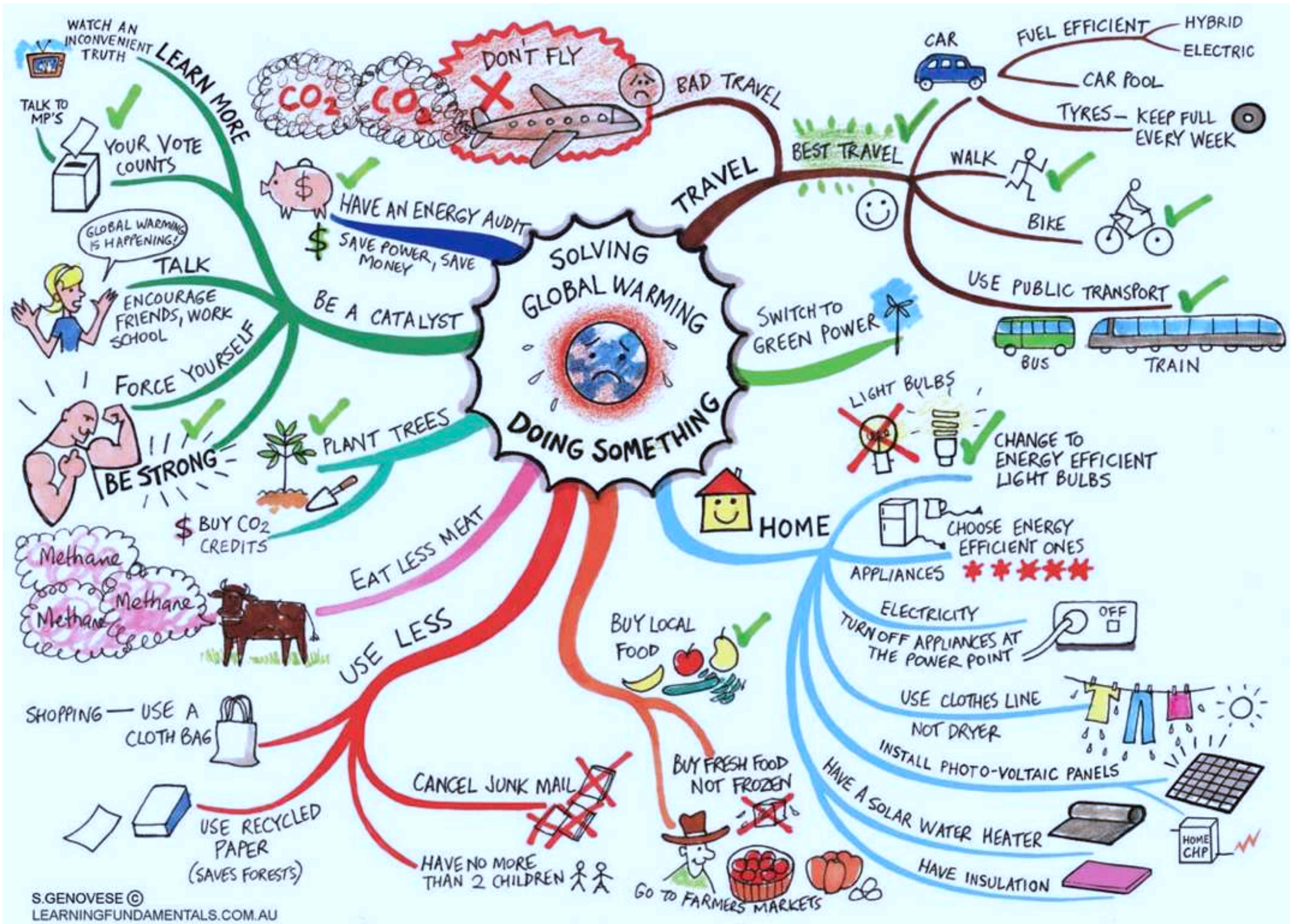
Welcome to ATMS 111 Global Warming

http://www.atmos.washington.edu/2010Q1/111



Today

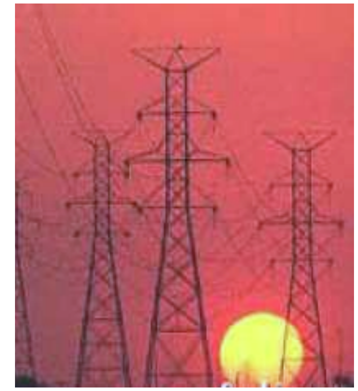
Finish up - Who is responsible?   Rough Guide p. 32-42

Summarize

The Greenhouse Effect - An Introduction to Radiation and Planetary Energy Balance

Homework 1 is open and due Friday at 11:55pm, includes material through today. Enrollment Key is noodle

Quiz 1 is one week away, similar to homework 1 plus new topics on Thursday

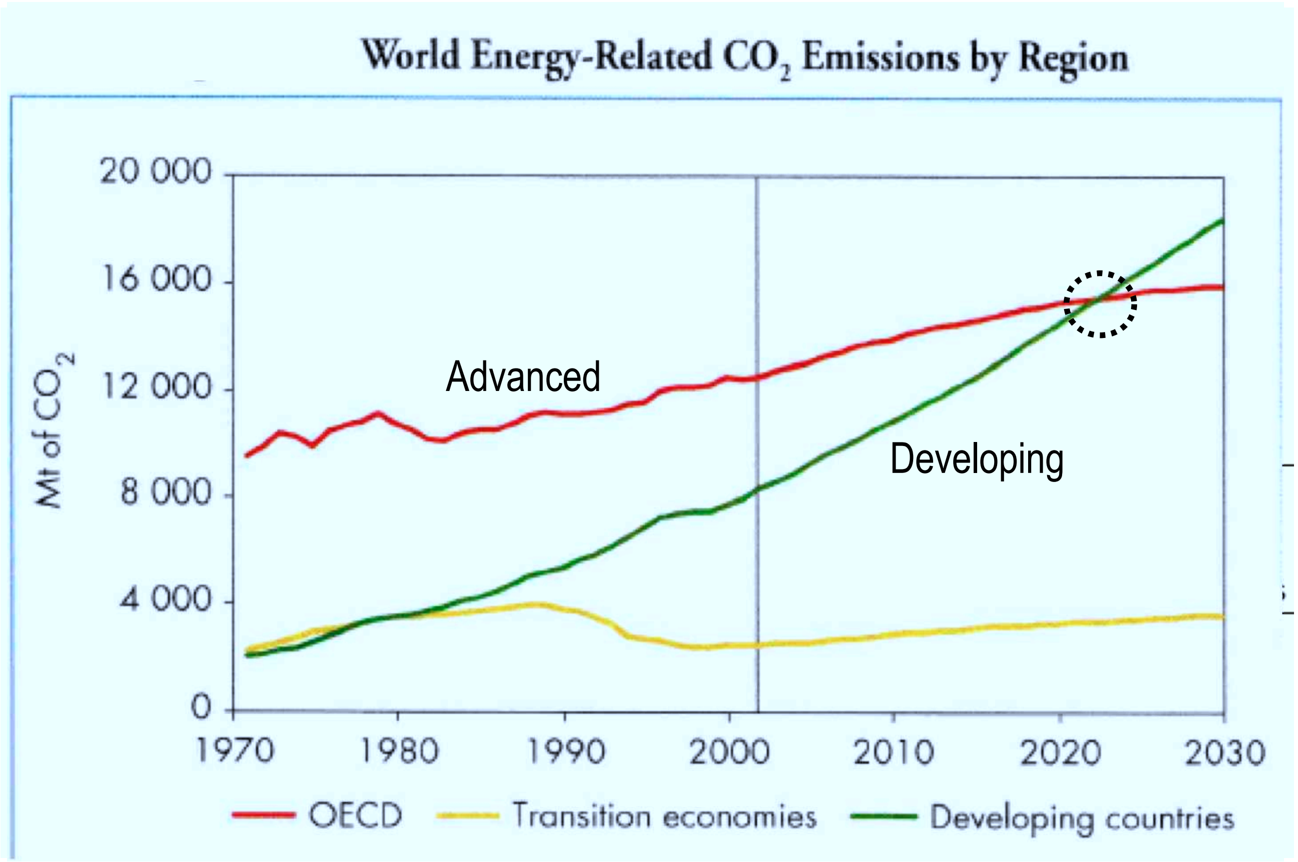


Half of the people in the world live on less than $2.50/day

2.1 billion live without access to electricity

What does this mean for emissions?

Future of Emissions is also with the Dev. Countries



In ~20 yrs, developing world <u>will surpass</u> advanced nations in CO_2 emissions

