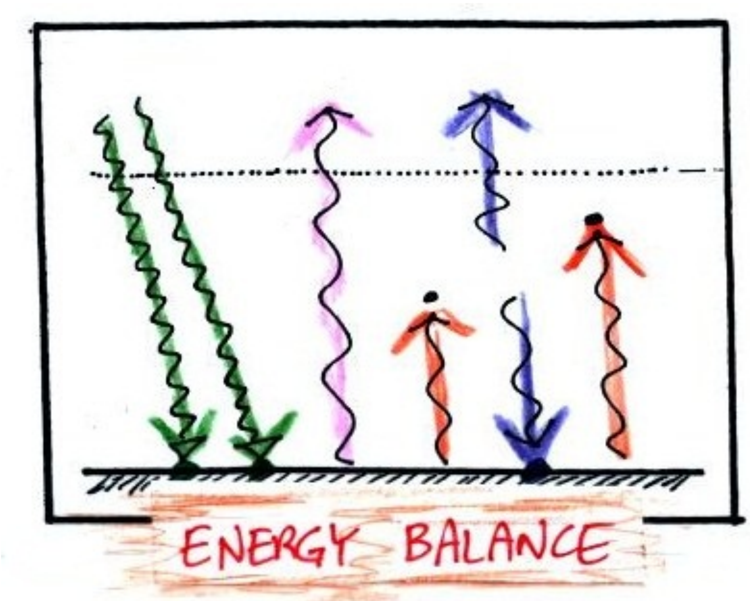
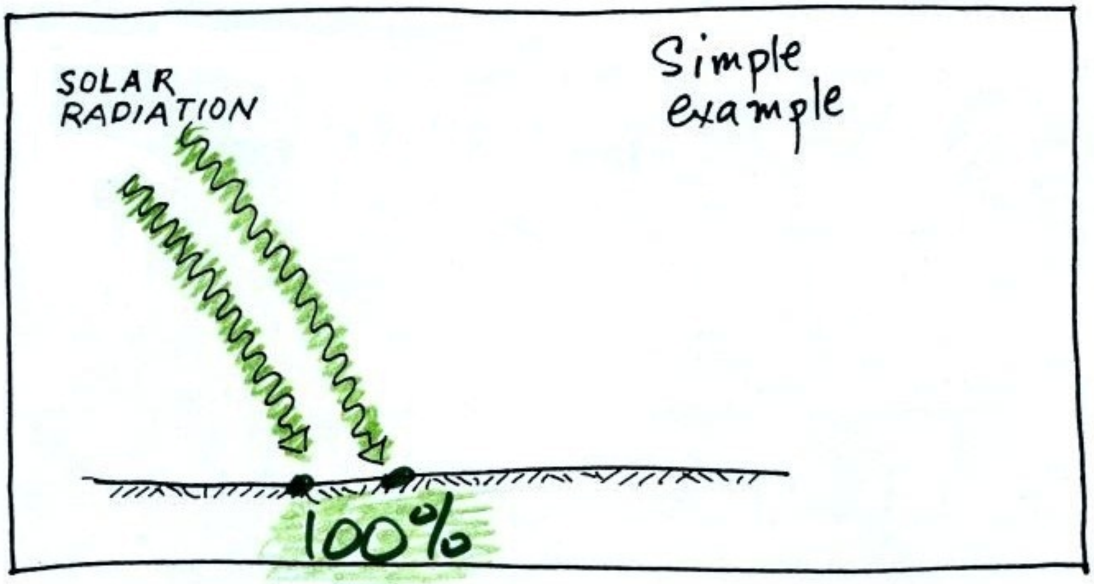
Module 5 - Lecture 15

