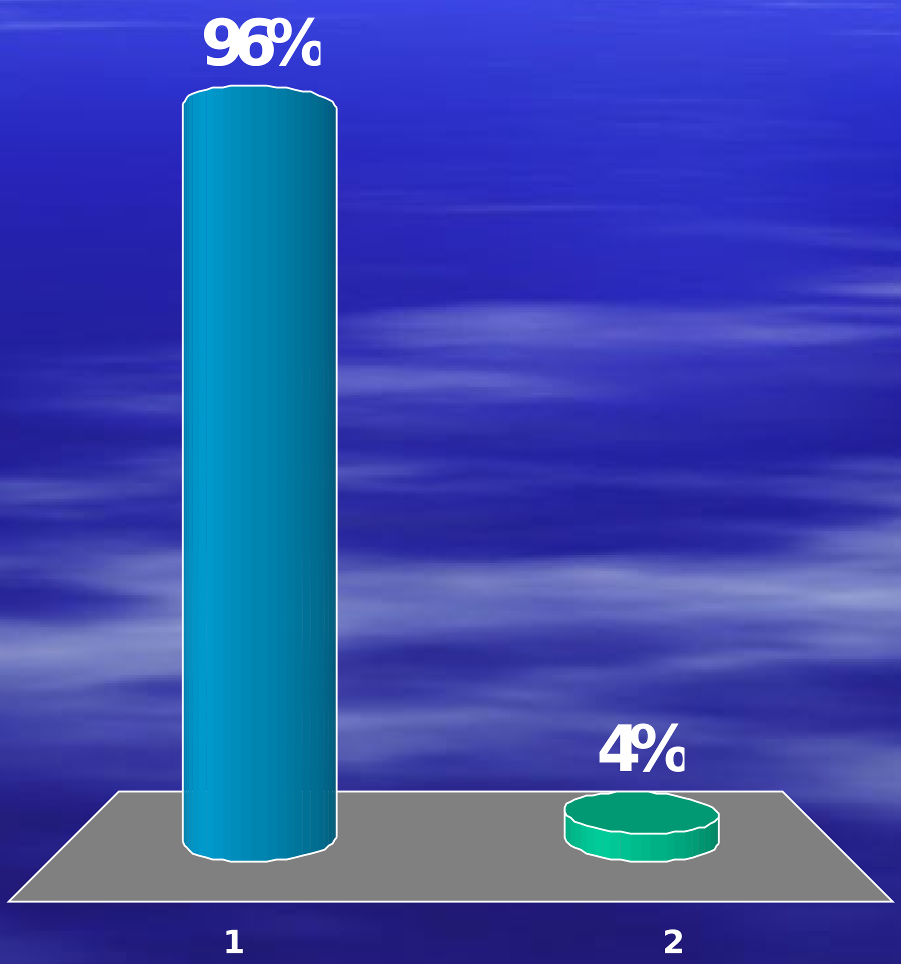
Earth's Temperature - Green House Effect and Global Warming

Many slides provided by Dr. Daniel Holland

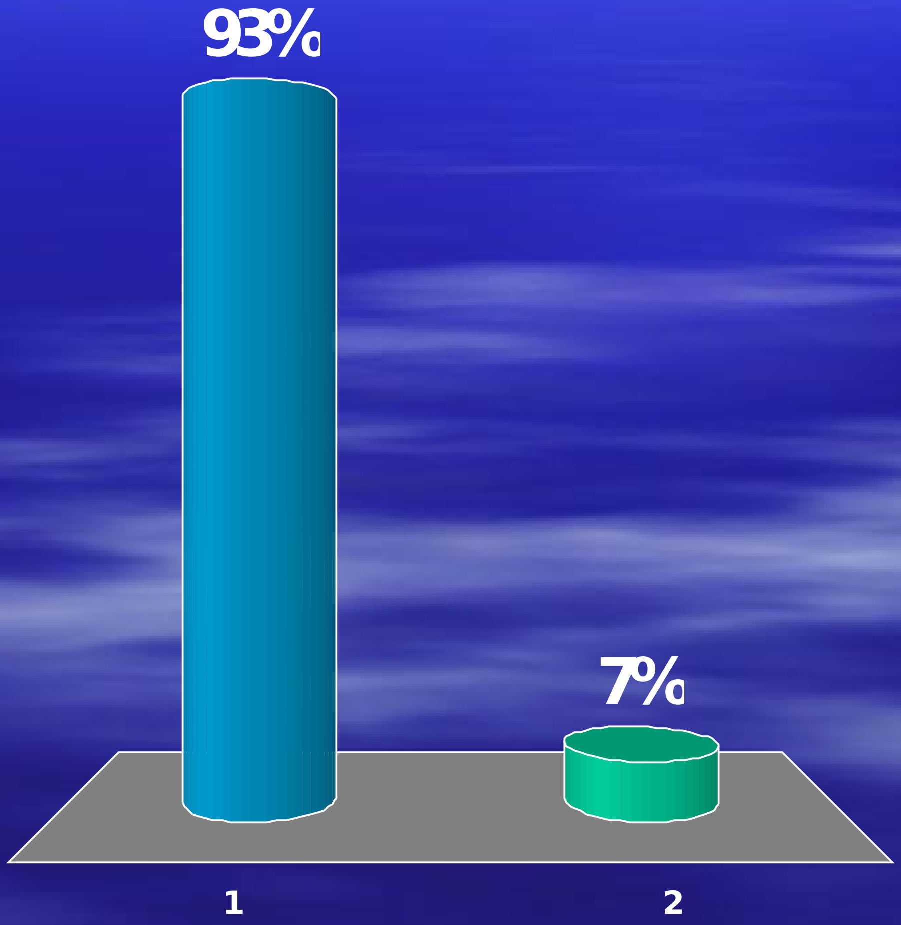
Do you believe that the planet is warming?

1. Yes
2. No



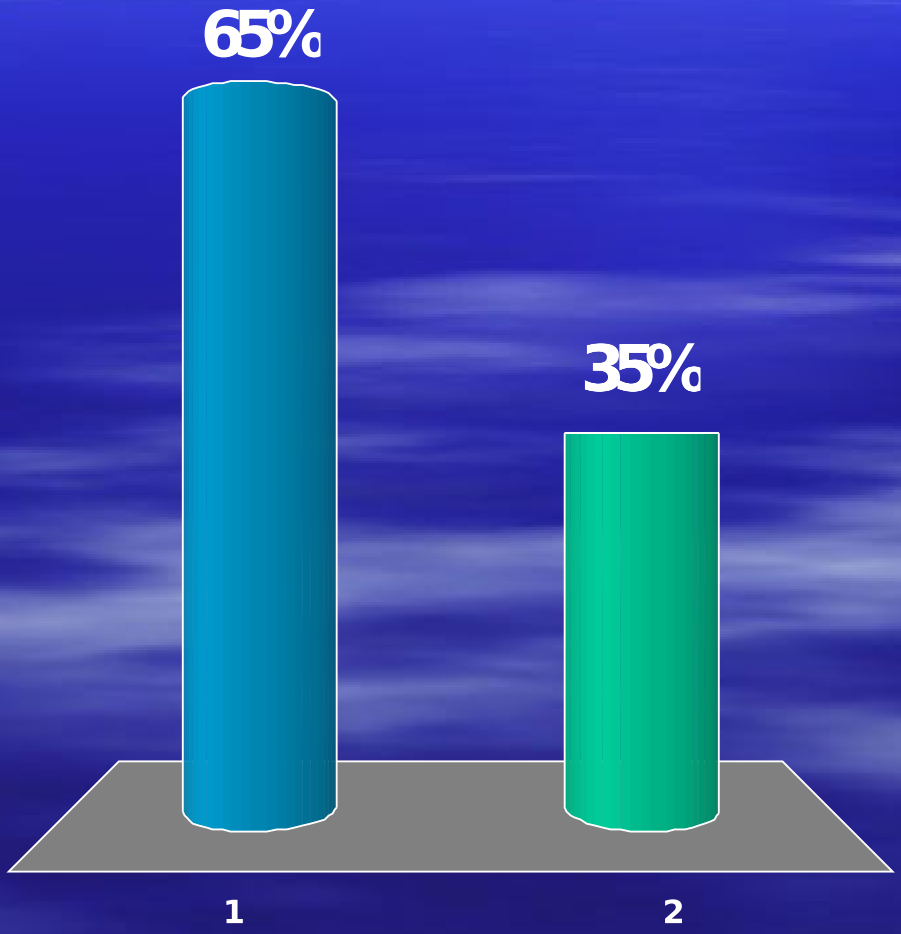
If you believe that the planet is warming, do you believe that human activity has contributed to the warming?

