E E / Mteor / Agron 518 Spring 2008
Problem Set 9
Due Tuesday, April 22, 2008

Assigned April 11, 2008
Updated April 21, 2008

1. Use the matlab m–file on the course website `erwater.m` to compute the relative permittivity (also called dielectric constant) of pure water.

   (a) Plot the real part of the relative permittivity versus frequency at two temperatures, 275 and 300 K. Describe how the real part of the dielectric constant changes with temperature.

   (b) Plot the imaginary part of relative permittivity versus frequency at 275 and 300 K. How does the frequency at which the imaginary part of the dielectric constant is greatest change with temperature?

   (c) Plot the real part of the dielectric constant versus temperature at two frequencies, 1 and 40 GHz. At which frequency does the real part change the most?

   (d) Plot the imaginary part of the dielectric constant versus temperature at two frequencies, 1 and 40 GHz. At which frequency does the imaginary part change the most?

   (e) Plot the real and imaginary parts of the refractive index versus frequency at 300 K. Does the imaginary part of the refractive index peak at the same frequency as the imaginary part of the dielectric constant?

   Use a frequency range of 100 MHz to 100 GHz and a temperature range suitable for liquid water on Earth. Consider using a log scale for the frequency axis.

2. (a) Plot the drop size distribution for a light rain (5 mm per hour) and heavy rain (40 mm per hour) using the Marshall–Palmer drop size distribution function. The Marshall–Palmer distribution is described by (5.116) in UMF.

   (b) Find the total number of rain drops per cubic meter for the light and heavy rain.

   (c) The Rayleigh scattering approximation can be used when $|n_s\, k_o\, d| < 0.5$, where n_s is the refractive index of the particles (assuming the background medium is air), k_o is the free–space wavenumber, and d is the diameter of the particle. If the temperature of the rain drops are 275 K (near freezing), for what frequencies can the Rayleigh approximation be used? Does your answer change significantly for warmer temperatures (around 290 K)?

3. (a) Find an expression for the absorption and scattering coefficients for rain, κ_a and κ_s, assuming rain drops can be approximated as spherical particles and assuming Rayleigh scattering. Use scattering cross sections given by (5.75) and (5.76) in UMF. To find the

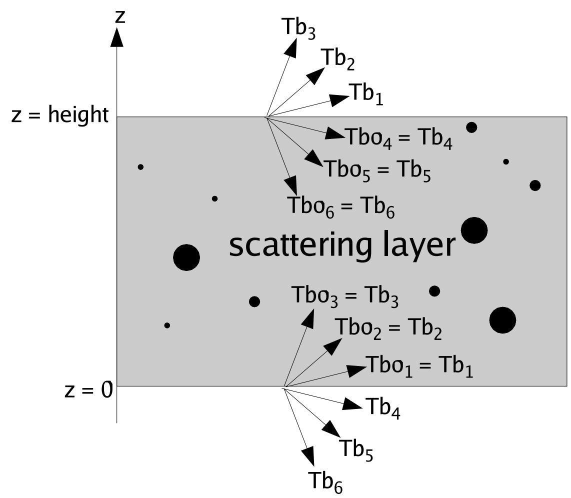

Figure 1: Scattering layer for Problem 4.

coefficients, integrate the product of the drop size distribution function and either the absorption of scattering cross sections, σ_a and σ_s, over all possible diameters.

$$\kappa = \int_0^\infty p(a)\ \sigma(a)\ da \tag{1}$$

where κ is either the absorption or scattering coefficient, $p(a)$ is the drop size distribution, $\sigma(a)$ is the cross section for absorption or scattering, and a is either the radius or diameter of the particles. Note that the absorption and scattering cross sections are called Q_a and Q_s in UMF. Write your answer in terms of the gamma function, $\Gamma(x)$, where

$$\Gamma(x) = \int_0^\infty t^{x-1} e^{-t}\ dt. \tag{2}$$

Check your calculations by comparing with Figure 5.26 in UMF. Use either MATLAB or lookup tables to find the value of $\Gamma(x)$.

(b) What is the the extinction coefficient, $\kappa_e = \kappa_a + \kappa_s$, and the scattering albedo, $\omega = \kappa_s/\kappa_e$, for a rain rate of 5 mm per hour assuming a temperature of 280 K at 10 GHz?

(c) What is the the extinction cofficient and the scattering albedo for a rain rate of 25 mm per hour assuming a temperature of 280 K at 10 GHz?

