Candidates are admitted to the examination room ten minutes before the start of the examination. On admission to the examination room, you are permitted to acquaint yourself with the instructions below and to read the question paper.

Do not write anything until the invigilator informs you that you may start the examination. You will be given five minutes at the end of the examination to complete the front of any answer books used.

April 2012

Answer Book
Data Sheet
Any bilingual English language dictionary permitted
Only Casio-fx83 calculators are permitted

Final Examination for MSc

Course in Applied Meteorology
Course in Atmosphere, Oceans and Climate

MTMG38

Remote Sensing

Two hours

Answer **ANY TWO** questions

The marks for the individual components of each question are given in [ ] brackets. The total mark for the paper is 100.

1.

(a) (i) The rainfall rate, R (mm/hr), is often estimated using an equation of the form $Z = a \cdot R^b$, where Z is the radar reflectivity factor in $mm^6\ m^{-3}$. There are N raindrops of size D per cubic meter. If all of the drops are identical and they have a terminal velocity $v(D) \propto D^{0.67}$, determine the value of the constant b.

[6 marks]

(ii) Using an empirical relationship $Z = 200 \cdot R^b$ and the value derived from (i), estimate the radar reflectivity (in dBZ) for a precipitating system with rain rate 50 mm/hr.

[6 marks]

(iii) In addition to uncertainty in calibration, Z-R relationships and attenuation (from rain, cloud, atmosphere, etc.), list and briefly describe two other sources of errors in surface rain rate estimates from radar signal.

[8 marks]

(iv) Consider a rain cloud in which the concentration of raindrops is 100 drops per cubic meter. Assume that all raindrops are 3.5 mm in horizontal diameter, and have axis ratios (horizontal/vertical) of 1.1. If the radar transmits vertically polarized pulses and receives vertical polarization as well, calculate the radar reflectivity factor in dBZ. [Hints: $Z = \sum_{UnitVolume} D_i^6$]

[5 marks]

Question 1 continued overleaf

Question 1 continued

(b) Atmospheric transmittance, single scattering albedo and asymmetry factor of cloud droplets at wavelengths of 400–2200 nm are shown in Fig. 1.