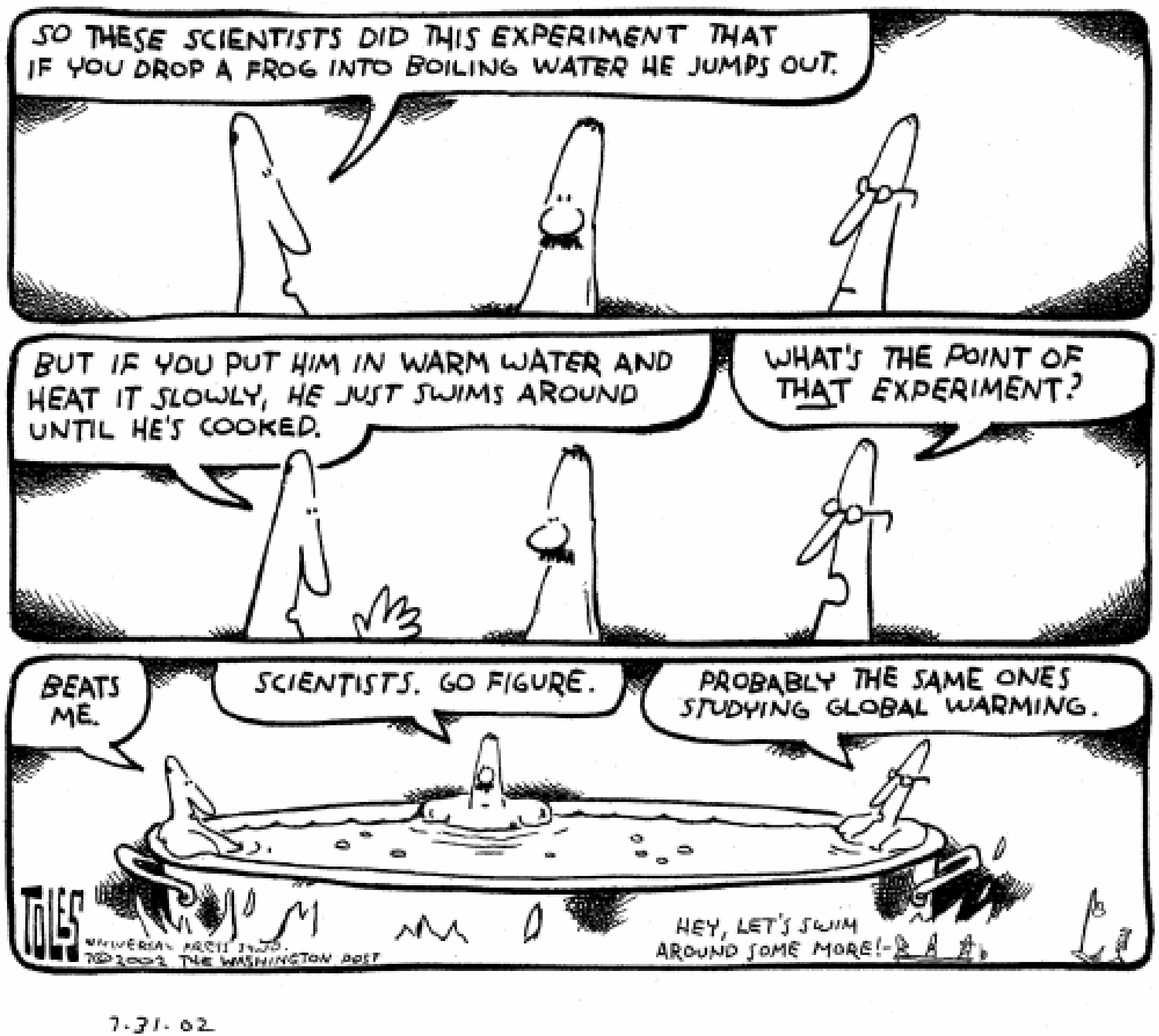
1. Yes
2. No



Do you believe that there is a lot of controversy in the scientific community abut climate change (global warming)?

1. Yes
2. No




SO THESE SCIENTISTS DID THIS EXPERIMENT THAT IF YOU DROP A FROG INTO BOILING WATER HE JUMPS OUT.
BUT IF YOU PUT HIM IN WARM WATER AND HEAT IT SLOWLY, HE JUST SWIMS AROUND UNTIL HE'S COOKED.
WHAT'S THE POINT OF THAT EXPERIMENT?
BEATS ME.
SCIENTISTS. GO FIGURE.
PROBABLY THE SAME ONES STUDYING GLOBAL WARMING.
HEY, LET'S SWIM AROUND SOME MORE!
TOLES
THE WASHINGTON POST
7-31-02

Simplest Picture

- How can we calculate a planet's temperature?
- Assume on average that the energy that is coming to us from the sun (mostly in the form of visible light) is balanced by radiation from the planet (mostly in the form of infrared light) (EQUILIBRIUM)

