**ATOC/ASTR 5560 Lab 10 Solutions**

November 16, 2001

*The purpose of this lab is to learn how to use a general purpose atmospheric radiative transfer model for "real world" type applications. SBDART is a plane-parallel radiative transfer model, built on DISORT, that also includes lookup tables of particle scattering information and molecular absorption data. An introduction to SBDART and a link to "SBDART on the Web" is available at URL* `http://www.crseo.ucsb.edu/esrg/pauls_dir/`. *If you want SBDART on your own computer, the distribution is available from the Web site or on nit in* `/home/rt/sbdart/sbdart_pkg.tar.gz`.

*Log in to nit and copy the following files to your directory:*

| | |
|---|---|
| `/home/rt/sbdart/sbdart` | *SBDART executable* |
| `/home/rt/sbdart/rt.doc` | *SBDART documentation file* |
| `/home/rt/sbdart/INPUT` | *SBDART namelist input file* |
| `/home/rt/sbdart/plotsbdart.pro` | *IDL file for plot SBDART spectra* |

1. *This lab will calculate solar flux spectra.*

   *a) What radiative transfer assumption does SBDART make that results in poor accuracy for radiances? Is this ok for fluxes? Explain. See the Web site introduction.*

   SBDART uses the Henyey-Greenstein phase function specified by the asymmetry parameter rather than the Mie phase function. This is a good approximation for fluxes, but is poor for radiances, especially in the optically thin limit (as you saw in the homework).

   *b) How is the molecular absorption handled (e.g. line-by-line, band model, k-distribution)? What is the source of absorption information?*

   SBDART uses a three term exponential sum fit, which is basically equivalent to a k-distribution with 3 k's. The source of the information is LOWTRAN which is a 20 $cm^{-1}$ band model that was fit to line-by-line data in the early 1980's. So the molecular absorption information is rather indirectly linked to an older line-by-line database.

2. *Look at the SBDART documentation file* `rt.doc`. *The initial SBDART* `INPUT` *file for the lab is listed below. You won't need to use any other parameters. For each parameter state the meaning of the particular value. Also give an overall description of the initial run (e.g. longwave broadband flux, for tropical atmosphere with a liquid cloud above the ocean in Hawaii on the solstice).*

| SBDART INPUT File | |
|---|---|
| isat=0 | user defined wavelength range with no filter function |
| nf=3 | use the more accurate MODTRAN3 solar spectrum |
| wlinf=0.25 | starting wavelength of 0.25 $\mu$m |
| wlsup=4.0 | ending wavelength of 4.0 $\mu$m |
| wlinc=-0.01 | wavelength increment is $d\lambda/\lambda = .01$ |
| sza=0 | solar zenith angle (not used if zero) |
| iday=316 | day of the year |
| time=19 | time in hours GMT |
| alat=40 | latitude on Earth |
| alon=-105 | longitude on Earth |
| isalb=3 | surface type: 3 is lake water |
| idatm=6 | atmosphere: 6 is US standard |
| uw=-1 | precipitable water vapor (-1 means use atmosphere) |
| uo3=-1 | total ozone (-1 means use atmosphere) |
| xco2=360 | carbon dioxide concentration (ppmv) |
| zcloud=0.5,-1.0 | height range of cloud (0.5 to 1.0 km) |
| lwp=0.0 | liquid water path of cloud (g/m$^2$) |
| nre=10 | effective radius in cloud layer ($\mu$m) |
| jaer=3 | stratospheric aerosol type: fresh volcanic |
| zaer=25 | height of the stratospheric aerosol layer |
| taerst=0.0 | optical depth of stratospheric aerosols |
| zout=0,100 | get output at the surface and top of atmosphere |
| iout=1 | output mode for TOA and surface spectral fluxes |
| nstr=4 | number of discrete ordinates in both hemispheres in DISORT |

This run computes broadband shortwave fluxes in a clear sky (no aerosols or clouds) US standard atmosphere over a lake surface in the Denver area at noon in mid-November.

3. *Run SBDART with the initial* `INPUT` *file. Type*

```
sbdart >specbase.out
```

*which directs the flux spectra to the desired output file. This will be the "base case".*

*a) Plot the top of atmosphere and surface upwelling and downwelling fluxes using the* `PlotOneCase` *section of the IDL file.*

*b) List the top of atmosphere incident and upwelling flux, and the surface upwelling and downwelling flux. What is the broadband albedo of the surface and atmosphere/surface?*

The top of atmosphere fluxes are $F_{top}^{\downarrow} = 742.8\ \mathrm{W/m^2}$, $F_{top}^{\uparrow} = 67.8\ \mathrm{W/m^2}$ and the surface fluxes are $F_{bot}^{\downarrow} = 555.5\ \mathrm{W/m^2}$, $F_{bot}^{\uparrow} = 23.8\ \mathrm{W/m^2}$.