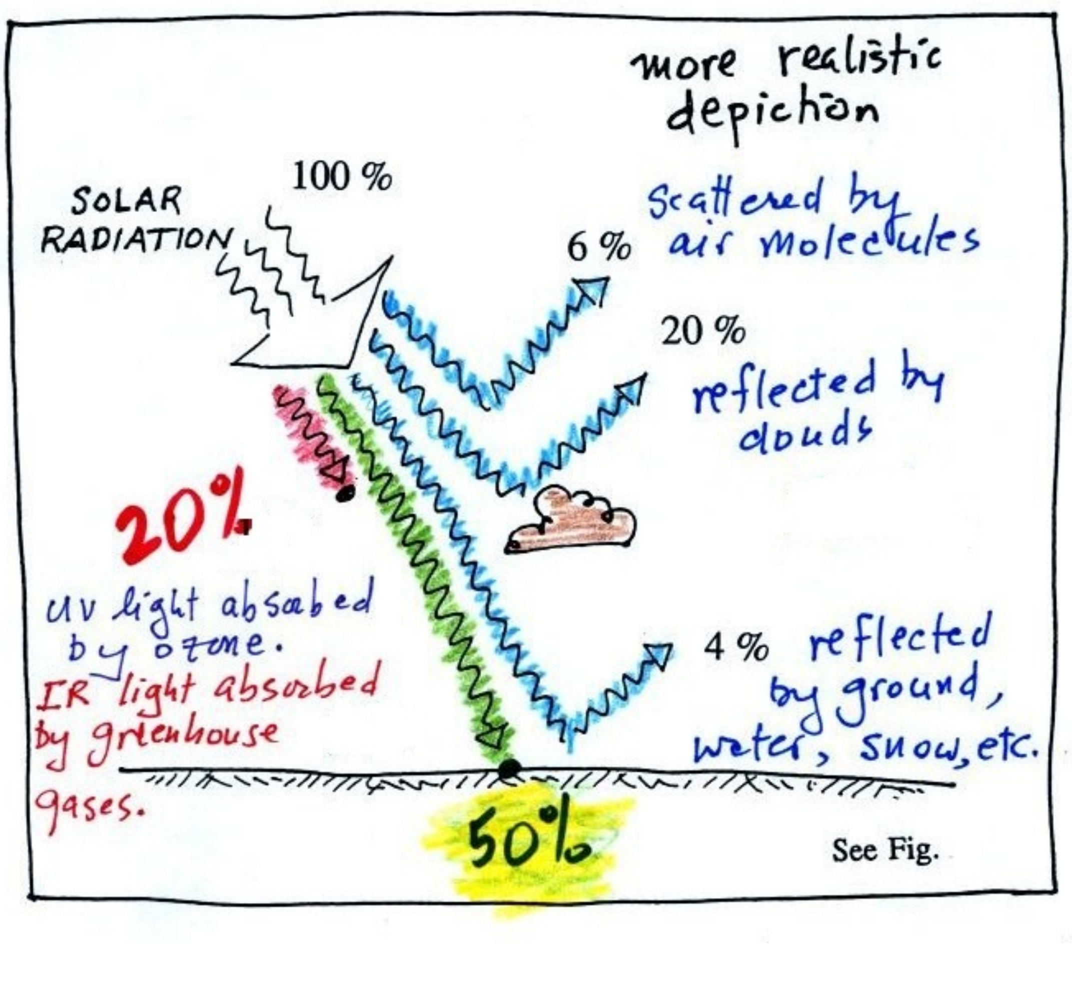
Here is the simplified picture of radiative equilibrium and the greenhouse effect that we came up with in the last lecture. We are assuming that 100% of the sunlight that reaches the earth passes through the atmosphere and is absorbed at the ground. The two green arrows represent the incoming sunlight. Some infrared radiation emitted by the ground passes out into space (pink arrow) and some is absorbed by the atmosphere (red arrows). The atmosphere emits infrared radiation back to the ground and also out into space (blue arrows). You should be able to identify each of the colored arrows in the figure below and explain what they represent.

Conduction, convection, and latent heat energy transport, which are not shown in our simplified model, are also needed to bring the overall energy budget into balance. The amount of energy transported by conduction, convection, and latent heat is small compared to what is transported in the form of EM radiation.



