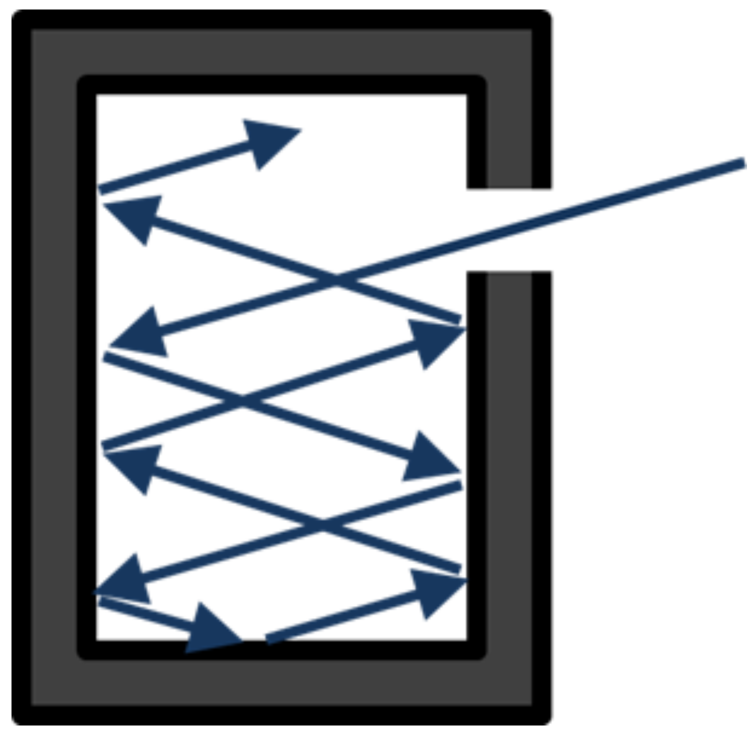
ATMOS 5140
Lecture 7 – Chapter 6

- Thermal Emission
  - Blackbody Radiation
    - Planck's Function
    - Wien's Displacement Law
    - Stefan-Bolzmann Law
  - Emissivity
    - Greybody Approximation
    - Kirchhoff's Law
    - Brightness Temperature

Blackbody Radiation

- Theoretical Maximum Amount of Radiation that can be emitted by an object
- Perfect emitter – perfect absorber
- Absorptivity = 1

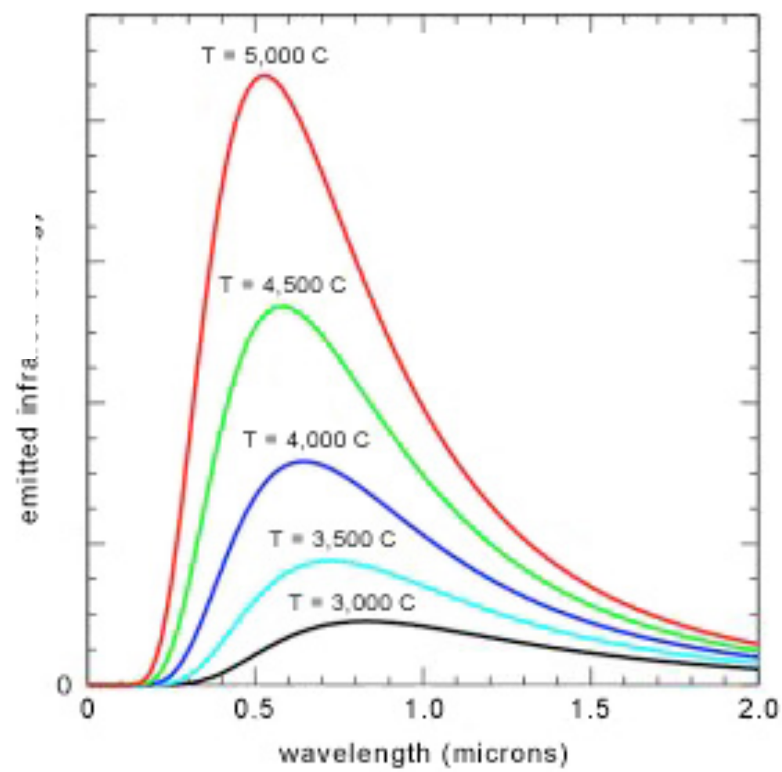


Planck's Law

- Defines the monochromatic intensity of radiation for a blackbody as a function of temperature.
- Physical Dimensions of intensity (power per unit area per unit solid angle) per unit wavelength: W m^{-2} um^{-1} sr^{-1}

$$B_\lambda(T) = \frac{2hc^2/\lambda^5}{e^{hc/\lambda kT} - 1}$$

Where:
h= Planck's constant = $6.626*10^{-34}$ J s
k= Bolzmann's constant = $1.381*10^{-23}$ J/K



Wien’s Displacement Law

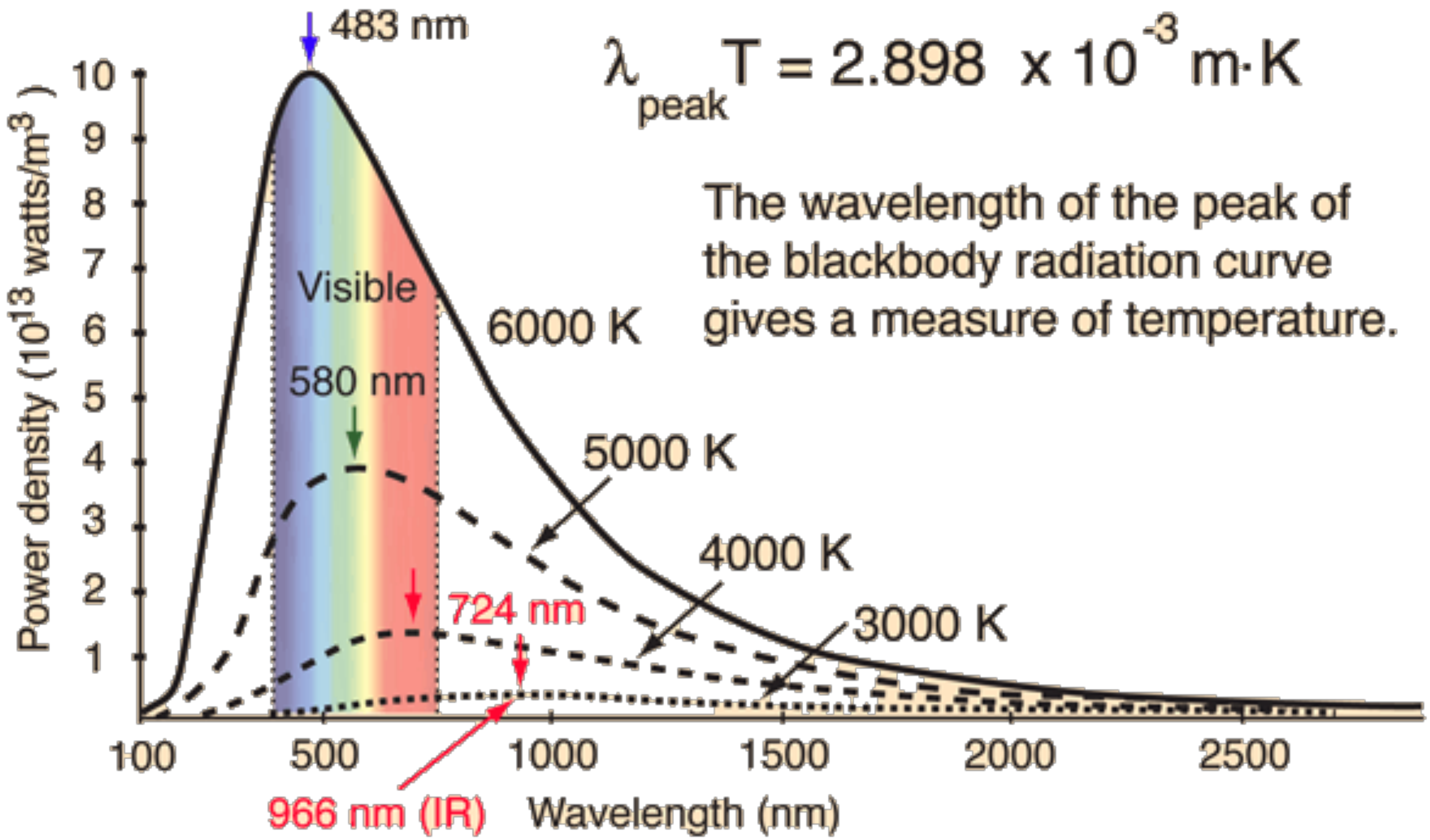
- The wavelength at which you find maximum emission from a blackbody of temperature T

