Etienne Cheynet **Excercise 1** March 10, 2023

Analysing atmospheric turbulence characteristics

1 Objective

A company wants to develop a wind farm on a site and deployed five masts to study the wind conditions. They contacted you to study the turbulence characteristics for this specific site. The company has a single request without any guideline: Summarize in a report the site-specific turbulence characteristics.

2 Data and masts

The data attached corresponds to wind velocity histories simulated on the top of the five masts. The array of masts is perpendicular to the wind direction. Each anemometer is mounted 60 m above the ground. The distance between each mast is 12.5 m. The data are stored in binary files (**Data_for_excercise_v2.mat**). The along-wind, cross-wind and vertical wind velocity components are denoted *u*, *v* and *w*, respectively. These velocity components are stored as [N x M] matrices where M is the number of anemometers and N is the number of time steps. The variable *t* is a [Nx1] matrix and is the time vector. Use the toolbox "functions" and the python script "script_to_be completed.py" to complete the task.

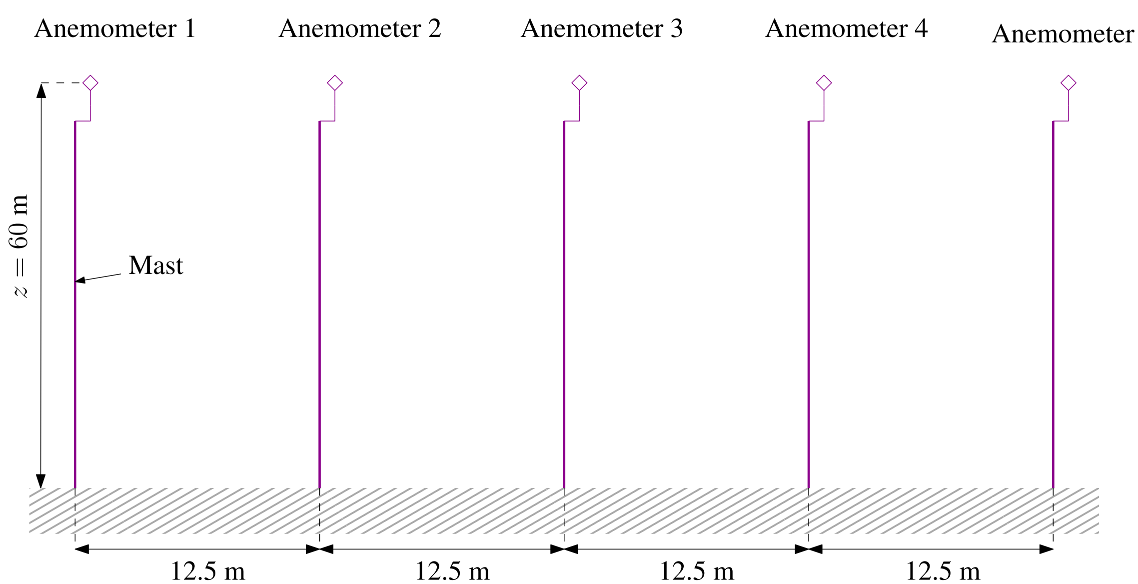

Figure 1: The time series used in this exercise are simulated from five imaginary masts. The anemometers are mounted on the top of five masts and measure the three velocity components.

3 Guideline to writing the report

To help you write the report, you can address the following questions. However, you should not organize the report by answering these questions point by point. You should **synthesis** the answers to these questions in the report using a thematic approach. So you need to **pedagogically** present the method, findings, and discussion to the contractor. To organize the report, you can get inspiration from section 6 in the lecture notes. All the python functions necessary to answer these questions are provided in "functions.py".

Question 1

Name some of the first and second-order turbulence characteristics. What is the difference between one-point and two-point turbulence characteristics? When studying turbulence characteristics, we often say they are "estimates". Why?

Question 2

What is the sampling time, sampling frequency, Nyquist frequency, and lowest measurable frequency of the time series?

Question 3

Plot the time histories of the three velocity components as a function of the time. The figure should look like fig. 2. Are the data stationary? Show that removing the linear trend is here necessary to study properly some of the turbulence characteristics.

Question 4

In the following, one assumes that removing the linear trend allows for the correction of the non-stationary fluctuations (if they exist). Calculate the skewness and kurtosis of the time series. Is the assumption of Gaussian fluctuations satisfied?

Question 5

Calculate the mean wind speed, turbulence intensity, skewness and kurtosis for the five anemometers. Is the assumption of homogeneous flow satisfied?

Question 6

Compute the Reynolds stress tensor R and the friction velocity. Elaborate on the value of the off-diagonal terms of R.

