Application of Periodic Hill Flow
Application: Locating a village based on CFD analysis.
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1 Method

A DDES turbulence model simulation was carried out for capturing the flow parameters. The parameters considered for evaluation includes mean wall shear stress(WSS) on the valley, instantaneous WSS- X and Z component at 6 locations and instantaneous WSS-X component on the valley.
The mean WSS magnitude obtained after time averaging signifies friction between the fluid and valley. Harsh winds, i.e. high magnitude winds, are not suitable for a living habitat. Based on this plot, the regions with low wall shear stress are considered for studying the wind direction. However, the points includes one region with peak WSS to understand how wind behaves in extreme conditions. A limitation with this investigation method is that regions with heavy fluctuations in opposite directions would give a low mean. When, in-fact, that region would be worse for a village when compared to some region with a constant direction but higher mean. Meaning this method alone is not good enough to place a village with confidence. It is, however, a fast way of determining roughly the wind speeds one can expect, being quite indicative in regions with little changes in flow direction.

The instantaneous X and Z WSS components captured at 6 locations for every ten time-steps was considered for wind rose plots to study the intensity and direction of wind. An advantage with this method is that the distributions of the fluctuations can be seen quite easily. Paired with the mean magnitude it is possible to rule out points which would give false positives for the mean magnitude. A limitation of the rose plots is that they have to be made for discrete points, meaning the candidate points become limited.

The instantaneous WSS-X captured on the valley for 15 flow cycles. A colormap describing the valley length and time-step in X and Y axis respectively. A contour of WSS-X acts a third axis showing the variation in streamwise flow of wind at different time-steps. An advantage of this method is that the fluctuations become quite clear through time. The data visualisation is also continuous, meaning any point can be evaluated. A limitation however is that evaluations are mostly qualitative, instead of quantitative like the other methods.

2 Results

The mean WSS plot was used as a reference to closely monitor the possible location for building the village. The peaks seen in figure 1 shows high magnitude of WSS until $X/h = 3.8$. The re-circulation is maximum in this region as the flow separates from the hill. High WSS signifies that the shear forces exerted on the buildings would be high. Figure 3 shows the intensity of the wind in the x-direction. The elevated wind speeds, or wall shear stress levels, are further supported by the high stresses shown in the rose plots in that region, see figure 2a-2b. It can be seen that from that point onward the mean WSS decreases and forms two local minimum. However, the rose plot, see figure 3a, and the varying instantaneous WSS-X component, see figure 3, indicate the wind speeds are in fact quite high. The reason the mean WSS shows such a low value is due to the flow fluctuating strongly in opposite directions, which makes the WSS cancel eachother out. Highlighting the limitation discussed in section 1.

The second minimum, see figure 1, show quite low WSS values in the rose plot, see figure 3d, while being quite spread in terms of directions. While the spread in directions might not be ideal, the low velocities make up for it, making it a good candidate point. It can be seen in figure 3 that the velocity in general is indeed rather low for $x/H = 6.85$, with a large spread of the major fluctuation frequencies. Figure 3 does, however, show that the region downstream of $x/H = 6.85$ to roughly $x/H = 7$ show similar, if not better, flow behaviour. Indicating that a true optimal point might be somewhere in that range. Since data was not collected for the rose plots in that region, however, it is not for certain. Thus the recommended place for the village is at $x/H = 6.85$. With a note that if it would expand, it should be toward $x/H = 7$.