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

Where k_w = 2897 um K

Wien's Displacement Law

- The wavelength at which you find maximum emission from a blackbody of temperature T



Stefan-Boltzmann Law

- Gives the broadband flux emitted by blackbody
- Integrate Planck's function over all wavelengths, and over a hemisphere (2π steradians of solid angle)

$$F_{BB}(T) = \sigma T^4$$

Where:

$$\sigma = \frac{2\pi^5 k_B^4}{15c^2h^3}$$ $= 5.67 * 10^{-8}\ W\ m^{-2}\ K^{-4}$

Rayleigh-Jeans Approximation

- For wavelengths of 1 mm or longer
- Used commonly in microwave band

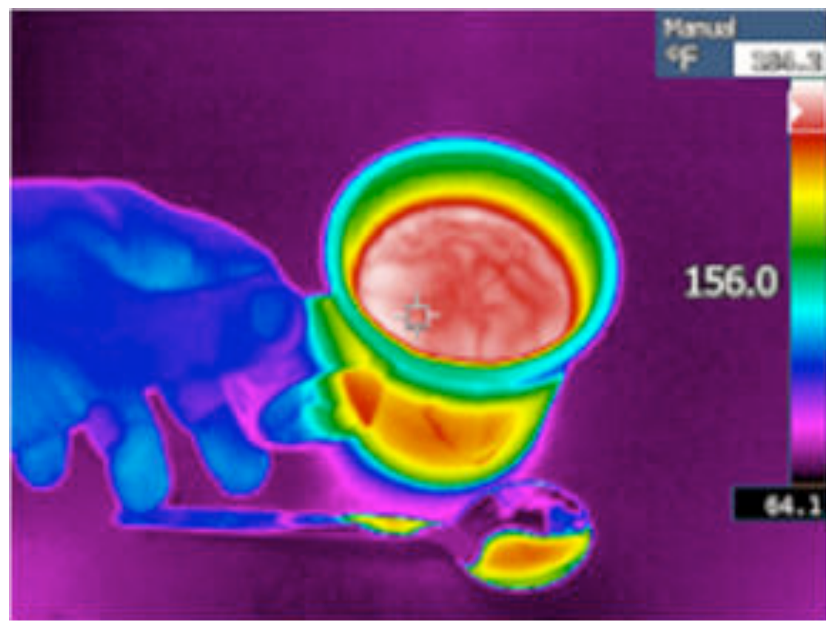
$$B_\lambda(T) = \frac{2ck_B}{\lambda^4}T$$

Where:
h= Planck's constant = 6.626*10^{-34} J s
k_B= Bolzmann's constant = 1.381*10^{-23} J/K

Emissivity

- Blackbody is an ideal situation (ε = 1)
- Typical Infrared emissivities (%, relative to blackbody)
  - Water = 92-96%
  - Concrete= 71-88%
  - Polished aluminum = 1-5%

"Typically shiny, polished metals will have a very low emissivity value making it hard to get an accurate infrared temperature reading. Polished silver, gold and stainless steel are examples of surfaces with a low emissivity. "



Monochromatic Emissivity

$$\varepsilon_\lambda \equiv \frac{I_\lambda}{B_\lambda(T)}$$

$$0 \leq \varepsilon_\lambda \leq 1$$

Greybody Emissivity

Assume there is no wavelength dependence

$$\varepsilon = \frac{F}{\sigma T^4}$$

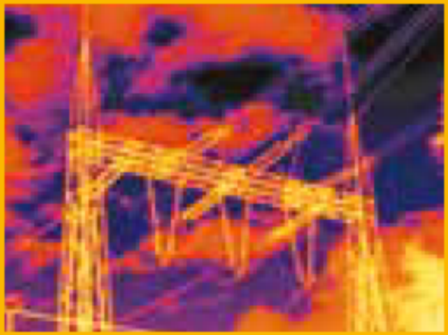
Kirchhoff’s Law

- Emissivity = Absorptivity
- Important, it implies wavelength dependences
- Also depends upon viewing directions (θ, Φ)
- Applies under conditions of local thermodynamic equilibrium