OECD = Organization for Economic Cooperation and Development

includes 30 countries, mostly industrialized

IPAT Identity for analyzing CO2 emissions

$$I = P * A * T$$

Impacts = Population Affluence Technology

CO2 Emissions rate

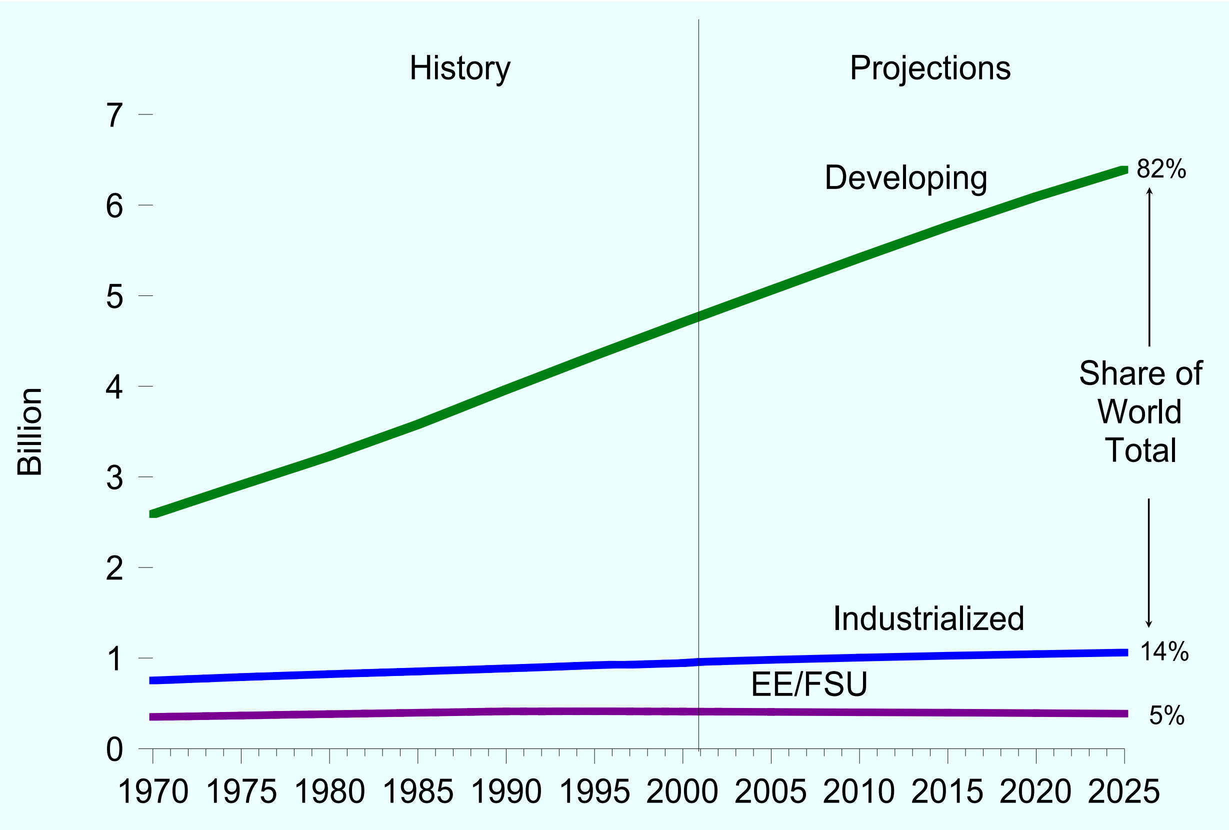
Per capita Income

Emissions per unit of Income

A similar identity exists known as kaya
Commoner (1972) and Ehrlich and Holdren (1972)

Global Population Trends

Developing Countries a HUGE market for future energy



EE/FSU = Eastern Europe/Former Soviet Union

$$I = P * A * T$$

Impacts = Population Affluence Technology

What is the effect on Impact/Emissions?

1. Improved gas mileage for cars
2. Solar power
3. Family planning to lower the birth rate
4. Economic recession
5. Carbon capture and storage (carbon sequestration)

$$I = P * A * T$$

Impacts = Population Affluence Technology

Which one is going to increase the most over the next 50 yrs?

Which one must we improve to compensate?

Summary so far

Unequivocal warming of about 0.7 C since 1900

CO_2 has risen by 100ppm or 1/3 since preindustrial times

Human addition of greenhouse gases and aerosols along with deforestation are the most likely cause of warming and the stall from 1950-1970

The changes over the next 100 years will be much greater

Summary so far, continued

Uncertainties lie in observations and predictions, but not in the basic greenhouse effect

Little disagreement among climate scientists about the fundamentals of the anthropogenic greenhouse warming, only a few percent are “skeptics”

Unsettled science remains in the details - detecting and attributing hurricane changes, amount of sea level rise, tipping points, etc

Summary so far, continued

The US emitted more CO_2 than any other country until China surpassed us in 2008. Our per capita emissions are about 4 to 5 times the global average, though not the highest in the world.

Ranking emissions by carbon intensity places rich countries lower on the list. In the last 20 years, the US carbon intensity declined, while actual emissions rose.

In cumulative emissions the US has contributed about 30% to the total.

Growing affluence is likely to cause emissions to rise fastest globally.

The Greenhouse Effect - RG p 20-31

Outline

i. Radiation (supplement with Ahrens p35-43)

ii. Global Energy Balance

Electromagnetic (EM) Radiation

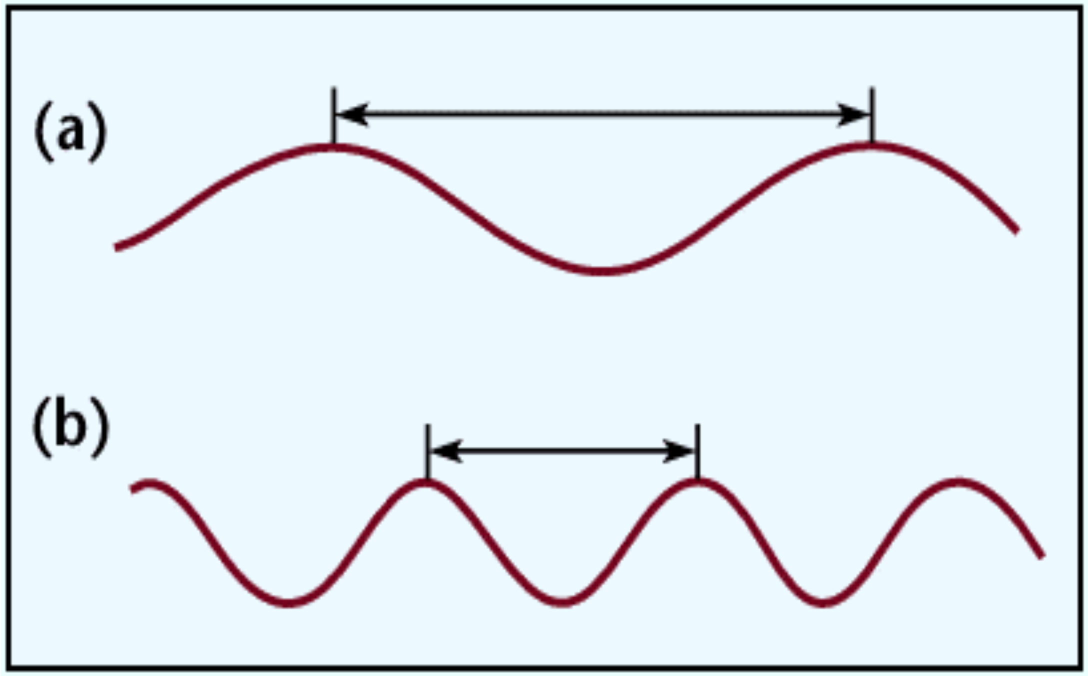
• Called radiation for short

• All bodies emit radiation, but gases do so selectively (will explain more)

• Radiation is an energy flux F (units of W/m^2)

• Radiation propagates through space at speed of light

• Radiation is classified by wavelength λ

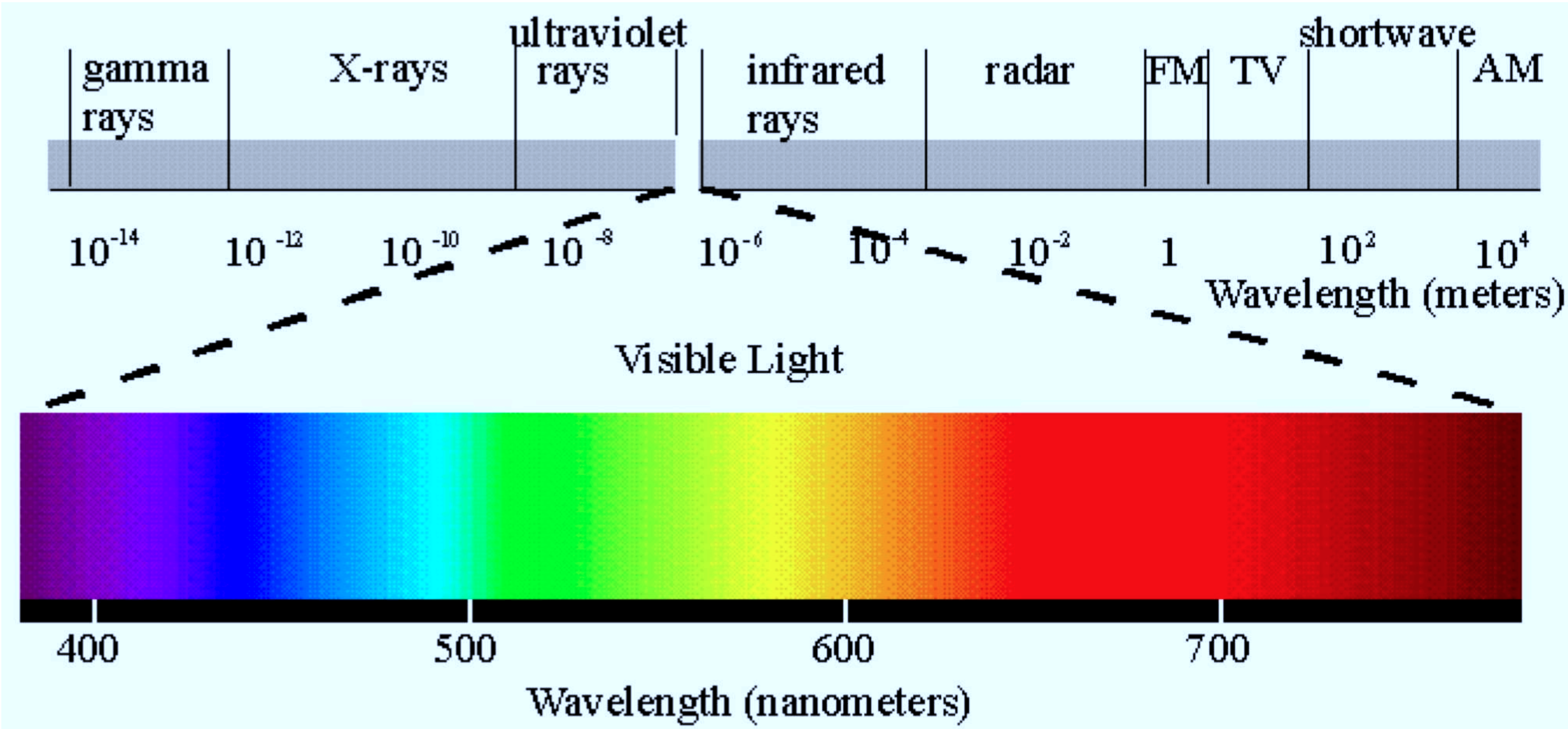


(a) has a long wavelength

(b) has a short wavelength

Which one is more energetic? Why

A typical wavelength of visible light is 0.5 micrometers or 5 x 10^{-6} m



Where and what is infrared light?