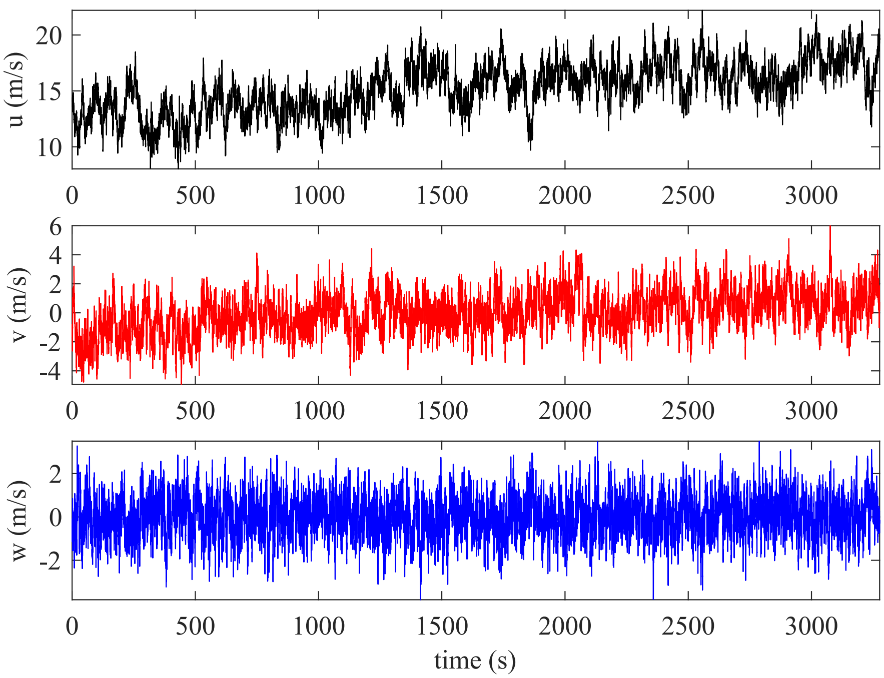

Figure 2: The time series used in this exercise are simulated from five imaginary masts. The anemometers are mounted on the top of five masts and measure the three velocity components.

Question 7

Estimate the integral length scale for each component at each anemometer. What can be said about the spatial variability of the integral length scale? Does it reflect a lack of homogeneity or a large random error? By using the concept of spatial averaging and the standard deviation operator, how could you quantify this spatial variability?

Question 8

Calculate the cross-correlation matrix associated with the fluctuating component u, v and w for the five anemometers. Plot the correlation coefficients as a function of the distance between each pair of sensors as in fig. 3. In this figure, an exponential function was fitted to the scattered data to estimate the turbulence length scales L_u^y, L_v^y and L_w^y. How can we physically interpret the fact that $L_u^y > L_v^y > L_w^y$?

Question 8

Using the Welch method plot in a semilog axis the normalized PSD estimates of u,v and w components as well as the co-spectrum between the u and w components. The Welch method provides a lowest frequency at 0 Hz. Is it meaningful? why?

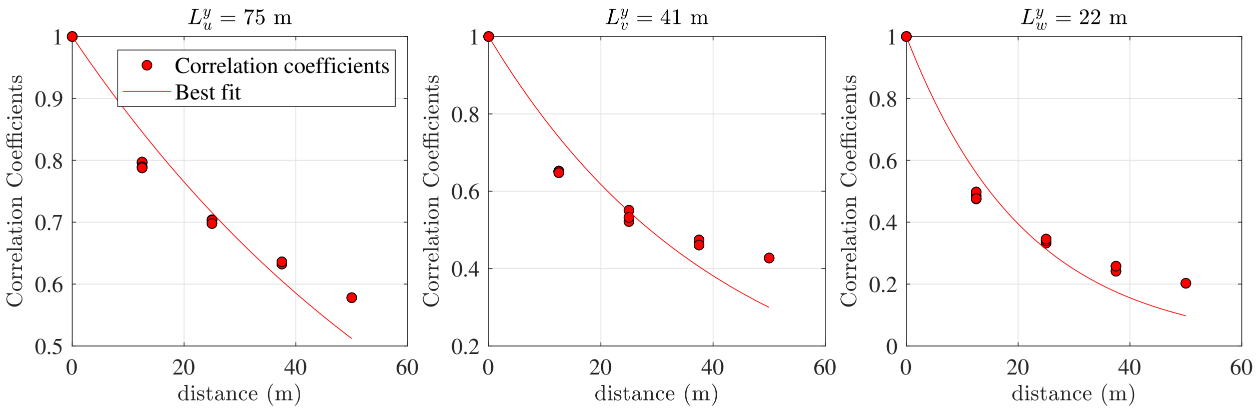

Figure 3: The time series used in this exercise are simulated from five imaginary masts. The anemometers are mounted on the top of five masts and measure the three velocity components.

Question 9

Use the function **binSpectra** to smoothen the power spectral density estimates. Shows that the smoothing allows for a large reduction of the measurement noise.

Question 10

Using the ratio Sw/Su and Sv/Su, show whether the so-called "hypothesis of local isotropy in the inertial subrange". It is reminded that the inertial subrange is the frequency range where the velocity spectra follow the -5/3 power law.

Question 11

The Davenport coherence model describes empirically the co-coherence of turbulence:

$$\gamma_u(d_y, f) = \exp\left(\frac{-C_u d_y f}{\overline{u}}\right) \tag{1}$$

where $\overline{u}$ is the mean wind speed; d_y is the lateral distance; f is the frequency and C_u a constant, empirically determined. What does the co-coherence of turbulence reflect? Plot eq. (1) as a function of the frequency for $d_y = 12.5m$, $\overline{u} = 15\,\mathrm{m\,s^{-1}}$ and various values of C_u with values from 3 to 20. What is the physical interpretation of C_u?

Question 12

Using the Welch method, estimate the co-coherence of the u component between anemometer 1 and anemometer 2. Assess the influence of the number of overlapping segments (4,6,8,10,30,60 segments) on the co-coherence estimates. For each case, fit the Davenport model using the **curve_fit** function to estimate the decay coefficient. How many segments would you advise using?