$$\varepsilon_\lambda(\theta, \phi) = a_\lambda(\theta, \phi)$$

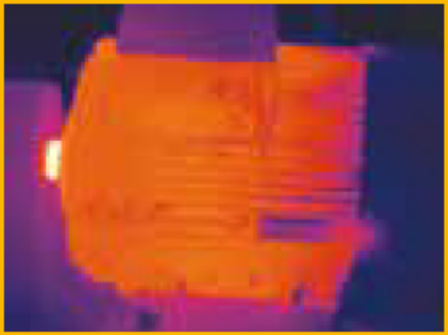
Thermal Imaging

Incorrectly secured connection



Inspection of high voltage power lines

Suspected roller

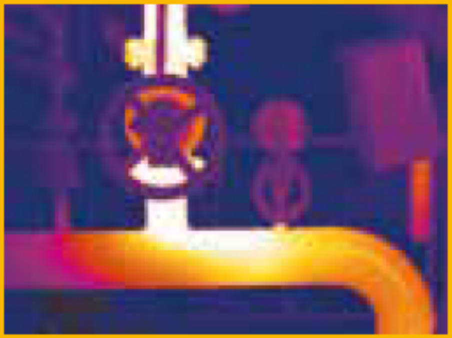


Overheated motor

Poor connection and internal damage

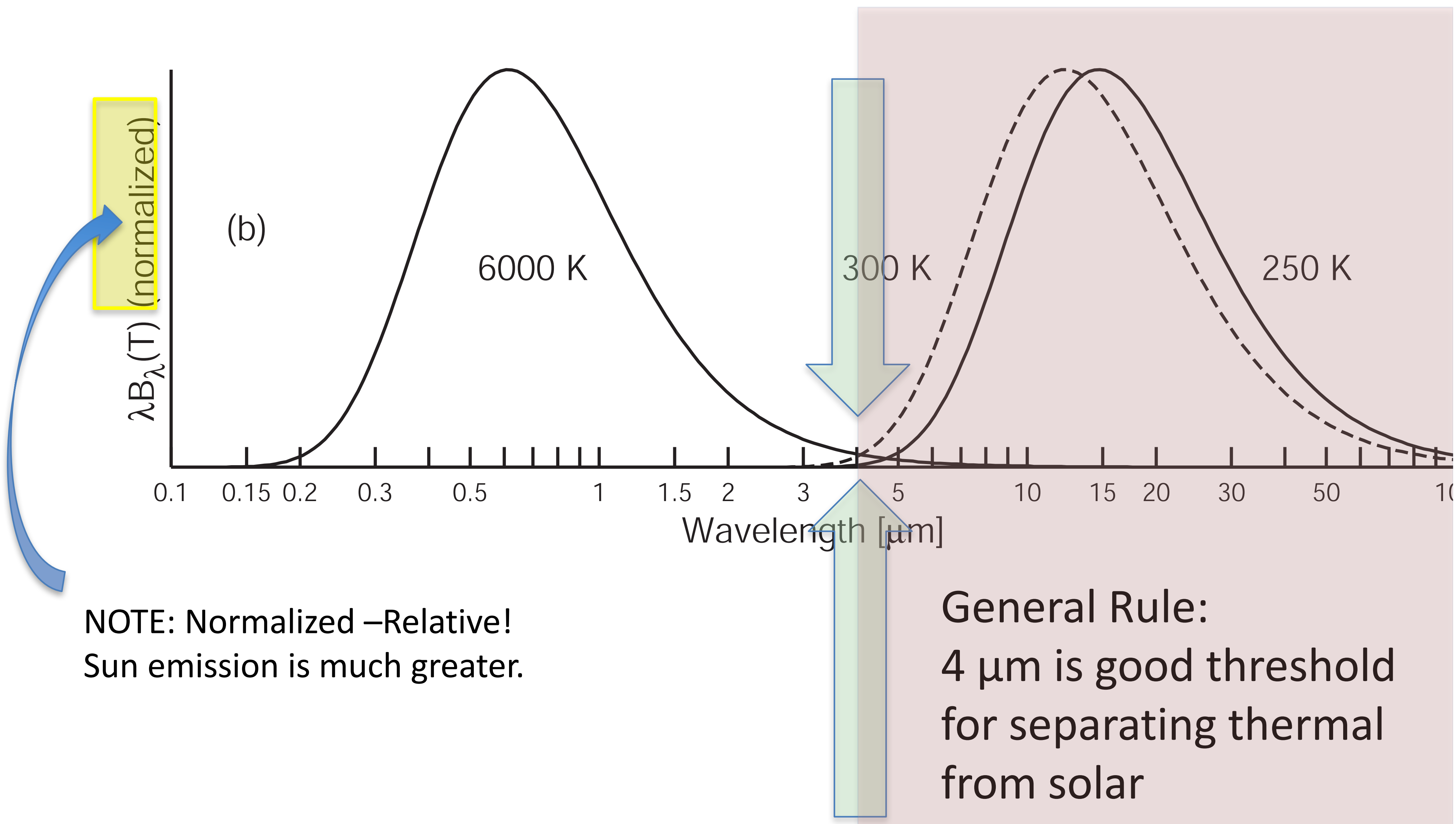
Internal fuse damage

Damaged insulation



Steam trap

When Does Thermal Emission Matter?



NOTE: Normalized –Relative!
Sun emission is much greater.

General Rule:
4 µm is good threshold for separating thermal from solar

Why is sun yellow?

http://www.iflscience.com/physics/why-sky-blue-and-sun-yellow-ls-currently-working/

Brightness Temperature

Planck's function describes a one-to-one relationship between intensity of radiation emitted by a blackbody at a given wavelength and the blackbody's temperature.

Brightness temperature is inverse of Planck's function applied to observed radiance.

Thus, when an object has a emissivity ~ 1, then the brightness temperature is very close to the actual temperature

- Extremely useful for remote sensing in Thermal IR

Brightness Temperature

$$T_B = B_\lambda^{-1}[\varepsilon B_\lambda(T)]$$

Ratio of:
Actual emitted radiation
Emission of blackbody

Recall

Planck's Function –
describes a direct relationship between temperature and emitted radiation

