ATOC/ASTR 5560 Lab 3 Solutions

September 14, 2001

The purpose of this lab is to learn how to run the LBLRTM line-by-line radiative transfer model and to gain some familiarity with molecular absorption in the atmosphere. LBLRTM is a standard community model for performing "exact" line-by-line molecular absorption and nonscattering radiative transfer calculations.

Since making an input file for LBLRTM is rather difficult, a Unix script has been provided to run LBLRTM. Log in to nit and copy the script `/home/rt/lblrtm/runlblrtm` *and the IDL plotting files* `/home/rt/lblrtm/plotlbl.pro` *and* `/home/rt/lblrtm/lbl_read.pro` *to your directory.*

You will need some standard McClatchey atmosphere files. These are in the `/home/rt/atmos/` *directory with names "mcatm???.dat", where ??? is "trp" for tropical, "mls" for midlatitude summer, "mlw" for midlatitude winter, "sas" for subarctic summer, and "saw" for subarctic winter.*

Please label all of your plots correctly using `title` *in IDL.*

1. *Read the* `runlblrtm` *script and look at the LBLRTM "documentation" file (*`/home/rt/lblrtm/lblrtm_instructions`*) to get an idea of how LBLRTM is run.*

2. *a) Use* `runlblrtm` *to compute the transmission spectrum for a standard midlatitude summer atmosphere for the troposphere (0-13 km) and the stratosphere (13-50 km). Make the two spectra for 0 to 2000 cm^{-1} at a resolution of 10 cm^{-1} (since LBLRTM can only compute 2000 cm^{-1} at a time). Use a new output file name in* `runlblrtm` *for each run.*

   b) Plot the two transmission spectra using the "Plottrans" section of `plotlbl.pro`*. Since you will be making several plots with the same section, you may want to rename the output Postscript file, e.g.* `mv Plottrans.ps trans0-2000.ps`.

   c) Label the molecular species causing the absorption features.

   d) Explain the difference between the stratospheric and tropospheric spectra.

   The stratospheric transmission is substantially higher because the absorber amount is generally much lower. For well mixed gases (e.g. CO_2) the stratosphere has about 20% of the atmosphere and the troposphere about 80%. Nearly all the water vapor is in the troposphere. Most of the ozone, however, is in the stratosphere. These relative abundances are reflected in the change in transmission between the two. The stratosphere also has higher transmission due to narrower absorption lines.

3. *a) Compute the transmission spectrum for a standard midlatitude summer atmosphere for the stratosphere (13-50 km) from 975 to 1075 cm^{-1} at resolutions of 1.0 cm^{-1}, 0.1 cm^{-1}, 0.01 cm^{-1}, 0.001 cm^{-1}, and 0.0001 cm^{-1}.*

   b) Plot the 1.0 cm^{-1} and 0.1 cm^{-1} spectra for the whole band from 975 to 1075 cm^{-1}, but plot the 0.1 cm^{-1}, 0.01 cm^{-1}, 0.001 cm^{-1}, and 0.0001 cm^{-1} resolutions for some 2 cm^{-1} region. Decide how much resolution is needed to fully resolve the absorption lines. Do the lines appear regularly spaced? Explain.

A resolution of 0.01 cm^{-1} shows the individual lines, but there is still some difference in the transmission spectrum between 0.01 cm^{-1} and 0.001 cm^{-1} resolutions, but not between the 0.001 cm^{-1} and 0.0001 cm^{-1} resolutions. Therefore 0.001 cm^{-1} resolution is needed to fully resolve the lines. The very high spectral resolution is needed because ozone is in the stratosphere at low pressures (down to a few mb) so the pressure broadened absorption line width is very small.

The ozone absorption lines are irregularly spaced because O_3 is an asymmetric top molecule.

4. *a) Compute the transmission spectrum for a standard* **tropical** *atmosphere for 0 to 50 km from 800 to 1000 cm^{-1} at a resolution of 1.0 cm^{-1} with the continuum absorption turned on and with the continuum turned off.*

   b) Plot the two transmission spectra. Compare the transmission in the one of the clearest parts of the window. How would this difference change in a dry atmosphere?

