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 2012 **Answer Book**
Data Sheet
Any bilingual English language dictionary permitted
Only Casio-fx83 calculators are permitted

Final Examination for MSc

Course in Applied Meteorology
Course in Atmosphere, Oceans and Climate
Course in Data Assimilation and Inverse Modelling in Geosciences
Course in Applied Meteorology and Climate with Management

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) Outline the two main physical processes that determine the thermodynamic structure and growth of the daytime convective boundary layer over land. Sketch the vertical profile of potential temperature that emerges, and its evolution in time.

[5 + 7 marks]

(b) The evolution of turbulent kinetic energy (TKE) per unit mass, e, is given by

$$\frac{De}{Dt} = -\overline{u'w'}\frac{d\bar{u}}{dz} + \frac{g}{\theta_0}\overline{w'\theta'} - \frac{d}{dz}\overline{w'e} - \frac{1}{\rho}\frac{d}{dz}\overline{w'p'} - \varepsilon$$

For each of the five terms on the right hand side of the above equation, give a brief physical interpretation.

[10 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

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

What does ζ tell us about the production of turbulence? Describe the physical circumstances in which ζ is (i) large and negative (ii) large and positive (iii) small in magnitude (iv) zero.

[5 marks]

(d) The wind shear in the surface layer in stable conditions is given by

$$\frac{d\bar{u}}{dz} = \frac{u_*}{\kappa z}\left(1 + 5\frac{z}{L}\right)$$

Assuming that conditions are steady use the TKE budget to calculate the dissipation rate at 3m if $u_* = 0.1$ ms^{-1} and $\overline{w'\theta'} = -10^{-2}$ ms^{-1}K. State any assumptions you make.

[8 marks]

(e) Describe the physical and chemical processes affecting ozone production throughout the daily cycle. Compare ozone concentrations in the city centre with those at a rural site downstream of a city. Make a reference to the urban heat island.

[10+4+1 marks]

2.

(a) The surface energy balance can be written as

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

Explain the meaning of all the symbols in the above equation, paying attention to the sign convention.

The Bowen ratio, B is defined as $B = H/(\lambda E)$

Derive an expression for H in terms of R_n, G and B.

Give typical values of B for the following surfaces: (i) rural, (ii) urban, (iii) ocean, (iv) desert.

[7 + 4 + 4 marks]

(b) The Carson model predicts that the height, *h,* of the convective boundary layer at time *t* after sunrise is given by

$$h(t) = \left(\frac{2(1+2E)}{\rho c_p \gamma} \int_0^t H_0(t)dt \right)^{\frac{1}{2}}.$$

Describe the assumptions made in the derivation of this formula.
If the initial potential temperature profile is described by γ= 3.8 K km^{-1} and in the 12 hours of daylight between sunrise and sunset the time-averaged surface sensible heat flux is 175 W m^{-2}, use the model to estimate the depth of the boundary layer at sunset.

[8 + 7 marks]

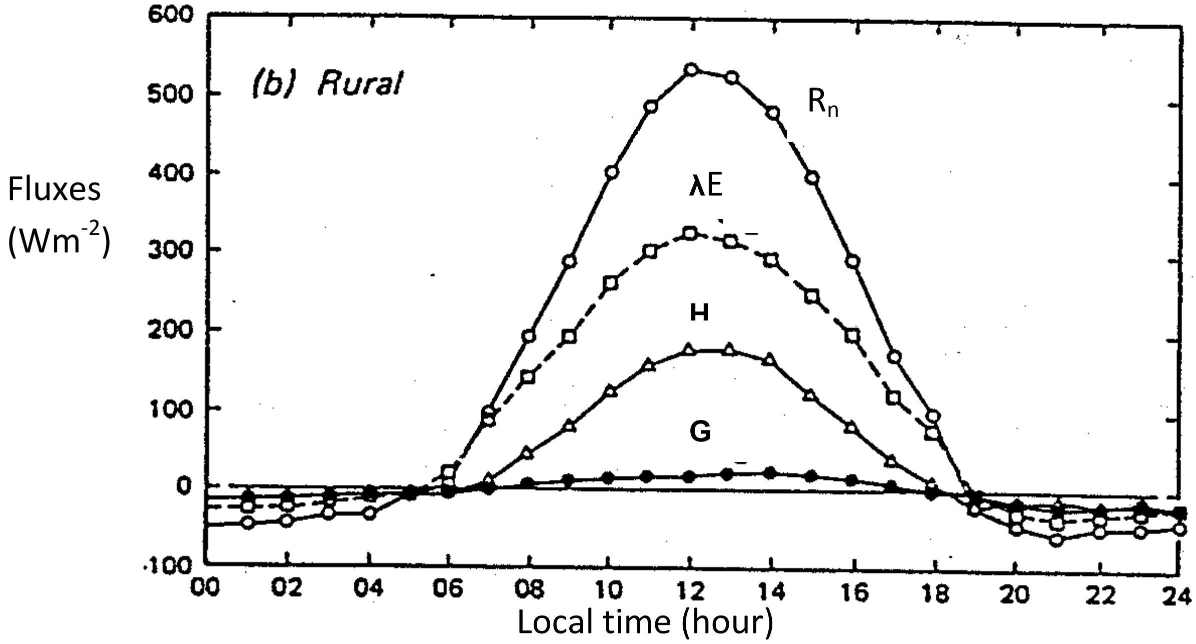
(c) Sketch the internal boundary layer at night starting with a stable profile after a cold hot transition. Explain the factors influencing the depth of the thermal internal boundary layer.

Explain how the friction velocity changes as air passes from a smooth to a rough surface and draw a sketch of the logarithmic wind profile for the rural and urban surface. [12 marks]

(d) Plume patterns from chimneys depend on the wind speed and the vertical temperature profile. Sketch plume patterns from a chimney and the corresponding temperature profile for (i) a convective and dry situation during daytime and (ii) a stable temperature profile during a clear night. [4+4 marks]

3.

(a) The following figure shows the diurnal cycle of the individual terms of the surface energy balance for a rural land surface.



Given the same synoptic conditions

(i) Describe the physical processes that lead to the difference between the rural and urban surface energy balance for all terms and state the time of the day when the urban heat island effect is strongest.

(ii) Draw the diurnal cycle of the corresponding terms of the surface energy balance for an urban area in comparison to the rural terms in a plot similar to the one above.

[10 + 6 marks]

(b) Sketch the spectrum of fluctuations of the wind in terms of wave-number for the atmospheric boundary layer. Mark on your sketch the important regions of the spectrum explaining what they represent.

Which part of the spectrum has the form $E(k) = \alpha\varepsilon^{2/3}k^{-5/3}$ where k is wave-number? Explain how this spectral form arises by referring to the turbulent processes.

[6 + 4 marks]

Question 3 continued overleaf

Question 3 continues

(c) By considering the force on an air parcel, and using suitable sketch diagrams, explain why, in turbulent conditions, the wind through most of the continental boundary layer is both *weaker than* and *not parallel to* the geostrophic wind.

[10 marks]

(d) At sunset at a cloudless site in the southern hemisphere, the geostrophic wind at a height of 100 m is 12 m s^{-1} from the west. Measurements at this altitude show the actual wind to have a westerly component of 9 m s^{-1} and a southerly component of 3 m s^{-1}. Sketch a hodograph of the expected evolution of the wind through the night. Assuming a Coriolis parameter $f = 10^{-4}$ s^{-1}, estimate the magnitude and time-after-sunset of the peak in the nocturnal jet.

[4 + 10 marks]

(End of question paper)