Basic Climate Physics #2

One fact at a time

This short essay is the second in a short series about basic (meaning all-inclusive) physics that pertains to the subject of climate.

Bear in mind that my purpose is not to engage in details about wind, rain, snow, storms, historical climatology, Milankovitch cycles, or any of the common topics discussed about climate. What I will discuss is some simple physics.

Terminology: The greenhouse effect

The greenhouse effect in a real greenhouse was initially thought to be due to the fact that visible light would enter the greenhouse, but the glass would block outgoing infrared (IR). Fleagle [1] refers to a 1909 experiment by Johns Hopkins University physicist Robert W. Wood who substituted rock salt for glass because it is transparent to IR and showed that it is just about as effective as glass in keeping the greenhouse warm. He found the greenhouse effect to be due mostly to the fact that the greenhouse is a confined space through which warm air was blocked from rising.

In the case of the atmosphere, the visible/IR explanation comes a lot closer to the truth, but it is still somewhat deficient. Again, the source of energy is the sun. The surface warms up and radiates IR. Certainly, the radiation to space is less than the surface radiates, but the interactions are many and complex. Greenhouse gases—we'll consider the five GHGs (H_2O, CO_2, O_3, CH_4, and N_2O) analyzed by van Wijngaarden and Happer [2]—absorb IR according to their own spectra. The absorbed energy excites vibrational/rotational modes in the molecules. That excess energy can be shed by collisions with other molecules (most likely N_2 and O_2), contributing to general heating of the region. They can also emit IR in random directions.

The process of radiating IR is often incorrectly called *reradiation*, somehow implying that the number of photons is constant (it is not), or that the molecule radiated once and does it again.

Molecular collisions can also excite GHGs into vibrational/rotational states that can radiate IR. In fact, thermal equilibrium requires that a certain temperature-dependent percentage of the molecules are in those states. The IR that goes into space is largely from this collision-induced radiation at high altitude where the GHGs are sufficiently sparse that the IR can escape.

The greenhouse effect is thus very complicated, and best comprehended by experts such as van Wijngaarden and Happer. However, a simplicity does emerge.

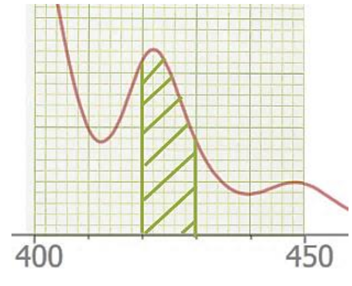
The IPCC has been discussing the greenhouse effect for three decades, and finally in its *Sixth Assessment Report* [3], has assigned a symbol G to the term and calculated its value: 159 W/m^2. The symbol disguises its close relationship to the "radiative forcing" ΔF, which is merely a difference in G.

Simple subtraction

The arithmetic version of G is that it is the simple numerical difference between the IR flux emitted by the surface and the IR flux emitted to space: $G = I_{\text{surf}} - I_{\text{out}}$. In the *Fifth Assessment Report*, the values in the equation were $I_{\text{surf}} = 398\ \text{W/m}^2$ and $I_{\text{out}} = 239\ \text{W/m}^2$, with the difference being $G = 159\ \text{W/m}^2$. The equation $G = I_{\text{surf}} - I_{\text{out}}$ is the important basic physics lesson in this essay. Remember it.

More elaborate subtraction

Infrared involves a spectrum. Notice that the vertical axis in Figure 2 has units of W/m^2 • cm, and the horizontal axis is in numbers of wavelengths per cm (cm^{-1} sometimes called wavenumbers). A vertical strip between two wavenumbers, as shown schematically to the right, thus has an area in units of W/m^2. The area under the whole curve represents the total amount of IR.



In Figure 1, the total area under the smooth curve represents the total IR emission from the surface. The total area under the jagged black curve represents the total IR emission to space. The total area between the smooth curve and the jagged black curve represents the net blockage (retention) or IR energy due to all atmospheric effects combined. Figure 2 shows the graphical version of $G = I_{\text{surf}} - I_{\text{out}}$