   The clearest part of the window for the no continuum case is around 900 cm^{-1} where the transmission reaches virtually 100%. With the continuum, the transmission is only 55%! For a drier atmosphere the continuum absorption would be much less. This is because much of the continuum water vapor absorption is *e-type*, meaning that the absorption coefficient is proportional to the water vapor amount (so the optical depth is proportional to the square). For example, the ratio of optical depth at 901 cm^{-1} for standard tropical and midlatitude winter atmospheres is 15.0, but the ratio of precipitable water vapor is only 4.9 (4.16 to 0.85 g/cm^2).

5. *a) Make three atmosphere files having one 10 mb layer with zero water vapor and zero ozone and the following layer thicknesses, mean pressures, and temperature:*
   i) $\Delta z = 88$ m, $p = 1000$ mb, $T = 300$ K, *ii)* $\Delta z = 293$ m, $p = 300$ mb, $T = 300$ K
   iii) $\Delta z = 59$ m, $p = 1000$ mb, $T = 200$ K.
   The first one is made for you in `/home/rt/lblrtm/layer1.dat`*.*
   Compute an **optical depth** *spectrum for each case from 625 to 715 cm^{-1} at a resolution of 0.01 cm^{-1}. Remember to set the* `z1` *and* `z2` *appropriately for each case.*

   b) Plot the optical depth spectra cases i) and ii) on one page and cases i) and iii) on another. Identify the P, Q, and R branches.

   c) Concentrate on the pressure effect. What is the maximum optical depth in the R branch for cases i and ii (use `print, max(taui[4500:*])`*)? What is the spectrally integrated optical depth from 670 to 715 cm^{-1} for cases i and ii (use* `print, total(taui[4500:*])`*)? What can you conclude about the effect of pressure on the absorption line shape and strength?*

   The maximum optical depths in the R branch are $\tau_{max} = 58.1$ for 1000 mb and $\tau_{max} = 184.8$ for 300 mb (at 635.77 cm^{-1}). This is a ratio of 3.2. The pressure ratio is 3.3. The spectrally integrated optical depth is $\int \tau_\nu d\nu = 198.54\ \mathrm{cm}^{-1}$ for 1000 mb and $\int \tau_\nu d\nu = 198.76\ \mathrm{cm}^{-1}$ for 300 mb, so there is little change. Since the absorption lines got taller, but the integral stayed the same, we conclude that the absorption lines must have gotten narrower by the same factor. This is what we expect from pressure broaden Lorentz lines - the halfwidth is proportional to pressure. The line strength is unaffected by pressure.

d) Consider the temperature effect. How does temperature affect the line center optical depths ("heights of the lines") across the P and R branches? What is the maximum optical depth and the corresponding wavenumber in the main P branch for cases i and iii (use `print, max(taui[0:4100],i),nu[i]`*)? Convert this wavenumber of the strongest line to the rotational quantum number J by counting the lines. Note: due to symmetries of CO_2, quantum mechanics only allows odd J's, where J is the lower state of the transition. The line position in the P branch is $\nu = \nu_k - 2B(J+1)$, where $\nu_k = 667.38\,\mathrm{cm}^{-1}$ is the band center.*

The lower temperature case has a narrower looking band, i.e. the strengths of the lines far from the band center are greatly reduced at 200 K compared with 300 K. The maximum P branch optical depth is $\tau_{max} = 43.5$ at $\nu = 653.46\,\mathrm{cm}^{-1}$ for 300 K and $\tau_{max} = 43.1$ at $\nu = 656.53\,\mathrm{cm}^{-1}$ for 200 K. The strongest line is $J = 18$ at 300 K and $J = 14$ at 200 K. This is what we expect from the dependence of line strength on temperature. The warmer temperature populates higher energy rotational states, so the strongest line is at higher J.

Please turn in your plots along with the answers to the questions. Delete the LBLRTM output files when you are finished (`rm *.lbl`*).*

The LBLRTM code may be obtained from `http://atmos.umd.edu/~bobe/LBLRTM`.