$$B_\lambda(T) = \frac{2hc^2/\lambda^5}{e^{hc/\lambda kT} - 1}$$

Brightness Temperature

$$T_B = B_\lambda^{-1}[\varepsilon B_\lambda(T)]$$

Ratio of:
Actual emitted radiation
Emission of blackbody

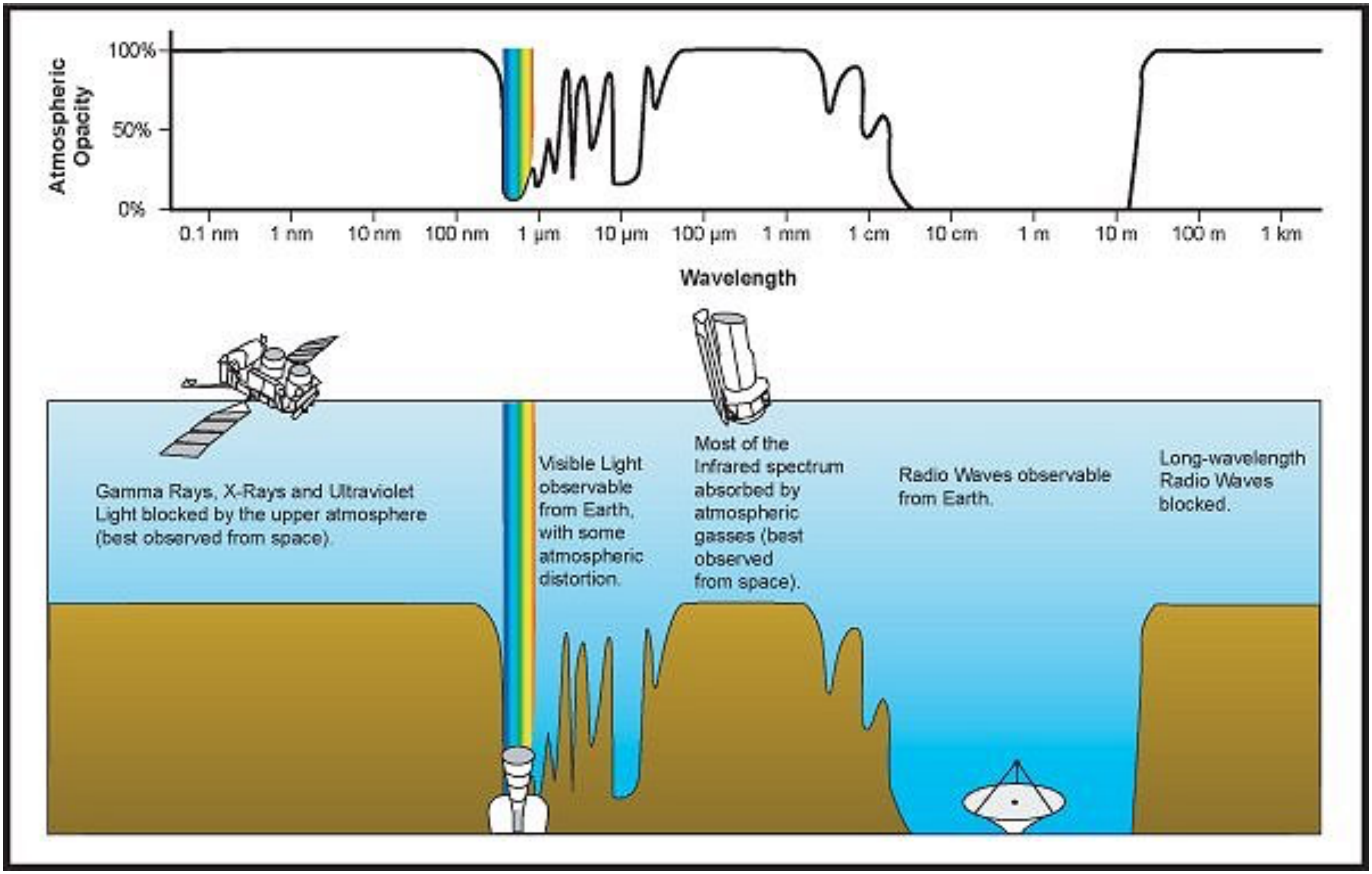
So when
$\varepsilon = 1$
$T_B = T$

Recall

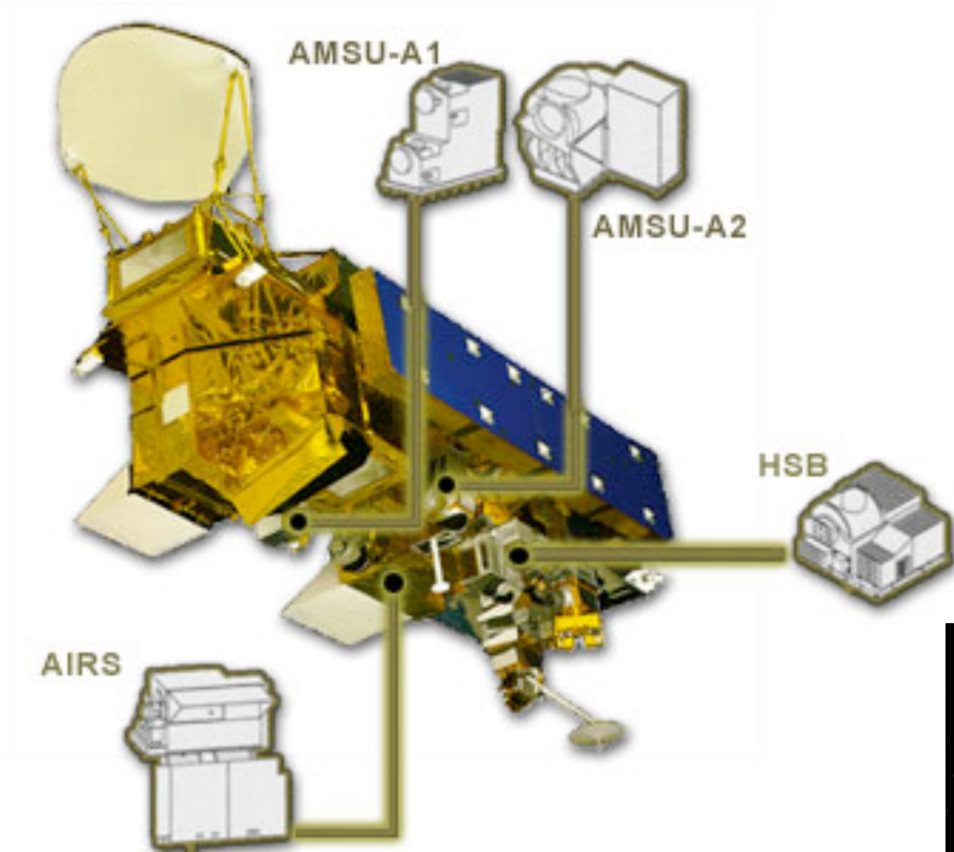
Planck's Function –
describes a direct relationship between temperature and emitted radiation

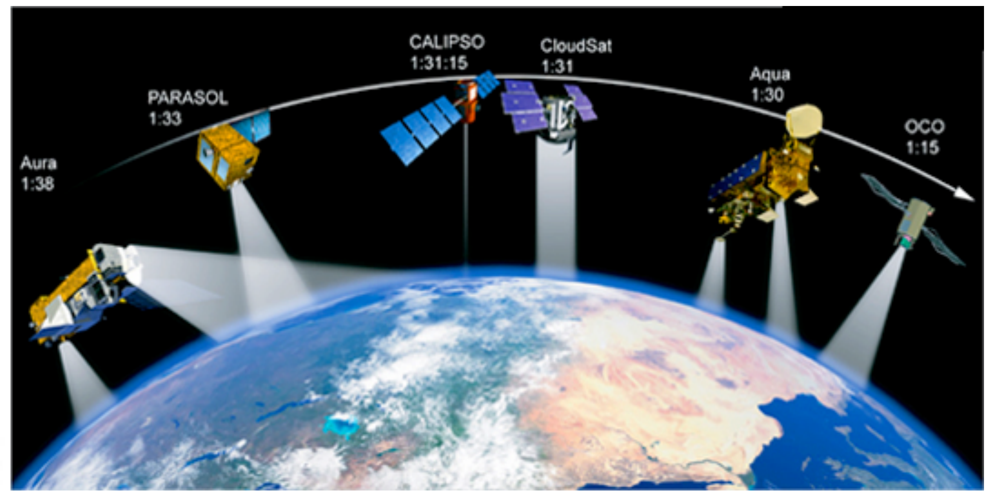
$$B_\lambda(T) = \frac{2hc^2/\lambda^5}{e^{hc/\lambda kT} - 1}$$

