AATM 505 Atmospheric Physics II – Homework #3 Aerosols
100 points total, 8% of final grade

1. (16 points) Based on the following figure from Ch. 2 of 2007 IPCC report (available at https://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-chapter2.pdf) and associated text, summary in your own words the four aerosol effects (direct, 1st indirect, 2nd indirect, and semi-direct) on radiation, cloud, and precipitation, explain briefly the physics underlying each effect and corresponding aerosol properties most important for the effect.

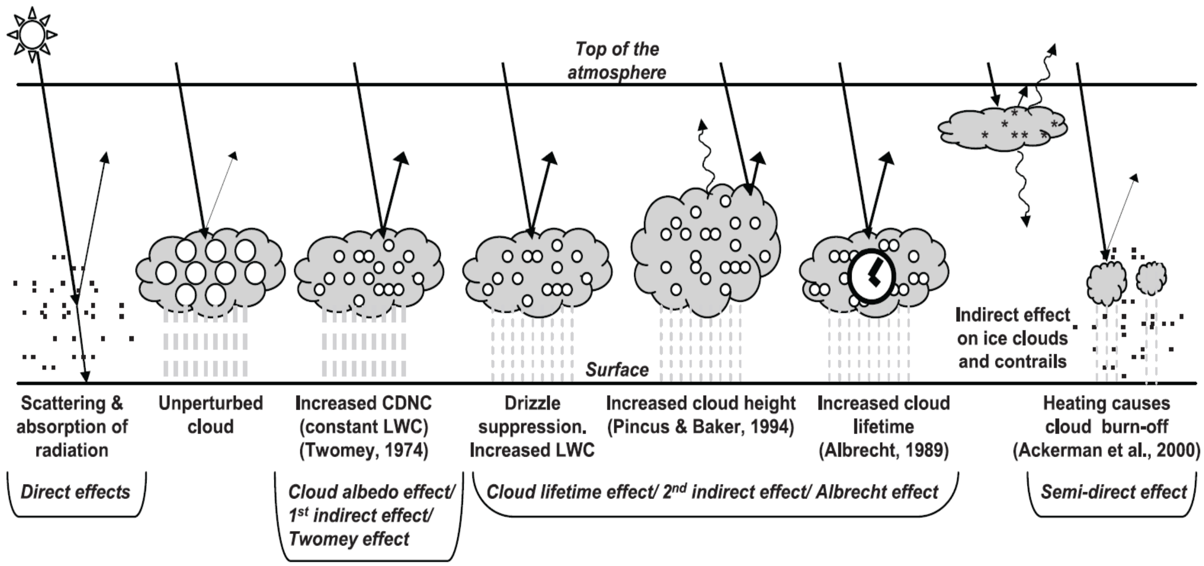

Figure 2.10. *Schematic diagram showing the various radiative mechanisms associated with cloud effects that have been identified as significant in relation to aerosols (modified from Haywood and Boucher, 2000). The small black dots represent aerosol particles; the larger open circles cloud droplets. Straight lines represent the incident and reflected solar radiation, and wavy lines represent terrestrial radiation. The filled white circles indicate cloud droplet number concentration (CDNC). The unperturbed cloud contains larger cloud drops as only natural aerosols are available as cloud condensation nuclei, while the perturbed cloud contains a greater number of smaller cloud drops as both natural and anthropogenic aerosols are available as cloud condensation nuclei (CCN). The vertical grey dashes represent rainfall, and LWC refers to the liquid water content.*

2. (24 points) Given the following data on the number of aerosol particles in the size ranges listed,

Size Interval (μm)	Mean of Size Interval (μm)	Number of Particles in Interval (# cm^{-3})
0.01 — 0.02	0.015	2.30E+03
0.02 — 0.04	0.030	6.50E+03
0.04 — 0.07	0.055	1.20E+03
0.07 — 0.10	0.085	1.50E+02
0.10 — 0.20	0.150	8.00E+02
0.20 — 0.50	0.350	1.00E+02
0.50 — 1.00	0.750	2.00E+00
1.00 — 2.50	1.750	6.00E-01
2.50 — 10.00	6.250	1.00E-01
10.00 — 20.00	15.000	1.00E-03

(1) (12 points) Tabulate and plot number (N), and mass (M) size distributions dN/dlogDp, and dM/dlogDp. Make sure to specify units. Use log-log scale for plotting.

(2) (4 points) What are the values of PM10, PM2.5, PM1, and PM0.1?

(3) (4 points) What are the number concentrations of particles or condensation nuclei (CN) with diameter larger than 10, 100, 500, and 1000 nm?

(4) (4 points) For the given size distribution, discuss the size ranges of particles dominating number and mass concentrations.

