiation Balance

- Greenhouse gases in the atmosphere absorb part of the infrared radiation emitted from the earth
- These greenhouse gases re-emit infrared radiation in all directions, in particular back towards the earth's surface
- In radiative equilibrium, with the observed distribution of atmospheric greenhouse gases, this extra gain of heat would lead to a surface temperature of 303 K (86 F – too warm)
- **What's missing?**

Radiative-Convective Balance



Convection transports heat away from the surface and redistributes it vertically across the atmosphere

Thomas Birner, ATS, CSU

Greenhouse Effect: Key Points

- The climate system as a whole emits radiation at a temperature of 255 K (-1 F = -18 C), without greenhouse gases this would be the temperature of the Earth's surface
- Atmospheric greenhouse gases are largely transparent to shortwave radiation but absorb and emit a great deal of longwave/infrared radiation
- Greenhouse gases absorb part of the outgoing infrared radiation and re-emit that back to the earth's surface, causing an extra warming

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Global Mean Energy Balance: Key Points

- The Earth's surface emits more radiation upward than it receives from the Sun
- More energy is gained from the atmosphere at the Earth's surface than from the Sun
- At the Earth's surface + in the atmosphere + at the top of the atmosphere, the heat coming in equals the heat going out → *a balanced state*

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