New light on global warming

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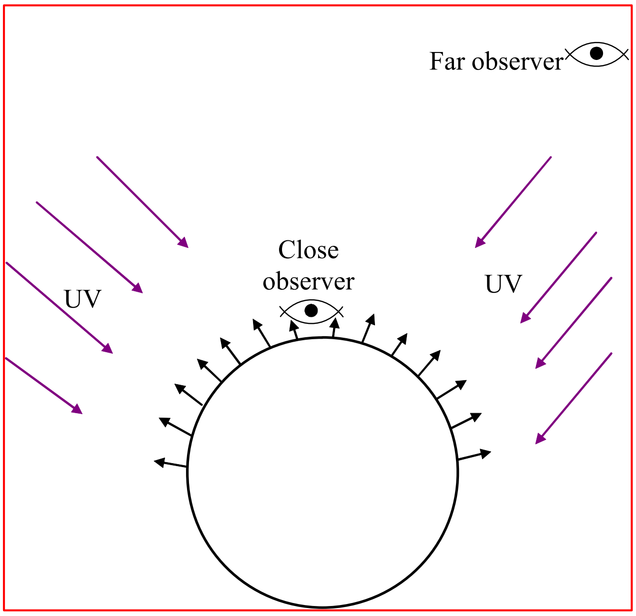
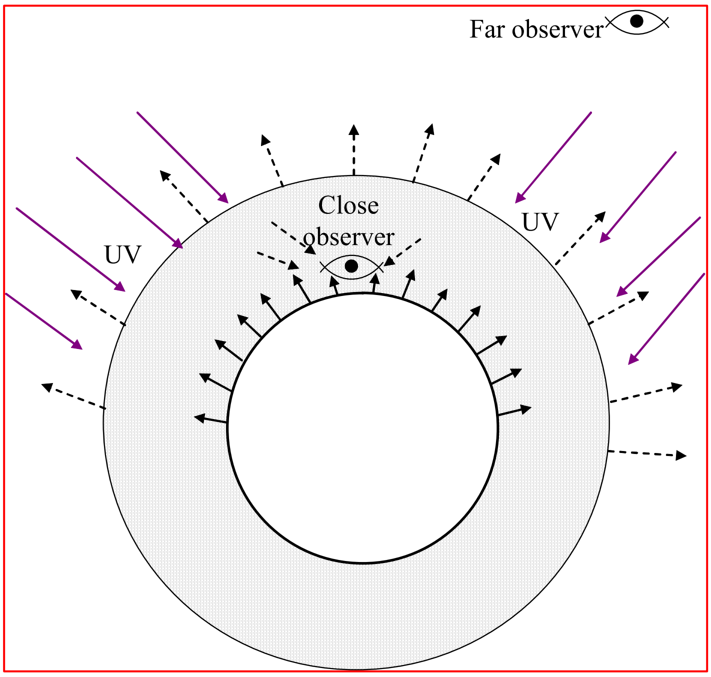
One of the troubles with the global warming phenomenon is that it's all going on in the infra-red (IR) and it requires more mental abstraction to get a feel for what is happening than if we could see it. What would the phenomenon look like if it happened at a wavelength we could see?

The analogy

Suppose we have a fluorescent ball that glows with white light when illuminated with ultra-violet (UV). In fact, suppose all the UV is converted to white light. Two people are looking at the ball, one from close by and the other from afar. They measure the amount of light where they are and both agree that the stronger the UV the more light there is.



Now let's surround the ball with a gas that's completely transparent to UV but absorbs red light and then re-emits it. The gas also partly absorbs green light, re-emitting what it absorbs, and is transparent to blue light. Now what changes do the two observers notice? The observer a long way away sees the ball in blue light just as before. In red light the ball is no longer visible from afar, only the surrounding gas is seen glowing red. The situation is rather like that of the Sun. Looking at the Sun we see only the outer layer glowing, the photosphere; any light that comes from deeper within loses its identity by being re-emitted by the photospheric layer. In green light the observer sees a hazy outline of the ball within some glowing gas. Adding it all up, the total amount of light coming from the ball plus gas is just the same as before since the total input of UV is the same and no light is actually lost.



The observer beside the ball sees it getting brighter when the gas is introduced, the reason being that the light from the ball is now supplemented by light from the glowing gas. – not blue light but a lot of red light and some green light.

Let's add more gas. What is the difference in illumination at the surface? In blue light there is no difference; in red light there is no difference because the original amount of gas was opaque in the red and opaque is opaque in the visible. Extra gas doesn't make it more opaque. In the green, though, the original gas let some light straight through but more gas will glow brighter and increase the illumination beside the ball. From afar, the total amount of light seen is just the same; less of the outline of the ball's surface can be seen in the green and more of the green light comes from the gas.

The application

All of the above may seem a little contrived and involved but it represents some of what is happening with the greenhouse gases in the atmosphere. Instead of UV and visible light, in the real world we have sunlight and IR. Brightness now equates with IR radiation and hence temperature. The 'red' effect corresponds to wavelengths above 13 μ and below 8 μ, were the greenhouses gases of CO_2 and water vapour (H_2O) are opaque. Adding more of these gases to the atmosphere makes no difference at these wavelengths. The 'green' effect happens near 8 μ and in the range 10 – 13 μ. The 'blue' effect of making no difference, or little difference, happens in the middle of the atmospheric transmission band between 8 – 13 μ. An added complication with the atmosphere is that ozone adds some of its own absorption in the middle of this transmission band but we aren't going to explore the effects of changing ozone levels.

