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 2009

Answer Book
Data Sheet
Calculators and programmable calculators are permitted

THE UNIVERSITY OF READING

MSc/Diploma
Course in Applied Meteorology
Course in Atmosphere, Ocean and Climate

PAPER 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) Write an expression for the radiance emerging from an atmosphere in local thermodynamical equilibrium as a function of the radiance emerging from the surface, the transmittance of the atmosphere and the Planck function. [10 marks]

(b) A remote sensing instrument measures the radiance emerging from the atmosphere at a given wavelength λ. Assuming an isothermal atmosphere, write an expression for the emerging radiance in the case when the surface-to-space transmittance at λ is zero. [10 marks]

Question 1 continues overleaf

Question 1 cont'd

(c) A remote sounding measurement y_i (i=1,…,m) is related to an unknown quantity x(z) at height z by

$$y_i = \int_0^\infty K_i(z)x(z)dz + \varepsilon_i$$

where ε_i is the observation error and $K_i(z)$ is a known function.

(i) Explain the meaning of $K_i(z)$ and its importance for determining x(z)

[10 marks]

(ii) Consider a set of atmospheric layers of depth Δz_j each centred on z_j. Write an expression for y_i as a function of $x(z_j)$. If $K_i(z_j)$ and $x(z_j)$ are the components of a vector **k** and **x**, respectively, find an expression for y_i as a function of **k** and **x**.

[10 marks]

(iii) Assume $K_i(z)$ is given by

$$K_i(z) = \begin{cases} 0 & z \le z_i - 1/a_i \\ a_i^2(z - z_i) + a_i & z_i - 1/a_i < z \le z_i \\ a_i^2(z_i - z) + a_i & z_i < z \le z_i + 1/a_i \\ 0 & z > z_i + 1/a_i \end{cases}$$

and that we need to estimate the value of x(z) over a 2 km deep layer centred on 1 km. Find suitable values of a_i and z_i to perform this task, explain your choice and sketch the resulting $K_i(z)$.

[10 marks]

2

In the following you may use the result that the inverse of a non-singular 2 x 2 matrix **A** is:

$$\mathbf{A}^{-1} = \begin{pmatrix} a & b \\ c & d \end{pmatrix}^{-1} = \frac{1}{ad-bc}\begin{pmatrix} d & -b \\ -c & a \end{pmatrix}$$

(a) Consider a remote sounding measurement vector $\mathbf{y} = (y_1, y_2, y_3)^T$ related to an unknown vector quantity $\mathbf{x} = (x_1, x_2)^T$ by

$$y_1 = x_1 + \varepsilon_1$$

$$y_2 = x_1 + x_2 + \varepsilon_2$$

$$y_3 = x_2 + \varepsilon_3$$

where $\boldsymbol{\varepsilon} = (\varepsilon_1, \varepsilon_2, \varepsilon_3)^T$ is the measurement error vector whose covariance is $\mathbf{S}_\varepsilon$. A short-range forecast at observation location and time prescribes the value of **x** equal to $\mathbf{x}_a = (x_{a1}, x_{a2})$ with error covariance $\mathbf{S}_a$. If we write $\mathbf{y} = \mathbf{Kx} + \boldsymbol{\varepsilon}$, the maximum a posteriori estimate of **x** is given by $\hat{\mathbf{x}} = (\mathbf{K}^T\mathbf{S}_\varepsilon^{-1}\mathbf{K} + \mathbf{S}_a^{-1})^{-1}(\mathbf{K}^T\mathbf{S}_\varepsilon^{-1}\mathbf{y} + \mathbf{S}_a^{-1}\mathbf{x}_a)$.

(i) Find $\hat{\mathbf{x}}$ in the case when $\mathbf{S}_\varepsilon = \mathbf{I}$, $\mathbf{S}_a = 2\mathbf{I}$ (where I is the identity matrix), as a function of **y** and $\mathbf{x}_a$. Determine the relative weight of the components of **y** and $\mathbf{x}_a$ on $\hat{\mathbf{x}}$.

[15 marks]

(ii) The error covariance of $\hat{\mathbf{x}}$ is given by $\hat{\mathbf{S}} = (\mathbf{K}^T\mathbf{S}_\varepsilon^{-1}\mathbf{K} + \mathbf{S}_a^{-1})^{-1}$. Write $\hat{\mathbf{S}}$ first in the case when $\mathbf{S}_\varepsilon = \mathbf{I}$, $\mathbf{S}_a = 2\mathbf{I}$ and then when $\mathbf{S}_\varepsilon = \mathbf{I}$, $\mathbf{S}_a = \begin{pmatrix} 2 & 1 \\ 1 & 2 \end{pmatrix}$. Determine whether the standard deviations of the estimate are smaller in the first or in the second case and explain why.

[10 marks]

Question 2(a) continued overleaf

(iii) Explain why the radar return from a precipitation target fluctuates from one transmitted pulse to the next transmitted pulse and how the rate at which the return signal fluctuates is a measure of the 'Doppler width' of the target. [7 marks]

(iv) Four phenomena are generally identified which lead to the return having a finite Doppler width. Briefly describe three of them. [12 marks]

(v) For the three components you have described in iv) explain why the magnitudes of each component might be different when the radar beam is pointing a) vertically or b) horizontally. [6 marks]

3

(a) The maximum unambiguous velocity, V_{max}, for a radar operating at a wavelength λ, and a time between transmitted pulses of t_s , is given by:

$$V_{max} = \lambda / \; 4 \; t_s,$$

Explain carefully how this limit arises. [12 marks]

(b) An operational precipitation radar has a maximum range of 150km and a wavelength of 5.6cm. What is the maximum unambiguous velocity it can detect? What will the performance be with this wavelength for measuring Doppler velocity and estimating precipitation accurately out to a range of 300km? [14 marks]

Question 3 continues overleaf

Question 3 cont'd

(c) Tornado chasing programmes on television often show images of the 'Doppler on Wheels' which operates with a 3cm wavelength radar and a 2m dish. The funnel clouds are very narrow. How close to the tornado must the truck be if it is to measure velocities in the funnel cloud with a resolution of 25m, and what would be the maximum unambiguous velocity? [14 marks]

(d) What would be the advantages and disadvantages of operating the 'Doppler on Wheels' using a 3.2mm radar? [10 marks]

(End of Question Paper)