In reality, only about 50% of the incoming sunlight (which is a mixture of ultraviolet, visible, and infrared light) is transmitted through the atmosphere to be absorbed by the ground. This is illustrated in the following figure, which gives global average values. Approximately 20% of the incoming sunlight is absorbed by gases in the atmosphere. Ozone and oxygen in the stratosphere will absorb most of the ultraviolet radiation and greenhouse gases will absorb some of the infrared radiation. The remaining 30% of the incoming sunlight is reflected or scattered back into space by the ground, clouds and even air molecules.


Simple example
SOLAR RADIATION
100%


more realistic depiction
100 %
SOLAR RADIATION
6 % scattered by air molecules
20 % reflected by clouds
20%
UV light absorbed by ozone.
IR light absorbed by greenhouse gases.
4 % reflected by ground, water, snow, etc.
50%
See Fig.

The previous figure shows how incoming solar energy is distributed. Now we will look at a more realistic picture of the earth's energy budget. The upper part of the next figures has already been shown in this lecture.

The lower part of the figure is quite complicated. Once you understand the upper figure, you should be able to find and understand the corresponding arrows in the lower figure. Just as we did earlier, you can check to see that each part of the lower figure is in energy balance: 147 units absorbed and lost by the ground, 160 units absorbed and emitted by the atmosphere, 70 units of incoming sunlight absorbed by the ground or atmosphere and 70 units emitted by the earth back into space by the ground or the atmosphere.

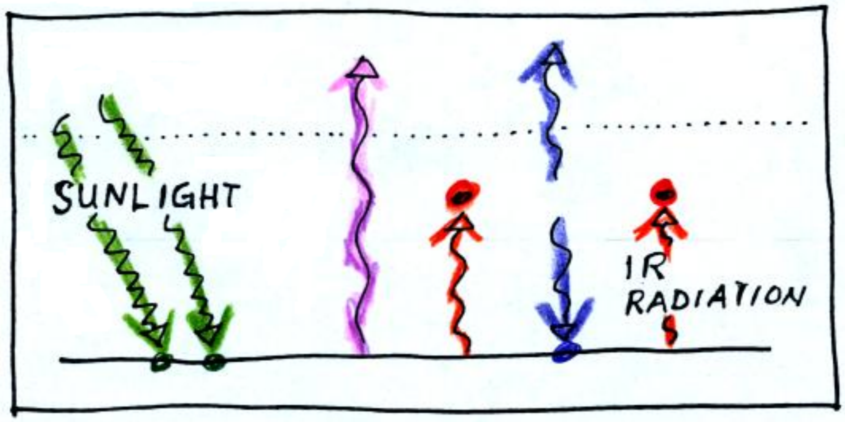
<u>There are a few other things to note.</u>

