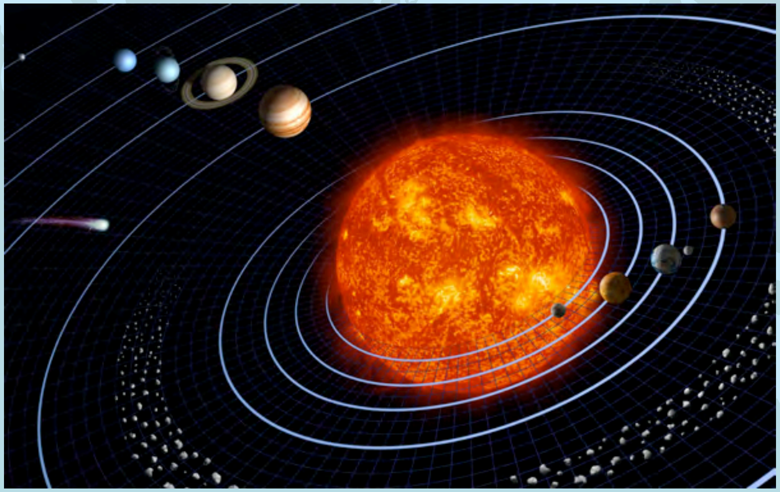
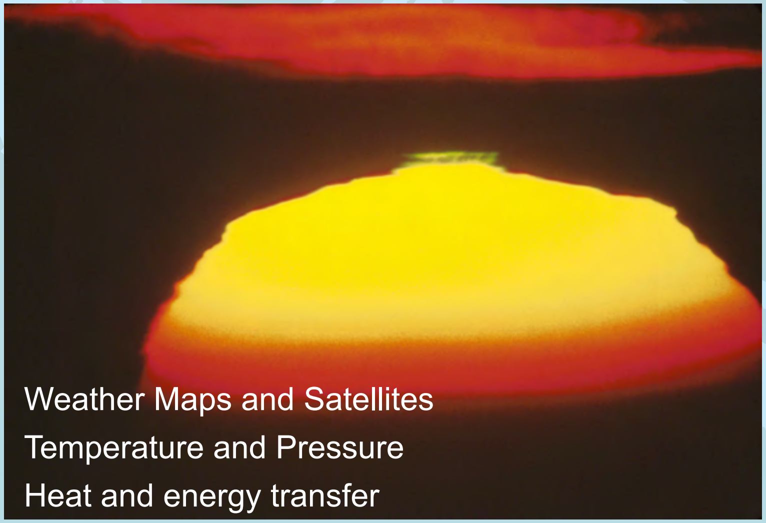
MET 200 Lecture 3
Radiation & Earth’s Radiation Balance



Outline of Previous Lecture



Weather Maps and Satellites
Temperature and Pressure
Heat and energy transfer

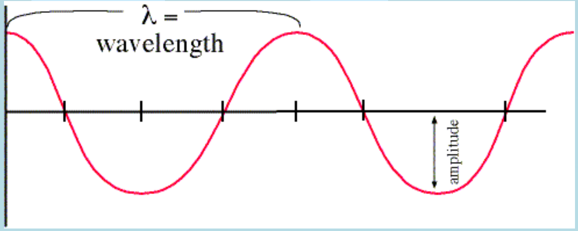
Lecture 3

Outline

- Laws of Radiation
- Earth’s Radiation Balance
- Greenhouse Effect

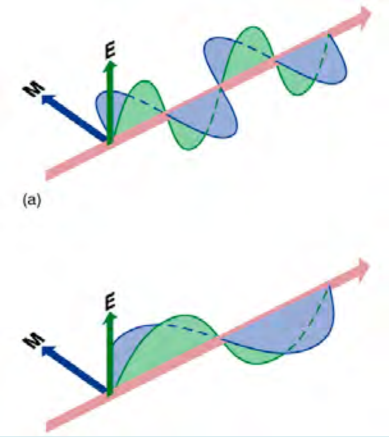
Radiation

- Radiation - energy leaving a body in the form of electromagnetic waves.
- Light is a form of electromagnetic radiation.
- The speed of light is 299,792,458 m/s or ~ 3×10^8 m/s through a vacuum (slightly slower through air).

