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12.815 Atmospheric Radiation  
Fall 2008

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## PCModWin Exercise

### 12.815 Fall 2006

Problems 1, 2, 5 and 6 are required. Problems 3 and 4 are optional.

#### 1. Introduction

This is a low-spectral-resolution, radiative transfer program. It can calculate radiances in any direction and at any height for an arbitrary structure of temperature and absorbers, including aerosol and clouds. It incorporates standard atmospheres and standard cloud models. You can invent your own structure if you wish.

There are two low-resolution options, MODTRAN (down to  $1\text{ cm}^{-1}$  resolution) and LOWTRAN (down to  $20\text{ cm}^{-1}$  resolution). For this exercise, we will only use the MODTRAN code. The accuracy of MODTRAN is perhaps a few percent – good enough for many practical problems.

The INTRODUCTION in the PCModWin manual (pp. 16-27) takes you through a test case. On p. 28 there are details of 28 other test cases. You may want to try some of these. Since they are all set up they do not take long to run. They illustrate a point. MODTRAN is not set up primarily for meteorologists, but rather for instrument design purposes. There is also the option for limb viewing at different tangent height. At the end of this course, you may wish to look at limb viewing and radiances generated over limited paths, but the following exercises only use upward and downward radiances, at the ground and at the top of the atmosphere.

#### 2. Getting Started

Start from the ONTAR window. **Modtran Input, Model Atmosphere** is the heart of the program. You can select one out of six model atmospheres or you can make your own. After you have made a run a file is created called MODOUT1 (Directory PCMODWIN) that contains all of the data used in the calculation. These data may be printed out by opening the MODOUT1 file in Wordpad.

For all of our work you require *Slant Path*, and *Radiance* option (Radiance also calculates Transmission; both are Print options). Other options of interest are *Temp at Boundary*, in case there is a boundary later, and *Surface Albedo*.

The next card contains cloud and aerosol options. Choose *No Aerosol Attenuation*, and *Use Cloud* only when you need it. The following cards may depend on your earlier selections. The last card sets the initial and final altitudes. The *Initial Zenith Angle* is the angle from the vertical (zenith) at which a detector would be placed to detect the pencil of radiation of interest. The *Initial Altitude* is the altitude at which the detector would be placed. For example, to measure radiation at the ground coming straight down from above, set the *Initial Zenith Angle* and the *Initial Altitude* to zero. Looking down from space, the *Initial Altitude must be more than 100 km*, and the *Initial Zenith Angle* is between 90 and 270 degrees.

The *Path Length Type* refers to tangent paths and is always *Short* for our purposes. I always work in wavenumbers rather than microns.

### 3 Exercises

#### 3.1 Exercise 1: Emission to space

Use the 1976 US Standard Atmosphere, and a surface albedo of 0.0. Calculate the vertical, outgoing radiance at the top of the atmosphere from 1 to  $1800\text{ cm}^{-1}$ . No scattering by cloud or aerosol. Plot this result and also plot the path transmission (the transmission for a vertical path from bottom to top of the atmosphere). You may use the input file `c:\pcmodwin\ex11.1tn` as starting point. If the plot looks obviously wrong, make sure there are reasonable entries in the Modtran Input/Plot Cases and/or Plot/Edit Plot menus. 'Auto-scale' is a useful feature on these menus. Print the result sideways, that is, in Landscape Mode. This option can be found on the File/Print/Setup menu.

##### 3.1.1 Absorption and emission

Think about the connection between emission from the top of the atmosphere and the atmospheric transmission. For example there are two regions in which the transmission is greater than 90%. From approximately what altitude do you think the outgoing photons in this region of the spectrum came? There are three spectral regions in which there is no detectable atmospheric transmission. Discuss level of origin of photons in these opaque regions. There is a feature centered on  $1013\text{ cm}^{-1}$  that transmits partially. Discuss the factors governing the radiance from this feature.

##### 3.1.2 Band identifications

Identify as many absorbing and emitting features as you can. Use figures 1.1 and 3.1 together with tabulated data in Chapter 3 of Liou (2002).

#### 3.2 Exercise 2: Brightness temperatures and emission levels

For most spectral regions (ozone is an exception and you should be able to say why at the end of the course) the emission to space acts as if it comes from a single level, which differs for each frequency, and emits according to the temperature of that level. The location of this "layer" is determined by the transmission from there to space being  $e^{-1}$ . The transmission depends on the absorption coefficient and the number of absorbers in the path. Thus, for large absorber densities and large absorption coefficients, the layer is high and vice versa. The spectral regions with low total path transmission will emit from high in the atmosphere; those with high transmission from low in the atmosphere, or from the surface. The temperature of the "layer" is known as the *brightness temperature*. Note that we have now associated a temperature with a layer the position of which can be determined, giving an elementary temperature profile. This simple idea, known as the Chapman layer, which we shall discuss later in the course, gives the practiced eye rapid insights into the outgoing radiance.

##### 3.2.1 The brightness temperature

The temperature of the “layer” corresponds to the observed outgoing radiance. We may therefore determine the temperature by inverting the Planck or black-body radiance. The formula is equation (5.48) on page 148 of *Principles of Atmospheric Physics and Chemistry* by Goody. It has been used to form a plot of brightness temperature against frequency for a spectral region from 2100 to 2500  $\text{cm}^{-1}$  in Fig. 5.10. The “layers” corresponding to certain frequencies are shown in Fig. 5.11.

