Using MODTRAN
Predicting Sensor-Reaching Radiance*

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February 5, 2007

Abstract

The purpose of this lab is to expose the individual to the utilization of MODTRAN and ENVI processing. Using GUI software, `tape5` input card decks will be modified with an explanation of relevant parameters. This card deck will be used to simulate an atmosphere over Rochester, NY during the summertime. The actual execution of the MODTRAN code will commence using a custom UNIX script written for the digital imaging and remote sensing (DIRS) laboratory. This script will also, automatically, parse the MODTRAN output and subsequently convert it to an ENVI spectral library. The output will be examined and used to assemble a sensor-reaching radiance equation. Along the way, ENVI functions such as Spectral Math, Spectral Resampling and the Spectral Library Viewer will be utilized.

It should be noted that this is a "live" document and is full of hyper-links to various web pages, etc. Hyper-links are in blue while section and Figure references are in red.

1 What is MODTRAN?

MODTRAN is an acronym for MODerate spectral resolution atmospheric TRANsmittance algorithm and computer model, which is developed by the Air Force Research Labs (AFRL) in collaboration with Spectral Sciences, Inc (SSI). It is a computationally rigorous radiation transfer algorithm that is used to model the spectral absorption, transmission, emission and scattering characteristics of the atmosphere. This is accomplished by modeling the atmosphere as a set of homogeneous layers. The characteristics of these layers are either drawn from several internal model atmospheres (urban or rural, equatorial or arctic, etc.) or can be characterized by (user provided) radiosonde data collected about a specific atmosphere.

MODTRAN calculates atmospheric transmittance and radiance for frequencies from 0 to 50,000 cm^{-1} at moderate spectral resolution, primarily 2 cm^{-1} (20 cm^{-1} in the UV). The original development of MODTRAN was driven by a need for higher spectral resolution and greater accuracy than that provided by the (much older) LOWTRAN series of band model algorithms. Except for its molecular band model parameterization, MODTRAN adopts all the LOWTRAN 7 capabilities,

*This is version 1.0 of this document. Next version will include section on how to run MODTRAN without the use of CIS scripts.

including spherical refractive geometry, solar and lunar source functions, and scattering (Rayleigh, Mie, single and multiple), and default profiles (gases, aerosols, clouds, fogs, and rain). MODTRAN version 4, for example, has been available to the public since January 2000 and remains the state-of-the-art atmospheric band model radiation transport model. Further information can be found on the CIS Wiki MODTRAN FAQ.

2 Objective

The intent of this exercise is to familiarize an individual with the atmospheric propagation code, MODTRAN. The overall goal will be to simulate what the sensor-reaching would be (using MODTRAN) as seen by JPL's hyperspectral sensor, AVIRIS. We will assume the sensor is flying over Rochester, NY in the summertime. Other details, such as time of day, day of year, etc., are given in the problem formulation below. The individual will also gain experience using some of ENVI's spectral tools. These include use of the spectral library viewer, spectral library resampling, and spectral math functionality.

2.1 Resources

This lab will be performed in a UNIX environment, since that is where all the programs and tools are installed. As an overview you will be using the following programs and scripts to complete the exercise.

tape5_edit You will need to edit the input file (card deck) to MODTRAN. This input file is usually called the `tape5` file. It can be edited using the program `tape5_edit` which lives in `/dirs/pkg/dirsig/bin`. You can type `/dirs/pkg/dirsig/bin/tape5_edit` from your current working directory to run it.

tape5_edit Help Files A series of MS PowerPoint slides have been created to further describe the entries in the `tape5` file. These can be found at `www.cis.rit.edu/class/simg762/Lab3`. Additionally, a detailed description of each entry in the card deck can be found on the CIS Wiki site HERE.

MODTRAN Script The actual UNIX script to run MODTRAN and compute an ENVI spectral library can be downloaded HERE. You will need the `Makefile`, the `IDL` .pro file, and the default `tape5` file. Additional help can be found on the CIS Wiki HERE

Imagery and Reflectance You will need a spectral reflectance file in addition to a small cube of AVIRIS hyperspectral imagery. These can be obtained HERE.

3 Using MODTRAN to Simulate the Atmosphere

3.1 MODTRAN Input: The Card Deck

MODTRAN uses a single ASCII file as input called. This file is called a "card deck". Historically, inputs were read from punch cards back in the day when computers used such cards for data entry. The name is simply a carry over. An example of such a card deck can be seen below.