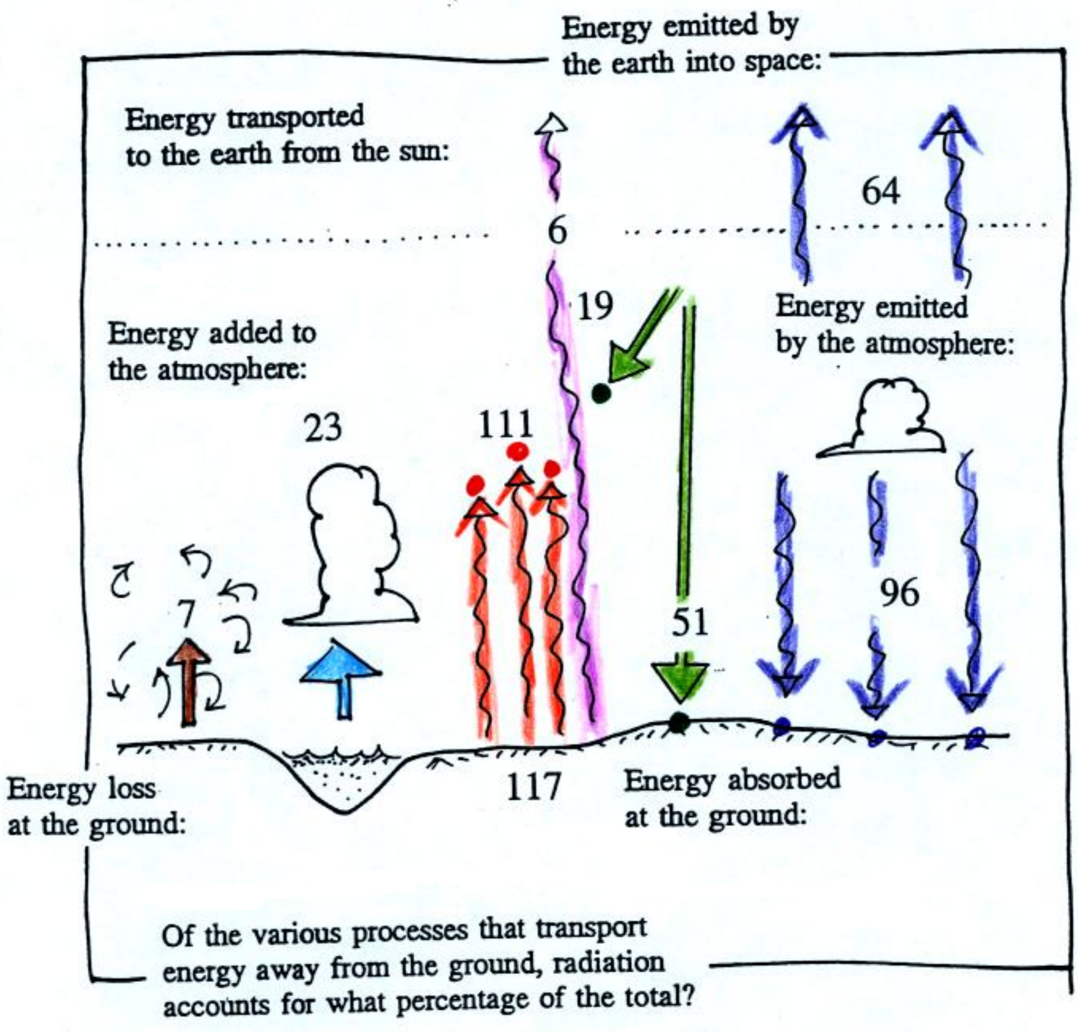
(i) First the ground receives more energy from the atmosphere (96 units) than it gets from the sun (51 units). Part of the reason for this is that the sun just shines for part of the day. We receive energy from the atmosphere 24 hours per day.

(ii) The ground emits more energy (117 units) than it gets from the sun (51 units). It is able to achieve energy balance because it gets energy back from the atmosphere.

(iii) The atmosphere emits 64 units upward and 96 units downward. This is partially because the lower atmosphere is warmer than higher up in the atmosphere. There is also more air in the bottom of the atmosphere than near the top of the atmosphere.

(iv) Note that energy transport by conduction and convection (7 units) and by latent heat (23 units) from the earth's surface to the atmosphere are needed to bring this figure into energy balance.

