On admission to the examination room, you should acquaint yourself with the instructions below. You <u>must</u> listen carefully to all instructions given by the invigilators. You may read the question paper, but must <u>not</u> 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.

DO NOT REMOVE THIS QUESTION PAPER FROM THE EXAM ROOM.

April 2015 **MTMG38/ 2014/15 A001**

Answer Book

Bilingual English language dictionary permitted
Non-programmable calculator is permitted

UNIVERSITY OF READING

Remote Sensing (MTMG38)

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) Sketch the relationship between particle size, radiation wavelength and scattering behaviour for atmospheric particles. Your sketch must include the following information:
   - Use radiation wavelength (ranging from 0.1 μm to 10 cm) as horizontal-axis, and note the corresponding spectral regions from ultraviolet, visible, near infrared, thermal infrared, to microwave;
   - Use particle radius (ranging from 0.1 nm to 1 cm) as vertical-axis, and note the corresponding particle types from air molecules, aerosol, cloud, rain drops to hail.
   - Label the corresponding regimes (including negligible scattering regime) based on size parameter.

[20 marks]

(b) For radar at 37GHz detecting clouds, which scatter regime can be applied? Please show your calculation about size parameter to support your conclusion.

[8 marks]

(c) From a recent marine field campaign between Los Angeles and Hawaii, a 37GHz ground-based radar has been used to derive a Z–R relationship $Z = 1.45\ R^{0.69}$ to estimate drizzle rate (mm d^{-1}) at cloud base height. At 20:20 UTC on 2nd June 2013, a rain layer was observed, which had a geometrical thickness of 500 m and reflectivity of –5 dBZ at cloud base height of 700 m. Please use this Z–R relationship to estimate drizzle rate (in mm d^{-1}) at 20:20 UTC.

[10 marks]

(d) For the same case as c), coincident measurements at 37GHz from TRMM Microwave Imager (TMI) were also collected. The incident angle of TMI is 53°. The ocean emissivity is 0.6; the sea surface temperature and rain layer temperature are 300 K and 297 K, respectively. Additionally, the extinction coefficient of 0.0003 km^{-1} is found at a given rate derived from (c). Estimate the brightness temperature that TMI should measure, and explain which process (e.g. emission from the surface, emission upward from the rain layer, and emission from the rain layer downward reflected off surface) dominates.

[12 marks]

[Total 50 marks]

2. (a) Table 1 lists a number of bands and wavelengths of The Moderate Resolution Imaging Spectroradiometer (MODIS). Please choose the best combination of two wavelengths for retrieving cloud optical depth and effective radius. Your answer must include the following:

- A sketch of relationship between reflectance and various combinations of cloud optical depth and effective radius, using reflectances at the two chosen wavelengths as axes
[5 marks]

- Explanations of the underlying retrieval principle;
[10 marks]

- Explanations of why the chosen wavelengths are superior to others.
[5 marks]

Table 1. MODIS bands and wavelengths.

Band	Wavelength (nm)
1	620–670
2	841–876
3	459–479
4	545–565
6	1628–1652
7	2105–2155

(b) Suppose an exponential absorber profile with a monochromatic, constant mass absorption coefficient *κ*. Prove that the peak of the weighting function for a nadir-reviewing sounding occurs at the altitude where the optical depth is 1.

[Hint: Start with $\sigma_{ext}(z) = \kappa\rho_0 e^{-z/H}$, where volume extinction coefficient σ_{ext} depends on altitude *z*, mass absorption coefficient *κ*, absorber density ρ_0 at surface (z=0) and scale height *H*.]

[15 marks]

(c) Figure 1 is the weighting function calculated for an instrument that capitalises on a strong absorption band at 60 GHz. Which of the following is this instrument likely to be, The Advanced Microwave Scanning Radiometer for EOS (AMSR-E), The Advanced microwave sounding unit (AMSU), The Atmospheric Infrared Sounder (AIRS) or a ground-based microwave radiometer? Please explain your reasoning.

[4 marks]

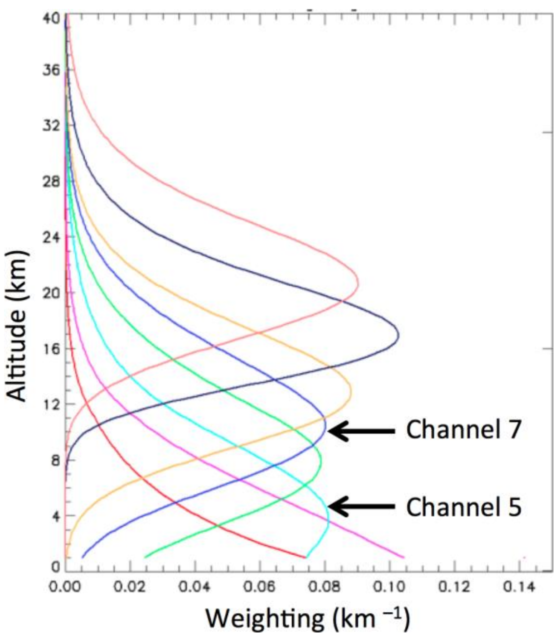

Figure 1. Weighting functions for an instrument of interest.