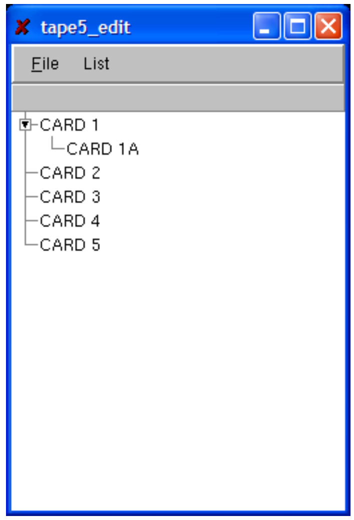

Figure 1: Screen shot of the tape5_edit program.

```
TS   2    2    2    1    0    0    0    0    0    0    1    0    0   0.000    1.00
T    8T    0 360.00000       0.8          0 T F F          0.000

     1    1    0    0    0    0    10.000     0.000     0.000     0.000     0.079
     20.533     0.079   180.000     0.000     0.000     0.000    0          0.000
     1    2  140    0
     43.260    77.610     0.000     0.000    15.670     0.000     0.000     0.000
      0.380     2.510     0.010     0.010RM        MR  A
     0
```

This card deck file contains all the parameters necessary to model a particular atmosphere given a spectral range and viewing geometry. Unfortunately, this file has strict formatting rules, which can make card deck editing and manipulation somewhat cumbersome. A detailed description of each entry in the card deck can be found on the CIS Wiki site HERE.

To create a card deck, one can simply open a new ASCII file and fill in the appropriate information. As previously mentioned, however, this can be complicated due to formatting issues. To make this process more intuitive, a graphical user interface (GUI) has been designed as a front end to the card deck. This program, which runs on the CIS UNIX systems, is called `tape5_edit`. See Sec. 2.1 on how to start it.

3.2 Using the tape5 Editor

The `tape5_edit` program is a graphical user interface (GUI) that can be used to aid in creating and/or modifying a `tape5` (card deck) file. A screen grab of the editor can be seen in Figure 1.

The `tape5` file actually contains a sequence of six or more "cards" (input lines). For example, `card 1`, which is the first line in the ASCII file, contains information about the band model, speed, multiple scattering, etc. while `card 4` specifies the spectral range, frequency/wavelength increments, and spectral degradation of the outputs using a slit function.

For this exercise you will want to simulate an atmosphere in Rochester (Lat = 43.26, Long = 77.61), where the altitude, relative to sea level is 260 feet (GNDALT), the sensor is imaging at an altitude of 67,365 feet (H1) (*i.e.,* AVIRIS nominal operational altitude), the "final altitude" (H2) is 260 feet and the sensor angle is such that it is pointing down (*i.e.,* initial zenith angle = 180 degrees (ANGLE)). Additionally, you will assume the collection occurred on May 5, 1999 at 12:40 EDT. Remember that there is a 4 hour difference to GMT (*i.e.,* at this time of the year, EDT versus EST), which you then need to convert to decimal time. Finally, you will want to generate radiance spectra from 0.380 μm to 2.510 μm in 0.010 μm increments with a slit function full width half max (FWHM) of 0.010 μm. To aid you in altering the default card deck (provided), you should be changing the following MODTRAN parameters:

- GNDALT
- H1, H2, ANGLE
- IDAY
- PARM1, PARM2, TIME
- V1, V2, DV, FWHM

All of the other input parameters can remain their default values. Save the `tape5` file in your working directory.

3.3 MODTRAN Output: Tape Files

Before you run MODTRAN, we should talk about what to expect from the program at completion. MODTRAN produces several output "tape" files. These are called tape files for historical reason since the output was recorded to several tapes to be disseminated at a later date. These files contain information such as the sun location, meteorological descriptions, and concentrations of aerosols. Additionally, they contain the spectral behavior of the atmosphere which is typically found in parameters such as transmission, scattered radiance, etc.

The "`tape7`" file, in particular, contains useful information for our purposes of modeling the sensor-reaching radiance. A detailed description of the various columns in the `tape7` file can be found on the CIS Wiki HERE. At this point one would usually import this file into a spreadsheet for further analysis and plotting. In this lab we will use the script provided to accomplish this. Feel free to examine the other output tape files using the following command:

At your command prompt type:
```
> more mytape.txt
```

where 'my tape' is the name of the tape file you wish to examine. Once the file opens, you can scroll through a page at a time by hitting the space bar, or exit out of the view by hitting the "q" (for quit) key.