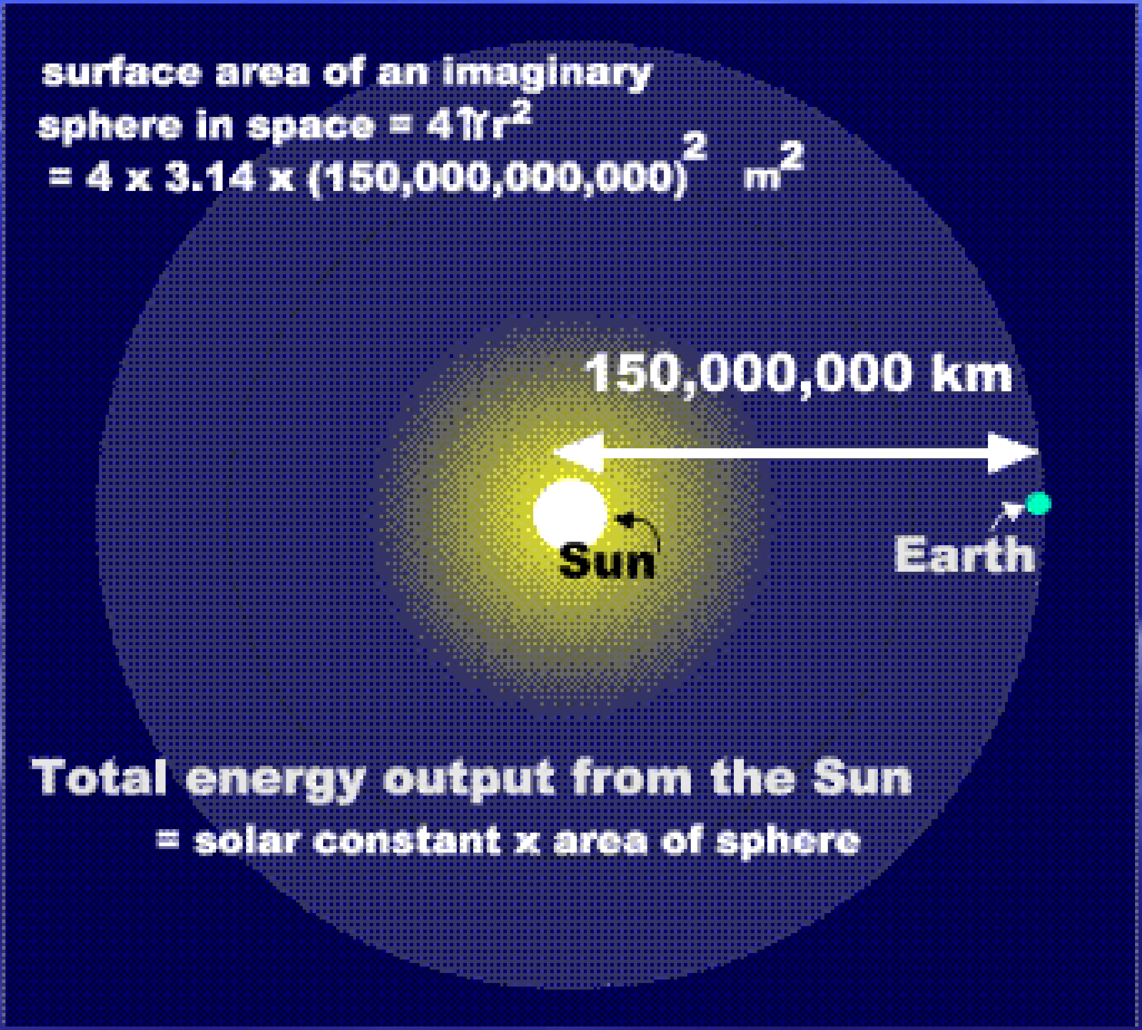
Audio Link

- If we are radiating faster than we receive energy we will cool down.
- If we are receiving energy faster than we reradiate it, we heat up.
- Eventually we will come to a new equilibrium at a new temperature.

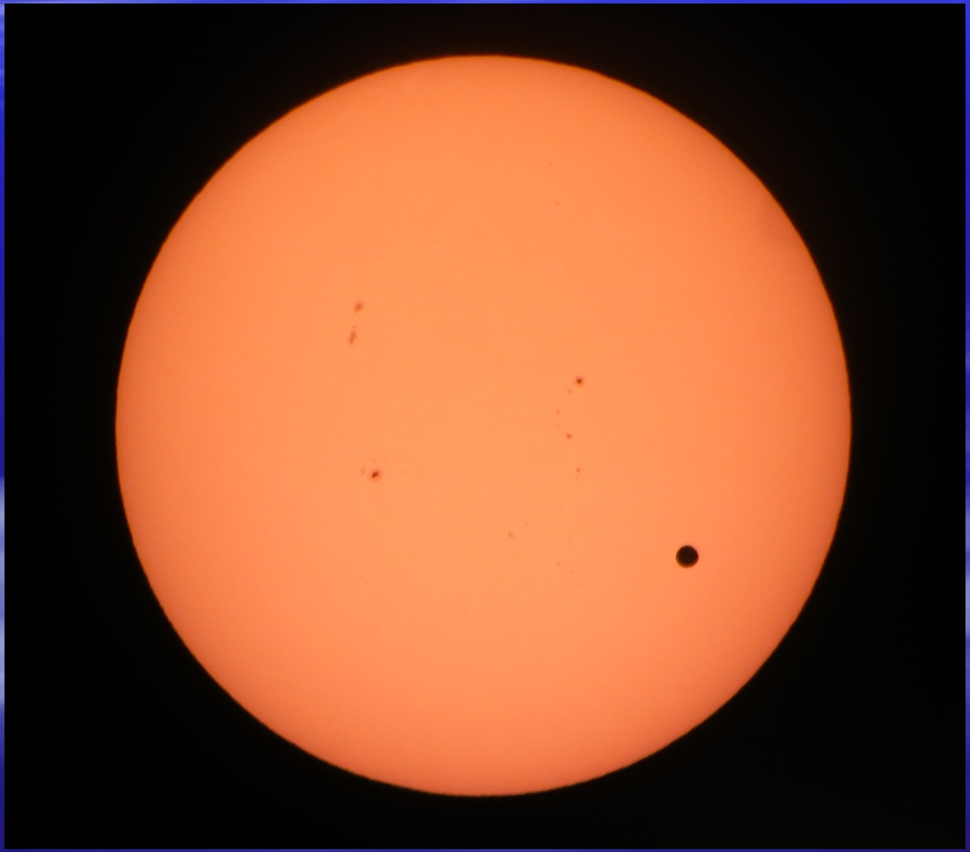
How much power do we get?

- We know that 99.98% of the energy flow coming to the earth is from the sun. (We will ignore the other .02%, mostly geothermal.)
- At a distance the of 1A.U. (1 astronomical unit is the distance from the sun to the earth) the energy from the sun is 1368 W/m^2 on a flat surface (solar constant).

