Assignment 2 (Wind profiles, shear, stability).

In this assignment you will study vertical profiles of the mean wind speed, over horizontally homogeneous terrain (i.e., flat with a uniform surface).

Data from cup and sonic anemometers, mounted on the meteorological mast at the Danish Test Center for Large Wind Turbines at Høvsøre from the year 2008 are provided (under `Data+Files for Assignments/Files for Assignment 2`) in DTU-Learn and should be used in the analysis. Download the data set (`Hoevsoere2008.csv`). It contains 10-minute averages of quantities measured from different heights, with 1 header-line to label the data columns; they are:

1. date [yyyymmddhhmm] ('name')
2. $u_\star$ [ms^{-1}] ('u_star')
3. Q_0 [K ms^{-1}] ('wsc')
4. incoming wind direction [deg. clockwise from N] at $z = 60$ m ('dir_metmast_60m')
5. surface-layer temperature [°C] ('T_10m')
6. mean wind speed [m s^{-1}] at 10m ('wsp_metmast_10m')
7. mean wind speed [m s^{-1}] at 40m ('wsp_metmast_40m')
8. mean wind speed [m s^{-1}] at 60m ('wsp_metmast_60m')
9. mean wind speed [m s^{-1}] at 80m ('wsp_metmast_80m')
10. mean wind speed [m s^{-1}] at 100m ('wsp_metmast_100m')

where the header-labels are given in parenthesis above.

The following tasks should be addressed:

1. Calculate the reciprocal of Obukhov length, L^{-1}, from the data (recall that since Q_0 is often close to zero, i.e. neutral conditions, then $1/L$ is more useful than L). Show its PDF.
2. Choose easterly wind directions (wind *from* the East) between 60–120°, and select wind speed data for *neutral* conditions from heights $z = \{10, 40, 60, 80, 100\}$ m; *in this assignment we'll use the criterion* $|L^{-1}| < 0.0008\, m^{-1}$ *for neutral stratification.*

   (a.) Average the 10-min. mean wind speeds at each height, then plot the wind profile in a semi-logarithmic coordinate system (with U on the horizontal axis and z on the logarithmic vertical axis); include 'error bars' corresponding to the long-term standard deviation of U at each z.

   (b.) Fit a straight line to the average profile of mean wind speeds you just found, for the anemometers from 10 m to 80 m; include/add this line to the plot you just made.

   (c.) From the fit and log-law, what are the resulting (mean) values of $u_\star$ and z_0?

   What type of vegetation does this z_0 imply?

   (d.) Via the log-law and the z_0 just obtained under neutral conditions, use the mean wind speeds at 60m and 80m (respectively) to predict $U_{N,100}$, the mean wind under neutral conditions at 100m. What is the %-difference between each predicted $U_{N,100}$ and the observed $U_{N,100}$ calculated in task 2a earlier?

   (e.) Now calculate the long-term mean shear exponent $\langle\alpha\rangle$ using a process analogous to 2b above: recalling $\alpha = d \ln U / d \ln z$, use a *log-log* plot of z versus U to find the mean $\langle\alpha\rangle$. What z_0 is implied by this neutral-condition $\langle\alpha\rangle$?

   (f.) Now calculate $\langle\alpha\rangle$ from the means at $z =$60 m and 80 m. How does it compare to the shear exponent calculated over the range of observations from 10-80 m done in task 2e?

(g.) From the two values of α you calculated in tasks 2e–2f above, employ the power-law profile to make two predictions of the mean easterly wind speed at 100 m height under neutral conditions, with the 'ref*erence*' wind taken as the mean at z =80 m.

(h.) How do the two α-based predictions of $U_{N,100}$ in 2g compare to the log-law predictions from 2d, and to the actual mean measurements?

3. Plot wind profiles (again from the East), for stable and for convective conditions, in the same graph along with the neutral profile; further, calculate and also plot the mean wind profile over *all* conditions. Use $0.0008 < L^{-1} < 0.05\,\mathrm{m}^{-1}$ for stable, and $-0.05 < L^{-1} < -0.0008\,\mathrm{m}^{-1}$ for unstable conditions, ignoring the more extreme stabilities.
Is it reasonable to neglect the very non-neutral conditions? Why?

4. The Monin-Obukhov similarity function

$$\Phi_m(z/L) = \frac{dU/dz}{u_*/(\kappa z)} \tag{1}$$

is actually a measure of dimensionless shear, in terms of the stability. Plot the 'profile' of Φ_m, i.e. z versus the right-hand side of the above equation; do this for the stable, neutral, and unstable cases analyzed above, on a single graph.
The neutral value of Φ_m should ideally be equal to 1. Why?
How much do your neutral Φ_m deviate from 1, and why?

5. Using the definition of Φ_m (e.g. task 4 above), derive the M-O wind profile

$$U(z) = \frac{u_*}{\kappa}\Big[\ln(z/z_0) - \Psi_m(z/L)\Big];$$

write an expression for $\Psi_m(z/L)$ in terms of $\Phi_m(z/L)$.
Explain what use/effect $\Psi(z/L)$ has, in terms of the wind profile (hint: consider what you plotted in task 3 above).

6. Which type of non-neutral conditions most strongly affect the wind profile (shear)? How frequently do these occur, relative to neutral and other non-neutral conditions?

7. Again as in step 3, plot the 'total' wind profile over all conditions for the easterly winds considered. Now also over-plot the power-law profile for two cases: [a] using α from 40-80m with the 40 m winds for the reference, and [b] using α from 60-80m and the 80m winds as reference. How do these compare?

8. For vertical extrapolation of wind speed statistics from measurement heights to hub-heights, the industry often uses α. What information is missing from the power-law, compared to M-O theory? What are the advantages (and assumptions) of using each type of profile?