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 2013 **MTMG49**

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

UNIVERSITY OF READING

Boundary Layer Meteorology and Micrometeorology (MTMG49)

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) Using dimensional analysis, describe how the Monin-Obukhov stability parameter ζ = z/L is derived, stating clearly any assumptions you make. Note that the Obukhov length is given by

$$L = -\frac{1}{\kappa}\frac{u_*^3}{(g/\theta_s)\left[H/(\rho c_p)\right]}$$

where the symbols have their usual meanings, and κ = 0.41.

[8 marks]

(b) The following measurements are made over a large expanse of short grass during a 30 minute period:

Height (m)	**Potential temperature (K)**	**Wind speed (m s^{-1})**
2	288.5	2.60
4	288.1	3.00

Noting that $Ri = (g/\bar{\theta})(d\bar{\theta}/dz)/[(d\bar{u}/dz)^2 + (d\bar{v}/dz)^2]$ is the gradient Richardson number, show that at a height of 3 m, the bulk Richardson number is approximately –0.17.

[8 marks]

(c) The mean wind shear in a non-neutral surface layer can be written as

$$\frac{d\bar{u}}{dz} = \frac{u_*}{\kappa z}\phi_m\left(\frac{z}{L}\right).$$

What instruments would be required to determine the functional form of ϕ_m (z/L) and in what atmospheric conditions would they need to be deployed?

[11 marks]

(d) Experiments have revealed that in unstable conditions a good approximation is $\phi_m = \left(1 - 16z/L\right)^{-1/4}$. Estimate the *friction velocity* u_* and the *surface sensible heat flux* H for the case above. You may make use of the fact that, in unstable conditions, $Ri \approx z/L$.

[13 marks]

(e) For the case above, state the primary mechanism for (i) turbulence generation at 3 m, (ii) turbulence destruction at 3 m, and (iii) turbulence generation at 60 m, in each case giving your reasons.

[10 marks]

2.

(a) The equations governing the horizontal momentum of air in the boundary layer in mid-latitudes may be written as follows, where the geostrophic wind is aligned in the *x* direction:

$$\frac{\partial \overline{u}}{\partial t} = f\overline{v} - \frac{\partial \overline{u'w'}}{\partial z} \tag{1}$$

$$\frac{\partial \overline{v}}{\partial t} = -f\left(\overline{u} - u_g\right) - \frac{\partial \overline{v'w'}}{\partial z} \tag{2}$$

With reference to the equations above, outline the main purpose of a *turbulence closure scheme* and what is meant by *first-order closure*. Give the main reasons why turbulence is important in boundary layer meteorology.

[14 marks]

(b) State the main assumptions required for the wind profile in the atmospheric boundary layer to be described by the *Ekman model*, explaining, where appropriate, the effect of each assumption on the various terms in equations (1) and (2) above.

[6 marks]

(c) Sketch a hodograph of the wind profile predicted by the *Ekman model* and describe how the predicted wind profile compares with observations, stating the main limitation of the model.

[10 marks]

(d) The depth of the Ekman boundary layer is $h = \pi\sqrt{2K_m / f}$. Assuming typical daytime boundary layer characteristics, estimate the value of K_m. By comparing this with the value for molecular viscosity $\nu = 10^{-5}$ m^{2}s^{-1}, explain why the mechanism for the friction in the boundary layer must be turbulence.

[10 marks]

(e) The friction velocity at the surface is $u_* = 0.3 \text{ m s}^{-1}$. If we assume that the turbulent momentum flux falls to zero at the top of the boundary layer, estimate the magnitude of the contribution of friction to the *mean acceleration of the horizontal wind* in the boundary layer. You may need to refer to equations (1) and (2) above.

[10 marks]

3.

(a) The following equation describes radiative processes at the Earth's surface

$$R_n = S_{\downarrow}(1-\alpha) + \varepsilon(L_{\downarrow} - \sigma T_S^4).$$

Explain the meaning of all the symbols.

[7 marks]

(b) Measurements of R_n are made at the same time in a city and in a rural area nearby. By considering the properties of the surface and air for both the urban and the rural areas, explain the differences in magnitude over each surface of each quantity on the right-hand side of the equation above.

Is there a significant difference in the overall magnitude of R_n? Briefly justify your answer.

[13 marks]

(c) Air is flowing from a rural to an urban surface. The change in surface roughness leads to the growth of an internal boundary layer over the urban surface. Estimate the maximum depth h of the urban internal boundary layer using

$$\frac{h}{z_0} = 0.38\left(\frac{x}{z_0}\right)^{0.8}$$

where z_0 is the roughness length and the fetch of the urban surface is x = 10 km. Use a reasonable estimate of the urban roughness length.

The flow then adjusts back to a rural surface. Calculate the fetch of rural surface required to grow an internal boundary layer to the same depth as the urban internal boundary layer.

[10 marks]

(d) Consider a similar situation as in (c), on a cloudless night with light wind conditions. Sketch the development of the urban and rural boundary layers with distance. Consider chimney stacks both upstream of and within the urban area, and describe qualitatively how the pollution will be dispersed with distance downstream from each source, taking into account any dynamical or thermodynamical processes affecting the boundary layer structure.

[10 marks]

(e) What were the chemical processes and meteorological conditions leading to the “London Smogs” of December 1952? Consider the main pollutant sources at the time in your answer.

Which key measures were implemented in the Clean Air Act to avoid recurrence of such smogs?

[10 marks]

[End of Question paper]