Downwelling IR – what is it?

[latexpage]

Radiation budget

In climate science we usually find a „radiation budget“ in order to display the energy fluxes that determine the climate:

[Radiation Budget of earth]
For a long time I have been wondering about the extremely high value $333 \frac{W}{m^2}$ of a downwelling radiation called „Back Radiation, absorbed by the surface“, which appears to be (over-)compensated by the „Surface Radiation“ of a comparable value ($396 \frac{W}{m^2}$), which is split into the „Atmospheric window“ and an upwelling radiation of $356 \frac{W}{m^2}$ into the atmosphere. Both downwelling and upwelling radiations are significantly larger than both the incoming SW radiation absorbed by the atmosphere ($78 \frac{W}{m^2}$) as well as the outgoing LW radiation ($169 \frac{W}{m^2}$).

Furthermore I was wondering about the strange phenomenon that there should be a radiation through the atmosphere apparently **transporting thermal energy from higher altitude to lower altitude**, which – in an atmosphere with lapse rate, where temperature decreases with altitude – **is physically not possible because it would break the 2nd law of thermodynamics**, which forbids spontaneous heat transport from a cold system to a warm system. So I questioned whether „downwelling radiation“ is in fact a real radiation at all – **if it was real, then why would I not use it for heating my house instead of burning fossil fuels** – catching downwelling radiation on an area of $18 m^2$ would be enough to provide $6 KW$ of permanent Energy supply.

A thought experiment

So for myself I came to the conclusion, that the downwelling radiation must be a model artefact and **the real energy transport must be associated with the difference between upwelling and downwelling radiation**, which in fact moves heat from the warmer surface to the colder atmosphere. At best the downwelling radiation can „slow down" the energy dissipation from the warmer body.
To clarify matters I made this thought experiment: There are 2 air parcels, a cold one p_1 with temperature T_1 and a hot one p_2 with temperature T_2 ($T_1 < T_2$), and they can „see" each other – the light path is reversible. They both emit radiation, p_2 emits more at all wavelengths due to Planck's law, therefore losing more heat than p_1 in the process of emission. The received radiation is only a part of what was emitted, and even if the full radiation from p_1 was absorbed, p_2 can never receive more radiation than it has lost by emission. Therefore the temperature of p_2 must necessesarily be smaller after the observed radiation process.

Sharing this conviction on Twitter quickly raised critical responses. But I was lucky in several ways: **Most responses were polite and respectful, yet very clear that they would not accept the „denial" of downwelling radiation**. As a „proof" they provided links to instruments that can actually measure downwelling radiation.

Instruments for measuring downwelling IR

The typical instrument to measure downwelling IR is a pyrgeometer. From its description we find the following features:

- It does not measure spectral components, but the total flux.
- Since the mean free path of IR radiation in the atmosphere is ~25 meters, this device typically measures IR flux within a cone with the height of 25 meter.

- The actual measurement is the **difference between the blackbody flux of the „surface" within the instrument and the incoming flux**, in combination with a temperature measurement inside the instrument. The measurement principle is the „Seebeck effect" which **measures by definition temperature differences**.
- Taking into accout the spectral composition of the IR Flux with a factor, the pyrgeometer effectively measures relative temperature (compared to its own temperature)

So at the end of the day, a pyrgeometer measures the difference of downwelling flux and the „upwelling" surface flux of the instrument. That confirms that only flux differences make a real heat flow possible.
And the measurement volume is a cone of height $25m$. This is in fact a local measurement, measuring the integral of the Planck spectrum of this cone. If it was a black body radiation, it would be the radiation equivalent of the local temperature according to the Stefan-Boltzmann law. **In reality it is a function of the local temperature, that also depends on the greenhouse gas content**. **And It actually says nothing about processes beyond 25m distance.**
The measured flux is therefore very close to just a temperature measurement, combined with a greenhouse gas dependent emissivity coefficient. It would be exactly measuring temperature, if the air was a black body. The radiating bands correspond to the available greenhouse gases.
The actual radiative heat flow ΔS from a location of hot temperature T_h to a location of cold temperature T_c is determined by $$\Delta S=\sigma\cdot\epsilon(T_h^4-T_c^4)$$ where ϵ depends on the emissivity and the geometry of the arrangement.

While the measurement can be refined by measuring the downwelling sprectrum, the basic principle remains. The analysed volume of data, a cone of about 25m height, is still the same as with a pyrgeometer

Thermodynamic equilibrium

The troposphere is considered to be in a state of local thermodynamic equilibrium. This has a few consequences:

- The atmosphere has a constant **lapse rate**, i.e. falling temperature with altitude, **while being in thermodynamic equilibrium**. This implies that there is no heat flow at all despite temperature difference, unless there are deviations from the lapse rate induced temperature difference.
- Due to thermodynamic equilibrium, according to Kirchhoff’s law all greenhouse gases emit the same amount of IR radiation as they absorb. This enforces a strong inter-dependency of the radiative processes with the dominant thermodynamics.
- Above the troposphere the thermodynamic equilibrium breaks down, and radiative processes become dominant. As discussed above, even then there is no heat transfer from cold to hot locations.