AOS 580 Aerosol, Cloud, Climate Change

FINAL EXAMINATION

Due by May 16 before 5:00pm.

1. Aerosol Properties

A one kilometer thick aerosol layer is composed of an external mixture of 3 aerosol types of 0.3 µm, 0.6 µm, and 1.2 µmdiameter. The number concentration for particles of each size is 1 x 10^8 particles per m^3, so that the total number concentration is 3 x 10^8 particles per m^3. Particle density is 1500 kg.m^{-3}.

a. What is the mass concentration of the total aerosol? Express your answer in µg.m^{-3}.
b. What is the settling velocity of each particle type? After ten days of travel under clear-sky (no wet deposition) over the ocean (no source of aerosols considered in this problem) what is the mass concentration?
c. Assume the particles have a refractive index m= 1.33 and use the following figure to estimate the extinction efficiency. What are the optical depths at 520 nm before and after 10 days of travel? What is the corresponding fraction of light transmitted through the aerosol layer before and after 10 days of travel?

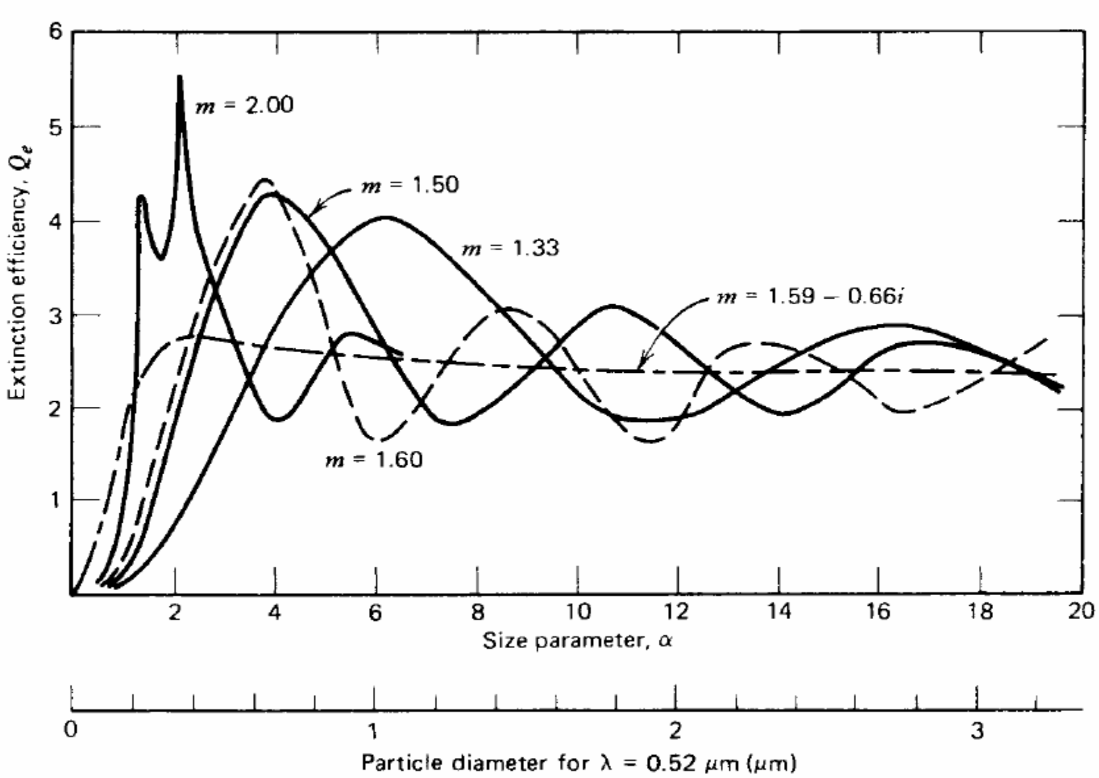

FIGURE 16.2 Extinction efficiency versus particle size for spheres (after Hodkinson, 1966).