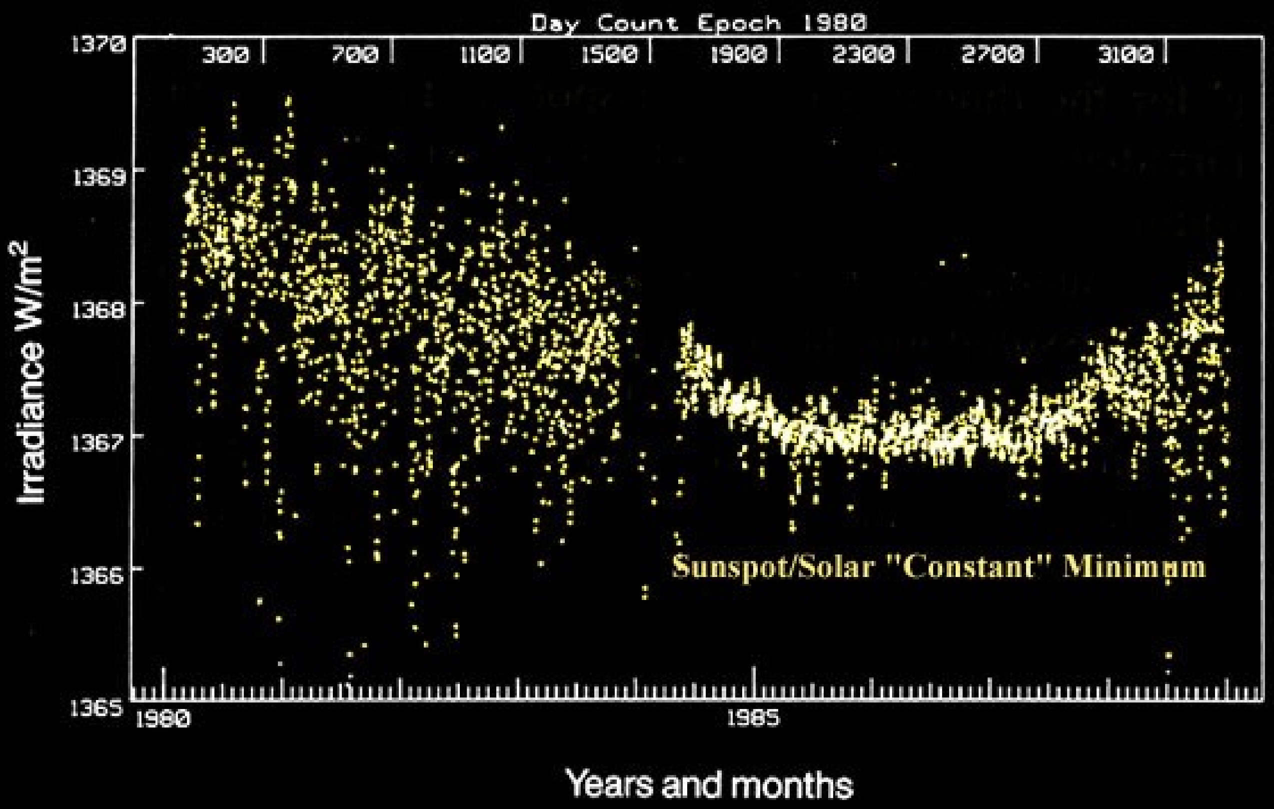
Solar Constant



Solar constant depends on base energy output of the sun, sunspot activity, and the Earths distance from the sun.