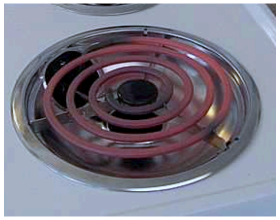
Where and what is ultraviolet light?

What wavelengths does the sun predominantly emit?

Radiation and Matter

hand warms
above hot burner

Absorption of radiation causes matter to gain heat (tend to warm up)



cools by emission
(may be balanced
by electrical input)

Emission of radiation causes matter to lose heat (tend to cool down)

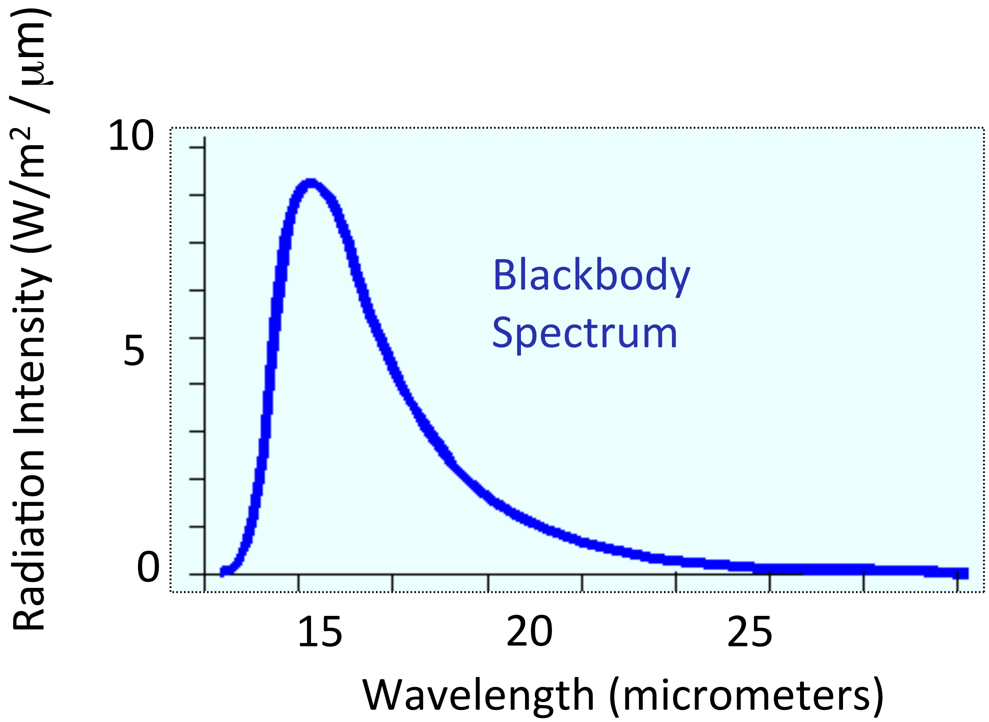
Matter absorbs and emits. In a purely radiative environment, temperature is constant when they are in balance.

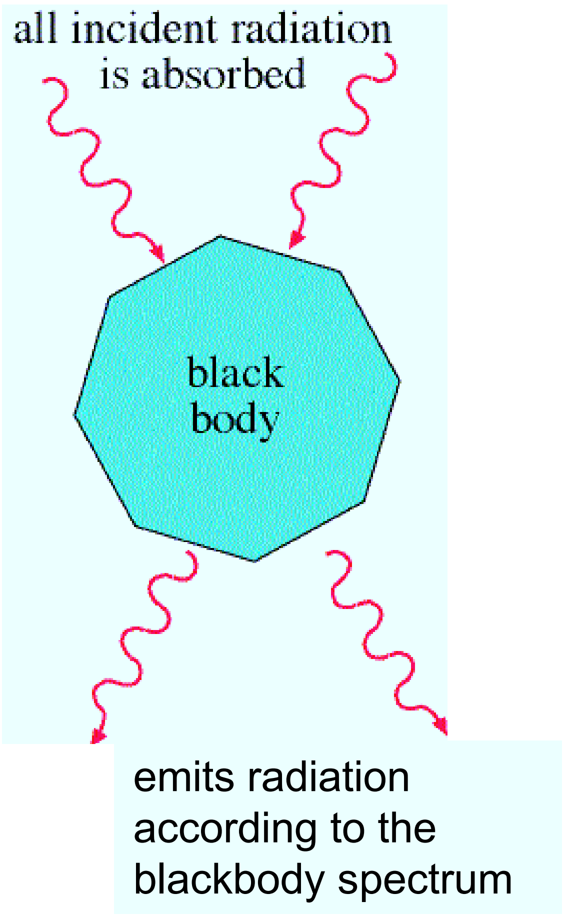
Does perfect reflection (so no absorption) of radiation cause matter to heat? No!

Blackbody

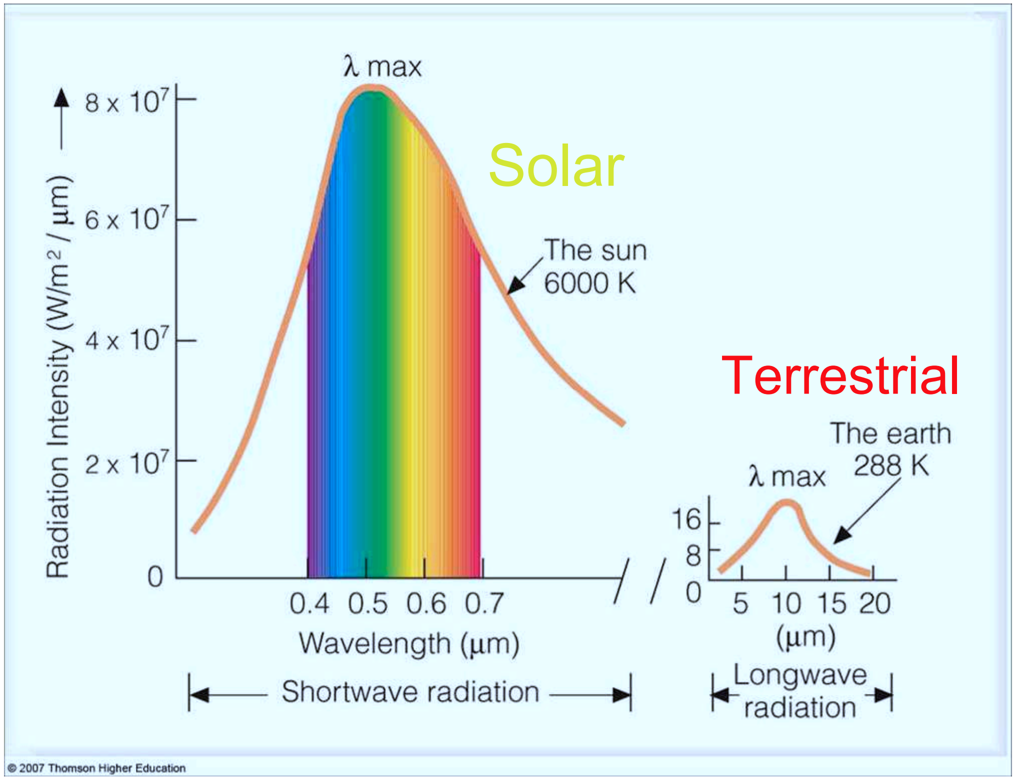
The sun and earth's surface are well approximated as "blackbodies".

Light is emitted over a range of wavelengths.





The spectra of the sun and earth are very different because the temperatures are different



Wien's Law

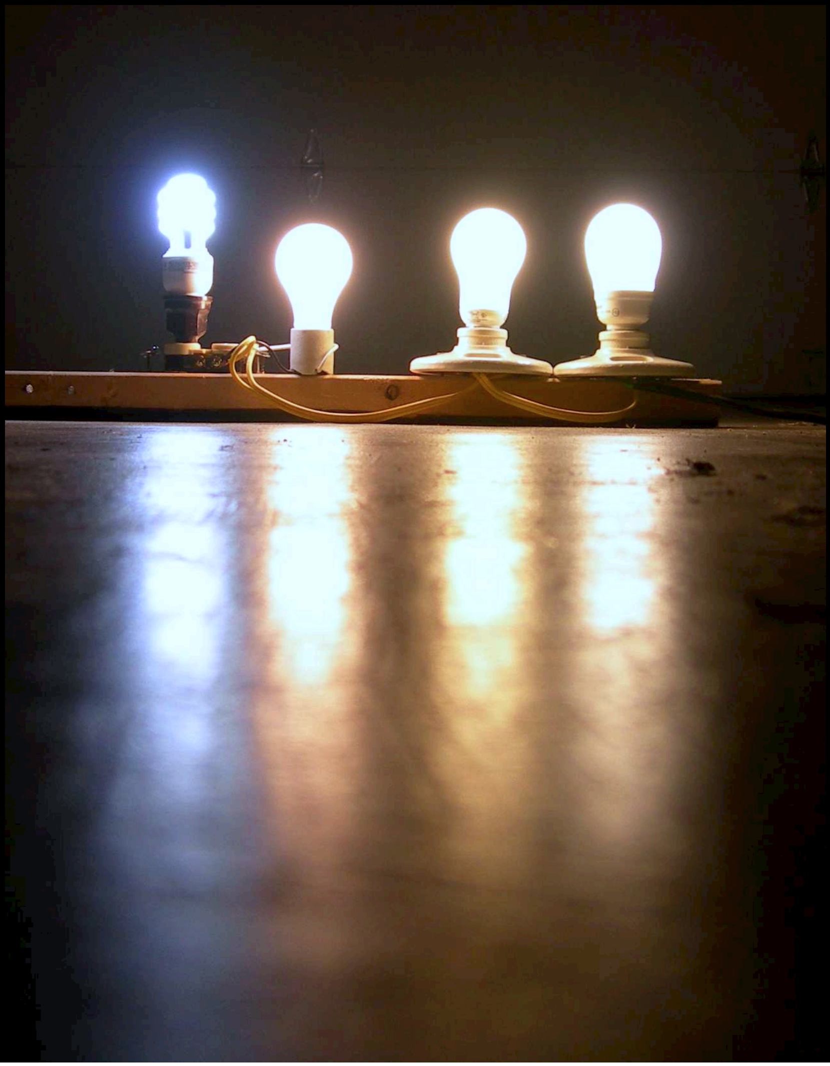
$$\lambda_{max} = \frac{2897 \mu m\ K}{T}$$