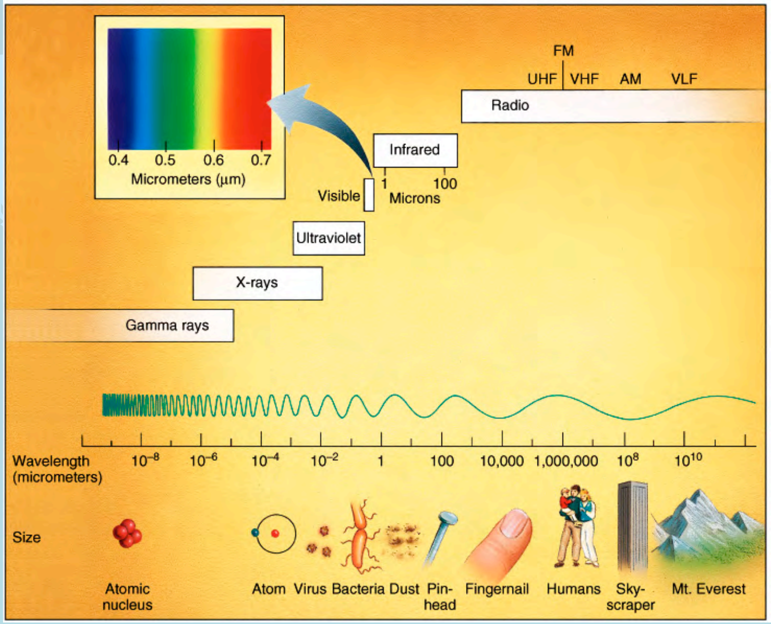


Radiation Quality and Quantity

- The amplitude corresponds to the energy carried
- The wavelength corresponds to the type

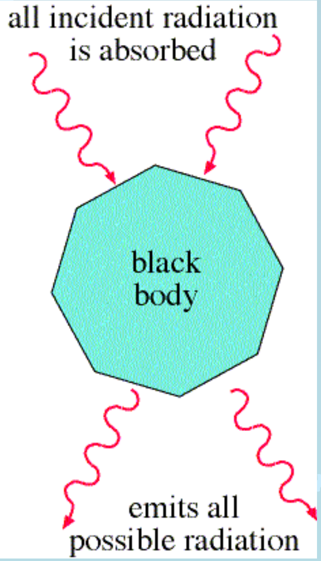


Radiation – Types



Radiation Concepts

Blackbody - is a theoretical object that absorbs all incident radiation and emits the maximum possible radiation for its temperature – according to Planck's Law.



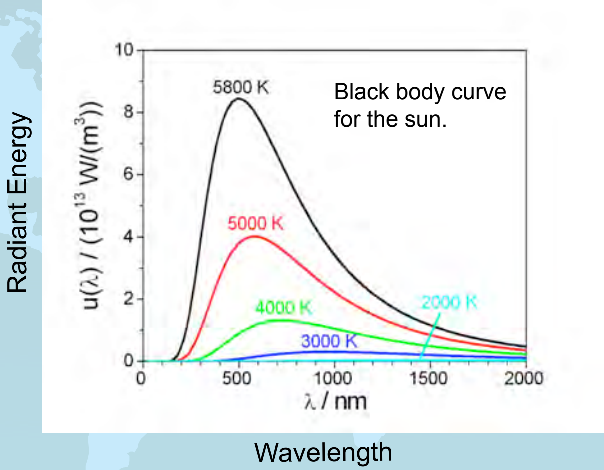
Planck's Law

The amount of radiation emitted by a blackbody is described by Planck's Law

$$E_\lambda = \frac{2hc^2}{\lambda^5\left[\exp\left(hc/k\lambda T\right)-1\right]}$$

