EAS 572: Assig. 1. Due 12 Oct 2010 Value: 10%

A. Dimensional Analysis

Let $U = U(x, z)$ represent the field of time-averaged wind speed about an infinitely-long, thin, porous windbreak fence that is oriented along the y-axis and thus perpendicular to the x-axis; let the angle of incidence of the mean wind relative to the fence be β. By symmetry, wind statistics are invariant along the axis (y) parallel to the fence, and so vary only with distance (x) normal to the fence, and with height (z). The windbreak has height h and porosity ϕ, while the state of the surface layer flow upwind of the windbreak is characterized by the friction velocity u_{*0}, the Obukhov length L, the depth of the boundary layer δ, and the surface roughness length z_0. On the principle of being cautious – unduly cautious – let's throw in properties of the fluid itself, namely mean density ρ and mean Kelvin temperature T.

Perform a dimensional analysis to determine the (dimensionless) factors upon which normalized mean windspeed U/u_{*0} might depend. Please report your results in an orderly way, and include a classification of the variables: e.g. x, z are coordinates, while h is a characteristic of the windbreak disturbing the flow. (Notes: β and ϕ are dimensionless properties. You probably do not need to use the method of indices, i.e. you may be able to find the needed ratios by inspection).

B. Computation of micrometeorological statistics

The accompanying data file 'utah.dat' (6.75 MB) contains a time series of wind and temperature registered at 20 Hz and covering one hour, from two sonic anemometers (1,2) at heights $z_1 = 3$ m and $z_2 = 25.69$ m standing on an isolated tower on a salt flat in Utah (24 May, 2005; the data span local midday). The data are arranged in columns in the order $u_1, v_1, w_1, T_1, u_2, v_2, w_2, T_2$, where u is the northerly component, v the easterly component and w is the vertical velocity. The number of entries (N) in each column should be 20×3600 (but may differ slightly, so either N should be computed from the number of lines of data read, or set slightly smaller than 72,000).

Write a program to read the data file, compute, and write to a file the following statistics for each of the two levels:

- mean velocity components U, V, W and mean wind direction $\beta = \arctan(V/U)$
- Reynolds stress tensor

$$\mathbf{R} \equiv R_{ij} \equiv \overline{u_i' u_j'} = \begin{pmatrix} \sigma_u^2 & \overline{u'v'} & \overline{u'w'} \\ \overline{u'v'} & \sigma_v^2 & \overline{v'w'} \\ \overline{u'w'} & \overline{v'w'} & \sigma_w^2 \end{pmatrix}$$

- the friction velocity

$$u_*^4 = \left(\overline{u'w'}\right)^2 + \left(\overline{v'w'}\right)^2$$

- the turbulent temperature scale $T_* = -\overline{w'T'}/u_*$
- the Obukhov length[1]

$$L = -\frac{u_*^3 \, T_0}{k_v \, g \, \overline{w'T'}}$$

  where $k_v = 0.4$ is the von Karman constant and T_0 [K] is bulk air temperature.

- heat flux density $Q_H = \rho c_p \overline{w'T'}$ (to compute the density, assume the local pressure was $p = 820$ mb).

[1] L is negative in unstable stratification, and infinite in magnitude in a neutral atmosphere where $\overline{w'T'} = 0$ by definition. It is sometimes called the 'substrate of dynamic turbulence', because in the region $z/|L| \ll 1$ the influence of buoyancy on the turbulence is negligible relative to that of wind shear. Conversely, at $z/|L| \gg 1$ buoyancy is the main generator of turbulent fluctuations.