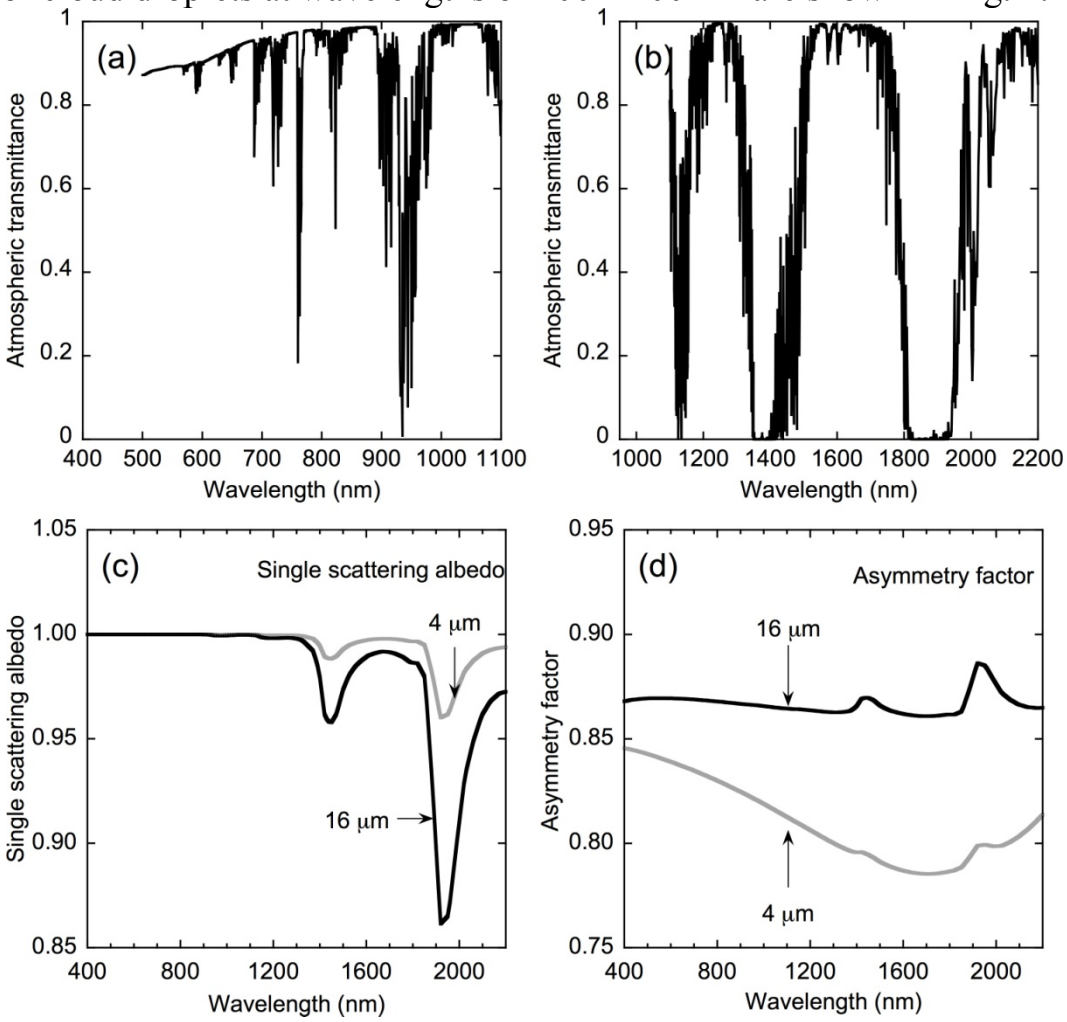

Fig. 1. (a) Atmospheric transmittance at wavelengths of 400–1100 nm. (b) Same as (a), but for wavelengths of 1100–2200 nm. (c) and (d) are single scattering albedo and asymmetry factor of cloud droplets, respectively. Two curves in each plot represent cloud droplet effective radius of 4 and 16 μm.

Question 1 continued overleaf

Question 1 continued

(b) Suppose you are asked to build a spaceborne passive radiometer for retrieving cloud optical depth and droplet size. Due to limited budget, you could only select two wavelengths for your radiometer.

(i) Identify what type of radiation measurements your radiometer will take, and explain what physical processes makes it possible for you to take such measurements?

[2 marks]

(ii) Select two wavelengths from 400–2200 nm for your radiometer and provide your reasons.

[8 marks]

(iii) Sketch the relationship between your measured variable and cloud optical depth for two droplet sizes. Use the sketch to describe the physical principle of how cloud properties can be retrieved from your measurements.

[8 marks]

(iv) If you turn your radiometer upside down and deploy it on the ground, explain which platform (i.e., spaceborne and ground-based) might help achieve higher accuracy in retrieved cloud droplet size.

[7 marks]

2.

(a) The Aerosol Robotic Network (AERONET) operates a sunphotometer at Chilbolton in the UK, which measures transmittance at wavelengths of 440, 675, 870, and 1020 nm. When this sunphotometer was calibrated with the Langley plot method at Mauna Loa Observatory in Hawaii, the voltage extrapolated to the top of the atmosphere was $V_0 = 2.0$ and 1.0 for 440 and 870 nm, respectively. The elevation of the Chilbolton site is 90 meters.

One day when the solar zenith angle is 30°, the sunphotometer measures a voltage of V = 0.2 and 0.5 at wavelengths of 440 and 870 nm, respectively.

(i) Rayleigh optical depth (τ_{Ray}), a function of wavelength (λ; μm) and altitude (z; km), can be parameterized as:

$$\tau_{Ray}(\lambda,z) \approx 0.0088 \cdot \lambda^{b}\left[e^{-0.1188z-0.00116z^{2}}\right] \quad \text{(Eq. 1)}$$

What is the value of coefficient b? Calculate Rayleigh optical depth at wavelengths of 440 and 870 nm.

[6 marks]

(ii) Calculate aerosol optical depths at these two wavelengths.

[10 marks]

(iii) If we suppose that two primary sources of aerosols for Chilbolton are smoke and dust, which type of aerosols is more likely for this particular day? State your reasons.

[9 marks]

Question 2 continued overleaf

Question 2 continued

(b) Figure 3 shows a histogram of brightness temperatures from Landsat Thematic Mapper (TM) measurements in the thermal emitted band (10.4 – 12.5 μm) for a cloud scene during the FIRE marine stratocumulus experiment on 7 July 1987 (*Cahalan and Joseph*, 1989). This stratocumulus cloud scene contained 512 x 512 pixels with a spatial resolution of 0.12 km.

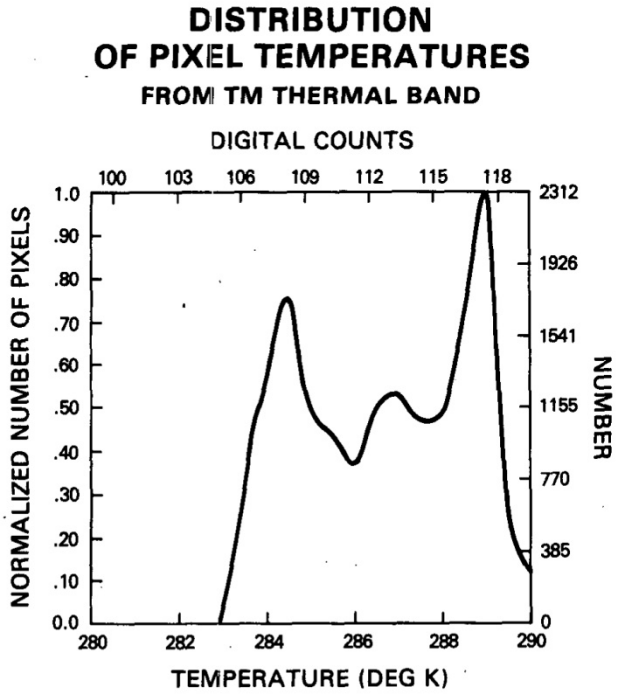

Fig. 3. The distribution of pixel temperatures from Landsat measurements during the FIRE experiment in 1987.