The TOA albedo is $R_{top} = F_{top}^{\uparrow}/F_{top}^{\downarrow} = 0.091$, while the surface albedo is $R_{bot} = F_{bot}^{\uparrow}/F_{bot}^{\downarrow} = 0.043$.

*c) Using your extensive knowledge of Radiative Processes, briefly explain the causes of the level and major features of each of the four spectra.*

Downwelling TOA flux: This is the incident solar flux. It is approximately a Planck blackbody curve at about 5800 K, but there are numerous absorption features in the visible and ultraviolet due to radiative processes in the Sun's photosphere.

Upwelling TOA flux: Since this case is for clear sky with a dark surface (lake water) only a small amount of solar flux is reflected. The sources of scattering/reflection are molecular Rayleigh scattering and the surface. The Rayleigh scattering decreases with wavelength, $\approx \lambda^{-4}$, but is cutoff at the shortest wavelengths by ozone absorption.

Downwelling surface flux: The transmitted flux has been attenuated by ozone absorption in the UV and visible, Rayleigh scattering in UV and visible, and numerous water vapor bands (around 0.94, 1.1, 1.4, 1.9, 2.7 $\mu$m). The broadband transmission for this case is about 75%.

Upwelling surface flux: The surface albedo is rather low for this lake surface and the reflection is confined to around the visible part of the spectrum. This fits with our understanding of Fresnel reflection by a water surface, which gives little reflection except for oblique angles. Also water is absorbing in the near IR, so we expect no reflection there.

4. *Now we will do a long series of sensitivity tests. This involves perturbing one aspect of the atmosphere or surface, running SBDART to compute the fluxes, and comparing the results with the base case.*

   *For each perturbation, make the appropriate change in the SBDART* `INPUT` *file, and make sure you start with the original* `INPUT` *file so you don't mix up perturbations.*

   *For each case, run SBDART, plot the base case and perturbation spectra using section* `PlotTwoCases`*, write down the TOA upwelling and surface downwelling broadband fluxes, and* briefly *explain the changes in the spectra.*

   *a) Change the surface type to vegetation. To see the surface effect, use section* `PlotOneCase` *instead so the upwelling flux is plotted. Calculate the broadband surface albedo for vegetation.*

   Change `isalb` to 6 for a vegetation surface.

   ```
   Integrated fluxes:  Ftopdn=742.8 Ftopup=186.5
   Fbotdn=557.2 Fbotup=154.4
   ```

   The broadband surface albedo is 0.277 compared with the lake surface albedo of 0.043. There is a large increase in albedo around 0.7 $\mu$m so there is upwelling flux in the near infrared.

   *b) Increase the vertically integrated water vapor amount by 50% (factor of 1.5).*

   The US standard atmosphere has $u = 1.418 \text{ g/cm}^2$. Increase this 50% to $u = 2.127 \text{ g/cm}^2$ (parameter `uw`).

```
Fluxes:  Ftopup1= 67.8 Ftopup2= 67.6
Fluxes:  Fbotdn1=555.5 Fbotdn2=544.3
```

The downwelling flux decreases in the near IR water vapor bands, except in the center of the strongest bands which are already saturated (the transmission can't decrease if it is alread zero). The TOA reflected flux virtually does not change because there is little decrease in the UV and visible where the atmosphere/surface is reflecting.

*c) Decrease the ozone amount by 50 Dobson units.*

The base case has 0.349 milli-atm-cm, so subtracting 50 Dobson units gives `uo3 = 0.299` milli-atm-cm.

```
Fluxes:  Ftopup1= 67.8 Ftopup2= 68.4
Fluxes:  Fbotdn1=555.5 Fbotdn2=557.1
```

The transmitted flux increases due to less ozone absorption in the weak Chappuis band (centered on 0.6 $\mu$m) and in the Huggins band (0.3 to 0.35 $\mu$m), but not at shorter wavelengths due to saturation. The TOA reflected flux increases due less absorption above the molecular Rayleigh scattering.