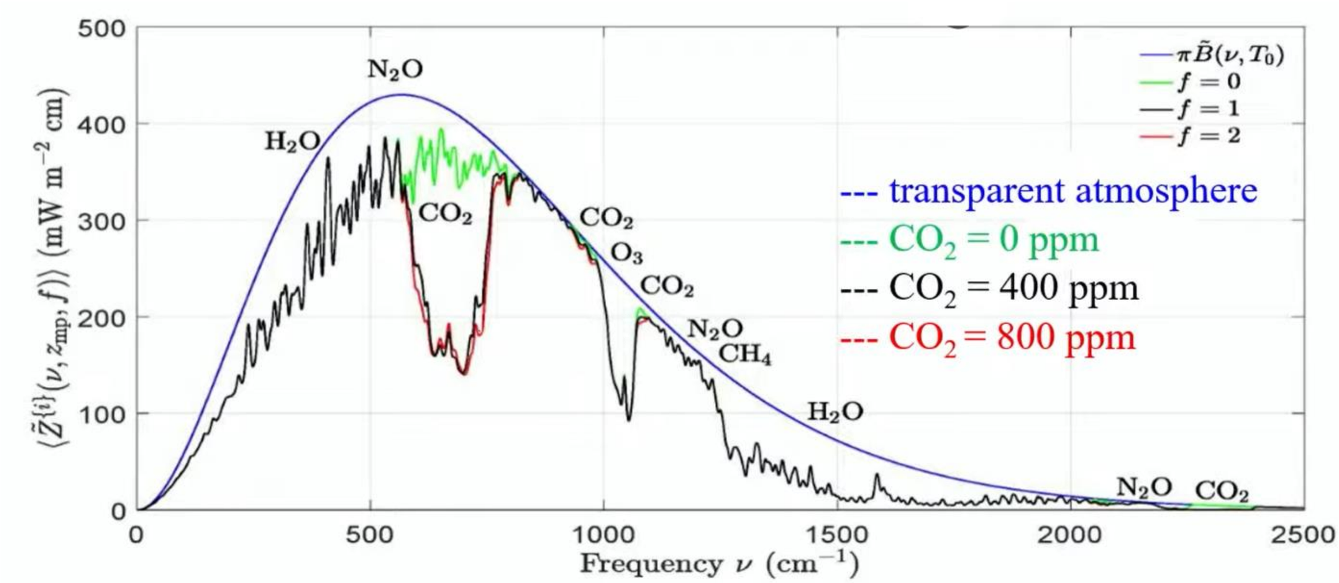


Figure 1: The smooth blue line represents the IR emitted by the surface of the earth. The jagged black line represents the IR emitted to space. The jagged green line represents what the black line would look like if all things were the same, but there was no CO_2 in the atmosphere. The red line represents the change in emission to space if the CO_2 concentration doubles. (Adapted from van Wijngaarden and Happer [2].)

We will discuss the matter further in the next short essay, but note that the effect of doubling CO_2 concentration is represented by the tiny area between the jagged black curve and the jagged red curve.

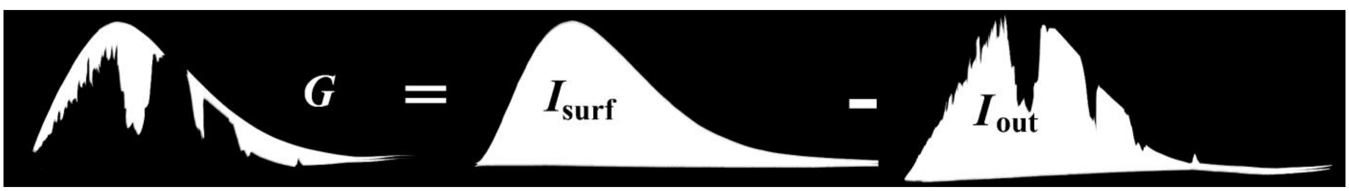


Figure 2: Graphical representation of the greenhouse effect.

Conclusion

All verbiage aside, the greenhouse effect is the readily calculable difference between the IR emission at the surface and the IR emission to space.

$$G = I_{\text{surf}} - I_{\text{out}}$$

Presently, G is (using IPCC data) 159 W/m^2. CO_2 is responsible for about 30 W/m^2 at present.

References

[1] Robert G. Fleagle and Joost A. Businger, The "Greenhouse Effect," *Science*, 12 December, 1975

[2] W. A. van Wijngaarden1 and W. Happer, "Dependence of Earth's Thermal Radiation on Five Most Abundant Greenhouse Gases," (arXiv:2006.03098v1 4 June 2020)

[3] All IPCC reports are available as PDFs at https://www.ipcc.ch/. *The Sixth Assessment Report* is presently (October 2021) incomplete.