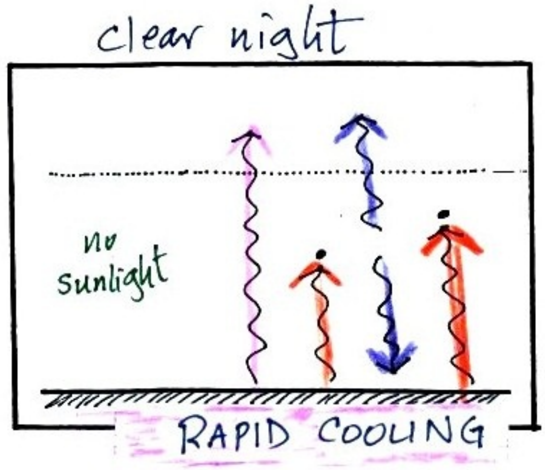

SUNLIGHT
IR
RADIATION

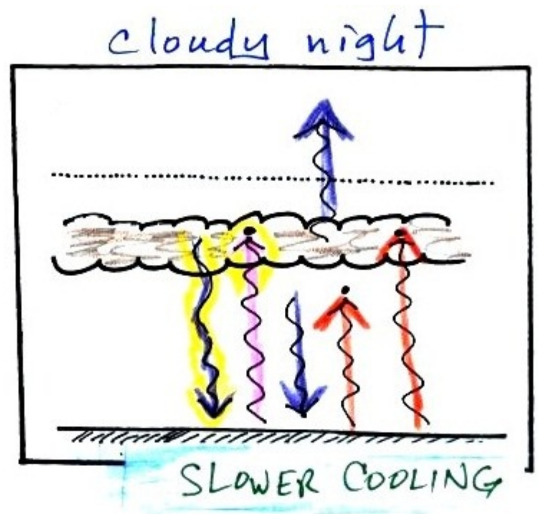

Energy emitted by
the earth into space:
Energy transported
to the earth from the sun:
6
64
19
Energy added to
the atmosphere:
Energy emitted
by the atmosphere:
23
111
7
96
51
Energy loss
at the ground:
117
Energy absorbed
at the ground:
Of the various processes that transport
energy away from the ground, radiation
accounts for what percentage of the total?

Next we will use our simplified representation of the greenhouse effect to understand the effects of clouds on daytime high and nighttime low temperatures.

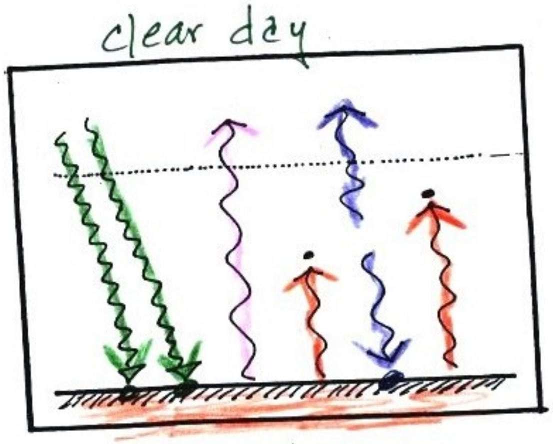
The two pictures below show what happens **<u>at night</u>** when you remove the two green rays of incoming sunlight. The picture on the left shows a clear night. The ground is losing three arrows of energy and getting one arrow back from the atmosphere. There is a net loss of two arrows. The ground cools rapidly and becomes cold during the night.

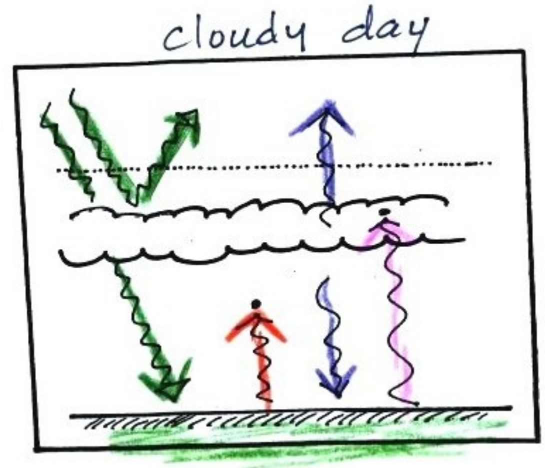
A cloudy night is shown at right. Notice the effect of the clouds. Clouds are good <u>absorbers</u> of <u>infrared</u> radiation. Now none of the infrared radiation emitted by the ground passes through the atmosphere into space. Instead all of the infrared radiation is absorbed either by greenhouse gases or by the clouds. Because the clouds and atmosphere are now absorbing three arrows of radiation, they must also emit three arrows: one arrow is radiated into space and the other two arrows are radiated downward to the ground. There is now a net loss at the ground of only 1 arrow. The ground will cool less quickly and not become as cold as it would during a clear night.