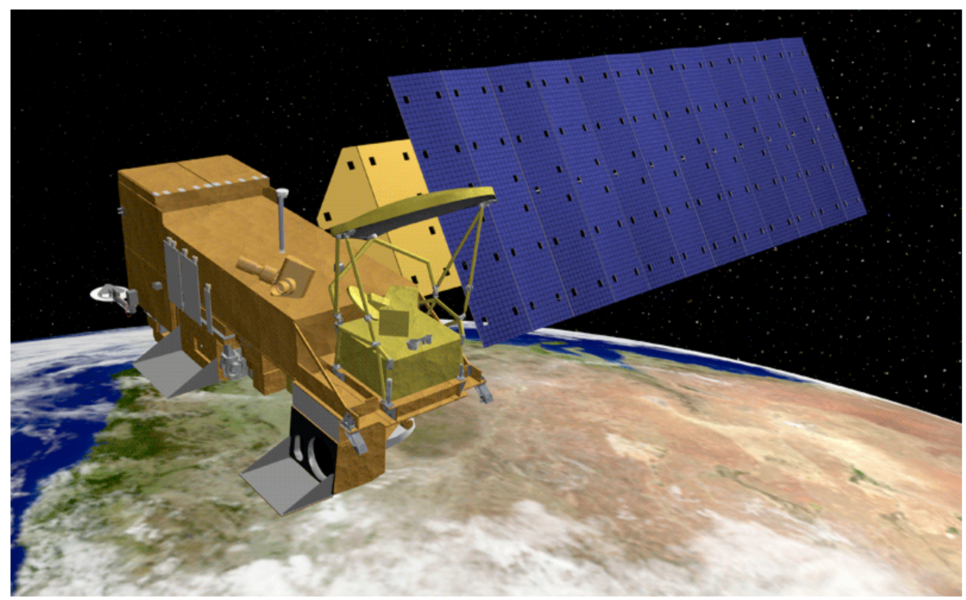
Spectral Window

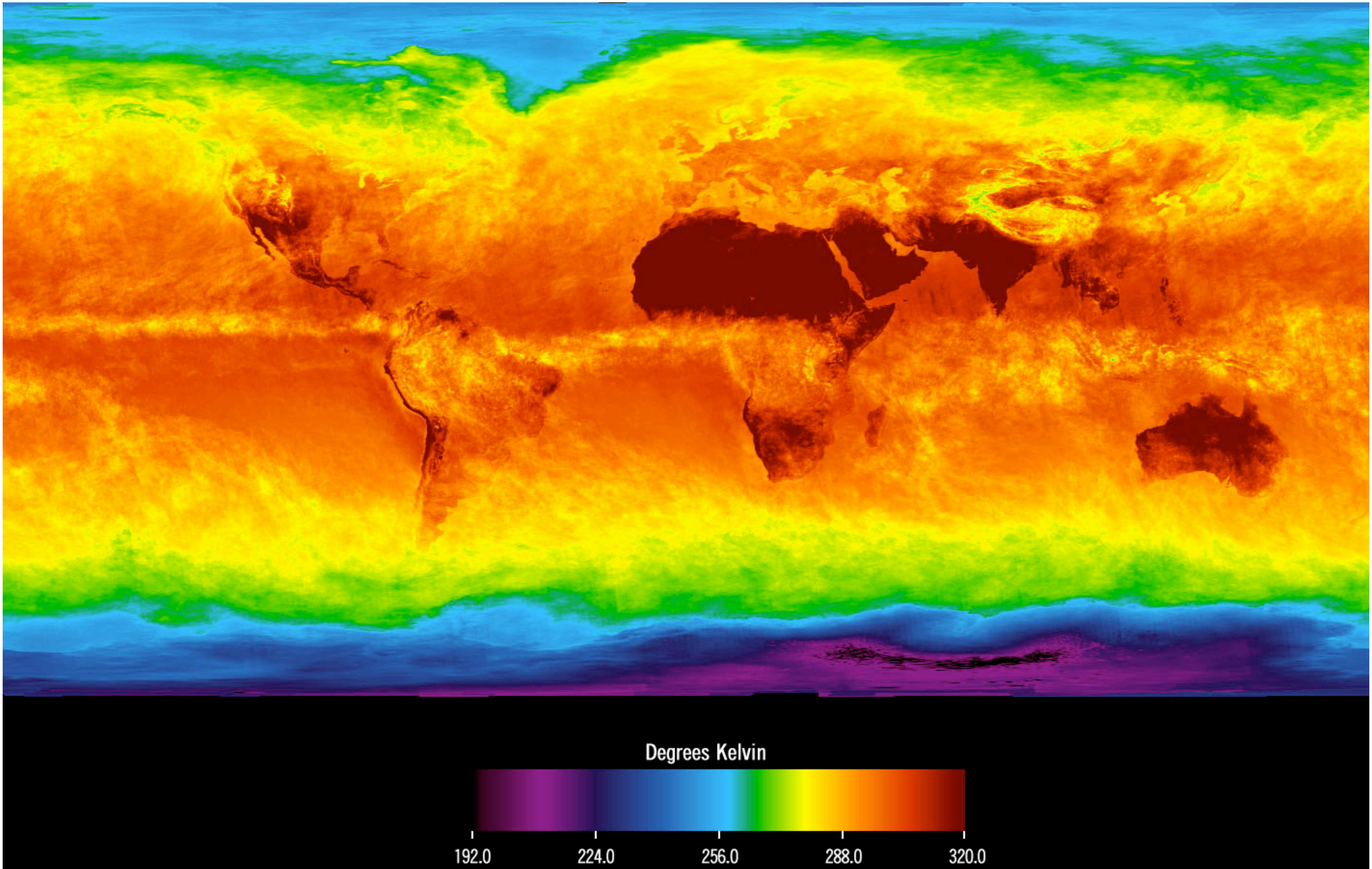


Atmospheric Infrared Sounder (AIRS) on AQUA







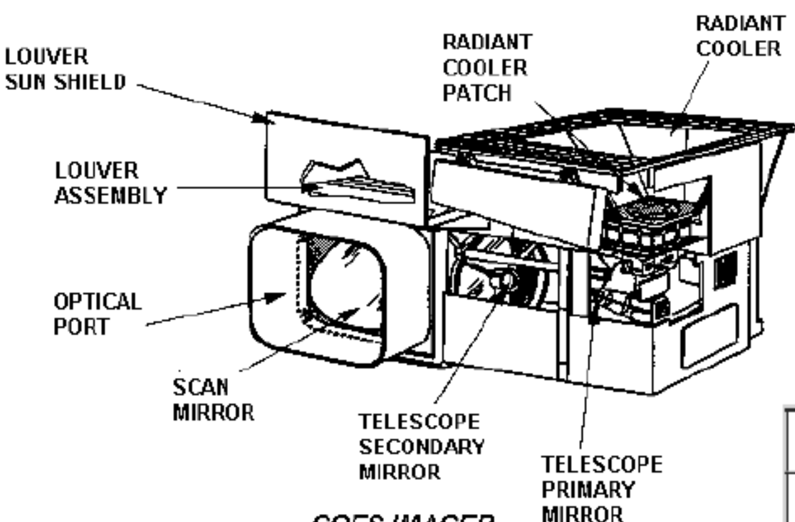


AIRS Average Brightness Temperature for month of April 2003

Data from AIRS Surface Channel 2616 cm^{-1}

GOES

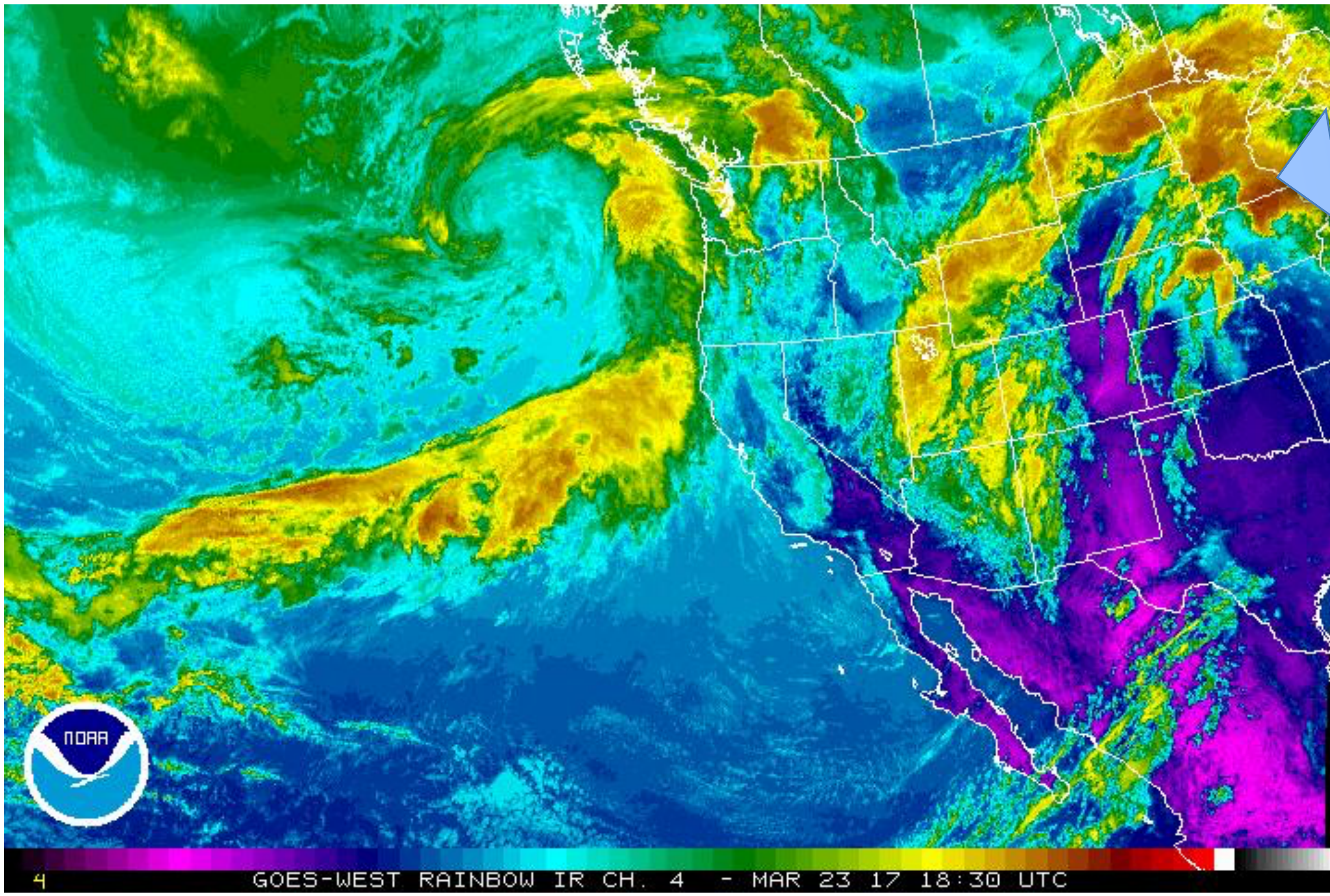
GOES Imager Instrument



GOES IMAGER

Imager Instrument Characteristics (GOES I-M)					
Channel number:	1 (Visible)	2 (Shortwave)	3 (Moisture)	4 (IR 1)	5 (IR 2)
Wavelength range (um)	0.55 - 0.75	3.80 - 4.00	6.50 - 7.00	10.20 - 11.20	11.50 - 12.50
Instantaneous Geographic Field of View (IGFOV) at nadir	1 km	4 km	8 km	4 km	4 km
Radiometric calibration	Space and 290 K infrared internal backbody				