(i) Explain and provide your best estimates for cloud top temperature and sea surface temperature.

[10 marks]

(ii) For a pixel that has a brightness temperature of 286 K, estimate cloud fraction for that particular pixel. Please clearly detail your retrieval method and state your reasoning.

[15 marks]

3.

(a) Cloud optical depth is one of the most fundamental cloud properties determining the Earth's radiative energy balance. To estimate cloud optical depth from surface measurements, the atmospheric science community has widely used flux measurements from both broadband and narrowband radiometers.

(i) On a clear day, when solar zenith angle (*SZA*) was 40°, the direct normal flux reading (i.e., radiation from the direction of the sun) from a narrowband radiometer was 0.83 $Wm^{-2}nm^{-1}$ at 440 nm wavelength. Later on when solar zenith angle was 75°, the direct normal flux reading decreased to 0.30 $Wm^{-2}nm^{-1}$. Suppose that atmospheric properties remain the same during the day and the air mass (m) can be approximated as $m = 1/\cos(SZA)$. Determine the atmospheric optical depth and the direct normal flux at the top of the atmosphere in $Wm^{-2}nm^{-1}$.

[12 marks]

Question 3 continued overleaf

(ii) On a cloudy day, the measured total downward horizontal flux is 0.35 $Wm^{-2}nm^{-1}$ at a solar zenith angle of 45°. At the same time, aircraft in-situ measurements show that the cloud layer is 500 m thick, and it has a liquid water path of 100 g m^{-2} and a monodisperse cloud drop distribution. Based on in-situ measurements along with Fig. 4, estimate cloud droplet size in **μm**. [Any equation used here needs derivations to prove your understanding.]

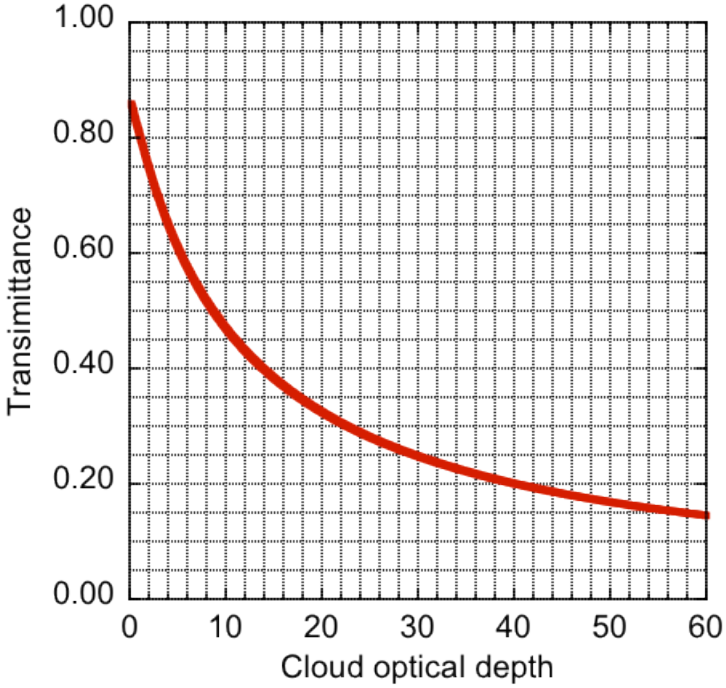

Fig. 4. Plot of transmittance vs. cloud optical depth at 440 nm for a given solar zenith angle of 45°, assuming that the underlying surface is black.

[14 marks]

(iii) For this cloudy day, estimate the direct normal flux in $Wm^{-2}nm^{-1}$ and state your reasoning.

[2 marks]

Question 3 continued overleaf

Question 3 continued

(b) (i) Sketch the relationships between absorption property of liquid droplets/ice particles and rain rate, using 19.35 and 85.50 GHz as examples. Summarize key points shown in your plot.

[5 marks]

(ii) Sketch the relationships between scattering property of liquid droplets/ice particles and rain rate, using 19.35 and 85.50 GHz as examples. Summarize key points shown in your plot.

[5 marks]

(iii) Based on your plots and key points in (i) and (ii), summarize how you can estimate surface rain rate over oceans and land from spaceborne microwave radiometer measurements (e.g., TRMM, SSM/I, AMSR, etc.). Make sure you outline the strength and limitations of your retrieval methods.

[12 marks]

(End of Question Paper)