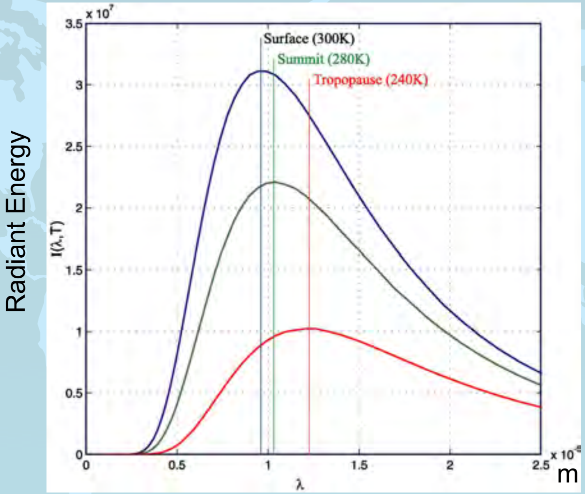
- k is the Boltzmann constant, and is 1.38x10^{-23} J/K
- h is Planck's constant and is 6.626x10^{-34} Js
- c is the speed of light in a vacuum and is 2.9979x10^{8} m s^{-1}.
- Blackbody radiation is isotropic, homogeneous, unpolarized and incoherent.
- Planck's Law means that the sun isn't special, all objects radiate

Planck's Law



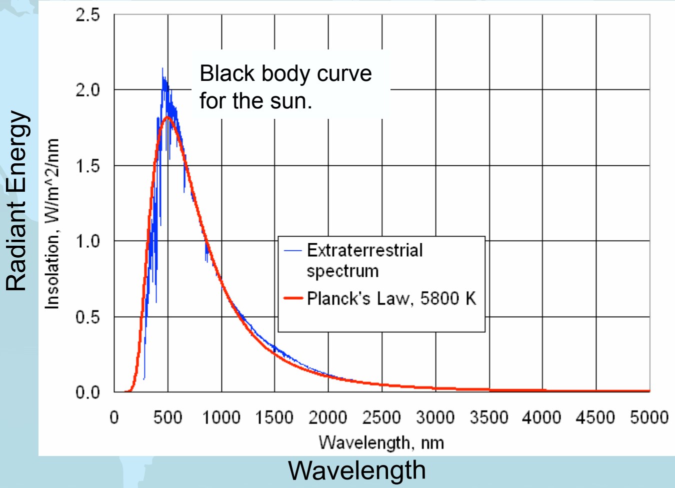
Planck's Law describes the radiant energy at all wavelengths emitted from a black body.

Planck's Law and Black Body Radiation



Planck's Law describes the radiant energy at all wavelengths emitted from a black body.

Planck's Law



Planck's Law describes the radiant energy at all wavelengths emitted from a black body.

STEFAN - BOLTZMAN LAW

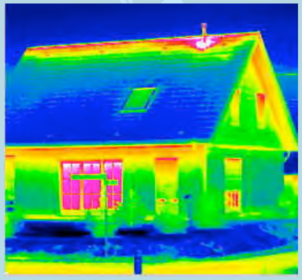
Stefan-Boltzman law is obtained by integrating Planck's Law across all wavelengths. As the temperature of a black body increases, the *irradiance* (E) emitted by that object per unit time and unit area increases by a power of 4.

$$E = \sigma T^4$$

where σ is a constant = 5.67×10^{-8} W m^{-2} K^{-4}

If T doubles, E increases by 16 times!

E is in Watts/m^2



Wein’s Law*

The wavelength (λ_{max}) of peak radiation emitted by an object is inversely related to temperature (T).

$\lambda_{max} \sim b/T = 2897/T$, b = Wien’s displacement constant

λ_{max} is in μm and T is in Kelvin

*Wein’s Law is obtained by taking the derivative of Planck’s Law

Kirchhoff's law of thermal radiation

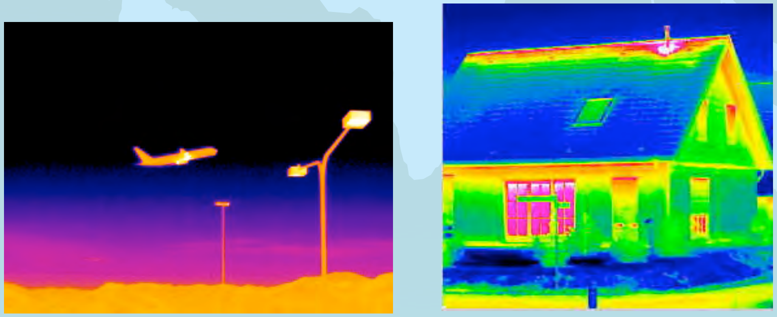
For an arbitrary body emitting and absorbing thermal radiation in thermodynamic equilibrium, the absorptivity is equal to the emissivity for each wavelength.