IR Imaging from Space

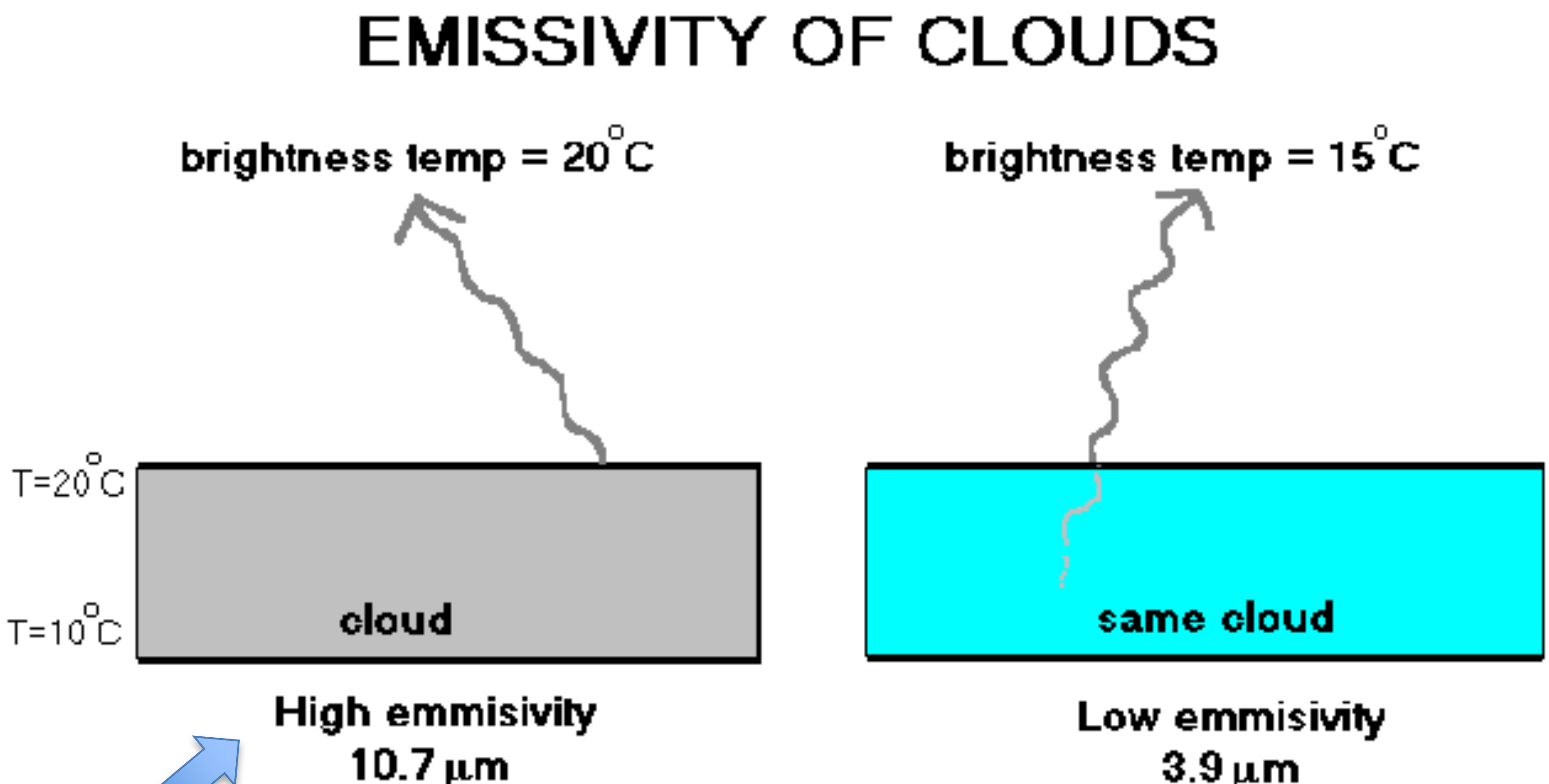


COLD TEMP

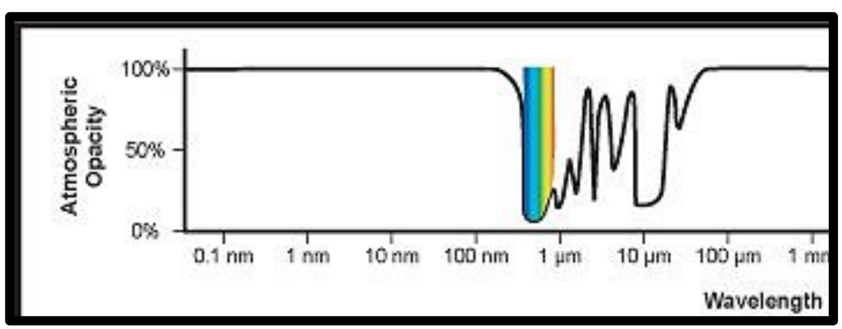
High Clouds

$$F_{BB}(T) = \sigma T^4$$

Brightness Temperature



Close to 1, get the temperature of top of cloud