The next two figures compare clear days and cloudy days. Clouds are good <u>reflectors</u> of <u>visible</u> light (that is why clouds appear white). The effect of this is to reduce the amount of sunlight energy reaching the ground in the right picture. With less sunlight being absorbed at the ground, the ground becomes less warm. It is generally cooler during the daytime on a cloudy day than on a clear day. Clouds raise the nighttime minimum temperature and lower the daytime maximum temperature.

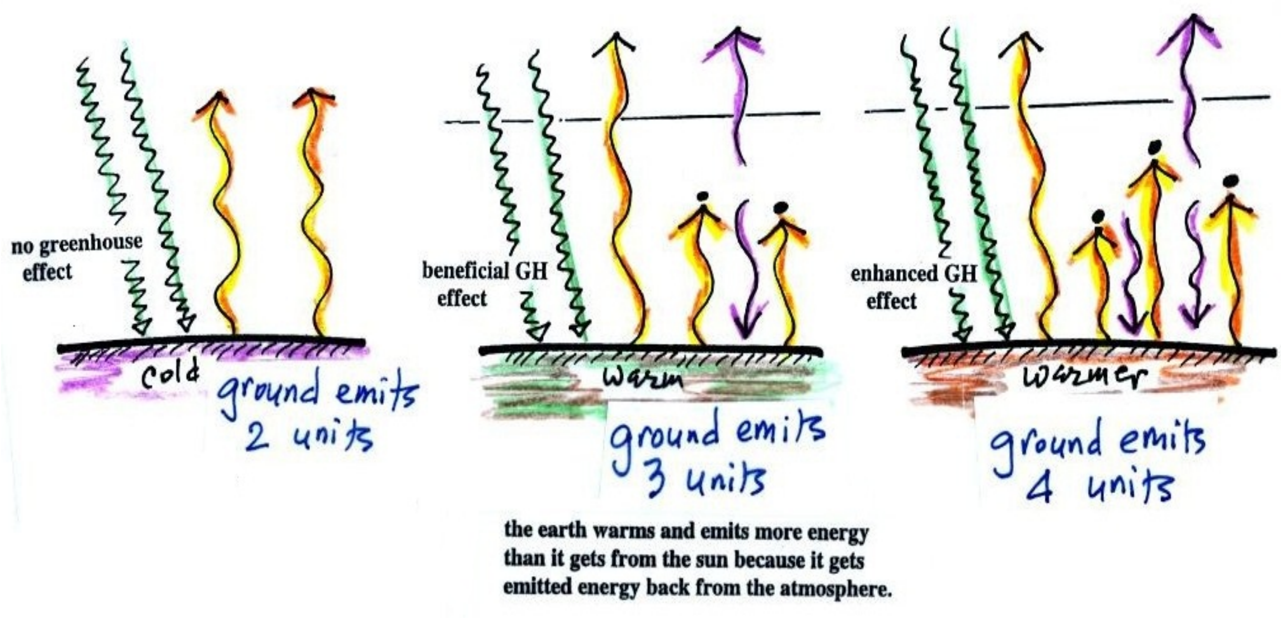




Here are some typical Tucson daytime high and nighttime low temperature values on clear and cloudy days for the fall and spring semesters when this course is normally taught.

	MARCH clear	MARCH cloudy	OCTOBER clear	OCTOBER cloudy
daytime HIGH	85°F	75°F	70°F	65°F
nighttime LOW	55°F	65°F	40°F	50°F

We will use our simplified representation of radiative equilibrium to understand the enhancement of the greenhouse effect, commonly known as global warming. The greenhouse effect makes life on earth possible. You can think of global warming having as a little too much of a good thing.

