

AT721
Assignment 4
Due Friday March 21, 2014

In this assignment you will build on your previous work to analyze the response of a microwave receiver to a simplified raining scene over ocean. You will estimate physical properties, calculate optical properties and run the radiative transfer to understand the system response at a few different frequencies.

1. Get your full Adding-Doubling code working, for two atmospheric. Test your code for the following situation, assuming two atmospheric layers with the following optical properties:

Upper Layer : $\tau = 1.0$, $SSA = 0.7$, $g=0.8$ (Henyey-Greenstein)
Lower Layer: $\tau = 0.3$, $SSA=0.8$, $g=0.2$ (Henyey-Greenstein)
Surface reflectivity : 0.5 (at all angles), assume specular.
Temperatures: 240 K (top), 275 K (middle), 290 K (surface)
Obs angle = 0 & 53.1 deg
Wavelength = Very Low (Rayleigh-Jeans approximation is valid)

TB Upwelling at TOA (0, 53.1 deg) = 216.2 K, 221.8 K

You should be able to get to within a few tenths of a K.

Let's now examine the relationship between upwelling brightness temperature at 53.1 deg observation zenith angle vs. a few atmospheric variables. We'll do just two frequencies: a lower frequency (19 GHz), and a higher frequency (89 GHz). Both of these frequencies are available on virtually all passive microwave imagers (AMSR's, SSM/I, TMI, GMI, etc). The situation will be a highly simplified convective case in which we'll put in prescribed amounts of graupel and rain over top an ocean layer.

----- 240 K, 6 km -----

Layer 1: Cloud water (0.3 kg m^{-2}), Graupel (mass path of 0 to 3 kg/m^2).
Ignore O_2 and water vapor absorption.

----- 275 K, 2 km -----

Layer 2 Water vapor (15 kg/m^2), Rain (RR of 0 to 50 mm/hr)
Ignore O_2 absorption.

----- 290 K, 0 km -----

Surface (290 K), Specular, Reflectivity = 0.5 all angles

You will next set up code to both calculate the optical properties and run the radiative transfer for this atmosphere, with varying physical properties. The steps are given below.

2. Calculation of layer optical properties.

- a. Calculate the rain optical properties. You will do a full calculation for this. Assume that the terminal velocity of the rain drops is given by

$$U(D) = 3.3 D^{0.76}$$

where D is the drop diameter in mm and U is in m/s. Further assume that the drops follow a “Marshall-Palmer” exponential distribution:

$$N(D) = 8000 \exp(-D/D_{mean}) \text{ [m}^{-3} \text{ mm}^{-1}\text{]}$$

- i. Show that the rain density is given by $8\pi D_{mean}^4$, where the rain density is in g m^{-3} and again D_{mean} is in mm.
 - ii. Using the $U(D)$ relationship, further show that $RR = 837 (D_{mean})^{4.76}$, where RR is the rain rate given in mm hr^{-1} , and D_{mean} is the mean rain drop diameter in mm.
 - iii. Find D_{mean} and the “rain water path” RWP in kg m^{-2} for rain rates of 0, 2 and 20 mm/hr over a 2 km deep layer.
 - iv. Assuming Mie spheres, and integrating over the DSD as you did in homework 2, write code to calculate the optical properties of our rain distribution for an arbitrary rain rate. Plot the mass extinction coefficient, single scattering albedo, and asymmetry parameter as a function of rain rate from ~ 0 to 20 mm/hr (you might find it useful to plot these quantities versus the logarithm of the rain rate). Do these intrinsic optical properties depend strongly on rain rate? Speculate on the behavior in each graph.
- b. Calculate the cloud water optical depth for each frequency. Recall that in the microwave, cloud water is purely absorbing and is independent of the cloud drop size distribution. You can use for instance eq. (12.19) in Petty.
- c. Calculate the optical properties of graupel. For (relative) simplicity, we will assume that graupel is given by a spherical mixture of ice and air. You may assume indices of refraction of these spheres at 19 and 89 GHz of (1.32, $1.8\text{e-}4$) and (1.32, $8.4\text{e-}4$), respectively. Assume that the graupel is distributed with a monodisperse distribution of diameter 3.5 mm. Use Mie theory to calculate the mass extinction coefficient [$\text{m}^2 \text{kg}^{-1}$], single scattering albedo, and asymmetry parameter of our graupel at both frequencies.
- d. For the water vapor, assume it roughly has a mass extinction coefficient of $0.002 \text{ m}^2 \text{kg}^{-1}$ at 19 GHz and $0.01 \text{ m}^2 \text{kg}^{-1}$ at 89 GHz near the surface. What are the corresponding optical depths for layer 2?

- e. Set up code to calculate the composite optical properties of each layer. Assume HG-phase functions all around, so you only need keep track of the asymmetry parameter g . What are the composite optical properties (optical depth, single-scattering albedo, and g) for each layer at 89 GHz frequency, assuming the graupel mass path = 3 kg/m^2 and rain rate = 20 mm/hr

3. Running the Radiative Transfer

- a. For $IWP = 0$, run the radiative transfer as a function of rain rate at both frequencies, and plot the upwelling TB (at TOA) at our view angle for both frequencies vs. RR (up to 20 mm/hr). Comment on the behavior.
- b. For $RR = 10 \text{ mm/hr}$, repeat step 3a but now varying the graupel mass path from 0 to 3 kg m^{-2} . Try to use physical arguments to explain the observed behavior.
- c. Repeat both steps 3a and 3b, but now over land. Assume a Lambertian surface with an emissivity of 0.95 (reflectivity = 0.05). Try to use physical arguments to explain the observed behavior. Also, comment on how our ability to sense rain over land might be confused with the presence of ice, and how that compares to the situation over ocean.