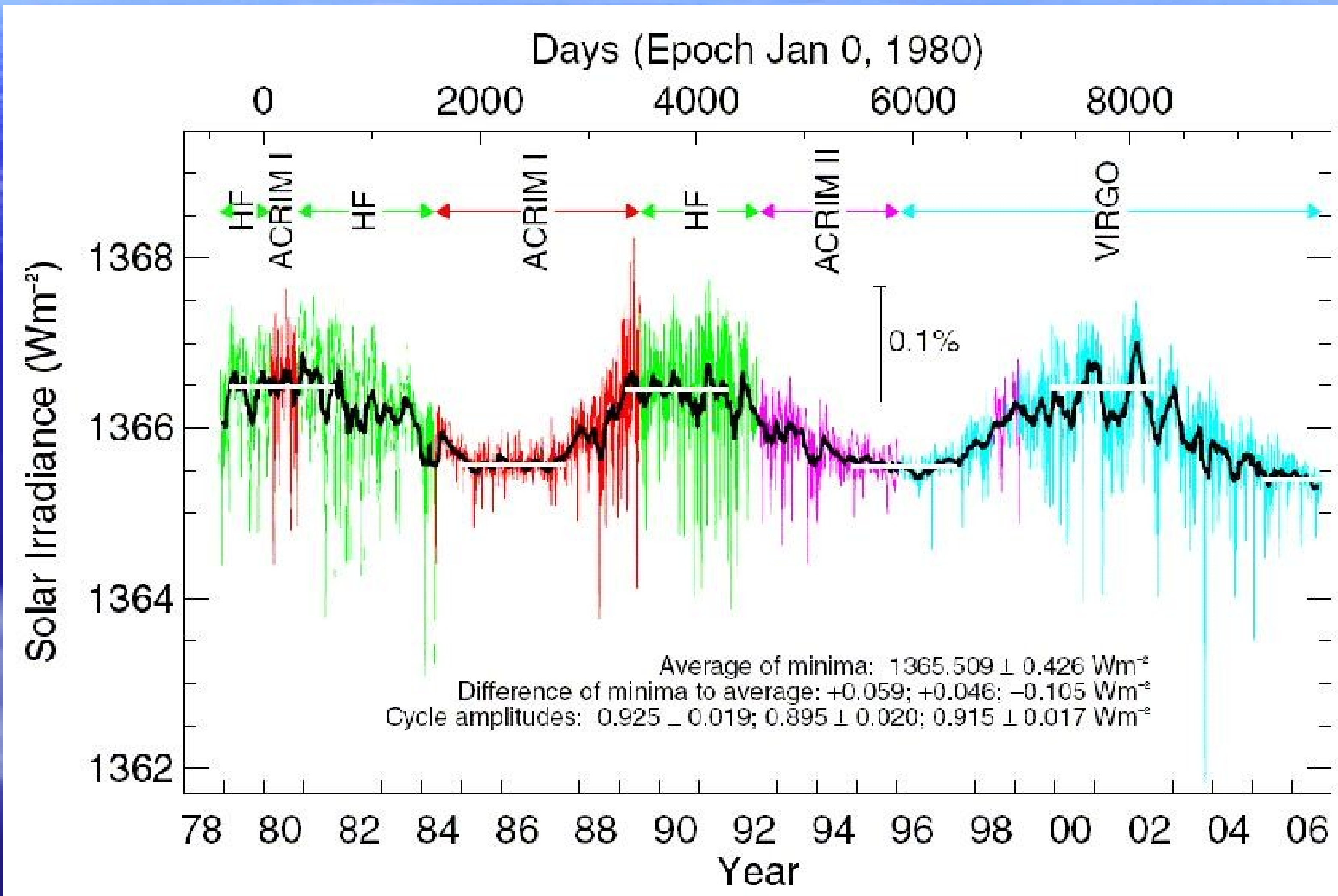


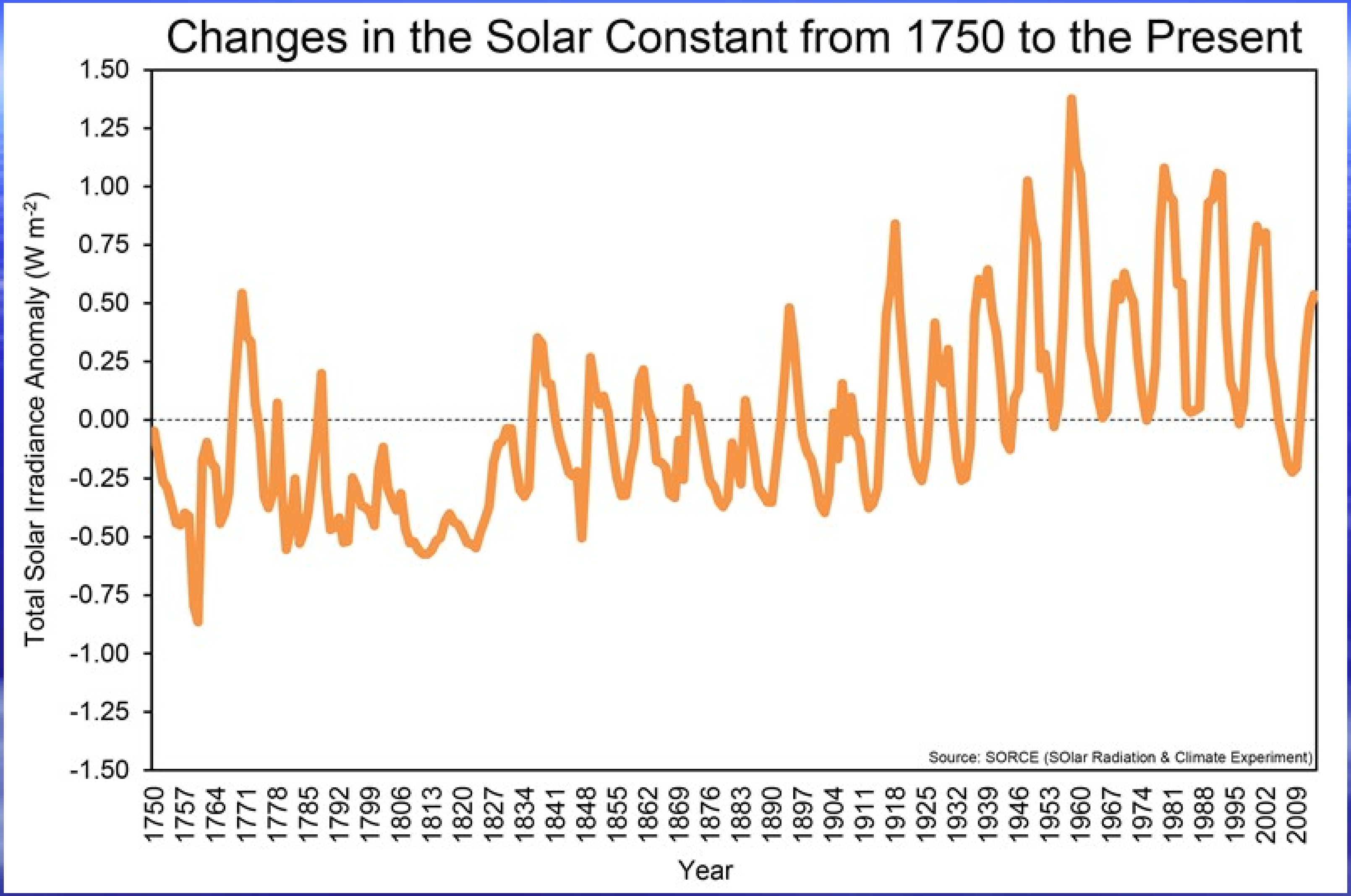
Picture of the sun showing Venus and sunspots from the 2012 transit.



The solar irradiance measured by ACRIM over the period 1980–88, showing sunspot-associated dips at times of large spot activity (1980–84 and 1988 onwards) and the prolonged minimum (1985–87) when solar activity was low. The observational errors are larger for the period between the end of 1980 and the beginning of 1984 because of a lower rate of data acquisition and the coarse pointing of the *SMM* spacecraft in this interval. (Courtesy R. C. Willson and H. S. Hudson)

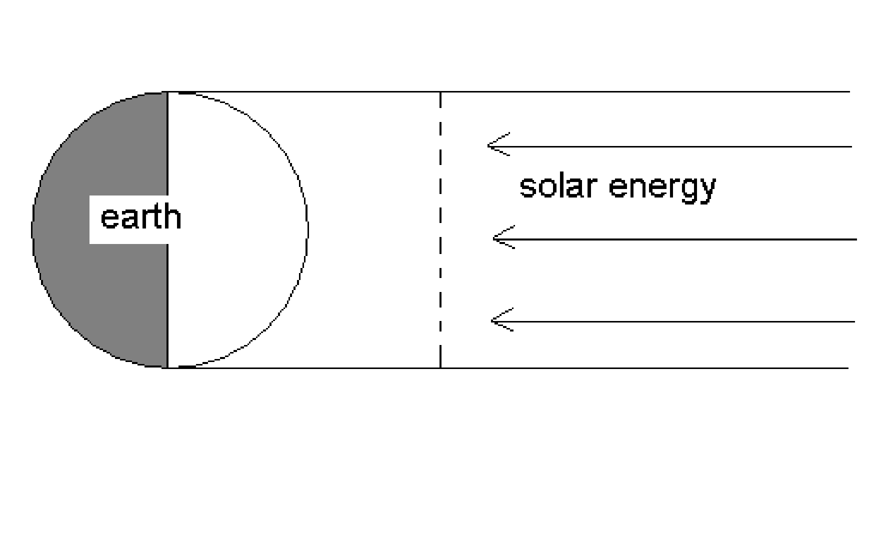
Measured Solar Constant





http://sites.gsu.edu/geog1112/global-surface-temperature/

- Power we get form the sun is the solar constant, S, times an area equal to a flat circle with the radius of the earth.
- $P=S\pi(R_E)^2$
- Note: Energy is not uniformly distributed because earth's surface is curved.



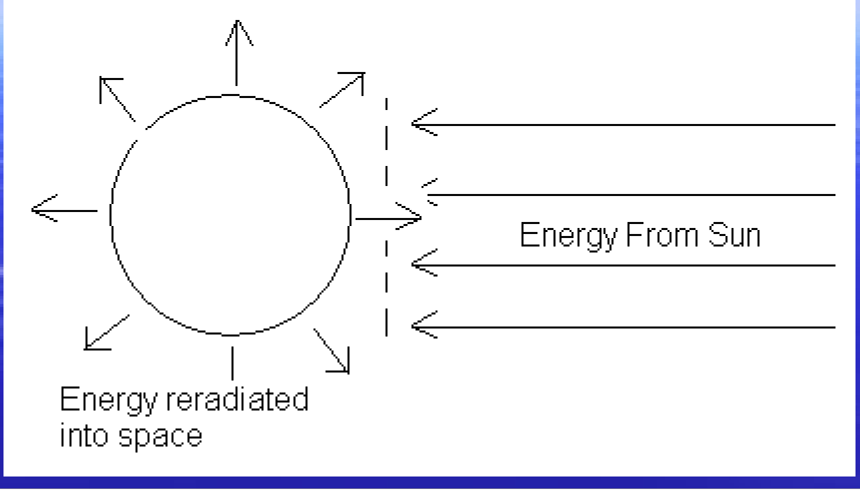
How much energy do we lose?

- Start simple: In equilibrium, we lose exactly as much as we get, ***but*** we reradiate the energy from the entire surface if the earth.

$$P=\sigma e A_E T^4$$

where $A_E=4\pi\,(R_E)^2$

Energy balance



$$\pi R_E^2 S = e\sigma\left(4\pi R_E^2\right)T^4$$

$$\frac{S}{4} = e\sigma T^4$$

Still an energy balance equation, but on a per-sqaure meter basis

- The factor of 4 accounts for two effects:
  - 1) Half of the earth is always in the dark (night) so it does not receive any input from the sun. (factor of 2)
  - 2) The earth is a sphere so the sun's light is spread out more than if it was flat. (another factor of two.)
  - Note: This equation works for any planet, not just earth, if we know the value of S for that planet. (easy since it just depends on the distance from the sun)

Subtleties in the equation.

- First, we need to know the emissivity, e. For planets like earth that radiate in the infrared, this is very close to 1.
- Second, not all of the light from the sun is absorbed. A good fraction is reflected directly back into space and does not contribute to the energy balance. For earth it is approximately 31% of light is reflected.
- Thus the correct value for S/4 is $0.69*(1368/4)=235 W/m^2$.