λ = wavelength

T = temperature in Kelvin

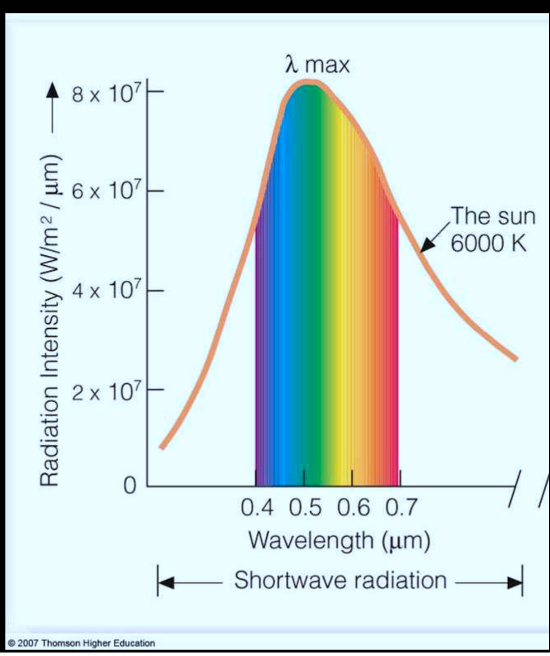
Color temperature of CF light bulbs

Bluer = Hotter

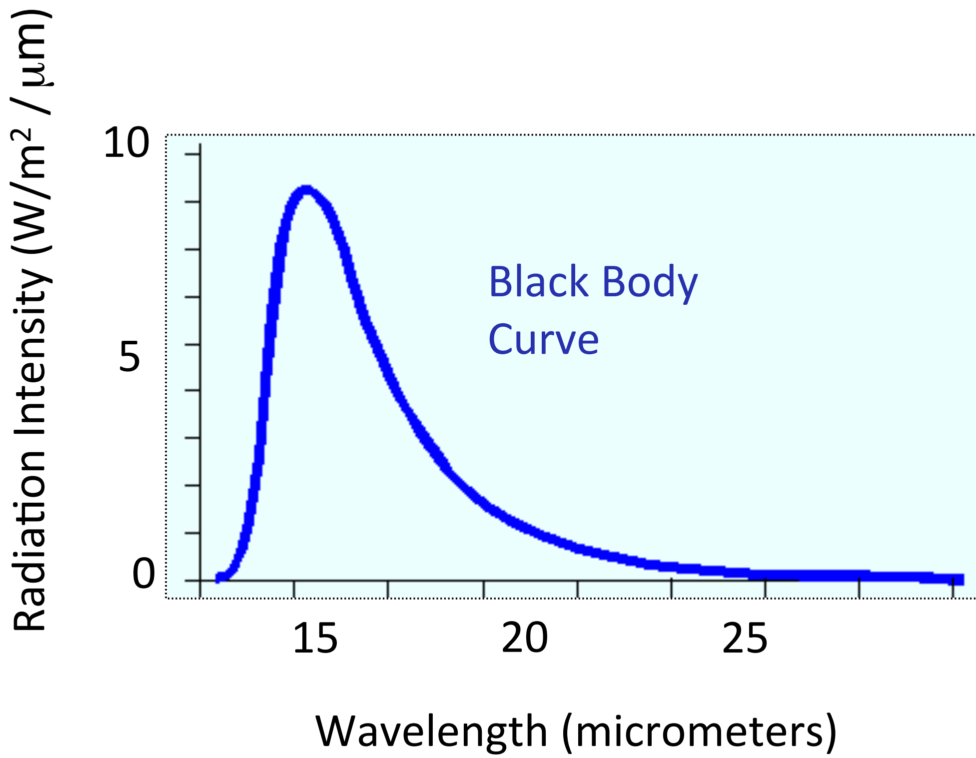


As a fire dies, the peak of the emitted radiation shifts toward longer wavelengths; the yellow and orange disappear first and the last to go is the deep red.

Even after the visible radiation disappears, the hot ashes continue to emit infrared radiation that you can feel if you are close to it.



Radiation Flux from a Blackbody



Radiation Flux
F = area under the blackbody curve, units of W/m^2

Stefan-Boltzmann Law

$$F = \sigma T^4$$

Stefan-Boltzmann constant
$\sigma = 5.67 \times 10^{-8}\ W/m^2/K^4$
T = temperature of black-body in Kelvin

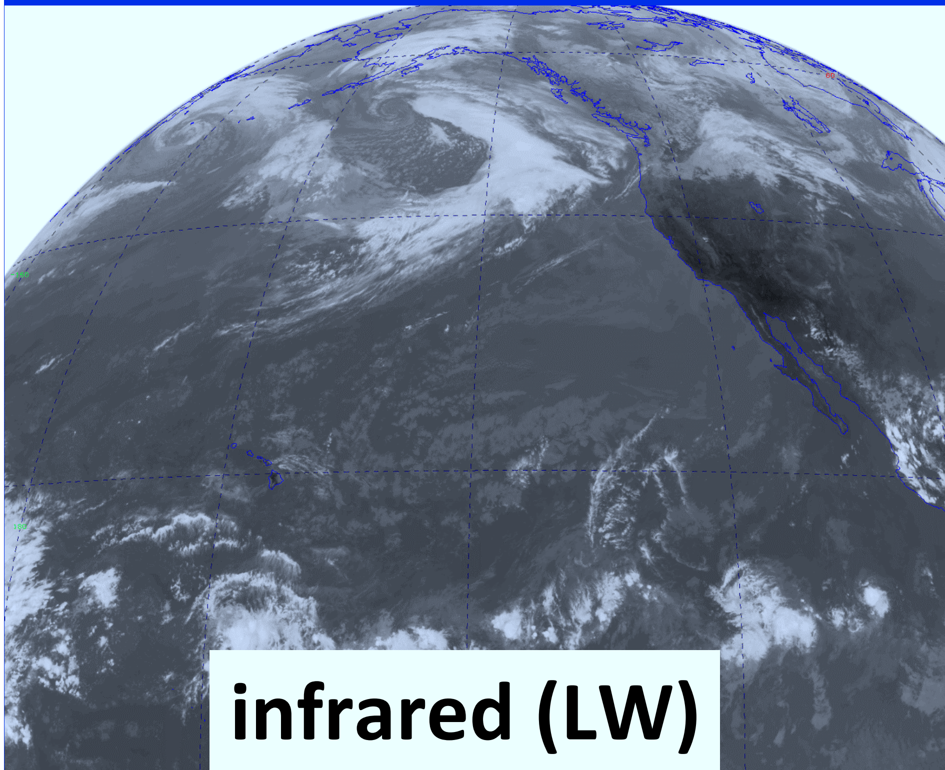
Infrared Radiation, IR

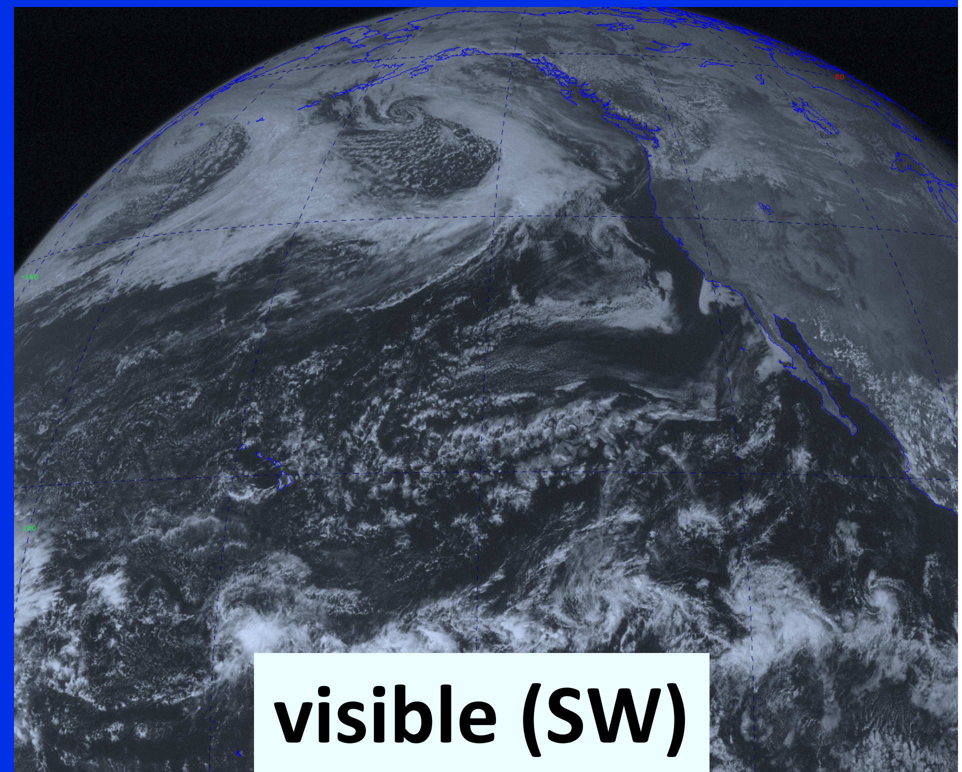
What do we see when we turn down the lights?

Only matter that emits radiation in the visible range.

The white paint is dark now because it does not emit visible radiation, it reflects visible light from the room lights.

