MTMG49 Boundary Layer Meteorology and Micrometeorology
Spring 2004 Examination

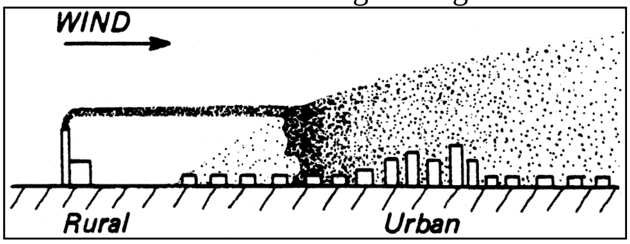
One and a half hours: Answer any two questions

1.

(a) Describe, using a sketch diagram, how the depth and nature of the boundary layer over land varies through a diurnal cycle under typical cloudless mid-latitude conditions.
[10 marks]

(b) Describe three ways in which the radiative properties of clouds change the properties of the boundary layer. [9 marks]

(c) The schematic below shows the dispersion of smoke emitted over rural grassland as it encounters an urban area on a cloudless night in light wind conditions.



Describe, with the use of sketch diagrams where appropriate, the two main ways (i.e. dynamical and thermodynamical) that the properties of the rural and urban surfaces in this situation lead to the observed distribution of smoke, including a careful discussion of the *internal boundary layer*.
[16 marks]

(d) Describe the dynamical and chemical processes that control the concentration of ozone near the ground over a diurnal cycle of a polluted boundary layer.
[15 marks]

2.

(a) Outline the physical processes that determine the thermodynamic structure and growth of the daytime convective boundary layer. Sketch the vertical potential temperature structure that emerges and its evolution in time. Sketch also the vertical profile of sensible heat flux through the convective boundary layer.
[15 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 carefully the assumptions made in the derivation of this formula.
[10 marks]

(c) On a particular day the initial potential temperature profile is described by γ= 5 K km^{-1} and in the 12 hours of daylight between sunrise and sunset the time-averaged surface sensible heat flux is 250 W m^{-2}. By assuming a suitable value for E, estimate the depth of the boundary layer at sunset.
[10 marks]

(d) Describe how the surface energy budget determines H_0. Hence explain, with reasoning, whether you expect the convective boundary layer to deepen most rapidly over a desert, an ocean or a forest, including in your argument a typical value of the *Bowen ratio* for each of these surfaces.

[15 marks]

3.
The following measurements are made by the 200-m meteorological tower at Cabauw in the Netherlands (latitude 52ºN) at 18 UTC, just after sunset. A synoptic pressure map indicates that the geostrophic wind is 10 m s^{-1} due westerly and the skies remain cloudless through the night.

Altitude, *z* (m)	**Potential temperature, θ (K)**	**Zonal wind, *u* (m s^{-1})**	**Meridional wind, *v* (m s^{-1})**	**Bulk Richardson Number, Ri**
50	280.0	3.0	1.8	
100	280.5	4.5	2.5	
200	282.0	6.0	3.0	

(a) By considering the force balance on an air parcel, explain qualitatively why the wind at these altitudes is both weaker than and not parallel to the geostrophic wind.

[12 marks]

(b) Bulk Richardson number, *Ri*, is defined as

$$Ri = \frac{\frac{g}{\theta_0}\frac{\Delta\theta}{\Delta z}}{\left(\frac{\Delta u}{\Delta z}\right)^2 + \left(\frac{\Delta v}{\Delta z}\right)^2}.$$

Calculate *Ri* in the layers 50-100m and 100-200m. State whether you would expect the flow in each of these two layers to be turbulent or laminar, giving your reasoning.

[12 marks]

(c) Sketch a hodograph of the evolution of the wind speed at 200 m through the night. From this, estimate the maximum intensity of the nocturnal jet at this height.

[10 marks]

(d) If instead the skies were cloudy and the temperatures did not change through the night, and the wind at 100 m remained constant, calculate whether a nocturnal jet of this intensity would still be expected at 200 m, giving your reasoning.

[10 marks]

(e) How would the nature of the nocturnal jet be different in (i) the tropics and (ii) at a latitude of 52ºS?

[6 marks]