Calculate an approximate global average temperature

$$\frac{s}{4} = \sigma e T^4$$

$$235\, W/m^2 = \left(5.67 \times 10^{-8}\, W/m^2 K^4\right)\left(1\right) T^4$$

$$T^4 = 4.14 \times 10^9\, K$$

$$T = 254\, K$$

Is this a reasonable answer.

- 254 K is -19°C or -2°F.
- It is in the right ballpark, and it just represents and average including all latitudes including the poles, BUT, the actual average global surface temperature is about 287K.

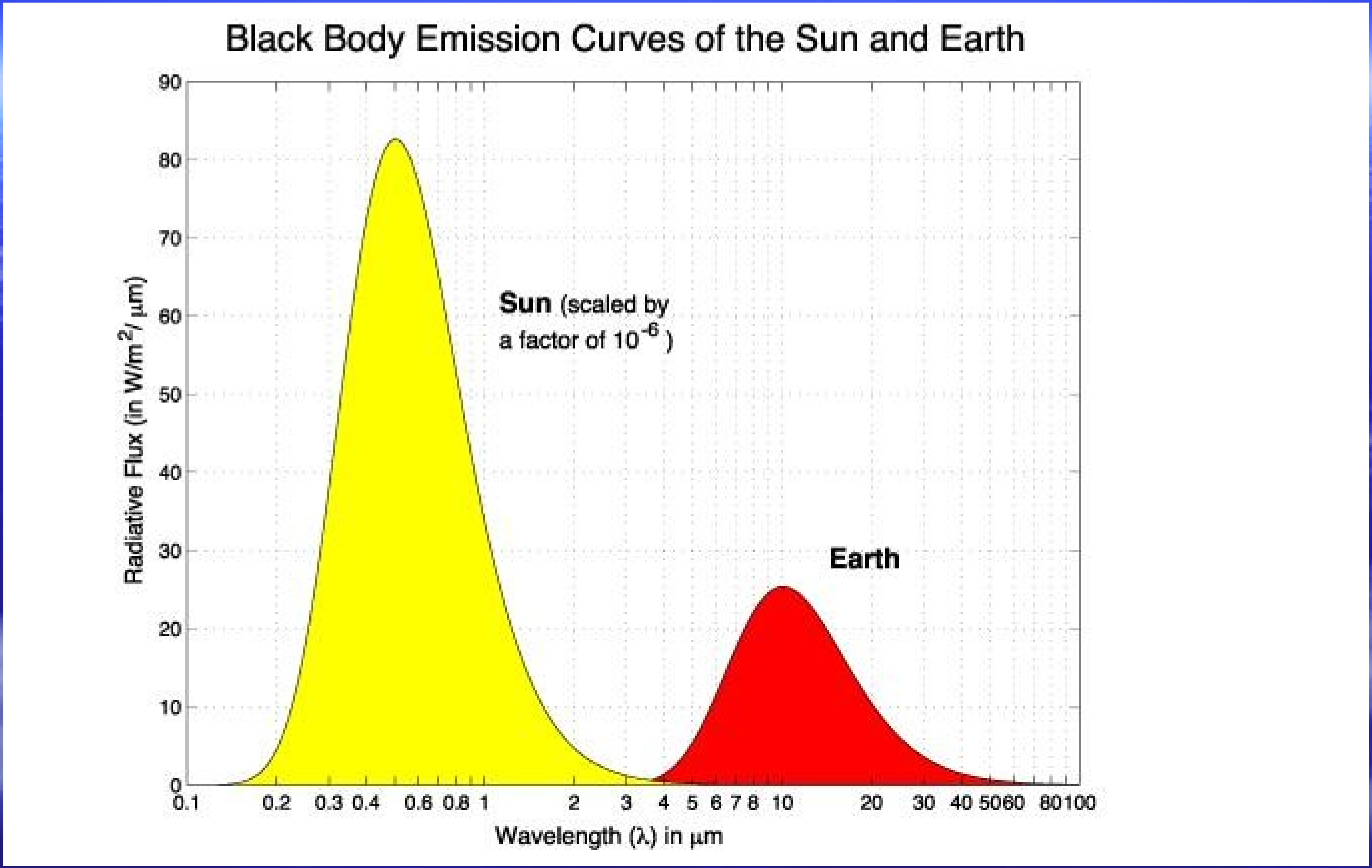
Note: This is a zero-dimensional model since we have taken the earth as a point with no structure. If we look at the earth from space with an infrared camera, we would see the top of the atmosphere, and 254K is not a bad estimate.

Why is the estimate 33°C too low at the surface?

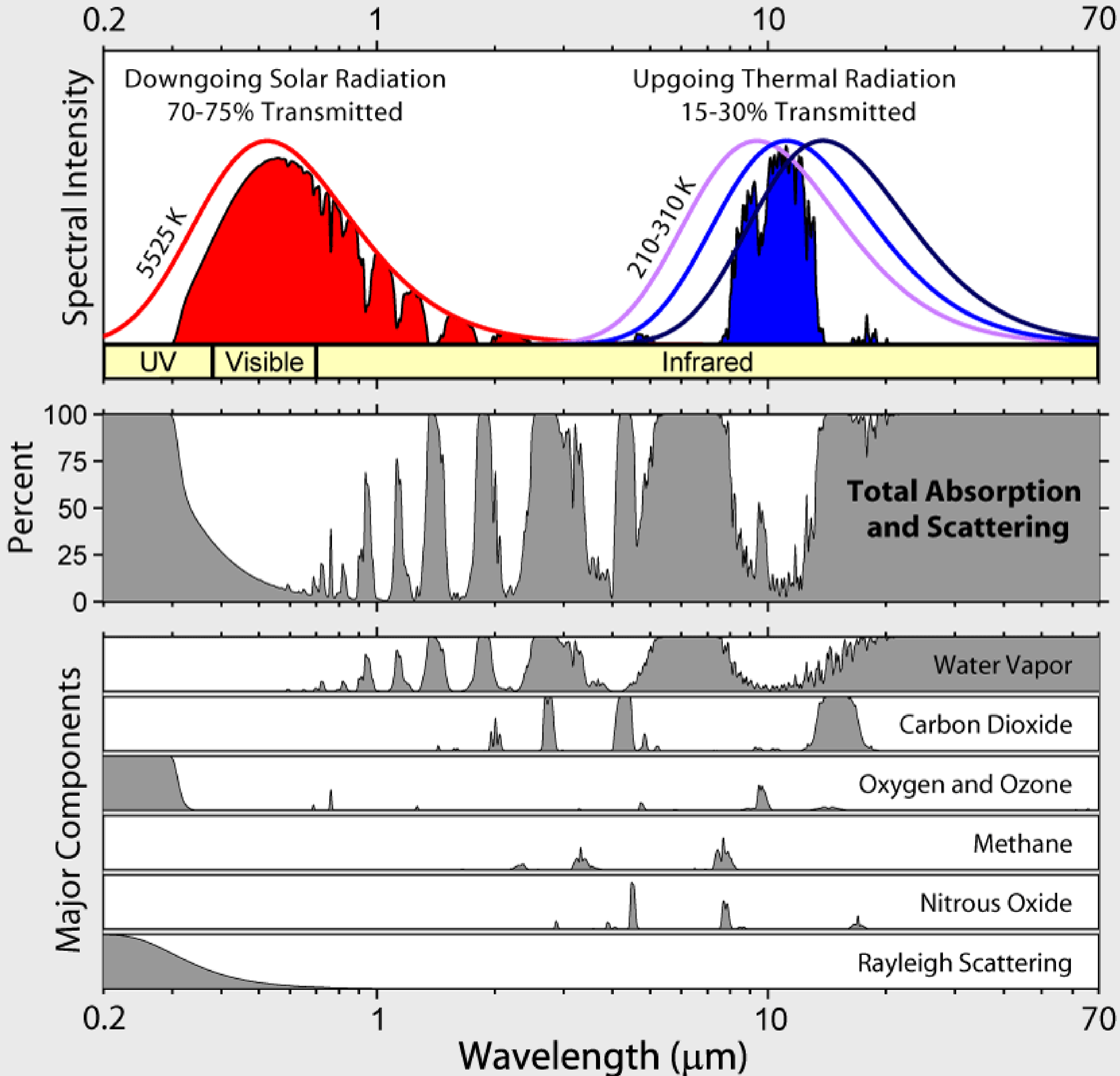
- Just as different rooms in a house may have different temperatures, the earth actually has many different regions (tropic, polar, forest, desert, high altitude, low altitude, etc.) which have different temperatures.
- Full scale models must account for all of this, but require large computers to solve the models.
- We will lump our planet into two regions, an atmosphere and the ground. The results are simple, yet account for much of the observed phenomena.