Visible and Infrared Satellite Pictures





a) Which is the "visible" image? How can you tell?

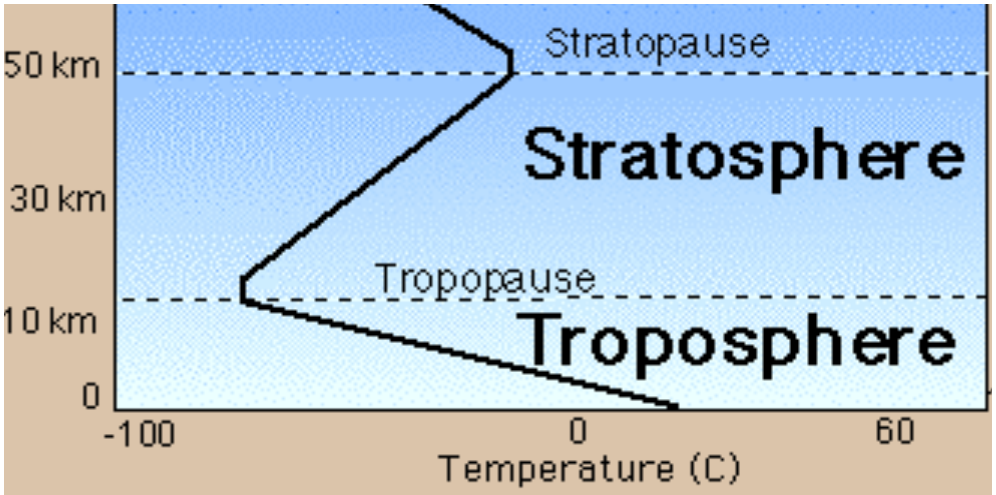
b) What is emitting the radiation in each case?

c) Which is more reflective: ocean or land?

d) On the infrared image, are higher temperatures lighter or darker?   How can you tell?

e) Which one can used at night?

Atmosphere's Temperature Profile



In Lowest 10k, the temperature decreases with height

Review from sections

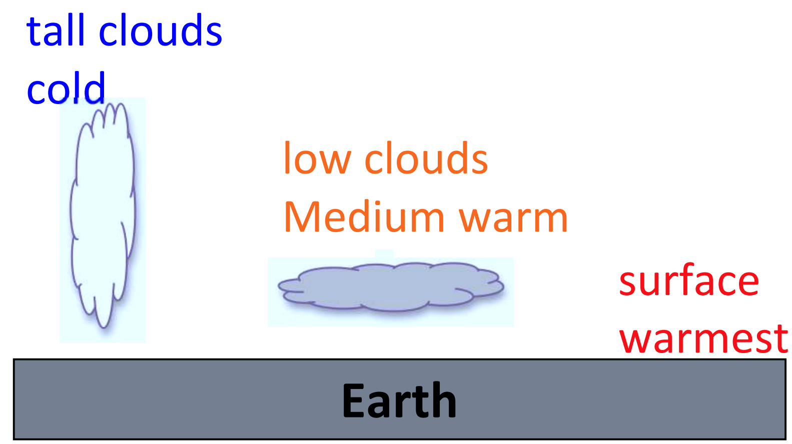
Where are nearly all the clouds? Troposphere

Why is the surface warm? Heated by the sun

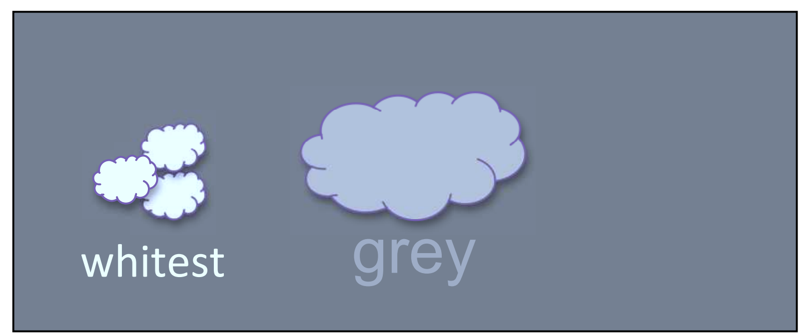
Why is the stratosphere warm? Ozone

IR Satellite View Explained

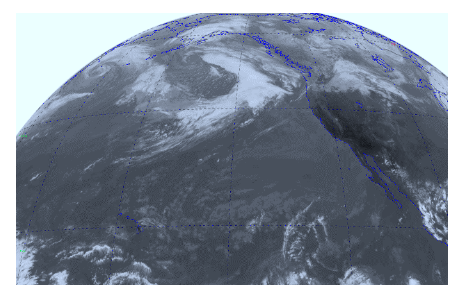
side view of clouds and earth



satellite view

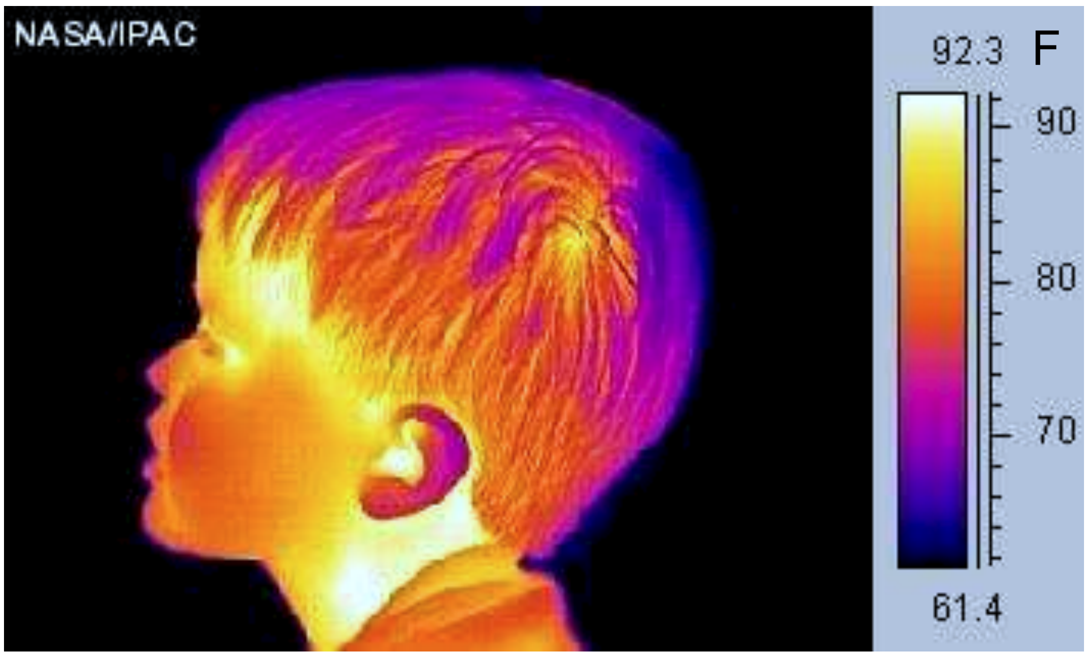


IR satellite: the warmest/darkest patches are at or near the ground, the cold patches are probably tall cloud tops



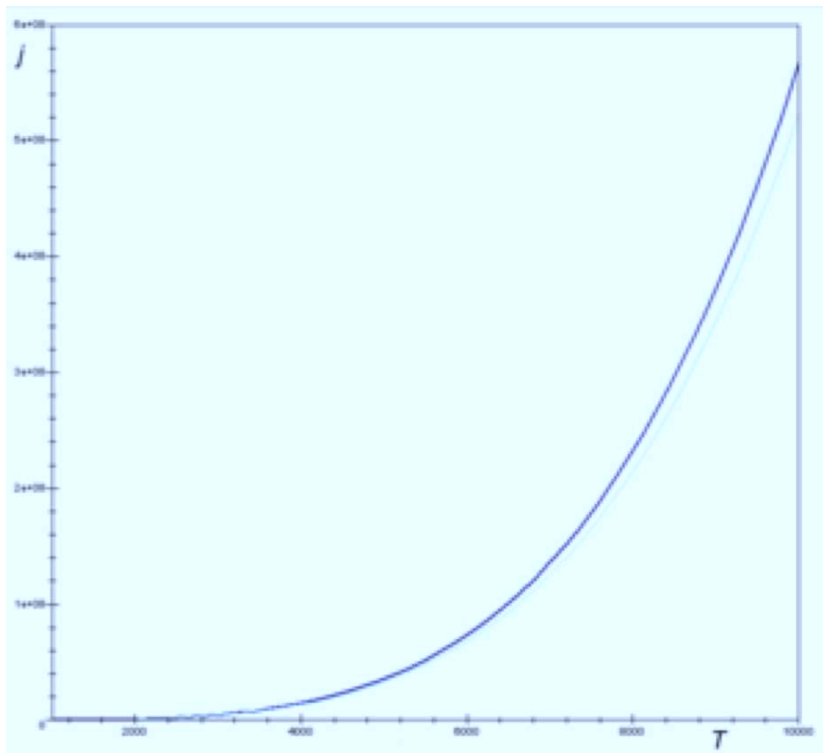
Infrared thermometer

measures emitted radiation
then converts it to an "*effective temperature*"



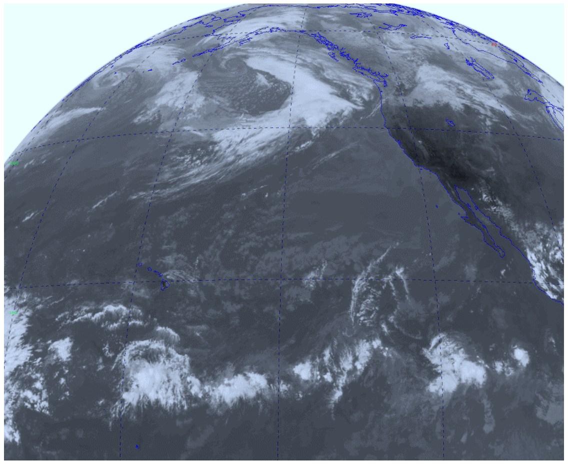
neck = hotter
hair = colder

Converting *emitted radiation* from **IR thermometer** to an "*effective temperature*" scale assumes perfect black body. Closeness to real temperature depends on how well the object approximates a blackbody.