3.4 Running MODTRAN using CIS Scripts

After editing and setting up your tape5 file, you are ready to run MODTRAN. **Important**: Be sure you save your output file with the name "tape5". Not tape5_test or tape5_aviris, just tape5.

For this exercise, and subsequent tasks in the remote sensing group, there are UNIX scripts that not only run MODTRAN, but parse its output into a format that is easily understood. That is, the scripts run MODTRAN and reformat the output into an ENVI spectral library (.sli) format to be subsequently viewed in ENVI.

To utilize the script, you need to first obtain the all the necessary files. These can be obtained HERE. You will need to download the Makefile, the IDL code make_modtran_envi_spectral_library.pro, and the example tape5 file. In general, we only want to run MODTRAN "locally" and only concern ourself with the 3 previously stated files. Additional help can be found on the CIS Wiki HERE.

To start MODTRAN, type the follow command at which time you will get the following logs:

```
terra> make local
make -e link
rm -f DATA
ln -s /dirs/lib/Mod4v1r1 DATA
time nice /dirs/bin/Mod4v1r1.exe
```

After MODTRAN completes its run (which can take up to 30+ minutes, depending on the speed of your machine) you should have a tape7 file in the form of an ENVI spectral library, as can be seen from the screen output below. You can view this tape7.scn.sli file in ENVI.

```
terra> ls -F
Makefile                                  tape6
make_modtran_envi_spectral_library.pro    tape7
pltout                                    tape7.scn
pltout.scn                                tape7.scn.sli
tape5                                     tape7.scn.sli.hdr
tape5_default                             tape8
```

4 Sensor-Reaching Radiance

You can now use ENVI to view some of the terms contained in the tape7 output file. Again, these terms are described in more detail on the CIS Wiki site HERE. You can view your tape7 file using ENVI by first starting typing the command:

```
terra> envi
```

This will start your ENVI session. You then need to select, from the menu bar, Spectral / Spectral Libraries / Spectral Library Viewer. This will bring up the Spectral Library Input File dialog box at which time you select tape7.scn.sli as your input file. Once the file is loaded you will have access to all the columns of the tape7 file, as seen in Figure 2. A plot will automatically be generated and displayed once you select a parameter from the list. You can compare these results to those found on the CIS Wiki HERE. Keep in mind, your results will not be exactly like those on the CIS Wiki, for you are using a slightly different tape5 file.

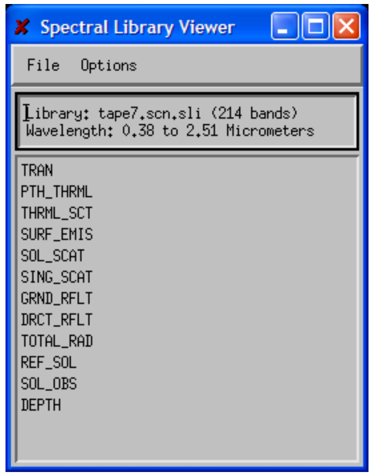

Figure 2: Screen grab of spectral library viewer in ENVI.

4.1 Obtaining Terms for your Sensor-Reaching Radiance Equation

Once we have all the atmospheric components, we can assemble them to form an overall sensor-reaching radiance or "big equation". A detail overview of this process can be found on the CIS Wiki HERE. The total sensor radiance is provided in `tape7` (TOTAL_RAD) but it is for a uniform spectral reflectance of 1.0. We would like to alter this.

We can represent the sensor-reaching radiance equation in 3 distinct parts. That is, the direct term, the downwelled (diffuse) term and the upwelled (path scatter or skylight) term.

```
L = (Dirct Reflected Radiacne)+(Diffuse Reflected Radiance)+(Path Radiance)    (1)
```

using specific radiometric terms we have

```
L = Es*cos(theta)*tau1*tau2*r/pi + Ld*tau2*r + (Lu + Ladj)    (2)
```

or

$$L(\lambda) = \left(E_s'(\lambda) cos\theta \tau_1(\lambda) \frac{r(\lambda)}{\pi} + E_{ds}(\lambda) \frac{r(\lambda)}{\pi} \right) \tau_2(\lambda) + L_{us}(\lambda) + L_{adj}(\lambda) \tag{3}$$

where the subscript "s" refers to solar scatter radiance. The definitions of these term can be found HERE. Furthermore, the previous hyper link tells us that we can extract the following terms from the `tape7` file:

- Direct reflected radiance term (DRCT_RFLT), assuming r=1.0
- Diffuse reflected radiance term (GRND_RFLT - DRCT_RFLT), assuming r=1.0

4.1.1 Special Case for Path Radiance

To obtain the path radiance, L_u, we actually have to create another MODTRAN run where we set earth albedo equal to 0.0. This will provide us with a total radiance (TOTAL_RAD) where the ground reflected term (GND_RFLT) is zeroed out and all we are left with is the path radiance and some adjacent radiance ($L_u + L_{adj}$). More information on this can be found on the Cis Wiki HERE.

For this exercise you will have to create another directory, and copy over the `Makefile`, the IDL file, and your `tape5` file. Open the `tape5_edit` program and change the albedo term in `card1` to 0.0. Then run MODTRAN like before, as explained in Sec. 3.4. This will create another `tape7.scn.sli` (which you might want to rename along with its corresponding header to something like `tape7.scn_r0.sli` and `tape7.scn_r0.sli.hdr`) file where we can now extract the path radiance from the total radiance (TOTAL_RAD).

4.2 Resampling

Before we can construct our sensor-reaching radiance equation, we need a valid spectral reflectance. More than likely, the pixel of interest in a given hyperspectral image will not be a uniform, spectrally flat, object. In this exercise we have provided the spectral reflectance of a red painted basketball court, as measured by a hand held spectrometer. However, the number of samples that make up the spectral reflectance (2151 bands) does not match the number of samples from our modeled spectra (214 bands). Therefore we need to resample the basketball reflectance file to that of the MODTRAN modeled output. Open the basketball court spectrum in ENVI by selecting, from the menu bar, `File` / `Open Image File`.

Resampling can be accomplished by selecting, from the ENVI menu, `Spectral` / `Spectral Libraries` / `Spectral Library Resampling`. This will bring up the `Spectral Resampling Input File` dialog box (see Figure 3). Select the the basketball court file as shown in Figure 3. This will bring up the `Spectral Resampling Parameters` dialog box, as seen in Figure 3. Select the Input Data File option and write the result to either a File or Memory. Lastly, you will be asked to enter the `File Containing Output Wavelengths`. This is the file in which ENVI will resample the basketball spectrum to. That is, resample the basketball spectrum (2151 bands) to the MODTRAN output file (214 bands). Select one of your simulations which contains 214 bands (see Figure 4). One of your data points may be out of the range of the input resampling range. Therefore you may receive a warning about this. We can ignore the warning for this exercise. You can then view the resampled spectrum using the spectral library viewer in ENVI.

4.3 Assembling Sensor-Reaching Radiance Terms in ENVI: Spectral Math

Once you have the desired reflectance and all the sensor-reaching radiance terms at your disposal, you can assemble them into a single spectrum that represents the spectral radiance as seen by the sensor, for the conditions, parameters and reflectance set forth in the example. This can be accomplished by using ENVI's spectral math feature. The ENVI on-line help provides an excellent explanation on how to use the spectral math feature. However, we will repeat some of the process here.

To start we will formulate the sensor-reaching radiance equation as follows:

```
L = (GRND_RFLT)r + (TOTAL_RAD_r0)
```
(4)