$a_\lambda = \varepsilon_\lambda$

A good absorber is a good emitter, and a poor absorber is a poor emitter. Naturally, a good reflector must be a poor absorber. This is why, for example, lightweight emergency thermal blankets are based on reflective metallic coatings: they lose little heat by radiation.

Summary of Laws of Radiation

1. All objects emit radiation (except at 0°K).
2. Hotter objects emit more energy per unit area than colder objects.
3. The hotter the object the shorter the wavelength of maximum radiation.
4. Objects that are good absorbers of radiation are good emitters of radiation.



Radiation Concepts

Solar constant - Amount of solar radiation passing through a unit area at the top of the earth's atmosphere perpendicular to the direction of the radiation at the mean Earth-sun distance.

Solar Constant = $S = E_s*(R_s /R_{sE})^2$

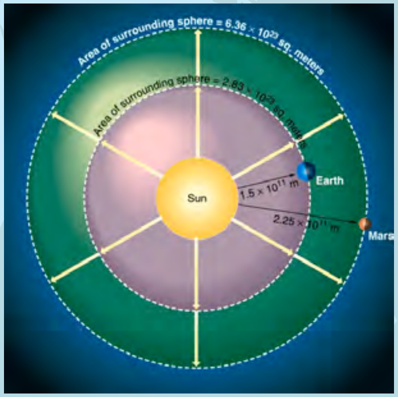
At the sun’s surface:

$E_s = \sigma T^4 = 5.67*10^{-8}$ W/(m^2*K^4)*(5800K)^4 = 6.416X10^7 W/m^2

The radius of the sun $R_s = 6.955 \times 10^8$ m

Distance of sun to Earth $R_{sE} = 1.5 \times 10^{11}$ m

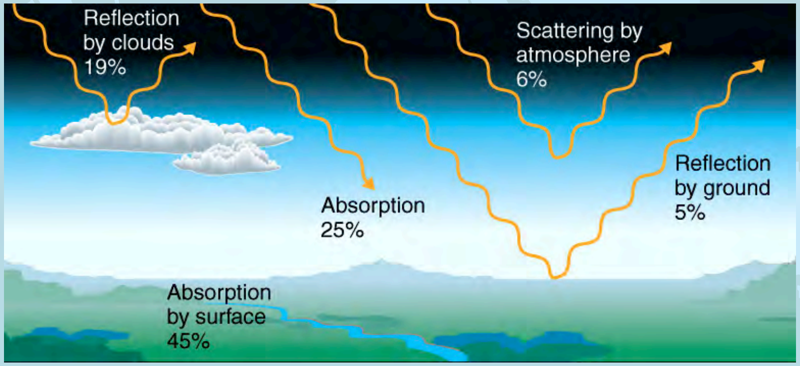
$S = E_s(R_s /R_{sE})^2 = 1379$ W/m^2



Radiation Concepts

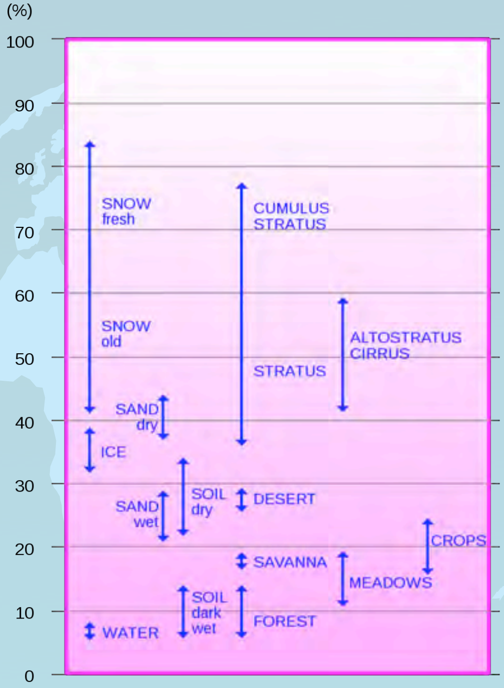
What happens to sunlight once it reaches the Earth?

