OLR computation for real-gas collision induced absorption

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Problem 0.1 *Radiative transfer for collision induced absorption*

In this problem, you will implement a simplified form of a radiative transfer code to compute the OLR for an atmosphere with a temperature profile $T(p)$, whose only infrared absorption in the form of a continuum. In this case, the absorption coefficient κ is a function of frequency ν, but it is a sufficiently smoothly varying fundtion that it is possible to do the calculation by just dividing the relevant part of the spectrum into bins, solving the Schwartzschild equation (in its integral form) in each bin, and them summing up the results.

(a) Write a routine to find the contribution to OLR from a wavenumber interval of width Δ, over which the Planck function and the absorption cross-section κ can be considered to be constant. Implement this assuming that the temperature $T(p)$ is specified as a function (e.g. the dry adiabat). You may ignore the temperature dependence of κ, but you should allow for its dependence on pressure. A simple way to implement this calculation is to use the `ClimateUtilities` routine `romberg` to carry out the definite integral in the Schwartzschild solution, and add in the contribution from the lower boundary. Alternately, you can implement your own solution using trapezoidal rule numerical integration.

Test out your routine with an isothermal case and a case on the dry adiabat, to make sure it has the expected behavior, especially in the optically thick and optically thin limits.

(b) Next, use the routine your wrote in part (a) as part of a loop over wavenumber intervals, covering the range for which the Planck function at a surface temperature of 300K has significant amplitude. Check your routine by making a plot of the OLR spectrum (i.e. the variation of outgoing radiation with ν) for $\kappa(\nu)$ given by an analytic function that peaks at 15 microns and decays away from there over a scale of 100 cm^{-1}, assuming the temperature profile on a dry adiabat and a peak value of κ that makes the atmosphere very optically thick there.

(c) Now let's apply your code to the actual $N_2 - N_2$ collisional continuum. First, a few words about the *binary absorption coefficient* which is customarily used to characterize continuum absorption. Let ρ be the gas density, measured in mass per unit volume. Then, the binary absorption coefficient $b(\nu, T)$ is defined such that for a box of gas with uniform density ρ and uniform temperature T,

a beam of light with frequency ν decays exponentially with distance at a rate $b\rho^2$, i.e.

$$I(x) = I(0)\exp(-b\rho^2 x)$$

We can use this definition to rewrite the absorption in terms of mass paths such as we have been using in our calculations, since $\rho \cdot x$ is a mass path, e.g. in kg/m^2. Thus, the expression $b\rho$ is simply the unary absorption cross-section κ we have been using all along. The factor of ρ, which increases linearly with density if T is fixed, is just like a pressure broadening coefficient for absorption in the strong line limit, except in this case there are no actual lines to worry about.

The binary absorption cross section is a function of temperature, but to keep this problem simple, you may ignore the temperature dependence. The data file `N2-N2_309K.cia` is a subset of the HITRAN CIA dataset for nitrogen, giving data at a temperature of 309K. After the header line, the file consists of two columns. The left one give the wavenumber in cm^{-1}, and the right gives the binary coefficient. The units of the binary coefficient assume the density is measured in molecules per cm^3, and that the decay length is measured in cm; thus, the units of b are $cm^5/molecule^2$. You will need to convert this to our customary units (which would be m^5/kg^2) using Avogadro's number and the molecular weight of N_2.

Read in the data file and make some plots of the absorption cross section vs wavenumber for a density of 1 kg/m^3. Use this to make some crude estimates of what surface pressure you would need under Earth gravity to make N_2 absorb significantly over some part of its spectrum. Where is the absorption strongest?

(d) Now read in the absorption file, convert it to appropriate units, and use it in your OLR routine to plot spectra of OLR for an atmosphere on the dry adiabat with surface temperature 300K, and a range of surface pressures. How high does the surface pressure need to get in order for the N_2 opacity to yield significant radiative forcing? Plot the wavenumber-integrated OLR as a function of surface pressure and discuss your results.

(e) If you are ambitious, you can adapt your routine to compute the back-radiation into the surface instead of OLR. Study how this behaves as a function of surface pressure. *Note:* this back-radiation would be most significant in a very dry atmosphere, since water vapor absorbs very strongly in more or less the same part of the spectrum, and would tend to dominate over the nitrogen continuum.