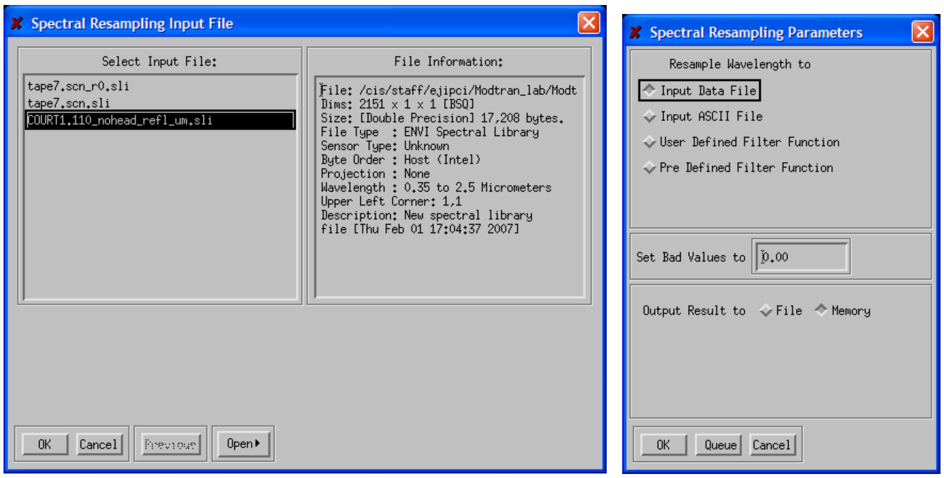

Figure 3: Screen grab of 'Spectral Resampling Input File' and 'Spectral Resampling Parameters' dialog box in ENVI.

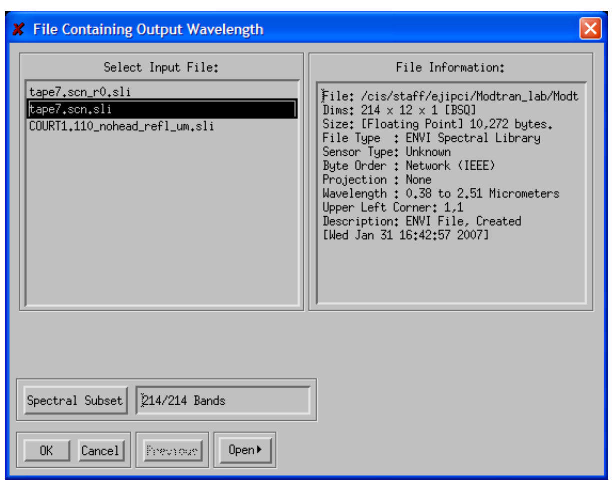

Figure 4: Screen grab of 'File Containing Output Wavelength' dialog box in ENVI.

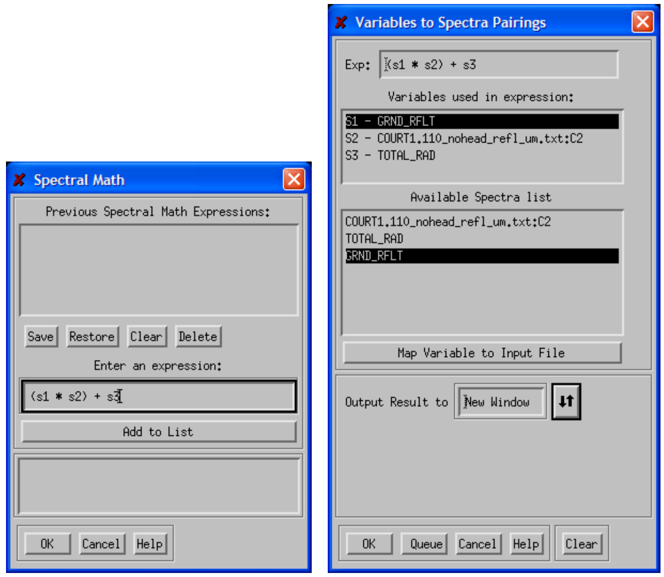

Figure 5: Screen grab of 'Spectral Math' and 'Spectral Pairing' dialog boxs in ENVI.

where GRND_RFLT is the ground reflectanced radiance (with r=0) as previously explained, 'r' is the basketball spectral reflectance (resampled), and TOTAL_RAD_r0 is the total sensor reaching radiance where the earth albedo is 0.0 (*i.e.,* path radiance). We can assemble this in ENVI by selecting, from the file menu, `Basic Tools` / `Spectral Math`. This brings up the Spectral Math dialog box. We then enter the expression `(s1 * s2) + s3`, as seen in Figure 5, followed by OK. This brings up the Variable to Spectra Pairing dialog box, where we map each variable to a spectrum. You must have each spectrum (GND_RFLT, TOTAL_RAD, and COUDRT1.110_nohead_refl_um.txt) open in a separate 'Spectral Library Plot' in order for it to show up in the 'Available Spectra List'. At this point you can pair the variables with the appropriate spectra and click OK. This brings up the final sensor-reaching radiance estimate, which can be seen in Figure 6.