Focusing on Channel 5 and Channel 7, identify which channel is more likely to be 53.6 GHz and which one is more likely to be 54.94 GHz? Please explain your reasoning.

[6 marks]

Identify and explain which atmospheric parameter Channel 5 and Channel 7 can help retrieve.

[5 marks]

[Total 50 marks]

3. (a) On a cloudless day, measurements of downwelling direct normal irradiance at location XX were collected, as shown in Table 2. Using this data table, estimate aerosol optical depths at 415 and 532 nm wavelengths.

[Hint: Approximate air mass by 1/cos(solar zenith angle).]

Table 2. Downwelling direct normal irradiance data.

Solar zenith angle (°)	Direct normal irradiance ($W\ m^{-2}\ nm^{-1}$) 415 nm	532 nm
40	0.968	1.286
60	0.942	1.254
75	0.874	1.170

[18 marks]

(b) At the same location, there was a coincident CALIPSO (the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations) overpass. To determine aerosol type and retrieve aerosol properties from CALIPSO, six aerosol models have been built using a cluster analysis of a multiyear ground-based dataset. Among these six aerosol models, information on three models is listed in Table 3, and their corresponding size distributions are shown in Fig. 2. Specifically, the dust model includes data from African/Asian dust, desert dust locations, and a bit of smoke mixtures. The polluted continental model includes data from urban–industrial locations, while the clean marine model includes data from oceanic sites and experiments near Hawaii.

Please match the size distributions shown in Fig. 2 with the aerosol models in Table 3, and briefly explain your reasoning.

[12 marks]

Table 3. Lidar ratio (the extinction-to-backscatter ratio) for the CALIPSO aerosol models.

Aerosol model	Lidar ratio at 532 nm(sr)
Dust	40
Polluted continental	70
Clean marine	20

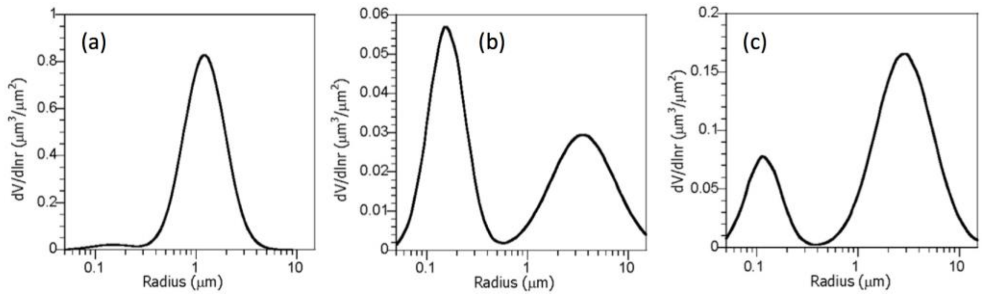

Figure 2. Size distribution of the CALIPSO aerosol models (Omar et al., 2009)

(c) Based on the results derived from (a) and information listed in Table 2, identify the most appropriate aerosol model for the coincident CALIPSO overpass. Please explain your reasoning.

[10 marks]

(d) Using proper lidar ratio concluded from the results in (a)–(c), identify aerosol layers in the coincident CALIPSO overpass (shown in Fig. 3) and estimate the corresponding aerosol optical depth.

[For this calculation, there is no need to take very accurate readings from Fig. 3; labels along with the colour bars shown should be sufficient. For example, take reading at $1.0\text{x}10^{-1}$, $1.0\text{x}10^{-2}$, $5.0\text{x}10^{-3}$, $1.0\text{x}10^{-3}$, and$1.0\text{x}10^{-4}$ km^{-1} sr^{-1}].

[10 marks]

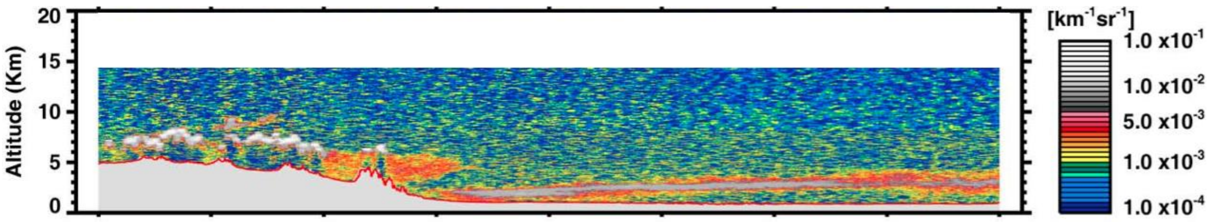

Figure 3. CALIPSO cross-section measurements of backscatter intensity (km^{-1} sr^{-1}) at 532 nm wavelength (image taken from Chen et al., 2010).

[Total 50 marks]

(End of Question Paper)