Blackbody Radiation Flux W/m^2

Effective Temperature (K)



Earth's effective temperature
(measured from IR satellite)

255 K −18°C 0°F

Just for comparison,
Earth's surface temperature
(measured with thermometers)

288 K +15°C 60°F

Why do they differ? Yeah, it's the GHE

GHG aren't good black bodies, so the "effective temperature" here is abstract

Planetary Energy Balance

At Equilibrium (a steady climate):

Energy Flux in = Energy Flux out

$$F_{IN} = F_{OUT}$$

For a planet:

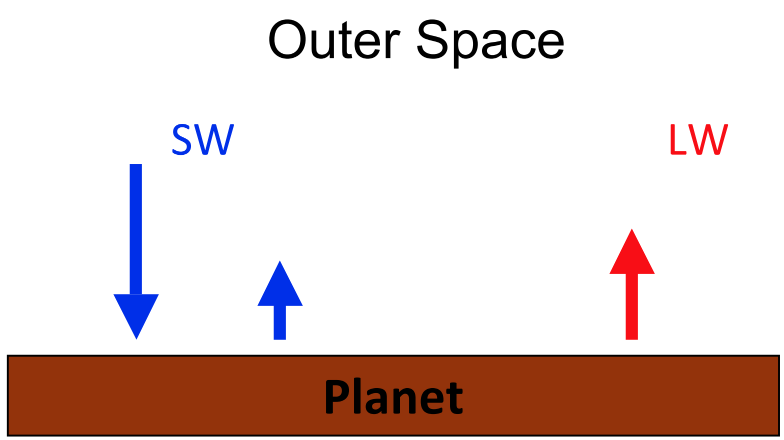
Absorbed solar energy = Heat energy lost to space *

* **depends on temperature T of the earth and atmosphere**

If something knocks a planet out of energy balance, it WILL warm or cool to eliminate the imbalance.

Consider Planet with No Atmosphere
Model A

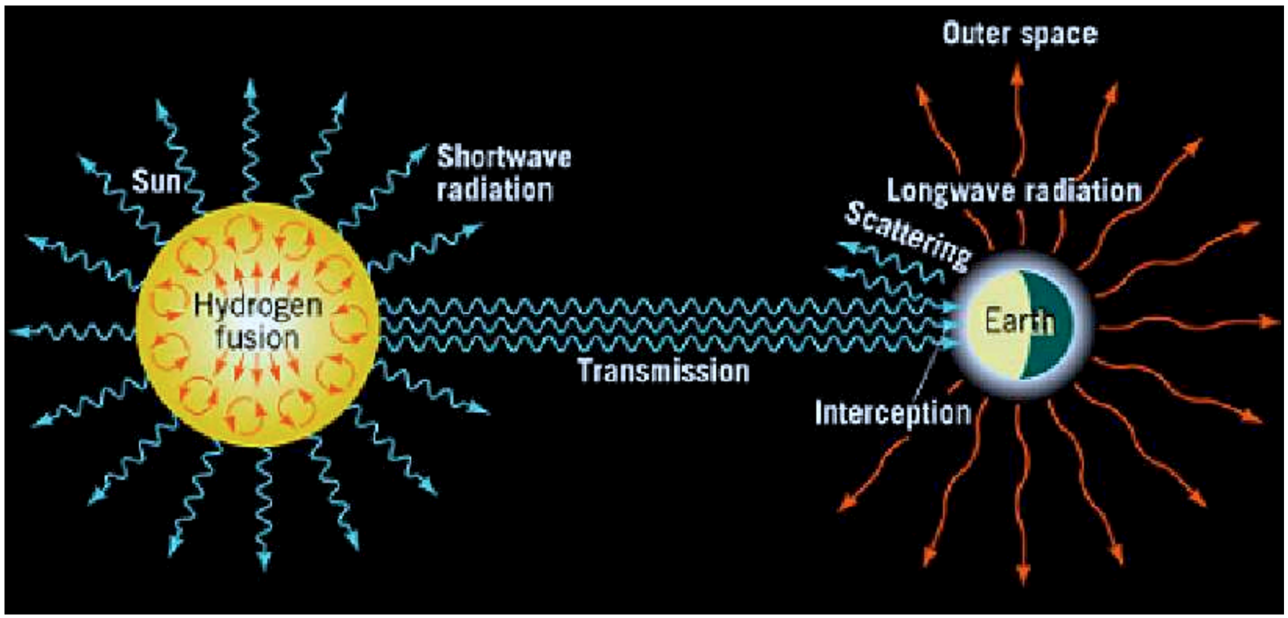
A model of heat entering and leaving the surface.
Incident sunlight is partly absorbed and reflected.



Arrow lengths indicate relative fluxes. Planet is in balance if they sum to zero.

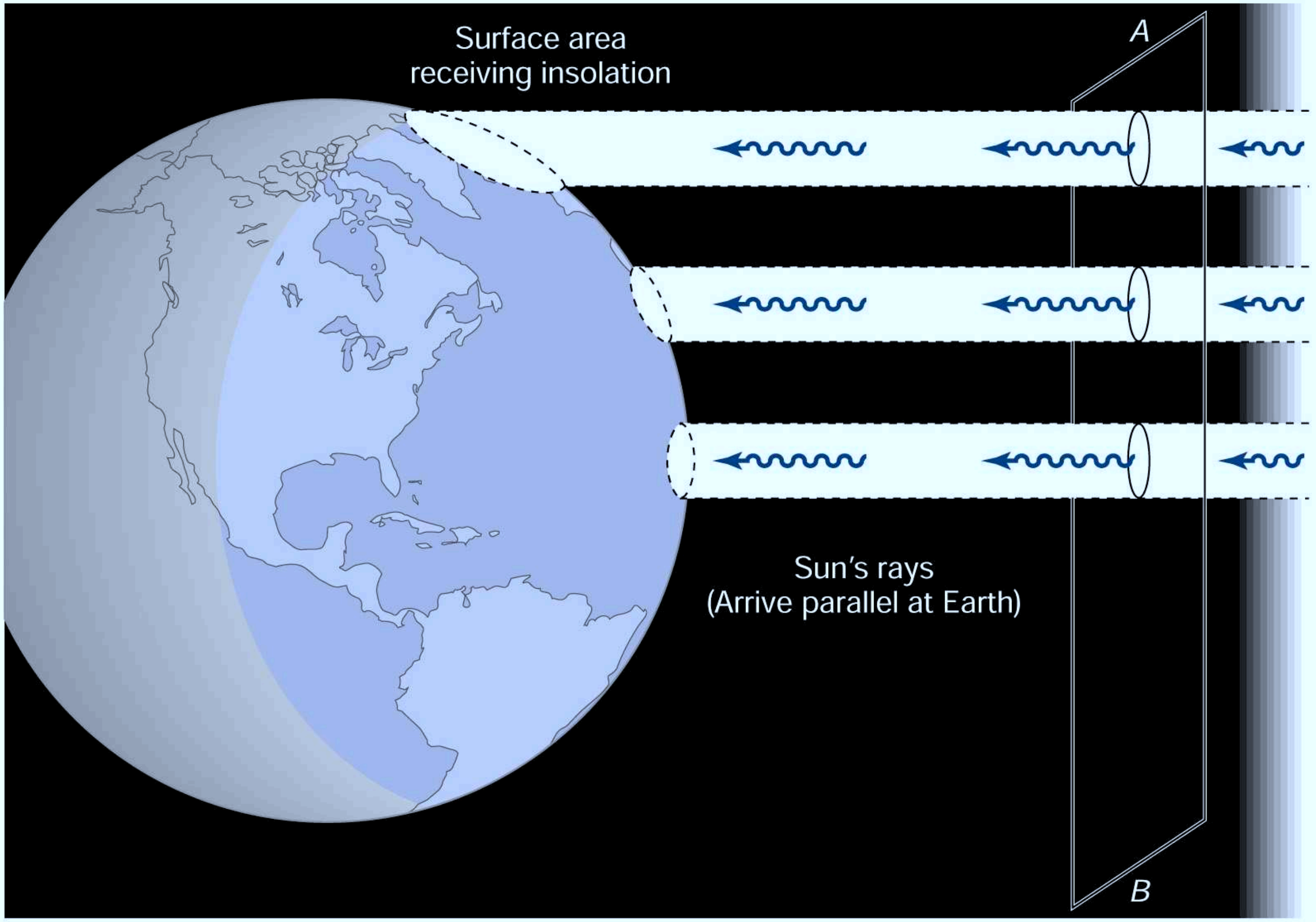
How much solar energy reaches the planet?

The solar flux reaching the planet is S

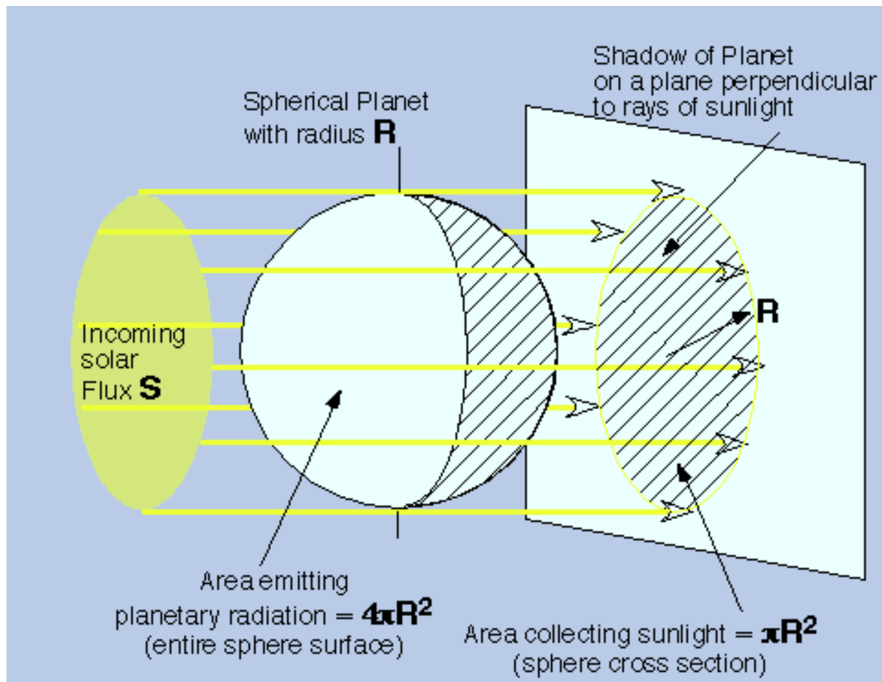


But it lights only half the planet at a time and the planet is a sphere, so…

The planet's surface only receives the full flux S in the tropics. Sunlight "spreads" out more at the poles, which makes it colder there.