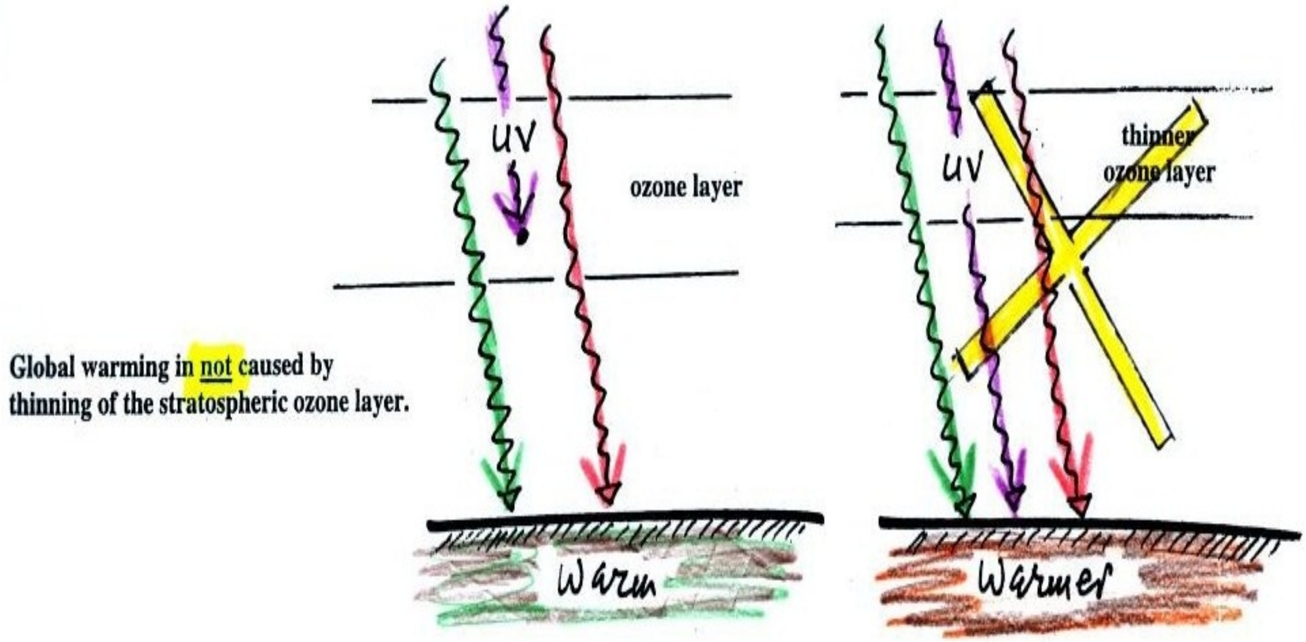


The figure on the left shows the energy balance of a planet with no atmosphere or an atmosphere without greenhouse gases. The ground achieves energy balance by emitting the two units of energy it receives from the sun. The ground remains cold.

If you add an atmosphere with greenhouse gases, the atmosphere absorbs some of the outgoing infrared radiation and radiates it upward into space and downward toward the ground. Now the earth has a new energy balance. The ground is warmer and is now emitting three units of energy even though it is only getting two units from the sun. An extra unit of energy from the atmosphere makes this possible.

In the right figure the concentration of greenhouse gases has increased due to human activities such as burning fossil fuels. As the atmospheric concentration of carbon dioxide increases, over time (months to years) the earth finds a new energy balance. The ground becomes warmer and emits four units of energy while still only getting two units from the sun. The atmosphere is now able to absorb three units of the infrared radiation emitted by the ground. The atmosphere sends two units back to the ground and one unit up into space.

The next figure shows a common misconception about the cause of global warming.



Many people know that sunlight contains ultraviolet light and that the stratospheric ozone absorbs much of this dangerous high energy radiation. People also know that release of chlorine-containing chemicals such as Freon are destroying stratospheric ozone and letting some of this ultraviolet light reach the ground. This is correct.

They then conclude that the additional ultraviolet energy reaching the ground is causing the globe to warm. This is not correct. The amount of ultraviolet radiation in sunlight is low and the small amount of additional UV light reaching the ground is not sufficient to cause global warming. It will cause cataracts and skin cancer but not global warming.