Advanced radiation and remote sensing

Manfred Brath, Oliver Lemke, Stefan Bühler

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Exercise No. 9 – Heating rate

The heating rate denotes the change of atmospheric temperature with time due to gain or loss of energy. Here, we consider only the gain or loss due to radiation. The heating rate including only radiation is

$$\frac{\partial T\left(z\right)}{\partial t}=-\frac{1}{\rho\left(z\right)c_p}\frac{\partial}{\partial z}F_{net}\left(z\right) \tag{1}$$

with $\rho\left(z\right)$ the density of dry air[1], $c_p = 1.0035\,\mathrm{J\,kg^{-1}K^{-1}}$ the specific heat capacity of dry air and F_{net} the net radiation flux. The net radiation flux is

$$F_{net} = F_{up} - F_{down} \tag{2}$$

with F_{up} and F_{down} the up- and downward radiation flux (irradiance), respectively. The density of dry air is

$$\rho = \frac{p}{R_s\,T} \tag{3}$$

with pressure p, temperature T and the specific gas constant $R_s = 287.058\,\mathrm{J\,kg^{-1}K^{-1}}$.

1. Run the Jupyter notebook heating_rates.ipynb. This will calculate the upward and downward longwave radiation fluxes. Here, we will consider only the longwave flux. Calculate the net flux and plot upward, downward and net flux together in one figure against altitude. Explain the plot.
2. Implement the function `calc_heatingrates(...)`. Use the function to calculate the heating rate. Plot the heating rate against altitude and explain the plot. How would a heating rate in thermal equilibrium assuming only longwave radiation look like? Why is the heating rate so much higher in the stratosphere than in the troposphere?
3. Uncomment the line with the function call `calc_spectral_irradiance` and calculate the spectral upward, downward and net flux.
4. Use the function `integrate_spectral_irradiance(...)` to integrate the spectral irradiance over three continuing bands:
   (a) the far infrared
   (b) the CO_2-band
   (c) the window-region and above.

   Calculate the heating rate for each band and plot them together with the total heating rate from Task 2. Compare the band heating rates with the total heating rate and explain differences.

[1] To keep it simple, we assume dry air. In reality the air is not dry. Nonetheless, the differnces are small.