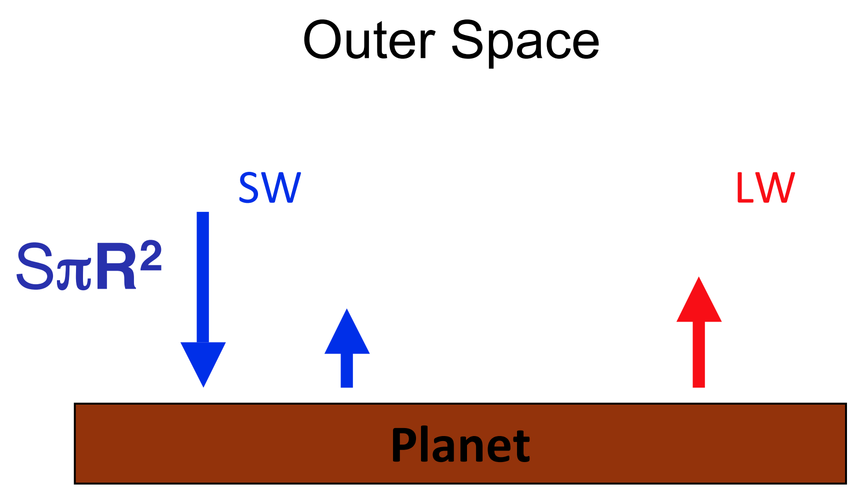


The solar energy reaching a planet is the solar flux **intercepted** by the area of the planet's shadow, πR^2



On average incident SW flux on planet is $S\pi R^2$

So far…

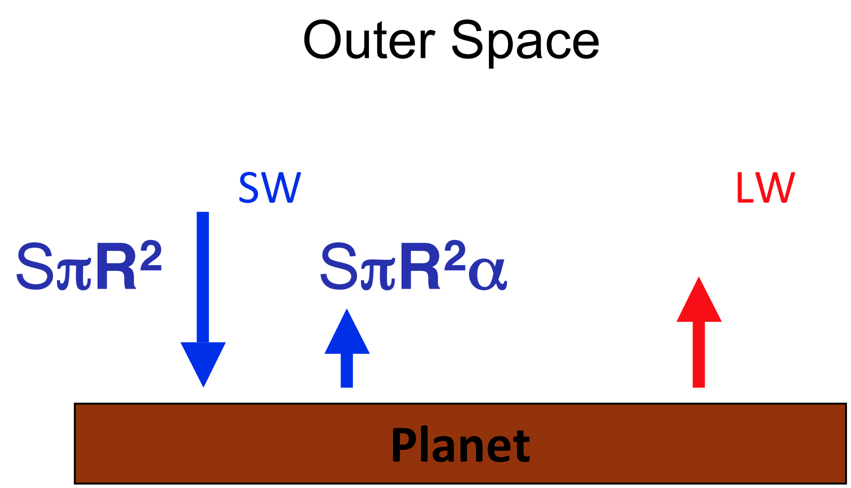


The fraction of incident solar energy that is reflected depends on the the planetary albedo, α

$$\text{albedo } \alpha = \frac{\text{energy reflected}}{\text{energy incident}}$$

Albedo	Amount reflected
0	none
1	all
0.3	partly reflected off surface, clouds, dust, etc

making progress…

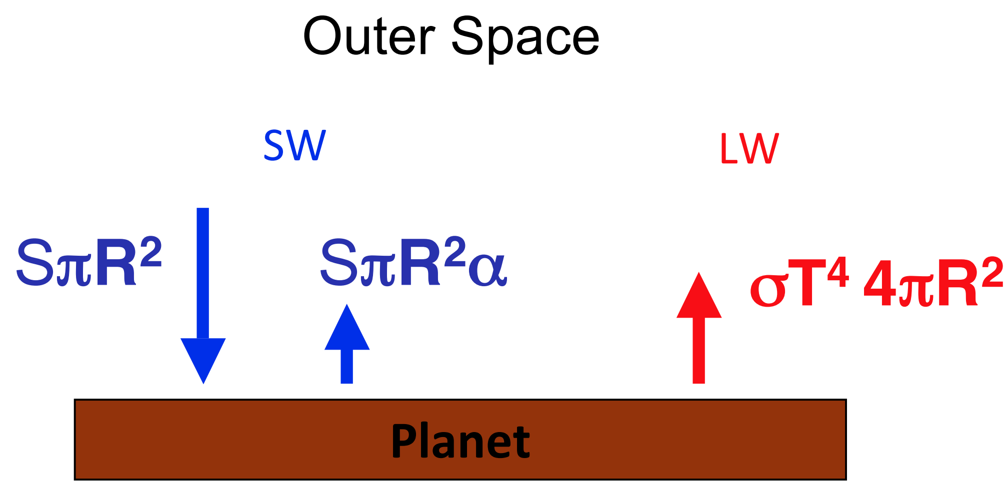


Make the approximation that the planet emits IR as a blackbody, σT^4

over the entire surface of a sphere, $4\pi R^2$

So the total is $\sigma T^4 \, 4\pi R^2$

AT LAST



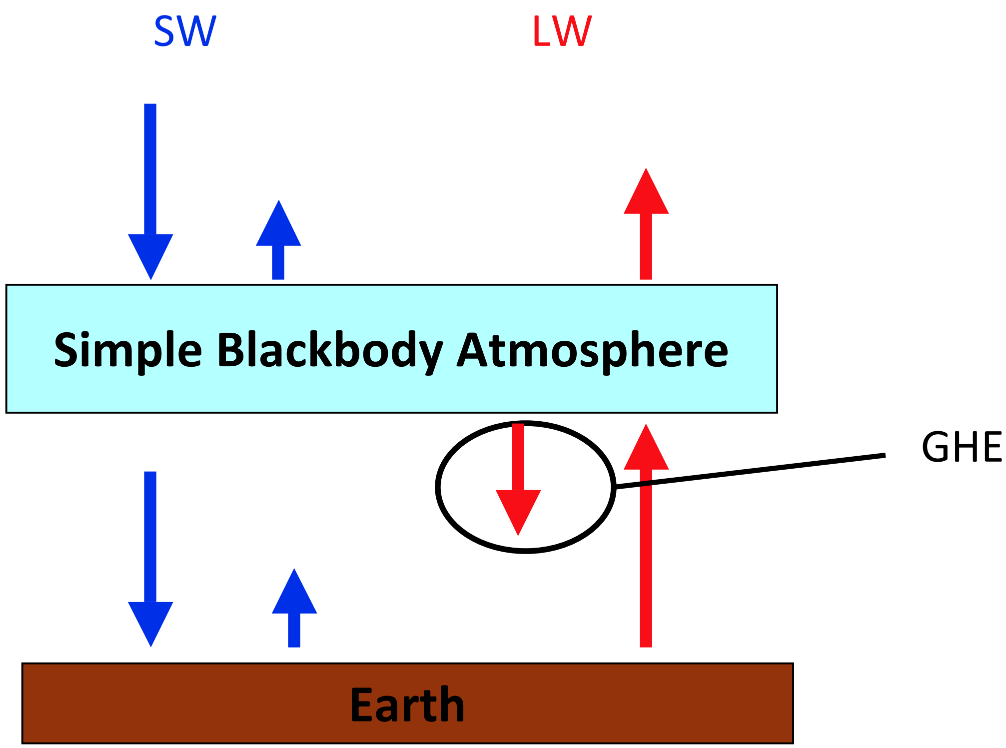
$$F_{IN} = F_{OUT}$$

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

$$\frac{S}{4}(1-\alpha) = \sigma T^4$$ Model A

$$T = \sqrt[4]{\frac{S(1-\alpha)}{4\sigma}}$$ Model A, solved for T

Earth with a Simple 1-Layer Blackbody Atmosphere Model B



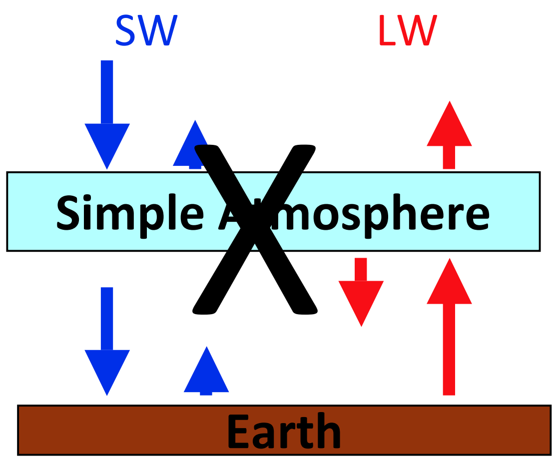
Take ATMS 211 or see optional reading for equations