3. (20 points) Based on the online nucleation rate calculators available at http://apm.asrc.albany.edu/nrc/, calculate the H_2SO_4 gas-phase concentration that produces a nucleation rate of 1 $cm^{-3}s^{-1}$ (named critical [H_2SO_4] or $[H_2SO_4]_{crit}$ when significant nucleation occurs) for H_2SO_4-H_2O binary homogenous nucleation (BHN), H_2SO_4-H_2O-NH_3 ternary homogeneous nucleation (THN), H_2SO_4-H_2O-Ions binary ion-mediated nucleation (BIMN), and H_2SO_4-H_2O-NH_3-Ions ternary ion-mediated nucleation (TIMN), under the conditions given below. Assume relative humidity RH=60% and surface area of pre-existing particles = 20 $\mu m^2/cm^3$ for all cases. For BIMN and TIMN, ionization rate Q=10 ion-pairs $cm^{-3}s^{-1}$.

(1) (4 points) BHN: T= 220K and 285 K.

(2) (4 points) THN: T=220K & [NH_3]=2.0E8 cm^{-3}; and T=285K & [NH_3]=1.0E10 cm^{-3}.

(3) (4 points) BIMN: T= 220K and 285 K.

(4) (4 points) TIMN: T=220K & [NH_3]=2.0E8 cm^{-3}; and T=285K & [NH_3]=1.0E10 cm^{-3}.

(5) (4 points) Comment on the results with regard to the impact of T, NH_3, and Q on $[H_2SO_4]_{crit}$.

4. (12 points) (a) For a particle in the kinetic regime with an initial diameter of D_{p0}, how does D_p change with time if the concentration of condensing vapor molecule is c_∞ far from the particle and c_s is its vapor-phase concentration at the particle surface. (b) If the observed growth rate (diameter) of 5-10 nm particles is 3 nm/hour and H_2SO_4 is assumed to be the only condensing gas (for H_2SO_4, you can assume negligible concentration at particle surface and unity accommodation coefficient) what is the concentration of H_2SO_4 gas? The particle density is 1.5 g/cm^3. T =298 K.

5. (10 points) Calculate the characteristic time for coagulation for: (1) Polluted urban regions with initial number concentrations of 2×10^5 cm^{-3}; (2) Geo-engineered stratospheric aerosol layer with initial number concentration of 200 cm^{-3}. Assume an average coagulation coefficient of 2×10^{-9} cm^3 s^{-1} among these particles.

6. (18 points) Particle dry deposition and wet scavenging rates depend on their sizes, as shown below.

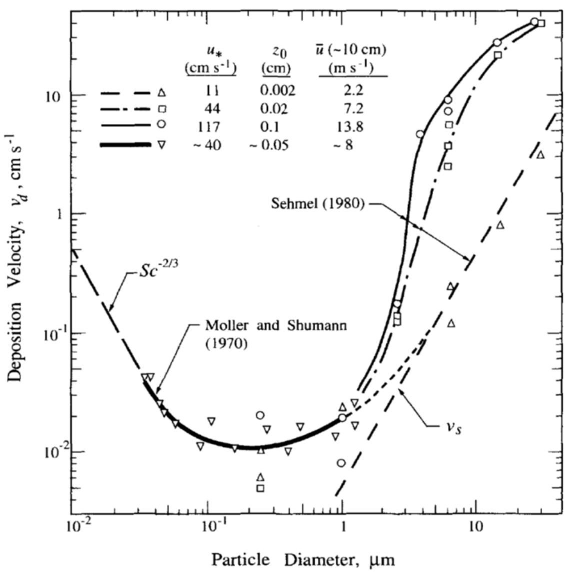

Fig. 1. Particle dry deposition velocity as a function of particle sizes.

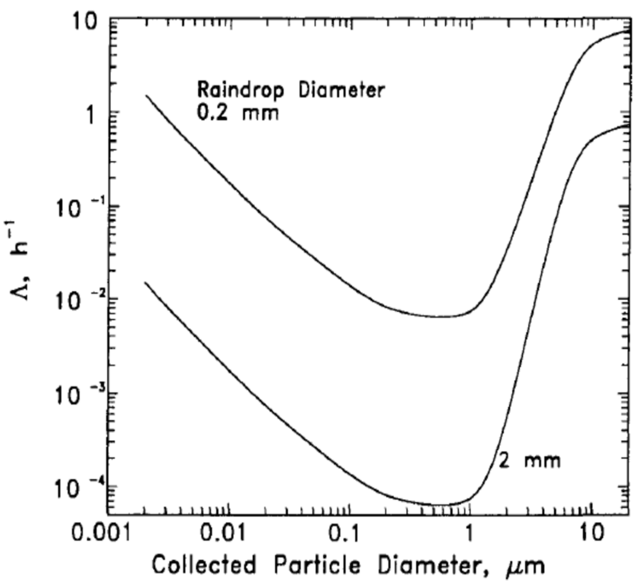

Fig. 2. Scavenging coefficient for monodisperse particles as a function of their diameter collected by monodisperse raindrops with diameters 0.2 and 2 mm assuming a rainfall intensity of 1 mm h^{-1}.

Calculate the lifetimes of particles with diameters of 0.01, 0.5, and 10 μm in the surface layer with depth of 100 m due to (a) dry deposition (using Sehmel curve for larger particles and assuming particles are welled mixed with in the layer), and (b) wet scavenging by rain (assuming droplet diameter of 0.2 mm and rainfall intensity of 1 mm/h).