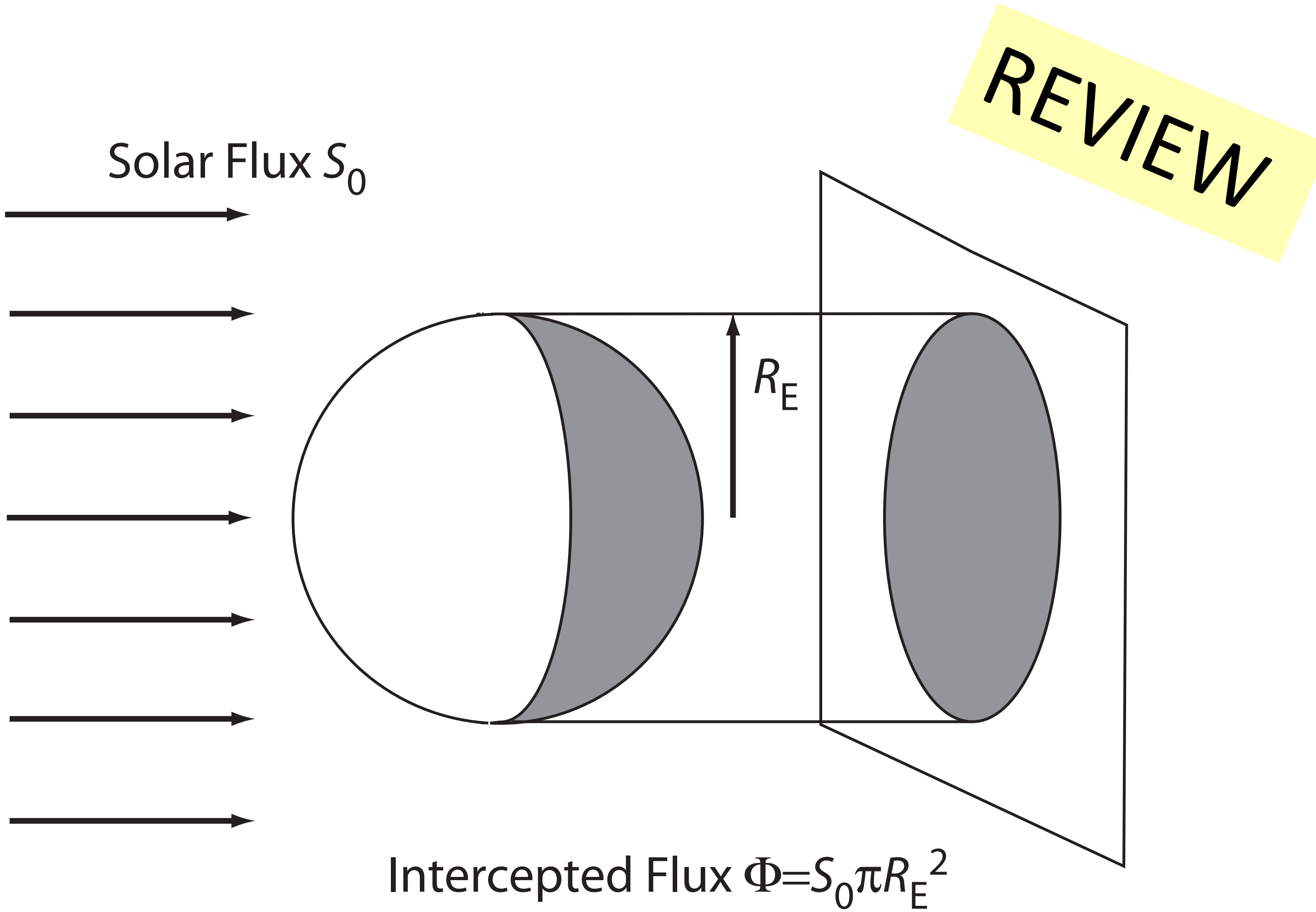
Radiative Equilibrium

$$(1 - A)S_0 \cos\theta = \varepsilon\sigma T^4$$

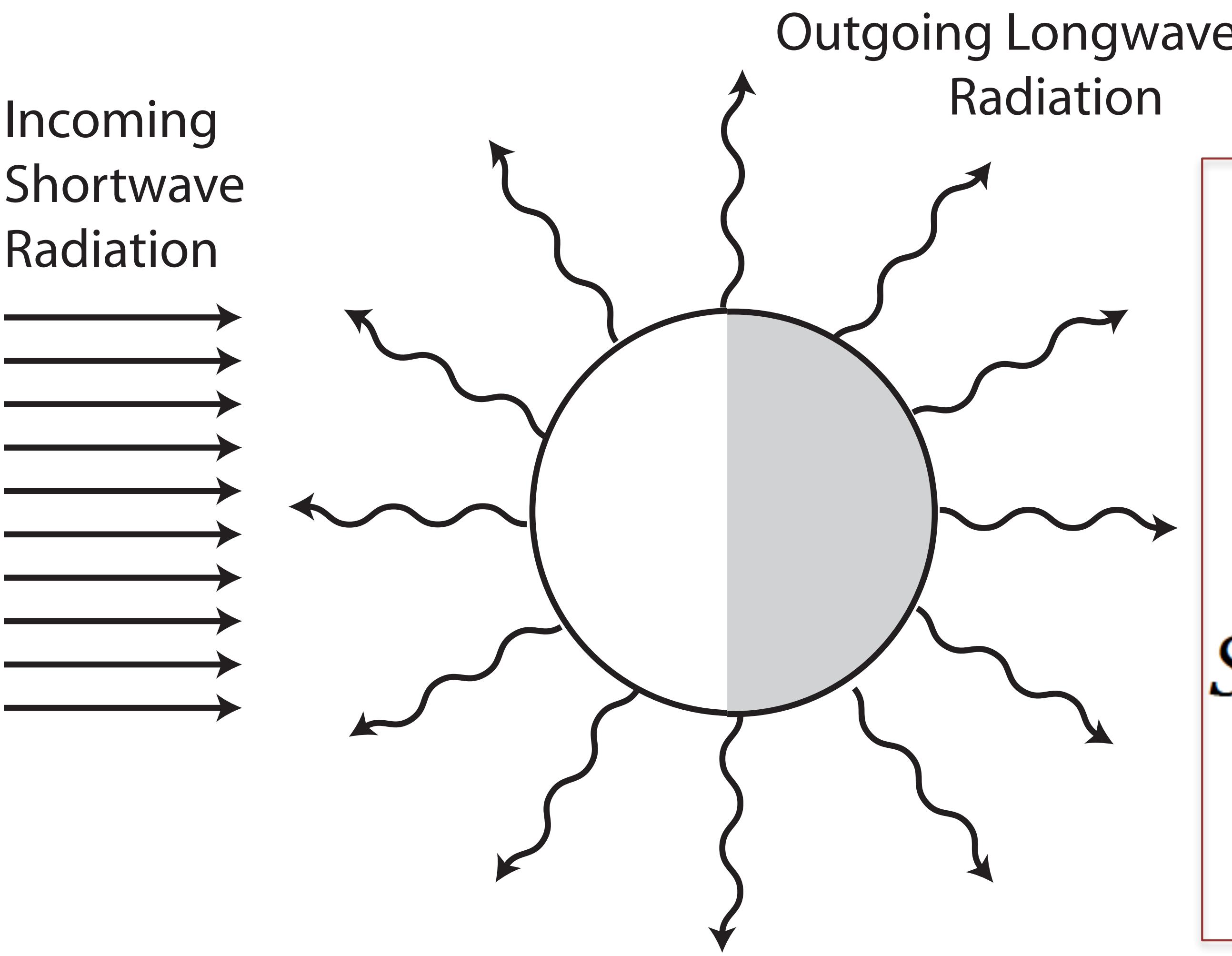
$$T_E = \left[\frac{(1 - A)S_0 \cos\theta}{\varepsilon\sigma}\right]^{1/4}$$