### 3.2.2 Black-body radiances

The program does not contain a sub-routine for calculating the brightness temperature, so we must do the best we can by plotting black-body curves and comparing them to the emitted radiances, using the same scales. Where the curves intersect, the brightness temperature of the radiance equals the black-body temperature.

Superpose a set of black-body emission curves at 20K intervals from 200 to 300K in the spectral range from 1 to 1800  $\text{cm}^{-1}$ . To form the black-body curves, calculate the upward radiance at a height of 1 m above the ground. Even a 1 m path has some absorption. To avoid this you need to construct your own two-layer atmosphere with a temperature equal to the ground temperature (I couldn't get a one-layer model to work). You may use the file `c:\pccmodwin\ex12.1tn` as a sample. With this input, a MODTRAN run will generate the output file `c:\pccmodwin\ex12.fl7`. This blackbody curve could be superposed with the radiance spectrum from Exercise 1, for example, by choosing the `c:\pccmodwin\ex12.fl7` and `c:\pccmodwin\ex11.fl7` files from the Plot/Multiple Files menu. In this exercise, I would like you to superpose all the blackbody emission curves listed above with the radiance spectrum from Exercise 1. To do this, generate all the appropriate blackbody \*.fl7 files (each with different names), and select all of them from the Plot/Multiple Files menu.

### 3.2.3 The height of the emission layer

From the data in MODOUT1 find the altitude that is principally responsible for the emissions that you identified in Exercise 1. You will note an ambiguity. Pay particular attention to the three sharp spikes or Q-branches in the 15  $\mu\text{m}$   $\text{CO}_2$  band, one in the center of the band and two on the flanks. All three represent strong absorption features; the middle being much stronger than the flanking Q-branches. How and why do the radiances of the three spikes differ? Why is the central spike upwards and the side spikes downwards?

### 3.3 Exercise 3: The 4.3 $\mu\text{m}$ $\text{CO}_2$ band

Figures 5.10, 5.11 and 5.12 in the Goody text are calculations for the 4.3 $\mu\text{m}$  band. For reasons that may not be clear yet, this band is the best band for remote sensing of meteorological parameters.

Use MODTRAN to plot the outgoing radiance and path transmission as in Exercise 1, but in the spectral range from 2100 to 2500  $\text{cm}^{-1}$ . Together with the three figures in the text this gives you a lot of information against which to test the ideas developed in Exercise 2. Note the three prominent bands, two of  $\text{CO}_2$  and one of  $\text{N}_2\text{O}$ . The two  $\text{CO}_2$  bands are identical except for a shift of 66  $\text{cm}^{-1}$  caused by a different carbon isotope, and except for the different molecular densities of the two isotopes. They both differ from the 15  $\mu\text{m}$   $\text{CO}_2$  band in having no central Q-branch. That is to say that while the 15  $\mu\text{m}$  band has a very sharp and strong absorption feature at the

center, the two 4.3  $\mu\text{m}$  bands have a dip in the absorption, with consequences for the height of the emission level.

Discuss the different appearances of the central regions of the three  $\text{CO}_2$  bands.

### 3.4 Exercise 4: Comparison between model atmospheres

Now that you understand the emission spectrum qualitatively, run the emissions as in Exercise 1 but for a tropical and a sub-arctic atmosphere (which can be chosen from the Model Input/Model atmosphere/Model Atmosphere menu). Discuss the differences in terms of the MODOUT1 data.

### 3.5 Exercise 5: Cooling by thermal emission

The radiation flux is related to the radiance by equation 1.1.8 in the Liou text. To avoid the angular integration, use an approximation that relates the flux to the radiance 57 degrees away from the vertical:

$$F_{+,-} \sim \pi I_{+,-} (\zeta = 57^\circ \text{ or } 123^\circ)$$

Where (+,-) represent upward and downward directed radiation streams. In other words use 57° for a downward-directed radiance, and 123° for an upward-directed radiance. You may start with the file c:\pcmodwin\ex15.1tn.

Use the 1976 US Standard Atmosphere with no clouds, no aerosols, and zero albedo. Calculate radiances both at the surface and at 100 km. Estimate *very roughly*, the net upward flux at the surface and above the atmosphere. (The radiance in the MODTRAN plot is given in units of  $\text{W cm}^{-2} \text{ster}^{-1} \text{wavenumber}^{-1}$ .) Alternatively,  $I_+$  and  $I_-$ , and hence the approximate fluxes, may be extracted from the data in MODOUT1. What is the average time rate of change of temperature of the atmosphere due to thermal radiation in this example? (See Liou, section 3.5, and particularly, Eq. 3.5.2.)

### 3.6 Exercise 6: Effect of cloud on emission

Repeat Exercise 1 but with a layer of altostratus cloud. (Altostratus cloud can be included with the Model Input/Aerosols/Use Cloud menu.) Print the radiance spectra with and without cloud on a single plot. Can you determine the cloud-top temperature and altitude? Why are some parts of the spectrum changed while others are not (in particular why is the 9.6  $\mu\text{m}$   $\text{O}_3$  band changed while much of the 15  $\mu\text{m}$   $\text{CO}_2$  band is unchanged)? You need to consider the path transmission in the absence of clouds to answer this question.

## 4. References

R. M. Goody and Y. L. Yung, 1989, *Atmospheric Radiation: Theoretical Basis*. New York: Oxford University Press.

PCModWin 4.0 Manual, 2002, Ontar Corporation, North Andover, MA.

R. M. Goody, 1995, *Principles of Atmospheric Physics and Chemistry*. New York: Oxford University Press.

K. N. Liou, 2002, *An Introduction to Atmospheric Radiation*. Academic Press.