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 2010

Answer Book
Data Sheet

Any bilingual English language dictionary permitted
Calculators and programmable calculators are permitted

UNIVERSITY OF READING

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

MSc in Mathematics and Numerical Modelling of the Atmosphere and Oceans

PAPER MTMG49

Boundary Layer Meteorology and Micrometeorology

One and a half 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) Describe , using a sketch diagram, how the depth and layering of the boundary layer vary throughout a diurnal cycle under relatively cloud-free mid-latitude conditions. Mark on your diagram typical values of boundary layer depth.

[15 marks]

(b) Sketch the dependence of turbulent spectral energy density *E(k)* on wavenumber *k*. Mark on your sketch three important regions of the spectrum and explain which processes are acting in each one.

How does the shape of the spectrum change between noon and mid-night? Include a description of the change in the nature of the turbulence in your answer.

[15 marks]

(c) The dynamic stability can be quantified using the Monin-Obukhov stability parameter $\zeta = z/L$, where the Obukhov length L is given by

$$L = -\frac{u_*^3/k}{\frac{g}{\theta}\frac{H}{\rho c_p}}$$

What does ζ tell us about the production of turbulence, and how does it vary under different atmospheric conditions?

What is the usual physical interpretation of L?

[10 marks]

(d) Using the equation above, estimate values of L for cloudless, calm conditions for noon and midnight. How would the values change if conditions became cloudy in either case?

[10 marks]

2

(a) The full surface energy balance equation is given by

$$\frac{dQ}{dt} = R_n - G - H - \lambda E$$

Explain the meaning of each of the terms.

[10 marks]

(b) A farmer in an arid region of Spain is trying to estimate the amount of water needed to irrigate a crop during summer. Climatologically, the daily average value of R_n is 250 W m^{-2}. Using the equation above, and stating any assumptions you make, estimate the irrigation rate in units of mm per day to compensate for evaporation.

[15 marks]

(c) The Carson model of the convective boundary layer gives the following expression for the height *h(t)* of the boundary layer as a function of time *t*:

$$h(t) = \sqrt{\frac{2(1+2E)}{\rho c_\rho \gamma} \int_0^t H(0) dt}$$

This model describes growth of the convective boundary layer by entrainment. Describe which heat fluxes are responsible for controlling the boundary layer depth, and how they are related. In doing so you should explain the meaning of the terms *E*, γ and *H(0)*.

Assuming *H(0)* increases linearly from zero at dawn *(t=0)* at a rate of β, derive an equation for the evolution of *h(t)*. For typical values of $\beta = 0.015 W m^{-2} s^{-1}$, $\gamma = 3.3 \times 10^{-3} K m^{-1}$, E = 0.21, thus calculate the boundary layer depth at 08:00 given that sunrise is at 06:00.

[25 marks]

3

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

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

Explain the meaning of all the symbols.

Measurements of R_n are made on the same day in a city and in a rural area nearby. By considering the properties of the surface and air for both the urban and rural areas, explain the differences in magnitude of each component of R_n measured over each surface.

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

[20 marks]

(b) 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 *x* of urban surface is 5km. Use a reasonable estimate of the urban roughness length.

The flow then adjusts back to the 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.

Hence, sketch the development of each internal boundary layer 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.

[20 marks]

Question 3 continued overleaf

Question 3 continued

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

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

[10 marks]

(End of Question Paper)