For the Moon – simple system

Radiative Equilibrium



Radiative Equilibrium



$$\Phi_{sw} = S_0 \pi r^2$$

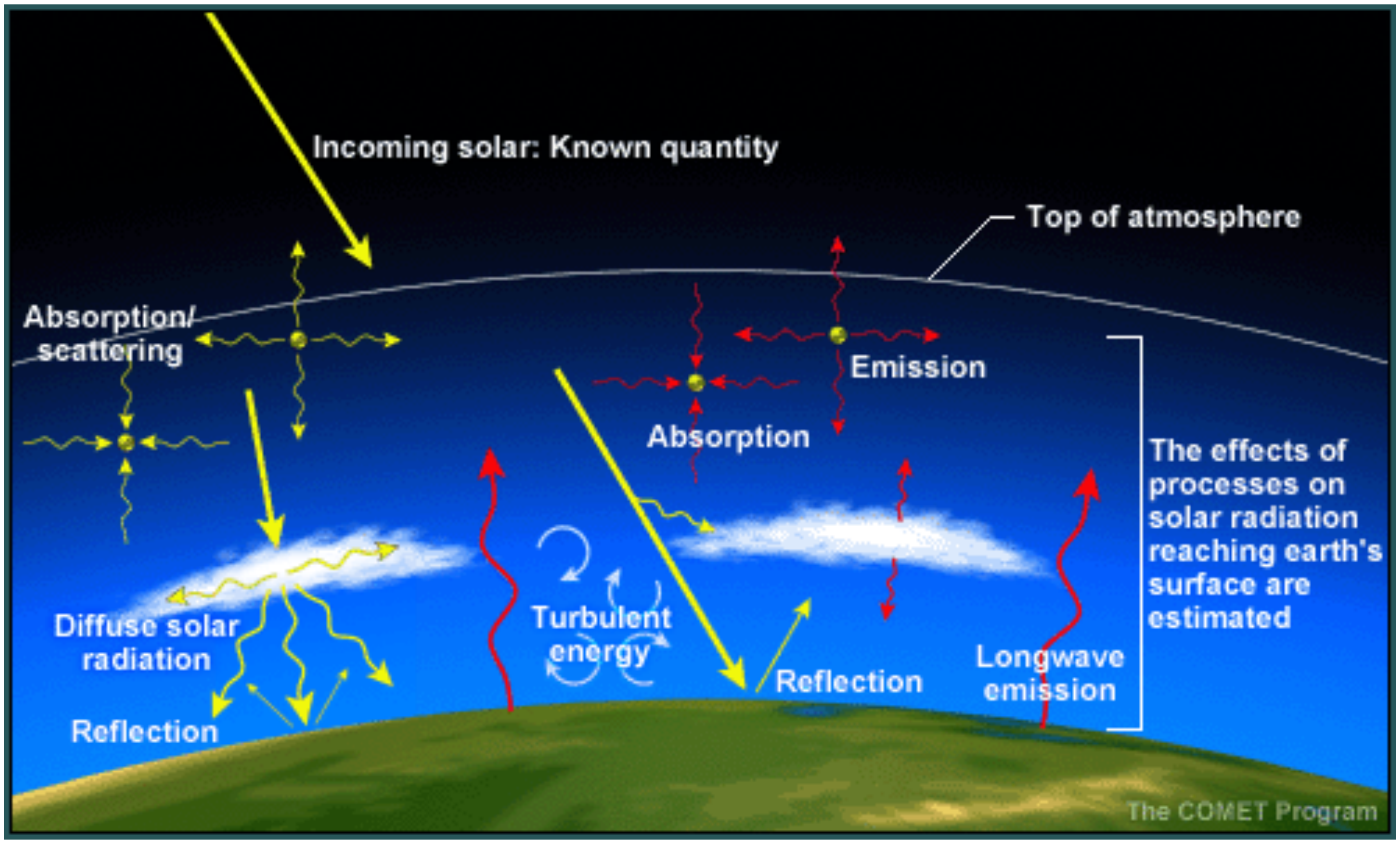
$$\Phi_{lw} = 4\pi r^2 \sigma T_E^4$$

$$S_0 \pi r^2 = 4\pi r^2 \sigma T_E^4$$

$$S_0 = 4\sigma T_E^4$$

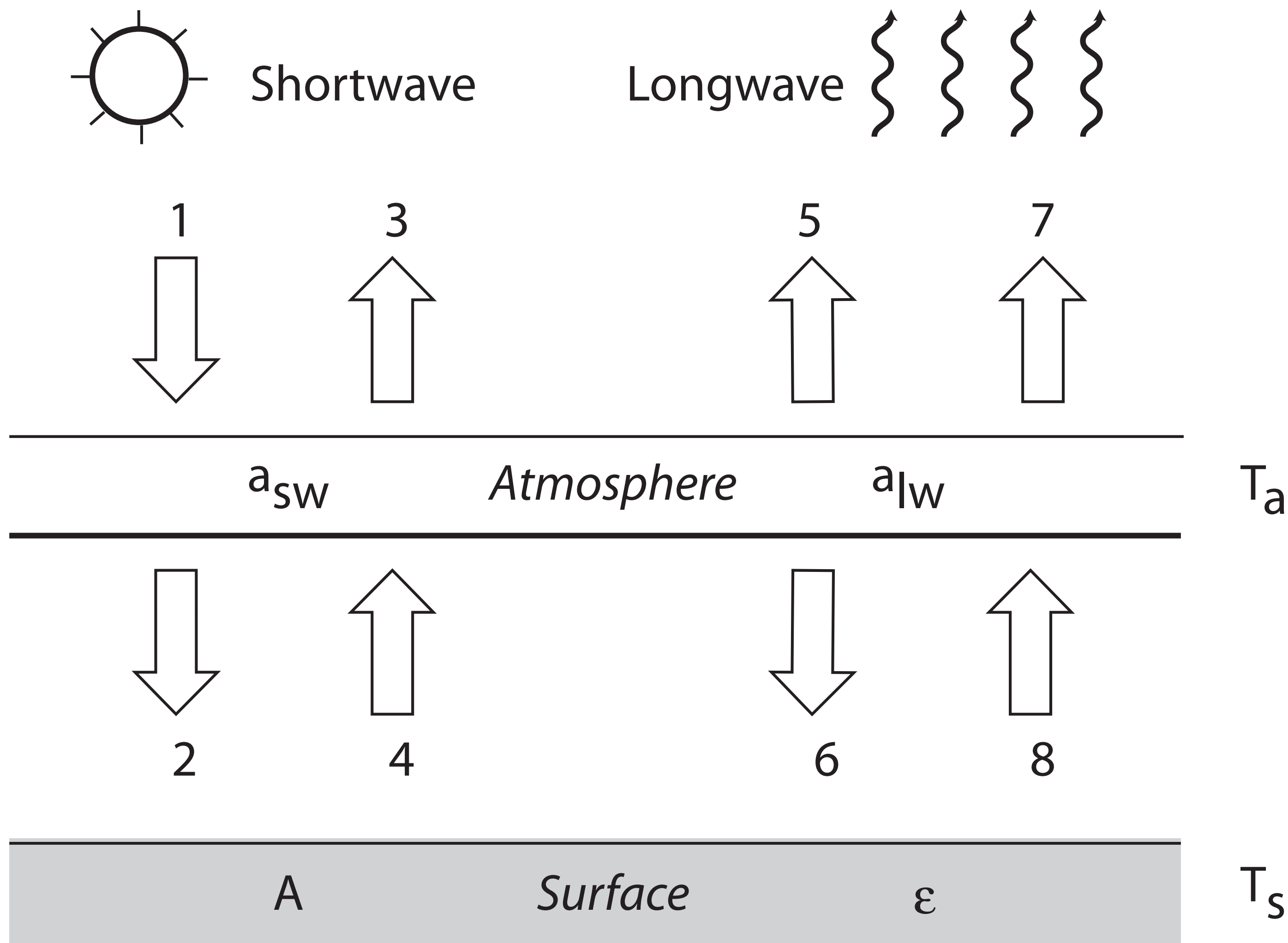
Top-of-the Atmosphere Global Radiation Balance

Earth is more complicated – yet can consider balance at the top (above) the atmosphere



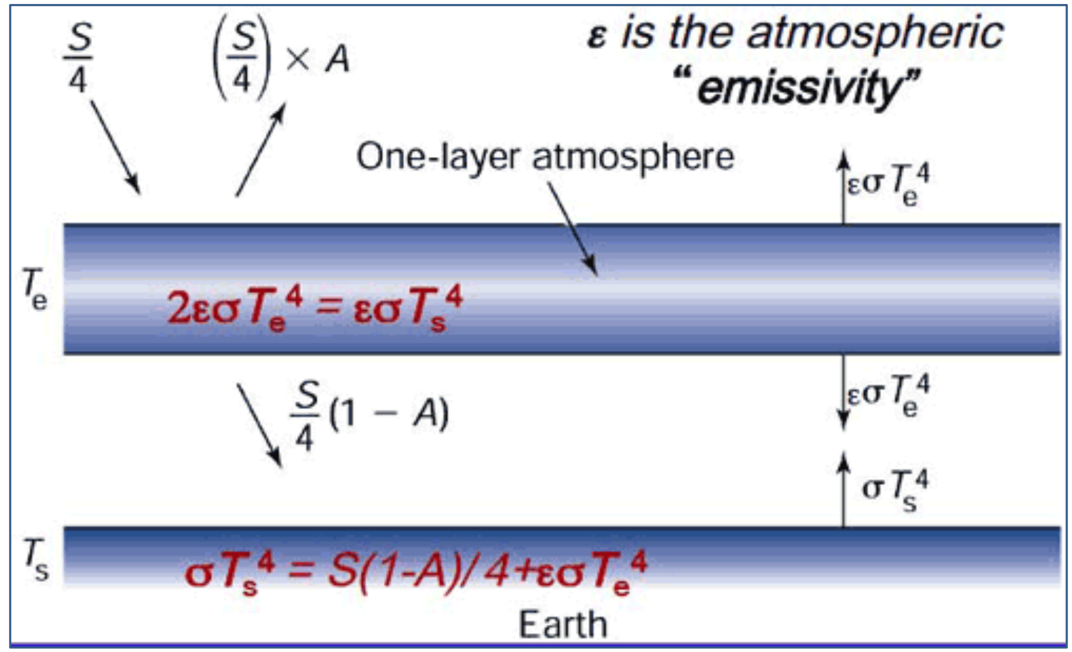
Simple Radiative Model of the Atmosphere

Single Layer, Non Reflecting Atmosphere



We can now express the condition of energy balance at each level in our simplified model of the Earth:

1. the top of the atmosphere
2. the atmospheric layer, which we can think of as centered in the mid-troposphere
3. the surface



Balancing incoming and outgoing radiation at the *top of the atmosphere* gives:

$$\frac{S(1-A)}{4} = \sigma\varepsilon T_e^4 + (1-\varepsilon)\sigma T_S^4$$

Balancing incoming and outgoing radiation from the *atmospheric layer* gives :

$$\sigma\varepsilon T_S^4 = 2\sigma\varepsilon T_e^4$$

(Note that short wave radiation is not included in this balance because the atmosphere does not absorb in short wave range.)

Finally, balancing incoming and outgoing radiation at the *surface* gives:

$$\frac{S(1-A)}{4} + \sigma\varepsilon T_e^4 = \sigma T_S^4$$

Credit: M. Mann modification of a figure from Kump, Kasting, Crane "Earth System"

Longwave / Atmospheric Emissivity

- Greenhouse effect
- Greenhouse gases are transparent in the shortwave, but strongly absorb longwave radiation
- Thus increasing value of α_{lw} will shift the radiative equilibrium of the globe to warmer temperatures.