**MTMG49 Boundary Layer Meteorology and Micrometeorology**
**Spring 2004 Examination**

One and a half hours: Answer any two questions

1.

(a) Describe, using a sketch diagram, how the depth and nature of the boundary layer vary through a diurnal cycle under typical cloudless mid-latitude conditions, annotating your diagram with typical values of the boundary layer depth.
Outline the processes that determine the height of the top of the boundary layer in the daytime and nighttime. [18]

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

$$\frac{d\bar{u}}{dt} = f\bar{v} - \frac{\partial\overline{u'w'}}{\partial z}, \qquad (1) \qquad\qquad \frac{d\bar{v}}{dt} = -f(\bar{u} - u_g) - \frac{\partial\overline{v'w'}}{\partial z}. \qquad (2)$$

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.
Sketch a hodograph of the wind profile predicted by the model and discuss how the predicted wind profile compares with observations. [16]

(c) Explain, with reference to the terms of the momentum equations above, how, and under what conditions, the nocturnal jet is formed. [16]

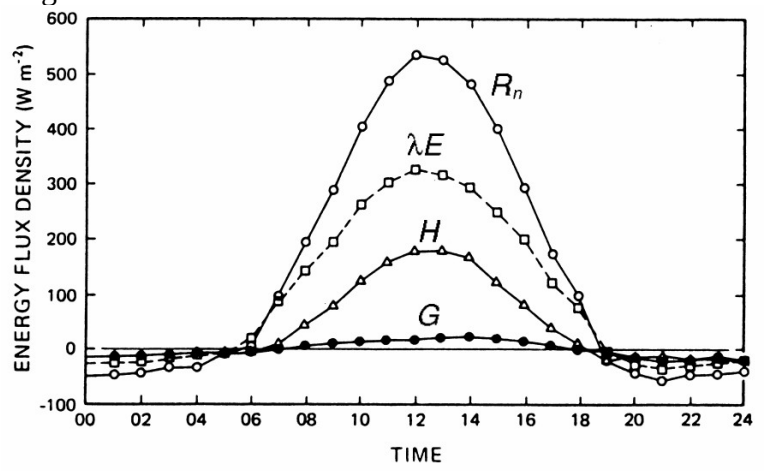
2.

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

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

Hence define the *Bowen ratio* and give the typical range of values of this parameter at midday over (i) short grass and (ii) an urban street. [10]

(b) The figure below shows measurements of the surface energy balance in a rural area over one diurnal cycle. Sketch the variation of these parameters that you would expect to see in the downtown area of a city under the same synoptic conditions, and describe the physical processes that lead to the differences between the parameters in the two areas. Hence state the (i) time of day and (ii) synoptic conditions when the urban "heat island" effect would be expected to be strongest.



How would you expect the boundary layer above the urban canopy to differ from that over nearby rural areas at the peak of the heat island effect? [22]

(c) Describe the chemical and dynamical processes that control the concentration of ozone near the ground, and explain the principal differences observed between urban areas and the rural areas downwind of them. [18]

3.

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

$$\frac{dU}{dz} = \frac{u_*}{\kappa z}\phi_m\left(\frac{z}{L}\right), \qquad (3)$$

where the Monin-Obukhov length is $L = -\frac{1}{\kappa}\frac{u_*^3}{(g/\theta_s)(H/\rho c_p)}$. [12]

(b) Describe the instruments and measurements required to estimate $\phi_m$, and the nature of the site required, stating clearly any assumptions that need to be made. [16]

(c) In stable conditions, the Monin-Obukhov function may be given by

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

Use this result, together with equation (3) above, to obtain the variation of wind speed with height in a stable surface layer.
Shortly after sunset, the 10 m wind speed over short grass is measured to be 3 m $s^{-1}$ and the surface temperature is 10ºC. Over a period of around half an hour the surface sensible heat flux falls from 0 to –10 W $m^{-2}$. Assuming for simplicity that the surface temperature and friction velocity remain constant, estimate the new 10 m wind speed, stating any further assumptions you make. Estimate also the height to which your expression for the variation of the wind speed with height would be expected to be valid at the end of the period. [22]