Transmission	45%+5%=50% reaches surface
Scattering (reflection)	19%+6%+5%=30%=Albedo
Absorption	45% by surface and 25% by atm.



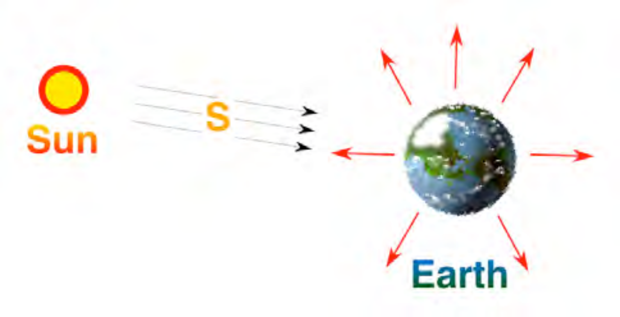
Reflection and Scattering of Incoming Sunlight

- Albedo: the ratio of reflected radiation to incident radiation
- Surface albedo varies geographically and in time.



Earth Radiation Balance

Without an atmosphere: radiative equilibrium temperature = **-18^{o}C**



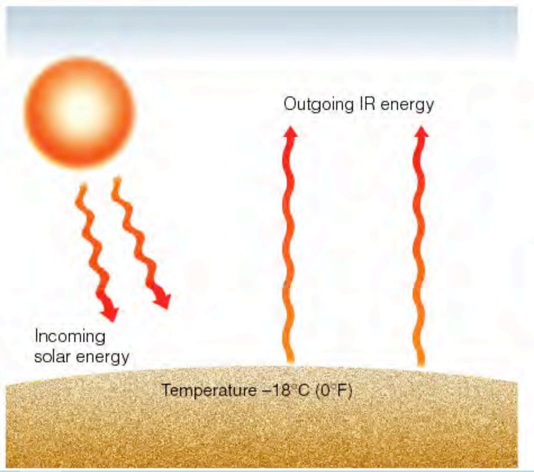
Incoming Energy (visible) = Outgoing Energy (IR)

$$S(1-a)\,\pi r^2 = \sigma T_E^4 (4\pi r^2)$$

$$T_E = [S(1-a)/4\sigma]^{1/4} = 255K = -18^{\circ}C$$

Where S = solar constant, a = albedo, and σ = constant.