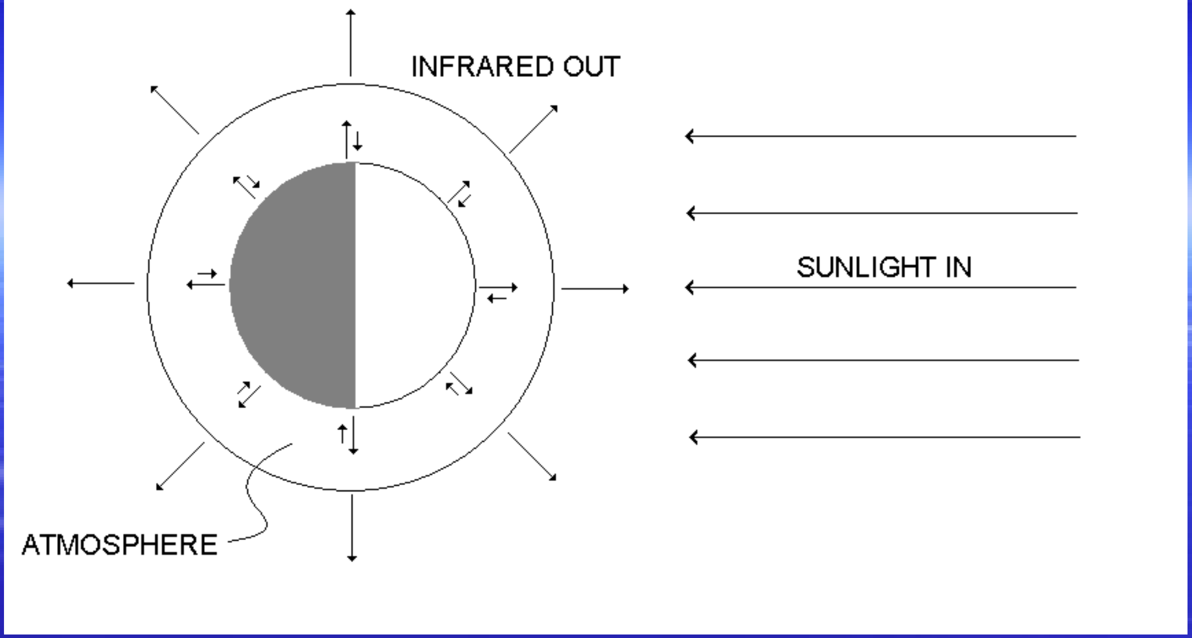
- As we saw in the section on light, most of the light from the sun is in the visible spectrum. This light passes right through the atmosphere with very little absorbed.
- The light that the earth emits is in the infrared. A large part of this get absorbed by the atmosphere (Water Carbon Dioxide, etc).
- The atmosphere acts like a nice blanket for the surface.

- Without our blanket, the surface of the earth would be quite cold.
- The difference between our 254K estimate and the 287K actual surface temperature is due to naturally occurring greenhouse gases.
- The predominant greenhouse gases are water vapor and to a much lesser extent, carbon dioxide.
- *Note: during the last ice age the average global temperature was 6°C lower than today. Without a natural greenhouse effect, the temperature would be 33°C lower.*


Black Body Emission Curves of the Sun and Earth
Radiative Flux (in W/m²/ µm)
90
80
70
60
50
40
30
20
10
0
Sun (scaled by a factor of 10⁻⁶)
Earth
0.1 0.2 0.3 0.4 0.6 0.8 1 2 3 4 5 6 7 8 10 20 30 40 50 60 80 100
Wavelength (λ) in µm