(d) What is the the extinction coefficient and the scattering albedo for a rain rate of 25 mm per hour assuming a temperature of 280 K at 37 GHz?

4. Use the m–file on the course website `scat_layer.m` to explore the radiometric characteristics of a scattering layer. To properly use this function, look at Figure 1 and read the comments at the beginning of the file or type `help scat_layer` at the MATLAB command prompt. Example: for height = 100, f = 37e9, T = 275, $\kappa_a = 1.7 \times 10^{-4}$ and $\kappa_s = 9.6 \times 10^{-6}$ corresponding to a 25 mm per hour rain, Tbo = [0 0 0 0 0 0], and z = 0, the result Tb = [0 0 0 18.87 6.97 4.96] is found, which corresponds to upwelling brightness temperatures at z = 0 of zero kelvin, and downwelling brightness temperatures of approximately 19 K at 103°, 7 K at 131°, and 5 K at 159° at z = 0 where 0° is defined as straight up ($+\hat{z}$ direction). Answer the following questions.

(a) If all boundary conditions are 0 K and the temperature of the scattering layer is also 0 K, what are the downwelling brightness temperatures at z = 0 m and the upwelling brightness temperatures at z = 100 m if f = 37 GHz and the rain rate is 25 mm per hour? Explain why this makes sense.

(b) If all boundary conditions are 275 K and the temperature of the scattering layer is also 275 K, what are the downwelling brightness temperatures at z = 0 m and the upwelling brightness temperatures at z = 100 m if f = 37 GHz and the rain rate is 25 mm per hour? Explain why this makes sense.

(c) If all boundary conditions are 0 K and the temperature of the scattering layer is 275 K, what are the downwelling brightness temperatures at z = 0 m and the upwelling brightness temperatures at z = 100 m if f = 37 GHz and the rain rate is 25 mm per hour? Explain the trend in brightness temperatures at both z = 0 and 100 m and why these brightness temperatures are different from Problem 4a.

(d) Simulate rain over a prairie grassland using the following conditions: scattering layer height of 2 km; temperature of rain is 275 K; downwelling brightness temperatures of 60 K at all angles at the top of the scattering layer (atmospheric emission from above the clouds); and upwelling brightness temperatures of 290 K at all angles at the bottom of the scattering layer (approximately the brightness temperature of a grassland). For a frequency of 37 GHz and a rain rate of 25 mm per hour, report the upwelling brightness temperatures at 2 km and the downwelling brightness temperatures at the surface. Why is the change with angle at the top of this scattering layer different than for Problem 4c? (Hint: observe what happens when you try different boundary conditions). What is the scattering albedo for the scattering layer?

(e) Use the same conditions in Problem 4d but change the frequency to 10 GHz. What is the new scattering albedo? Report the brightness temperatures at 2 km and at the surface and explain why the variation with angle at 2 km is different from Problem 4d.

(f) Use the same conditions in Problem 4d but change the rain rate to 5 mm per hour. What is the new scattering albedo? Report the brightness temperatures at 2 km and at the surface and explain why the variation with angle at 2 km again the same as for Problem 4d.

(g) Make up and answer your own problem by changing boundary conditions, frequency, rain rate, height of the scattering layer, etc.

5. Read Chapter 2 of the Decadal Survey on Earth Science and Applications from Space, titled "The Next Decade of Earth Observation from Space."

   (a) What is the overall goal of the authors in Chapter 2?

   (b) Currently, how many operating spacecraft and how many instruments on board these satellites have some type of U.S. involvement? Is this number scheduled to increase in the future?

   (c) What has contributed to the decline in Earth–observing satellites?

   (d) List three climate measurements whose continuity is in danger of being interrupted.

   (e) What is geosynchronous orbit (GEO)? It is not defined in the chapter. You will have to consult another source. What is special about GEO?

   (f) How many missions do the authors recommend for NOAA and NASA? How many missions were originally recommended by the individual science panels as "high–priority?"

How many missions were submitted by the scientific community in response to the request for missions?

(g) List four of the criteria used by the panels to rank the proposed missions.

(h) Why did the authors assign some of the missions to NOAA as opposed to NASA?

(i) How accurate are the cost estimates provided in the report? Do you think the accuracy of these estimates are reasonable? Why?

(j) The SMAP (Soil Moisture Active Passive) mission concept is an L–band (1.4 GHz) radar and radiometer. To which areas in Figure 2.14 does the committee see SMAP contributing? In view of Table 2.3, which additional area does it appear that SMAP would contribute?