Basic Climate Physics #8

One fact at a time

This short essay is the eighth 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.

The Adiabatic Lapse Rate

Occasionally, I encounter climate skeptics who take the view that there is no such thing as the greenhouse effect; the lapse rate explains why the surface is hotter that the earth as a whole. I have also encountered the argument that the surface is warmer that the air at high elevation because of pressure. I assume that the same is true of many readers of this essay, and herein will discuss the counterarguments that you can use.

If a kilogram of air descends, it warms up by compressional heating. If a kg of air rises, it cools by expansion. For this reason, dry air is cooler by 9.8ºC for every km of altitude, up to about 10 km (roughly the peak of Mt. Everest). For humid air, the rate is lower, but is of no concern to us here. Readers who are interested in the details can find them on Wikipedia and other places.

The rate of change with altitude is called the *lapse rate*, and because the derivation involves no exchange of heat between our little kg of air with the environment, the rate is often called the *adiabatic lapse rate*.

Heat in = Heat Out

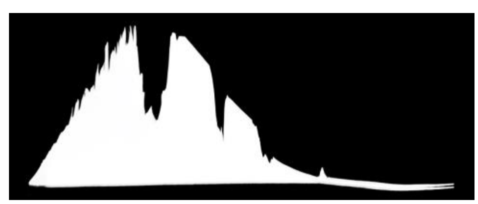
Spectra

As geothermal heating is negligible on the global scale, the only source of heat for the Earth is the sun, and the only way for the Earth to shed heat is through infrared (IR) that goes into space. At equilibrium (by definition) the two quantities are equal. Averaged over the sphere, we have $I_{\text{out}} = I_{\text{in}} = \frac{I_{\text{sun}}}{4}(1-\alpha)$, where α is the albedo (for the earth, presently $\alpha = 0.3$.

At our orbit, the spectral nature of sunlight is the blackbody curve characteristic of the sun's surface temperature. Similarly, the spectral nature of IR from the surface is the blackbody curve characteristic of the Earth's surface temperature. By contrast, the spectral nature of the IR radiated to space from the top of the atmosphere is a very jagged spectrum

To put it bluntly, but fairly, it is physically impossible for a temperature gradient (such as the lapse rate) to convert this kind of spectrum (radiation from the surface)

into this kind of spectrum



that goes into space.

The Lapse RATE

A rate tells how fast some variable *y* changes with another variable *x*. However, the rate does not tell you what the value is. For example, knowing that a car is moving at 100 km/hour does not tell you where the car is or how long it will take to get to Chicago.

Similarly, the lapse rate tells you how much the temperature changes as you rise vertically but does not tell you what the surface temperature is or what the temperature is at the top of the atmosphere.

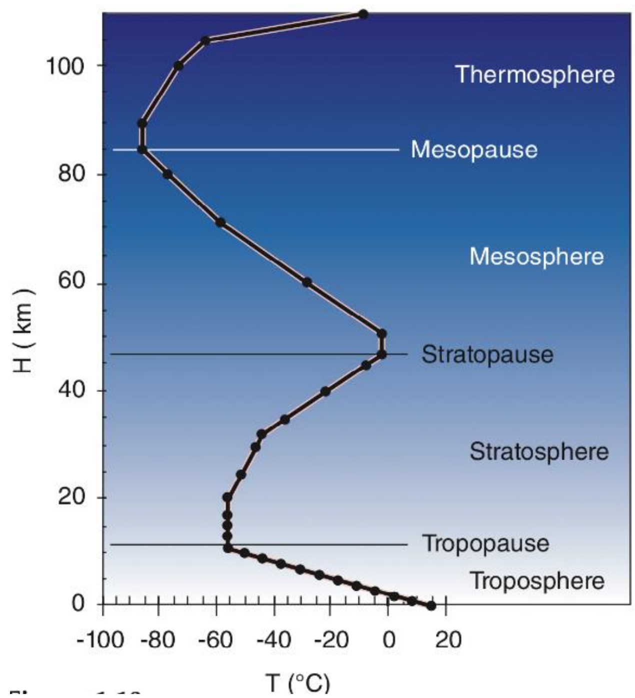
Consider a hypothetical Earth that is nothing more than a spherical stone in our orbit that has the same albedo as the Earth. The temperature is calculable from $I_{\text{sun}} = 1366\ \text{W/m}^2$, using the Stefan-Boltzmann law $I = \sigma T^4$, where

$\sigma = 5.67 \times 10^{-8}$ W/(m^{2}K^4), and turns out to be 255 K (= –18ºC). The radiative flux absorbed and emitted is 239 W/m^2.

Now imagine the Earth with the same albedo but with an atmosphere composed of N_2 and O_2, both of which are transparent to both visible light and to IR. The same calculation as that in the previous paragraph would apply. The surface absorbs and must radiate 239 W/m^2, and its temperature would be 255K. But now, since there is an atmosphere, there must surely be a lapse rate. Simply put, the temperature would drop from 255 K by 9.8ºC for every km of altitude, just as on our present globe. The outer reaches of the atmosphere would be very cold indeed, but in an astronomically meaningless way. That is, if you were about 10 km up from the surface, your thermometer would say 155 K, but since the atmosphere neither absorbs nor radiates IR, nobody would notice but you.

Where the Lapse Rate Does Not Apply

For at least 60 years, scientists have investigated the atmosphere from the ground up. They have developed what is called the *Standard Atmosphere*, a graph of temperature versus altitude. The graph can be found many places on the internet, such as the one at the right from https://www.eoas.ubc.ca/courses/atsc113/flying/met_concepts/03-met_concepts/03a-std_atmos/index.html.



The lapse rate idea works at altitudes up to about 10 km, but obviously cannot explain the *increase* in temperature from about 20 km to 45 km, or the other peculiarities.

Final Note

Another common misconception is that the atmospheric pressure heats the lower atmosphere, and that is why the surface is warm.

At the grade-school science level, work is defined as force multiplied by the distance through which is applied. The three-dimensional version is that work is done on a gas when outside pressure moves the surface inward, decreasing the volume. The work done—pressure times the change in volume—becomes heat. That is, when you pump up your bicycle tires, you push air into a smaller volume, and the air warms up a bit. As soon as you quit, the air begins to cool down to ambient temperature.

The pressure inside an oxygen tank is typically about 20 times sea-level atmospheric pressure. That high pressure does not make the tank hot.

Conclusion

The greenhouse effect is real. You cannot explain the IR spectrum to space without it. (But that doesn't mean that we are facing a climate catastrophe!)

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