2. Sunphotometer data
    a. Explain briefly the method used to calibrate sunphotometer instruments.
    b. Compare optical properties of urban and dust aerosols, using retrieved properties from Almucantar AERONET data shown in Lecture 10.
    c. In what aspect of the retrieval of aerosol extinction profile out of micropulse lidar data, is it useful to have concurrent and collocated sunphotometer data?

3. TOMS data
    a. Is the TOMS aerosol index less or more sensitive to the presence of smoke than of dust at the same altitude and same single scattering albedo?
    b. Is the TOMS aerosol index increasing or decreasing with altitude for absorbing aerosol?
    c. What is the main advantage and disadvantage of retrieving aerosol properties in the near-UV compare to the visible?
4. Mathematical models
    a. Give a mathematical expression of the hydrostatic approximation.
    b. Explain briefly the method of nudging and a reason for its use by atmospheric models.
    c. What is the CFL condition? Is it important for semi-lagrangian scheme?
5. Climate
    a. Why the change of obliquity of the Earth is negligible in term of global radiative forcing but may have been the key element starting the Last Glacial Maximum?
    b. Is there a decrease or an increase of shortwave radiation at the top of the atmosphere (TOA) in presence of an aerosol layer for the following situations :
        i. Dust over ocean
        ii. Dust over ice
        iii. Black carbon over ocean
        iv. Black carbon over clouds

6. Climate simulation
    a. What are ensemble runs of climate models, and what are they used for?
    b. What are the SRES scenarios used for?
    c. By considering only natural forcing, can the climate models reproduce the observed time series of the global mean sea surface temperature? What type of forcing is needed to improve the model results?

Please answer Questions 7 to 10 on a separated piece of paper from the previous questions as they will be corrected by Dr. Yi Ming.

NOTE: Please assume Standard Temperature and Pressure when necessary.

7. For the sake of simplicity, let us group the whole size spectrum of cloud droplets into two bins. The number concentrations of Bin 1 (10 μm) and Bin 2 (40 μm) are 200 and 10 cm^{-3}, respectively. What is the coalescence rate between them? Could you also estimate (to the order of magnitude) how fast coagulation is? When the rates are compared, which microphysical process is more efficient in terms of growing droplets into raindrops? What is the physical explanation?

8. Aerosols affect cloud properties by being activated into droplets.

(1) Could you sketch a typical Kohler curve and explain in words why aerosols in some cases undergo uncontrolled growth and what conditions favor this type of growth?

(2) Obviously the growth cannot continue forever in reality. Could you explain the microphysical process that leads to its termination?

9. As a primary aerosol species mainly resulting from incomplete combustion, black carbon is water-insoluble, and thus cannot act as cloud condensation nuclei in its own right. Here, let us examine two cases:

In the clean case, aerosol is composed entirely of $(NH_4)_2SO_4$ (density: 1740 kg/m^3) with a log-normal size distribution (see the table).

Total Number Concentration (cm^{-3})	*Median Diameter (μm)*	*Geometric Standard Deviation*
120	0.07	2

In the polluted case, black carbon (density: 1000 kg/m^3) emitted from diesel engines is internally mixed with the pre-existing $(NH_4)_2SO_4$ particles and accounts for 20% of aerosol mass at all sizes.

(1) What's the aerosol size distribution in the polluted case?

(2) If the maximum supersaturation in a cloud is 0.05%, what is the change in cloud droplet number concentration due to black carbon emissions? Can you briefly explain how black carbon affects clouds?

10. After a dreadful semester, it is time to set your sprit free. Remember I challenged you at the beginning of the semester to come up with your own climate feedback loop. Now it is time. An example is the CLAW hypothesis. To make things more interesting, you will be awarded extra credits for bringing in some kind of human activity. For instance, people tend to use air conditioning more in a hot summer, thus hike up the consumption of electricity, etc.