How rising carbon dioxide levels cause global warming

Eleanor asked me after yesterday's lecture to explain in words (as opposed to psychedelic graphics) how rising carbon dioxide levels cause global warming, and how this explanation differs from the traditional school text-book picture.

The traditional explanation of the "greenhouse effect" is that the Earth receives energy continuously from the sun, most of which is absorbed at the Earth's surface because a cloud-free atmosphere is largely transparent to shortwave (visible) radiation. Because the Earth's surface is much cooler than the sun, it can't emit energy in visible wavelengths, and the infrared wavelengths that it can emit are strongly absorbed by greenhouse gases (essentially those that can create those little molecular dipoles) in the atmosphere. That energy is radiated back down, keeping the surface much warmer than it would be in the absence of an atmosphere.

The problem with this picture is that it implies that infrared radiation from the surface, and the fraction of that radiation that is blocked by the atmospheric "greenhouse layer", is somehow central to the explanation. Adding extra panes of glass in a "multi-layer greenhouse" doesn't really help, since it still implies that infrared radiation is the main mechanism controlling surface temperatures. It isn't: the Earth's surface gets rid of most of the energy it receives from the sun by heating the air above it, causing convection, or through the evaporation of water, which carries energy away in the form of latent heat.

You could argue that it doesn't really matter because it is just an analogy, but the analogy has practical consequences: the simultaneous equations exercise showed how doubling the concentration of CO2 in the atmosphere had remarkably little impact on the fraction of infrared radiation from the surface that escapes to space, which if the analogy were valid would imply that such a doubling would have only a very small effect on surface temperatures.

This was essentially the argument that misled Ângstrom. He worked out that the total amount of CO2 between us and space is equal to about a 3m path of pure CO2 at room temperature and pressure, so he repeated Tyndall's experiment doubling the pressure of CO2 in a 3m pipe (more-or-less) and showed it made almost no difference to the transmitted infrared radiation, particularly if water vapour was thrown into the mix. This seemed to people at the time to be convincing evidence that Arrhenius was wrong, and the "CO2 theory" was largely ignored until Gilbert Plass resuscitated it in the 1950s.

What Plass realised was that convection carried energy away from the surface up to altitudes several kilometres up where air is some 30°C colder than the surface with a much lower density (both inevitable consequences of the fact that air is a compressible gas held down by its own weight and heated from below) and with a much lower moisture content. The fraction of air molecules consisting of CO2 is almost the same at all altitudes, so the density of CO2 molecules per cubic metre also thins out as you go higher, until eventually there are few enough left above a given altitude to allow infrared energy to escape to space.

If we double the concentration of CO2 at all altitudes, energy has to be carried higher to reach an altitude where the density of CO2 molecules is low enough for infrared energy to escape. This higher air is colder (because temperatures decrease predictably with height over this altitude range), and so the CO2 molecules radiating energy to space are colder than they were before (they are different molecules, of course, but all that matters is their temperature). So the planet as a whole loses energy to space at a lower rate than it did before the doubling, creating an imbalance between incoming and outgoing energy. That has to warm the planet: what happens next, and how much warming is required to restore the balance between incoming and outgoing energy, depends on lots of other things that change as well, but that, in a nutshell, is how CO2 actually causes global warming. Notice we haven't mentioned infrared energy being radiated by the surface at all: it's more like a fluffy blanket effect than the traditional greenhouse effect picture. If you're trying to work out how much energy you are losing through a blanket, what matters is the temperature at the top of the blanket, not the temperature of your skin underneath it.

Should you worry about this? On one level, this is not contentious science: no one apart from a few white male pensioners with time to write me long emails still seems to buy Ångstrom's argument that increasing CO2 concentrations won't make any appreciable difference to global temperatures at all, ever. And we have direct observations from satellites of outgoing energy falling in the wavelengths we expect. So this is one part of the story where I really might get away with saying "trust me". But it troubles me that so many people who are genuinely concerned about the CO2 climate problem have such a misleading picture of how it actually works. The rest of the lectures deal with more practical issues, like how fast we expect it to warm up, and what we need to do to stop it.

I hope this helps.

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