The conclusion

The analogy shows several important effects of the Earth's atmosphere on the Earth's temperature. First, it's not the radiation from the surface of the Earth that has to balance the input of energy from the Sun but the radiation from what is seen from afar, mostly the upper atmosphere. In practice, what is seen from afar is from the top half of the troposphere.

Secondly, because everything emits in the IR by virtue of its temperature, 'absorption' isn't the concept that best applies to atmospheric gases, though it's often the word used. A better word is 'opacity'. Greenhouses gases don't let radiation directly through in their absorption bands; they scatter like a piece of tissue paper, or ground glass, or white cloud. 'Absorption' implies removing energy but one can't remove IR because everything emits IR by virtue of its temperature.

Thirdly, the analogy shows why changes in levels of CO_2 and other greenhouse gases have an effect that depends on the wavelength you look in. In regions where greenhouse gases don't absorb there is no effect. In regions where they partially absorb, more gas sends more radiation back to the Earth. In regions where they are totally opaque then increasing their concentration makes an indirect difference, discussed in the next section. The effect can be calculated without the need for very complicated climate modelling computer programs and the result is that the increase in CO_2 concentration over the last two centuries does account for a significant amount of the observed global warming.

Haven't I forgotten something?

Surely the story above can't explain why the surface temperature of Venus is over 400º C due to 'the runaway greenhouse effect' of CO_2 in Venus atmosphere? No it can't. An important ingredient is missing from the story.

What is conspicuous in Venus is that there is so much CO_2 in the atmosphere that the thickness of the atmosphere is much greater than on Earth. Seen from the outside, Venus has the expected temperature for its distance from the Sun. What we are looking at, though, is the radiation from high up in Venus' troposphere. Below this level, the temperature increases at the adiabatic lapse rate for CO_2 (see the piece on *ideal gas meteorology*), as one goes inwards towards the surface, which is a lot further down than on Earth. Ball-park figures are a temperature of -50 °C at 50 km above the surface, with a lapse rate of 10.5 °C km^{-1}. These predict a surface temperature of 475 °C, not far off the observed 464 °C. Hence the surface is very much hotter than the Earth's. In other words, convection, the gas laws and thermodynamics determine the surface temperature of Venus once the level at the top of the troposphere has been set by radiation balance. At least it's good to know that the Earth will never heat up to the extent of Venus, or if it does we'll all be suffocated with CO_2 long before we're roasted.

There are no special laws for Venus. Its case highlights that even on Earth convection, the gas laws and thermodynamics also determine the temperature of the surface. The other factor in the greenhouse effect works like this.

The Sun shines on the Earth supplying an energy of 342 W m^{-2} averaged over the year, over all places. This is mainly in the form of ultraviolet (UV), visible light and infrared (IR). Of this, 31% (109 W m^{-2}) is reflected away into space without contributing any heat. That leaves 235 W m^{-2} of heat that itself must be radiated away since any warming is very small on an annual basis. 40 W m^{-2} goes directly into space from the surface, leaving 195 W m^{-2} to be radiated from the atmosphere. This is where the greenhouses gases come in.

In the IR the greenhouse gases provide an opaque fog around the Earth in the wavelength bands where they absorb and re-radiate. (The 40 W m^{-2} mentioned above comes through the fog between the absorption bands). Since the fog must emit 195 W m^{-2}, the Stefan-Boltzmann radiation law tells us that a perfect radiator will have temperature of -31°C. This rightly predicts that looked at from space in the IR, the layer emitting the radiation is several km up in the troposphere. What then determines the surface temperature? It is the lapse rate down to the surface, however far that is beneath. The result is that the average surface temperature on Earth is 15 °C.

So what happens when CO_2 concentrations double, say? The greenhouse gas fog must still emit 195 W m^{-2}, for that figure is mainly set by the solar energy input. It now happens a bit higher up in the atmosphere because at the old level there is now extra greenhouse gas that will absorb some of the radiation that would otherwise have gone into space. The distance to the surface from the radiation escape level is now a bit greater and since the lapse rate is the same then the surface temperature will be a bit higher. This is the second mechanism present in the greenhouse gas effect and it makes a difference even if the atmosphere is already 'opaque' in the absorption band wavelengths.

In short, what's happening on Venus gives us an insight into what's also happening on Earth.

Corollary

One interesting implication of all of the above is the rôle of nitrogen in the Earth's atmosphere. Nitrogen bulks up the Earth's atmosphere, comprising some 78%. If it wasn't there but all the other gases were present in the amounts we find then the atmosphere would be much thinner; the tropopause would be considerably lower and the increase in temperature from the tropopause to the surface would be much less than it now is. Hence by merely bulking out the atmosphere, the nitrogen does warm the Earth and is essential to the biosphere, although chemically very few organisms can directly utilise this gas.

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