You are allowed ten minutes before the start of the examination 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 2002 **DE 0567**

Data Sheet
1 x Answer Book
Calculators are permitted

THE UNIVERSITY OF READING

MSc/Diploma
Course in Applied Meteorology
Course in Weather Climate and Modelling

MSc in Mathematics and Numerical Modelling of the Atmosphere and Oceans

PAPER MTB50

Boundary Layer Meteorology and Micrometeorology

One and a half hours

Answer QUESTION 1 and **one** other question

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

1.

(a) Explain the meaning of all the symbols in the surface energy balance equation

$$R_n - G = H + \lambda E \, .$$

[5 marks]

(b) Sketch the diurnal variation of all the terms in the surface energy balance for a surface covered in short grass in cloud-free conditions at mid latitudes. State clearly any assumptions you make and indicate typical values. Describe how the balance shifts throughout the course of the day.

[15 marks]

(c) Explain how the diurnal variation of the surface energy balance for short grass drives the diurnal variation in the atmospheric boundary layer under ideal cloudless conditions. Use sketch diagrams to illustrate (i) this cycle and (ii) the vertical thermodynamic structure of the boundary layer at key stages in the cycle. Annotate your sketch diagrams with typical values of temperature and boundary layer depth.

[15 marks]

(d) Explain how your answers to parts (b) and (c) would differ if the surface was an urban area rather than a vegetated surface.

[15 marks]

2.

(a) Explain what is meant by the roughness length, z_0, of a surface and the friction velocity, u_*, and give a typical range of values for a grass covered surface.

[5 marks]

(b) Describe how the Monin-Obukhov scaling parameter, $\zeta = z/L$, is derived stating clearly any assumptions that you make. Hence, explain why the wind shear in a non-neutral surface layer can be written as

$$\frac{dU}{dz} = \frac{u_*}{\kappa z}\phi_m\left(\frac{z}{L}\right), \qquad (1)$$

where the Monin-Obukhov length is $L = -\frac{1}{\kappa}\frac{u_*^3}{(g/\theta_s)(H/\rho c_p)}$.

[10 marks]

(c) Explain the physical meaning of the Monin-Obukhov length L.

[5 marks]

(d) Describe the instruments and measurements required to estimate ϕ_m. State clearly any assumptions that need to be made and quantify any assumptions about the nature of the experimental site.

[15 marks]

(e) In stable conditions, the Monin-Obukhov function is given by

$$\phi_m = 1 + 5\frac{z}{L}.$$

Use this result together with equation (1) to obtain the variation of wind speed with height in a stable surface layer.

Over a grass-covered surface the 10m wind speed is measured to be $2ms^{-1}$ and the surface temperature is 5^oC. Calculate the heat flux required for the wind speed at 10m to deviate by more than $0.5ms^{-1}$ from the neutral value, assuming that the friction velocity and surface temperature remain constant.

[15 marks]

3.

(a) Define the gradient Richardson number Ri and explain how it can be used to diagnose dynamical stability.

[5 marks]

(b) State the main assumptions required for the atmospheric boundary layer to be described by the Ekman model. The winds in the Ekman model satisfy the equations

$$-fv = K_m \frac{d^2u}{dz^2}, \qquad f(u - U_g) = K_m \frac{d^2v}{dz^2},$$

which have the solution

$$u = U_g[1 - \exp(-z/h)\cos(z/h)], \qquad v = U_g \exp(-z/h)\sin(z/h),$$

with $h = (2K_m/f)^{\frac{1}{2}}$. What does h represent physically? For typical values of the parameters estimate a typical value for K_m. How does this value compare with the molecular viscosity of air? Sketch the vertical profiles of the two components of the mean wind predicted by the model. How do these predictions compare with observed values?

[20 marks]

(c) Explain, with reference to the Ekman model described above, how, and under what conditions, the nocturnal jet is formed.

[15 marks]

(d) Why is the nocturnal jet not observed close to the ground or in the free troposphere?

[10 marks]

End of Question Paper