Without an Atmosphere

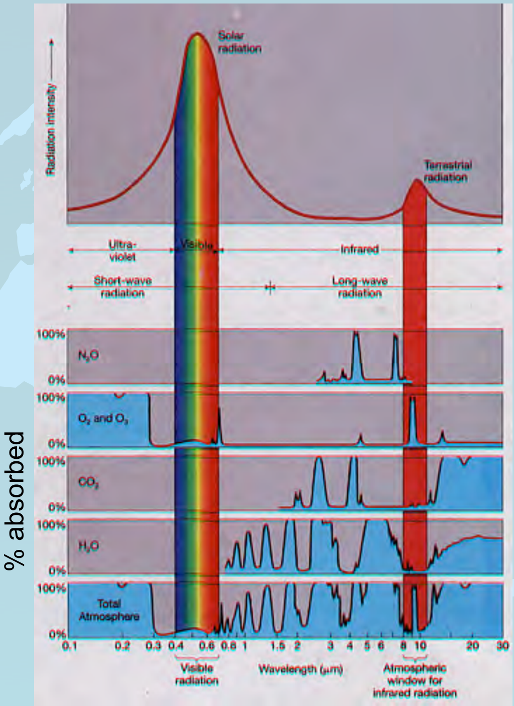


Radiative Equilibrium Temperature = **-18°C**
and we would have an frozen planet

Atmospheric Windows

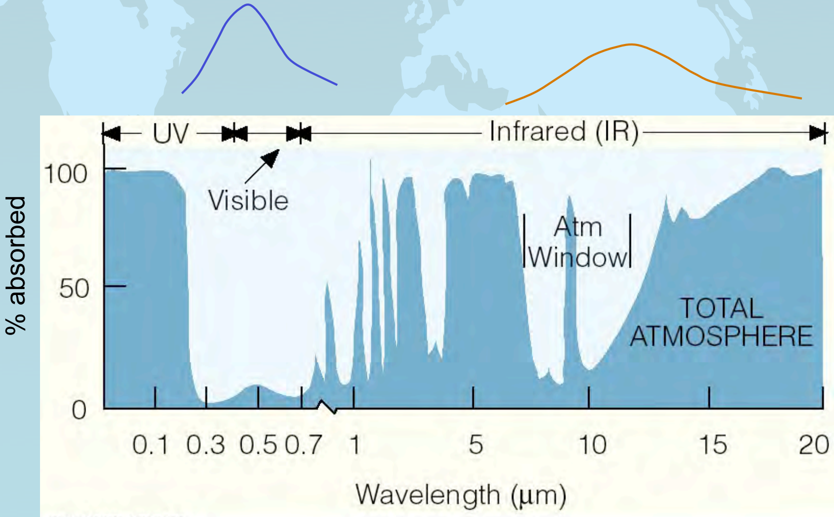
Transmission vs Absorption

The Atmosphere is nearly transparent for shortwave or visible radiation, but strongly absorbs longwave radiation.

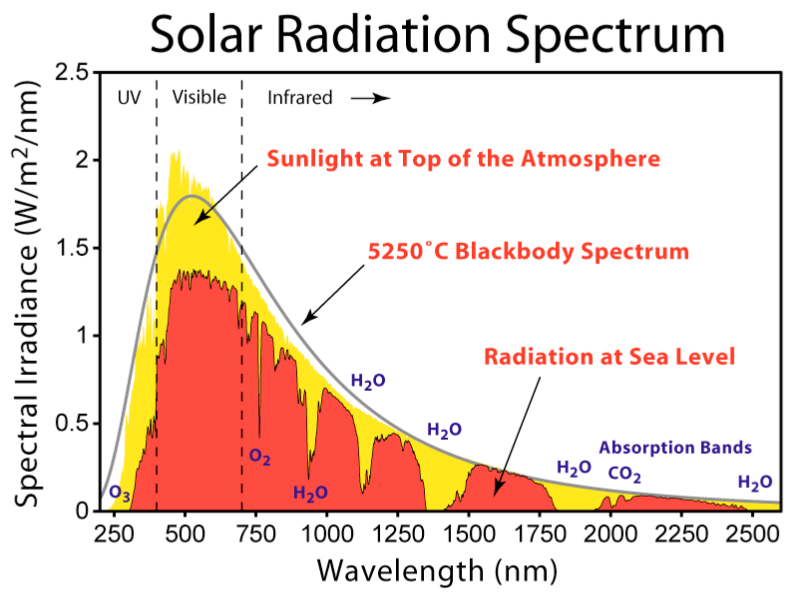


Atmosphere Absorbs Radiation

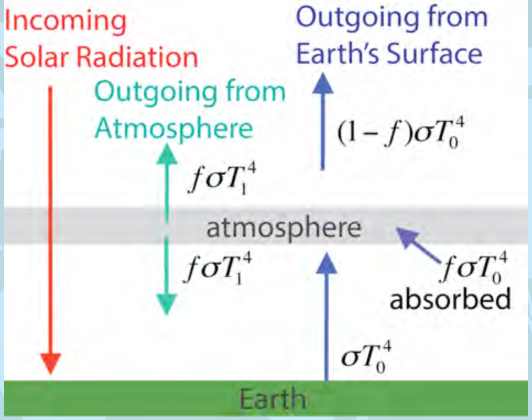
The Atmosphere is nearly transparent for shortwave but absorbs strongly longwave radiation.