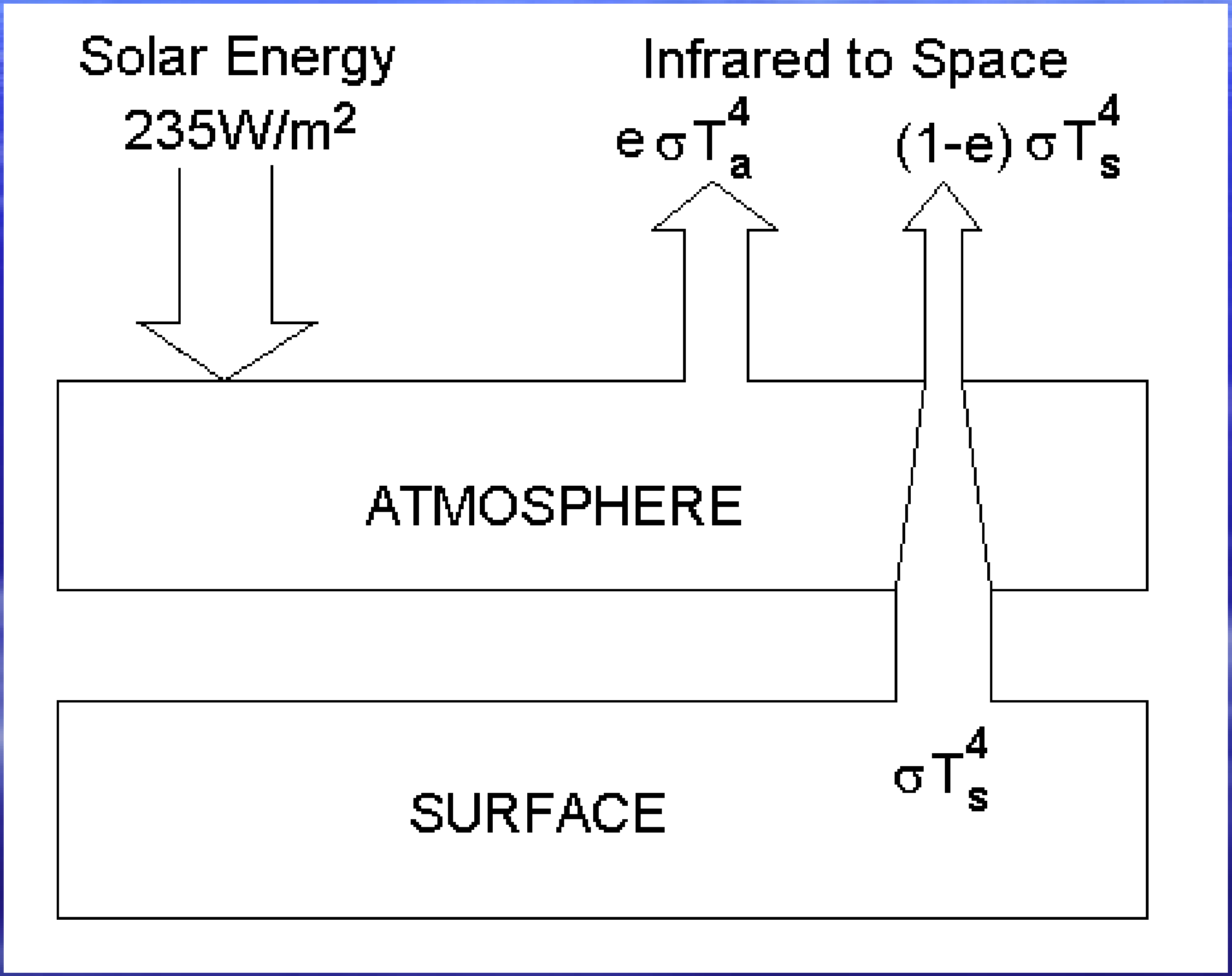
Radiation Transmitted by the Atmosphere





- With the atmosphere present, the surface must radiate at a higher $\sigma e T^4$ since not as much energy is escaping.
- In addition a lot of the energy absorbed by the atmosphere is reradiated back to the earth, further driving up the temperature.

Simple two level model



- Incoming energy to the surface/atmosphere is still 235 W/m^2.
- Outgoing energy has two parts: One is infrared radiation from the atmosphere, the other is infrared radiation from the surface.
- *Notes:1) The temperatures of the atmosphere and the surface do not have to be the same.*
- *2)The sum of the two outgoing energy fluxes must still equal the incoming energy fluxes.*

- Note that the arrow representing the IR from the surface tapers as it passes through the atmosphere. This is to indicate that part of the energy is being absorbed. The amount depends on the concentration of greenhouse gases.
- The *emissivity* of a particular gas also reflects the amount of energy that a particular gas will absorb. We may also call it the *absorptivity.*

- If we start with a surface radiation of

$$P_s=\sigma T_s^4$$

- and we absorb an amount

$$P_{absorbed}= e_a\ \sigma T_s^4$$

- We have a total surface radiation actually reaching space of

$$P_s=(1-e_a)\sigma T_s^4$$

- In addition to this we have power radiated directly from the atmosphere:

$$P_a= e\sigma T_a^4$$

Total power radiated to space

Power radiated to space = $(1-e_a)\sigma T_s^4 + e\sigma T_a^4$

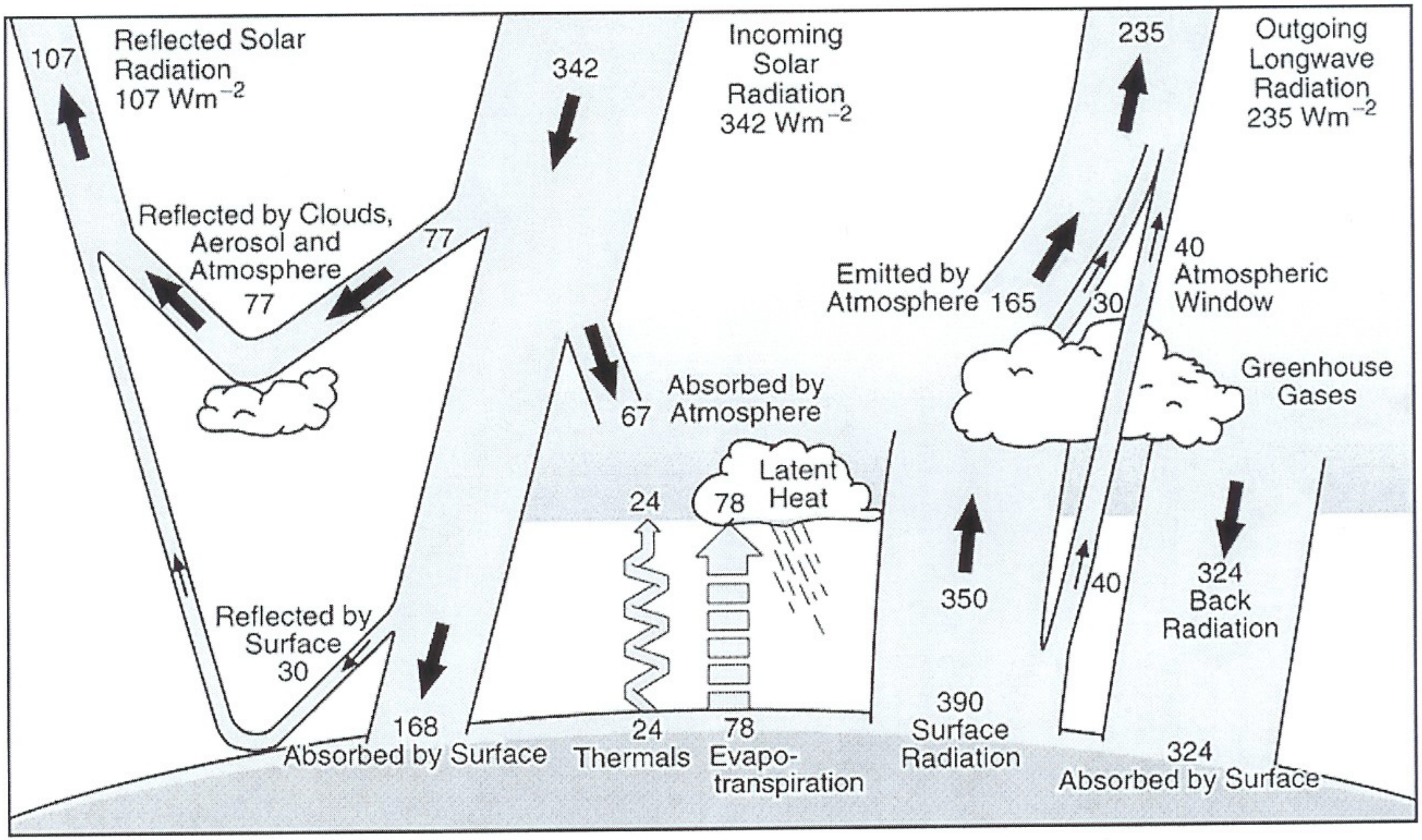
OR since $e_a = e$

Power radiated to space = $\sigma T_s^4 - e\sigma(T_s^4 - T_a^4)$

- Note: Assuming that $T_s > T_a$, the second term on the RHS is negative. This means that the surface temperature must higher than in the absence of the atmosphere in order to radiate enough energy to stay in equilibrium.

- Notes:
- 1) For a given concentration of greenhouse gases (i.e. given e) a colder atmosphere actually enhance the greenhouse effect.
- 2) If e=0, we recover our old result of no atmosphere.

More complete picture.



- A 2005 study suggest that currently we receive approximately 0.85 W/m^2 more than we are radiating.