GEOG 321 - Reading Package Lecture 15

THE LAMINAR BOUNDARY LAYER

Immediately above the surface is the *laminar boundary layer* (LBL). It is the thin skin (only a few millimetres) of air adhering to all surfaces within which the motion is laminar (i.e. the streamlines are parallel to the surface with no cross-stream component). The connotation is that adjacent layers (*laminae*) of the fluid remain distinct and do not intermix. The flow is therefore smooth in appearance. The slow flow of water from a laboratory faucet, or of smoke from a smouldering candle in a still room, are laminar initially. Figure 1 shows how a boundary layer grows with distance over a flat plate. The thickness of the laminar boundary layer grows but eventually a critical combination of properties (speed of flow, distance and viscosity) is exceeded after which the flow breaks down into the haphazard jumble of eddies characteristic of turbulent flow. However, note that a laminar sub-layer still remains at the surface. The thickness of the sub-layer mainly depends upon the roughness of the surface and the external wind speed. Over relatively smooth surfaces, and especially with high wind speeds, the layer becomes very thin or is temporarily absent.

Exchange in the LBL. In the laminar sub-layer there is no convection, therefore all non-radiative transfer is by molecular diffusion, and following equation 7.3 we can express the flux of heat through the layer as:

$$Q_H = -\rho_a \, c_p \, K_{Ha} \, \frac{\partial T}{\partial z} = -C_a \, K_{Ha} \, \frac{\partial T}{\partial z} \quad \star \qquad (8.1)$$

and for water vapour:

$$E = -K_{Va} \, \frac{\partial \rho_v}{\partial z} \quad \star \qquad (8.2)$$

and for momentum:

$$\tau = \rho \, K_{Ma} \, \frac{\partial u}{\partial z} \quad \star \qquad (8.3)$$

where ρ - air density ($\mathrm{kg\,m^{-3}}$), c_p - specific heat of air at constant pressure ($\mathrm{J\,kg^{-1}\,K^{-1}}$), ρ_v - vapour density, u - horizontal wind speed ($\mathrm{m\,s^{-1}}$) and K_{Ha}, K_{va} and K_{Ma} are the molecular diffusion coefficients (diffusivities) in air for the subscripted entities ($\mathrm{m^2\,s^{-1}}$). The values of these diffusivities are essentially constant depending only slightly on temperature. K values are very small, of the order of $10^{-5}\,\mathrm{m^2\,s^{-1}}$, thus providing an important insulating barrier between the surface and the bulk of the atmosphere. Thus the gradients of climatic properties (T, ρ_v, u, etc.) are very steep in the LBL, and since both the flux and the diffusivity are constant with height the vertical profile of a property is approximately linear, i.e. the gradient is constant.

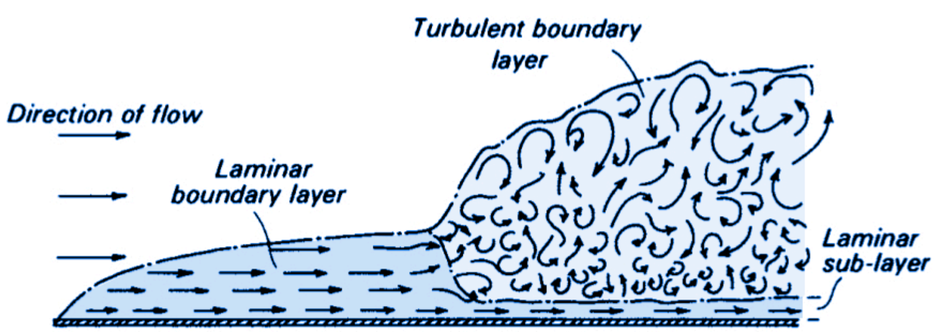

Figure 1: Development of a laminar boundary layer over a flat plate and its transition to turbulent flow.