CHAPTER 10

Broadband Fluxes and Heating Rates in the Cloud-Free Atmosphere†

In Chapter 9, we examined the physical basis for absorption and emission of radiation by atmospheric gases, focusing on the factors that determine line positions, shapes, and widths. There now exist extensive (though by no means perfect[1]) tabulations of line positions, strengths, and broadening parameters for all significant atmospheric absorbers. The most complete and widely used of these tabulations is the HITRAN spectroscopic data base maintained by Phillips Laboratory (formerly the Air Force Geophysics Laboratory). The 1992 edition listed 709,308 lines covering the range 0 to 2.3×10^4 cm^{-1} (i.e., wavelengths longer than 0.43 μm); new additions and corrections to existing line parameters continue to be made based on new laboratory measurements.

In short, any unfortunate soul tasked with calculating broadband fluxes and/or heating rates in the cloud-free atmosphere has to contend with the enormous complexity of the absorption spectra of atmospheric constituents. This chapter is intended to give you just a cursory survey of the tricks and simplifications used by the experts, and why they are necessary. Although some of these tech-

[1]The line intensities in the current data base are believed correct to within 5–10% for strong lines; weak lines are harder to measure accurately in the laboratory.

niques are also applicable to atmospheric absorption of solar radiation (especially in the near IR band), we will keep things simple by limiting our attention initially to the emission and absorption of radiation in the thermal IR band.

10.1 Line-by-line Calculations

For monochromatic radiation, we can easily generalize (8.27)–(8.30) to describe the upward and downward intensity at any level z in a plane-parallel, nonscattering atmosphere with a black lower boundary at temperature T_s and no extraterrestrial sources:

$$I_{\tilde{\nu}}^{\downarrow}(z) = \int_z^{\infty} B_{\tilde{\nu}}[T(z')] W_{\tilde{\nu}}(z', z)\, dz' \;, \tag{10.1}$$

$$I_{\tilde{\nu}}^{\uparrow}(z) = B_{\tilde{\nu}}(T_s) t_{\tilde{\nu}}(0, z) + \int_0^{z} B_{\tilde{\nu}}[T(z')] W_{\tilde{\nu}}(z', z)\, dz' \;, \tag{10.2}$$

where

$$t_{\tilde{\nu}}(z_1, z_2) = \exp\left[-\frac{\tau_{\tilde{\nu}}(z_1, z_2)}{\mu}\right] \;, \tag{10.3}$$

$$\tau_{\tilde{\nu}}(z_1, z_2) = \left| \int_{z_1}^{z_2} \beta_{a\tilde{\nu}}(z)\, dz \right| \;, \tag{10.4}$$

and

$$W_{\tilde{\nu}}(z', z) = \left| \frac{\partial t_{\tilde{\nu}}(z', z)}{\partial z'} \right| \;. \tag{10.5}$$

Note that we have introduced the subscript $\tilde{\nu}$ to make explicit the dependence on wavenumber,[2] and we have introduced absolute value operators to permit a more compact set of expressions valid for both upwelling and downwelling radiation.

In view of what we learned from the previous chapter about absorption spectra, it is evident that the absorption coefficient $\beta_{a\tilde{\nu}}(z)$

[2] Traditionally, spectroscopists working in the thermal IR band are accustomed to using wavenumber rather than wavelength to describe where they are in the spectrum.

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can be expanded as

$$\begin{aligned}\beta_{\mathrm{a}\tilde{\nu}}(z) &= \sum_{i=1}^{N} \rho_i(z) k_{\mathrm{a},i}(z) \\ &= \sum_{i=1}^{N} \rho_i(z) \left[k_{\mathrm{cont},i}(\tilde{\nu}; z) + \sum_{j=1}^{M_i} S_{ij}(z) f_{ij}(\tilde{\nu} - \tilde{\nu}_{ij}; z) \right] ,\end{aligned} \tag{10.6}$$

where ρ_i is the local density of each of N atmospheric constituents, M_i is the number of significant absorption lines associated with the ith constituent, S_{ij}, f_{ij} and $\tilde{\nu}_{ij}$ are the respective line strengths, shapes and positions, and $k_{\mathrm{cont},i}$ represents the continuum component of absorption for that constituent, if applicable. The z-dependence in many of the above parameters arises from the influence of local temperature, pressure and constituent partial pressure on line strength and width.

In other words, in order to compute the monochromatic intensity at altitude z and zenith angle $\mu = |\cos\theta|$, you have to evaluate the sum of the contributions of all relevant absorption lines to the absorption coefficient β_{a} at your chosen wavenumber $\tilde{\nu}$, and you have to repeat this for all z'. Then you can numerically evaluate (10.1) and / or (10.2) to get the corresponding radiant intensity at your chosen level z. The above procedure is the essence of so-called *line-by-line* (LBL) calculations of radiative transfer — that is, there is an explicit summation of the individual contributions of all lines in the vicinity to the emission and absorption at each wavenumber of interest. Note that "in the vicinity" means all lines whose wings contribute nonnegligible absorption at the wavenumber in question.[3]

A couple of comments are in order. If the intended application for your radiance calculation is remote sensing, then a full LBL treatment is reasonably manageable, since you're often dealing with only an extremely narrow range of wavenumber for each sensor channel and therefore don't have to repeat the calculation many times. In fact, if the wavenumber of the calculation is far enough

[3] Actual LBL computer codes in wide use include FASCODE, GENLN2, and LBLRTM. All of these use various strategies to maximize computational efficiency without sacrificing precision, but the essence of the calculation remains as outlined above.