Atmospheric Absorption of Solar Radiation

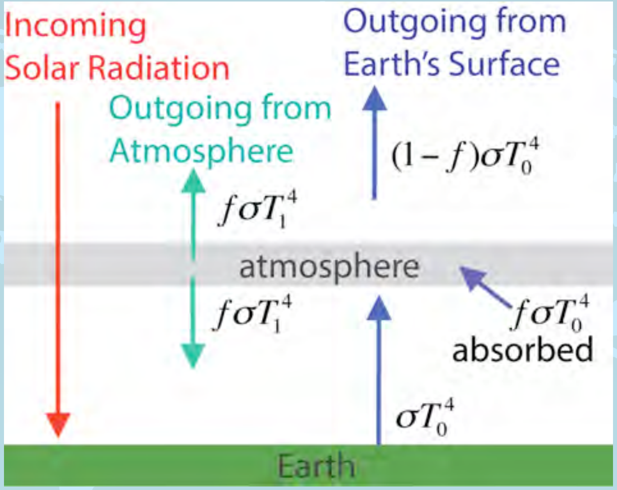


A Simple Greenhouse Model



- Incoming solar radiation = (0.7*1379)/4 W m^{-2} = 241 W m^{-2}
- IR flux from surface = σT_o^4
- Assume atmospheric layer has an absorption efficiency = $f \sim 0.77$
- Kirchhoff's law: absorptivity = emissivity
- IR flux from atmospheric layer = $f \sigma T_1^4$ (up and down)

A Simple Greenhouse Model

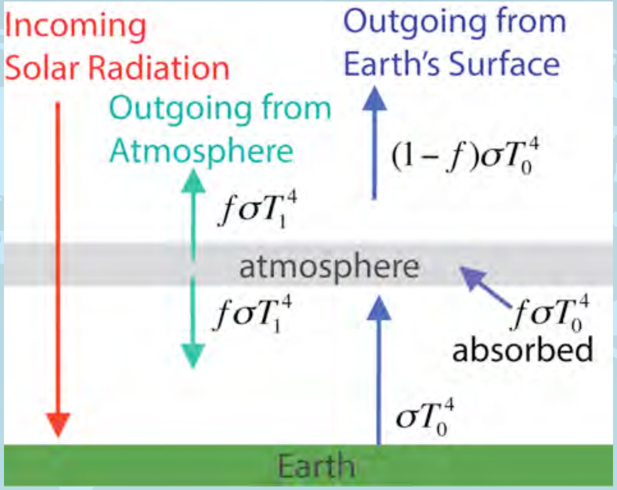


Balance at top of atmosphere $f \sigma T_1^4 + (1-f) \sigma T_o^4 = 241$

Balance for atmospheric layer $f \sigma T_1^4 + f \sigma T_1^4 = f \sigma T_o^4$

Balance at the surface $\sigma T_o^4 = 241 + f \sigma T_1^4$

A Simple Greenhouse Model



We have two equations and two unknowns, can solve.
$T_o = 288$ K ; $T_1 = 241$ K
Greenhouse gases affect *f*; as *f* increases, T_o and T_1 increase

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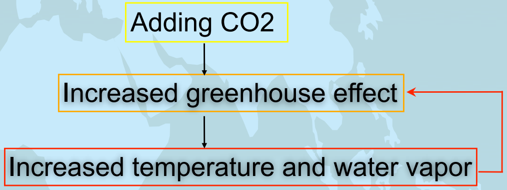
Increasing the Greenhouse Effect

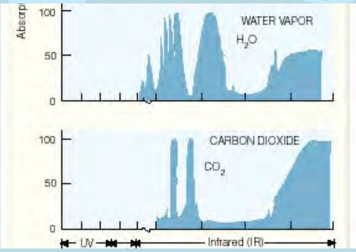
Water vapor feedback



Adding CO2

Increased greenhouse effect

Increased temperature and water vapor



Questions?