The Greenhouse Effect GHE

Makes us warmer by about 30 C

It is only natural!
It is no longer debated by scientists

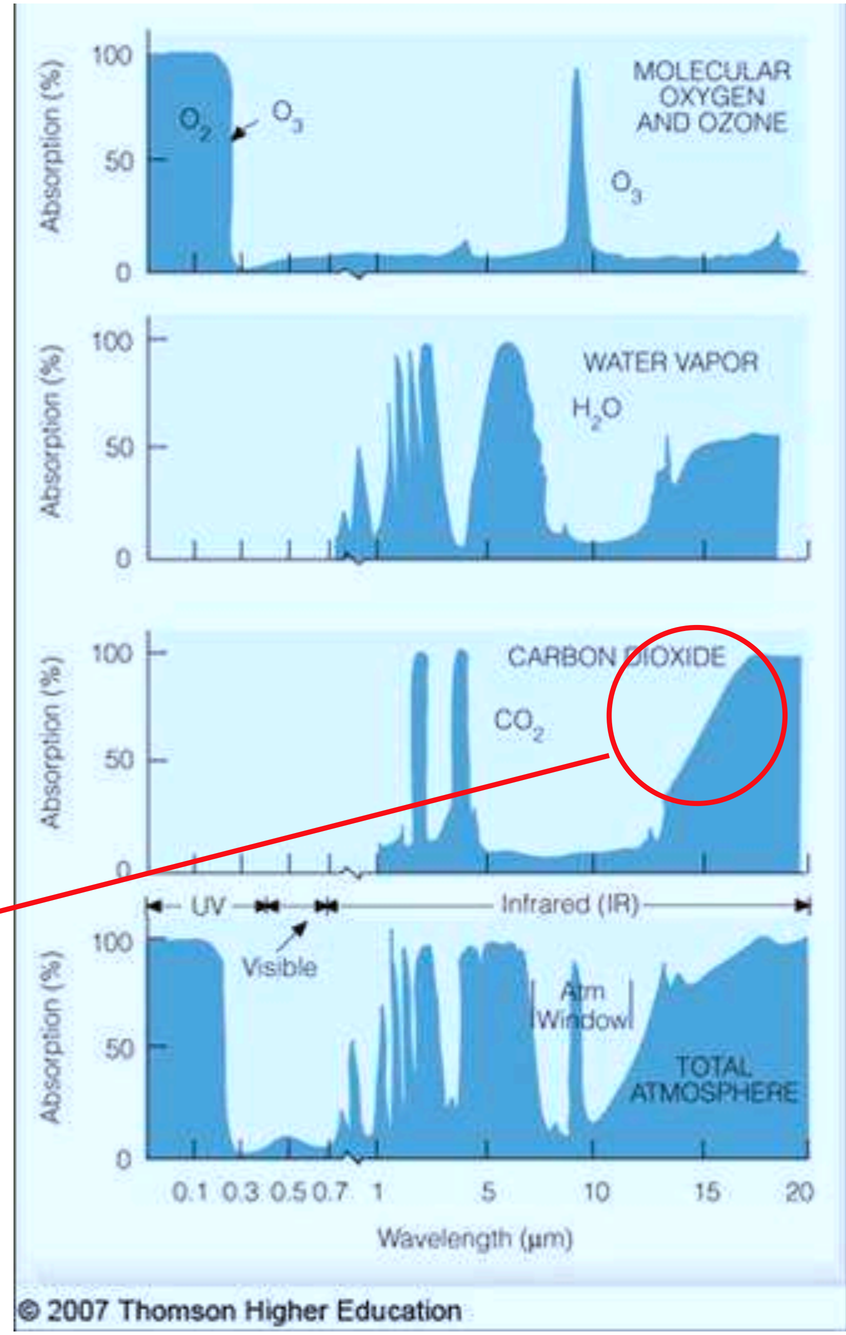
Enhanced or Anthropogenic GHE



Even Model B is too simple because it assumed the atmosphere was a blackbody, which doesn't change if there are more GHGs

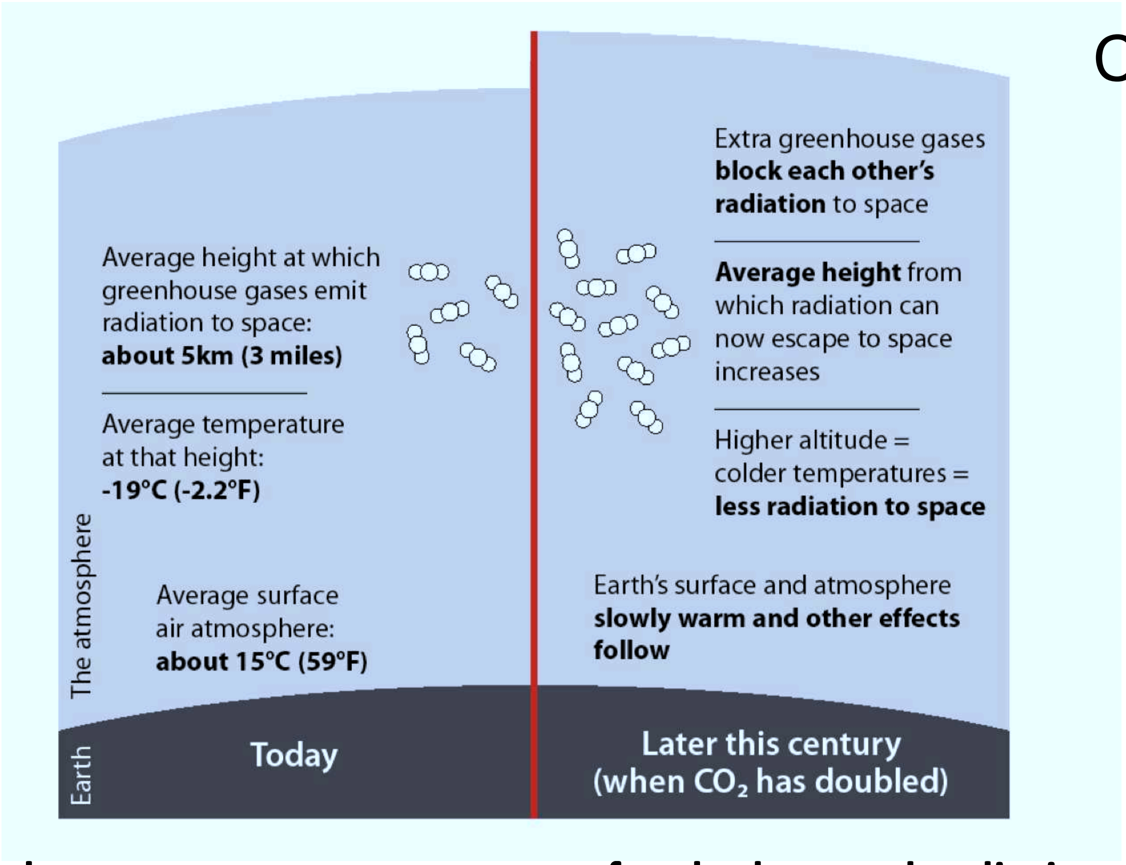
Scientist can compute the GHE accurately with models of many layers.

These models take into account the unique absorption and emission spectra of individual GHGs, which are selective absorbers as opposed to black bodies.



Bottom line, adding more CO2 to the atmosphere increases absorption where it is ~10-90%

Too much of a good thing? The Anthropogenic GHE



Crucial 4 steps

1

2

3

RG p24

4) The Earth must warm to compensate for the lowered radiation to space - Nature seeks to eliminate the imbalance.

The atmosphere height (troposphere specifically) moves up, but this is not a major factor driving surface warming.

Planetary Energy Balance

At Equilibrium (a steady climate):

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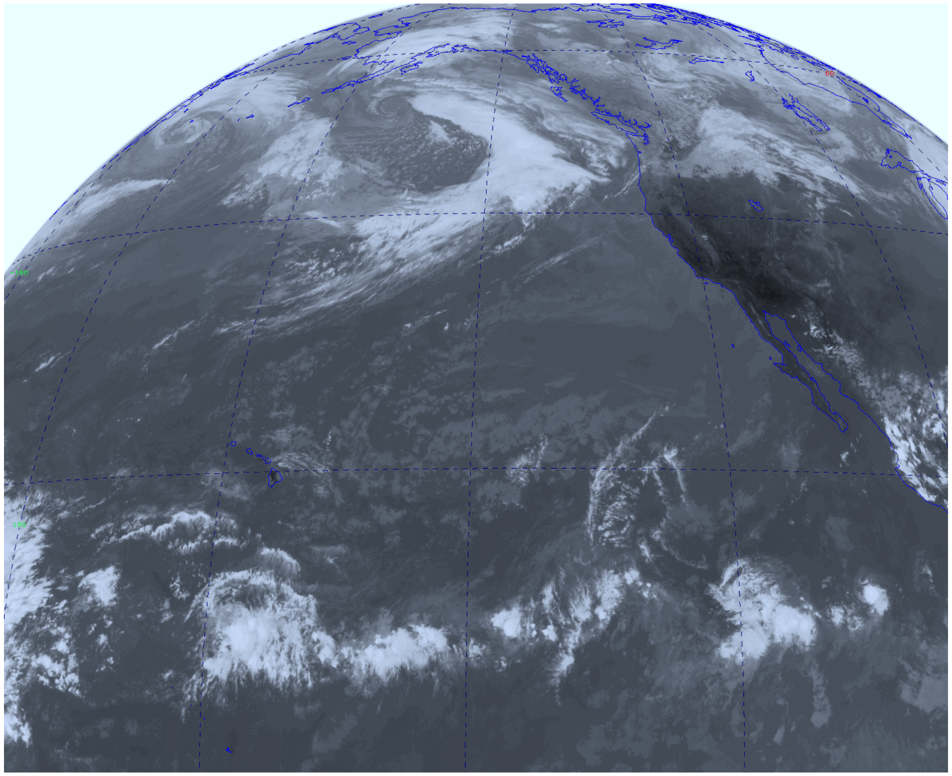
* **depends on temperature T of the earth and atmosphere**



Adding more GHG is a little like adding more high clouds.

The are cold and high, so Less heat escapes, and

F_{OUT} decreases

At first, energy is not in balance

Which is bigger **F_{IN} or F_{OUT}?**

How will the system respond to the imbalance?

Is the GHE Like A Blanket?

Blankets mostly warm by reducing air circulation, or convection.

Human-induced global warming: add more blankets?

Not a great analogy but
it is used all the time