4.4 Applying AVIRIS Sensor Response

The last thing we would like to do is convolve or resample our sensor-reaching radiance estimate so that it has the same band centers as the AVIRIS sensor. This can be done very easily in ENVI. All you need is some AVIRIS imagery (with the full width half max (FWHM) information in the header) and the spectral curve you wish to resample. The process is exactly the same as previously explain in Sec. 4.2.

First we need to save our `(s1 * s2) + s3` results as a spectral library. This can be done by selecting, from the Spectral Math Result window, `File` / `Save Plot As...` / `Spectral Library`. Highlight the plot you wish to save and select OK. You can then name this file (*e.g.,* `s1\_s2\_s3.sli`) and save it to the hard drive.

Now you need to open the AVIRIS data cube provided (`aviris_roch_220bnd_Wcmsrum.img`). Then select, from the ENVI file menu, `Spectral` / `Spectral Library Resampling`. This brings up the Spectral Resampling Input File dialog box, as before in Sec. 4.2. We will be resam-

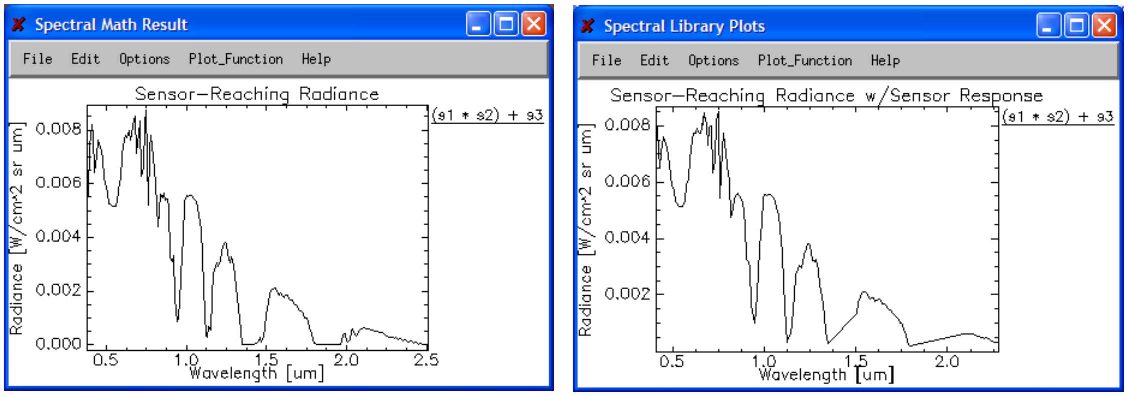

Figure 6: Result of assembling the sensor-reaching radiance equation with a spectral reflectance. (a) Shows the spectrum with 214 MODTRAN bands while (b) shows the spectrum convolved with the AVIRIS sensor response and reduced to 152 bands (i.e., water vapor regions removed).

pling the derived sensor-reaching radiance equation (`s1\_s2\_s3.sli`). So select `s1\_s2\_s3.sli` and hit OK. For the 'Spectral Resampling Parameters' dialog box, select 'Input Data File' and a name for the output file (*e.g.,* `s1\_s2\_s3\_resamp.sli`). Finally select the file that contains the band centers you want to resample to. In our case this will be the AVIRIS image (`aviris_roch_220bnd_Wcmsrum.img`). Select this file followed by OK. As a side note, the original AVIRIS sensor has 224 bands (0.4 μm to 2.5 μm). Our sample data has a few of the channels truncated due to low SNR thus leaving 220 bands. Furthermore, the data cube has many of the water absorption bands marked as 'ignore'. This is actually called a 'bad bands list' in ENVI, where the location of the bad bands are stored in the image header file. Therefore, the final resampled sensor-reaching radiance will only have 152 band due to these omitted water bands.

Lastly, the results of the sensor respampling will appear in the 'Available Bands List'. You can view the resampled result by 'right' clicking on the `s1\_s2\_s3\_resamp.sli` filename which brings up the Spectral Library Viewer. Your final sensor-resampled result should look similar to that shown in Figure 6(b).

5 Report Details

For this exercise you need to hand in your `tape5` file along with (LABELED) spectral plots of the direct term, diffuse term and path radiance term. In addition, include (LABELED) spectral plots of your sensor-reaching radiance with and with out the sensor response.

So that your report does not look like two pages of plots, include a brief write-up / explanation of what you did and how you did it. That is, explain some of the process and results you are handing in.