*d) Double the carbon dioxide concentration.*

The carbon dioxide concentration is doubled by changing `xco2` to 720.

```
Fluxes:  Ftopup1= 67.8 Ftopup2= 67.8
Fluxes:  Fbotdn1=555.5 Fbotdn2=554.5
```

There is a small decrease in the shortwave transmitted flux near 2 $\mu$m due to a weak $CO_2$ absorption band. There is no effect on the TOA reflected flux because there is no reflected flux from the clear sky in the near IR.

*e) Set the stratospheric aerosol optical depth to 0.3 and fresh volcanic aerosol type.*

Keep `jaer=3` and set the optical depth to `taerst=0.3`.

```
Fluxes:  Ftopup1= 67.8 Ftopup2= 98.2
Fluxes:  Fbotdn1=555.5 Fbotdn2=478.8
```

There is a large decrease in transmitted flux due to reflection by the aerosols. The reflection spectrum is relatively flat, so the downwelling surface flux decrease mirrors that of the downwelling clear sky surface flux. The TOA upwelling flux increases due to reflection from the aerosols except for the ultraviolet, where the aerosols must be absorbing.

*f) Put in a cloud from 0.5 to 1.0 km height with a liquid water path of* $100\ \mathrm{g/m^2}$ *and effective radius of* $10\ \mu$*m.*

Change the cloud LWP to $100\ \mathrm{g/m^2}$ with `lwp=100`.

```
Fluxes:  Ftopup1= 67.8 Ftopup2=386.7
Fluxes:  Fbotdn1=555.5 Fbotdn2=181.6
```

The transmitted flux decreases by a huge amount for this optically thick cloud. The transmissivity is flat across the spectrum, so the spectrum change mirrors the downwelling flux. The

TOA reflected flux increases due to the cloud reflection in almost the same amount as the transmitted flux decreases. The increase in reflection is less than the decrease in transmission because the cloud absorbs radiation.

*g) Change the cloud height to 1.5 to 2.0 km (LWP of* $100\ \mathrm{g/m^2}$ *and* $r_e$ *of* $10\ \mu$*m). Compare the fluxes using section* `PlotTwoCases` *to the* cloud case *in f.*

Change the `zcloud` to 1.5,-2.0.

```
Fluxes:  Ftopup1=386.7 Ftopup2=396.8
Fluxes:  Fbotdn1=181.6 Fbotdn2=182.2
```

The transmitted flux changes little, as it is the optical depth of the cloud and not its height that affects transmission. The TOA reflected flux, however, increases in the water vapor absorption bands. This happens because the higher cloud shields the sunlight from the high water vapor amount in the lowest part of the atmosphere. The higher cloud reflects some of the light before it is absorbed by the water vapor.

*h) Finally, make a table of the TOA upwelling and surface downwelling fluxes for all perturbations. List the changes from the appropriate base case in W/m*$^2$.

| Case | $F_{top}^{\uparrow}$ (W/m$^2$) | $F_{bot}^{\downarrow}$ (W/m$^2$) | $\Delta F_{top}^{\uparrow}$ (W/m$^2$) | $\Delta F_{bot}^{\downarrow}$ (W/m$^2$) |
|---|---|---|---|---|
| Base clear | 67.8 | 555.5 | - | - |
| Vegetation | 186.5 | 557.2 | 118.7 | 1.7 |
| Water vapor ($\times 1.5$) | 67.6 | 544.3 | -0.2 | -11.2 |
| Ozone (-50 Dobson) | 68.4 | 557.1 | 0.6 | 1.6 |
| Carbon dioxide ($\times 2$) | 67.8 | 554.5 | 0.0 | -1.0 |
| Strat. Aerosol ($\tau = 0.3$) | 98.2 | 478.8 | 30.4 | -76.7 |
| Liquid cloud ($\tau = 15, r_e = 10\ \mu$m) | 386.7 | 181.6 | 318.9 | -373.9 |
| Cloud ($z = 1.5 - 2.0$ km) | 396.8 | 182.2 | 10.1 | 0.6 |

For TOA reflection the vegetated surface and cloud case give huge increases and the aerosols give a large increase in flux. The other perturbations are insignificant.

For transmission the increase in water vapor decreases the flux significantly, while the addition of an aerosol layer or a cloud decreases the flux by a large amount. Changing ozone, $CO_2$, or the surface reflection has a small effect. Note, that increasing the surface reflection would have much more impact on the downwelling flux in a cloudy sky.

Changing the effective radius, while holding the geometric optical depth fixed, has a relatively minor effect. Increasing the cloud height increases the reflection significantly without changing the transmission.