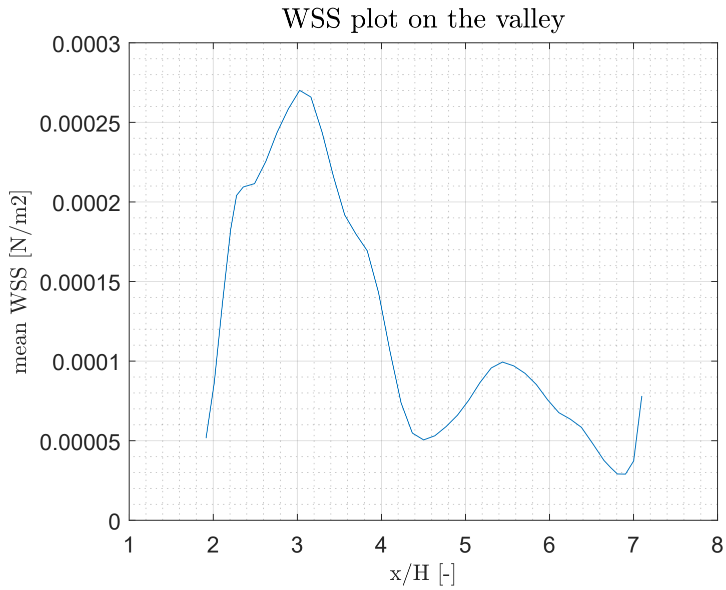
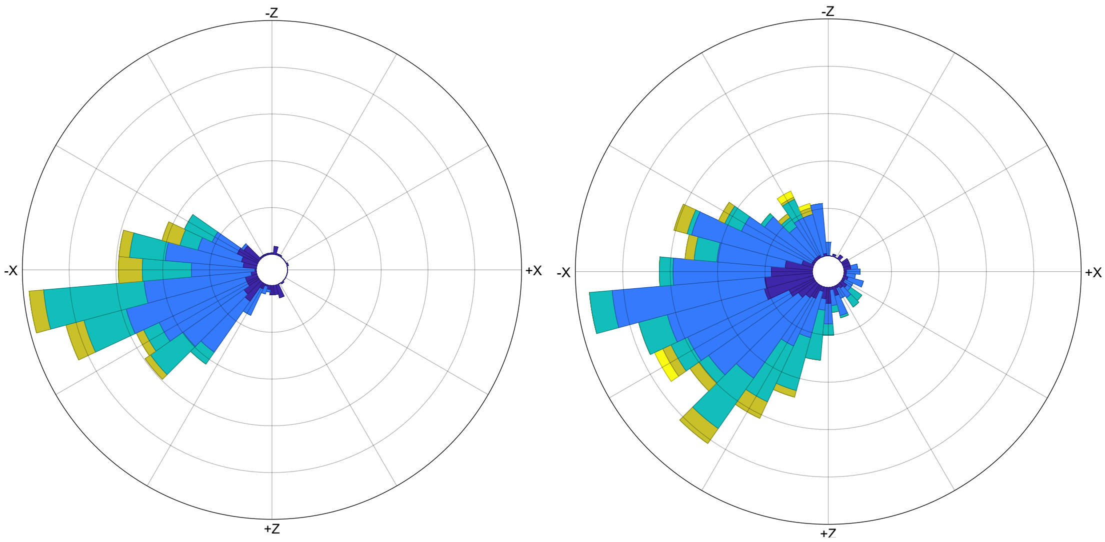
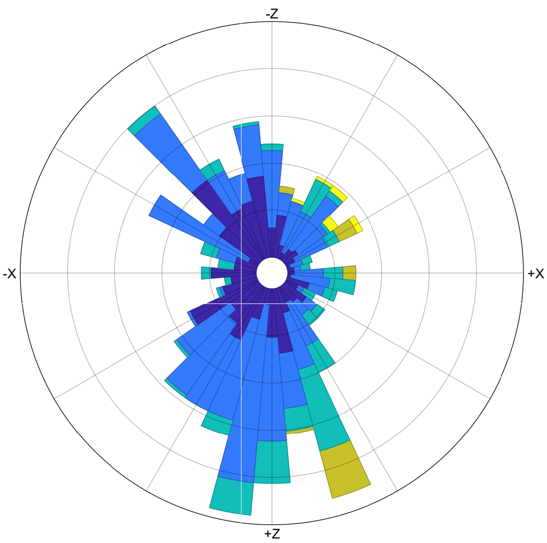


Figure 1: Mean WSS on the valley.

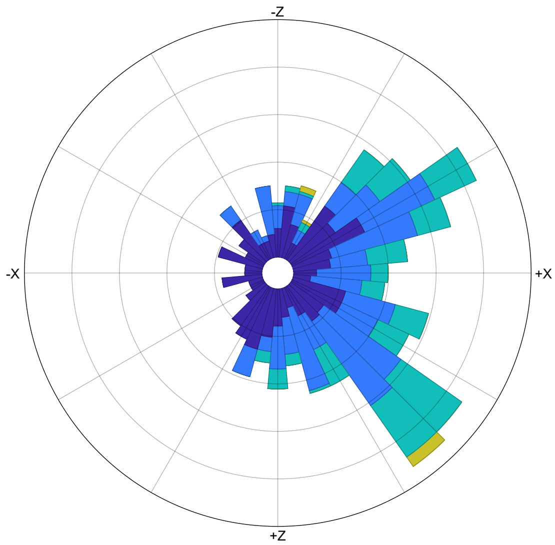


(a) $x/H = 3$

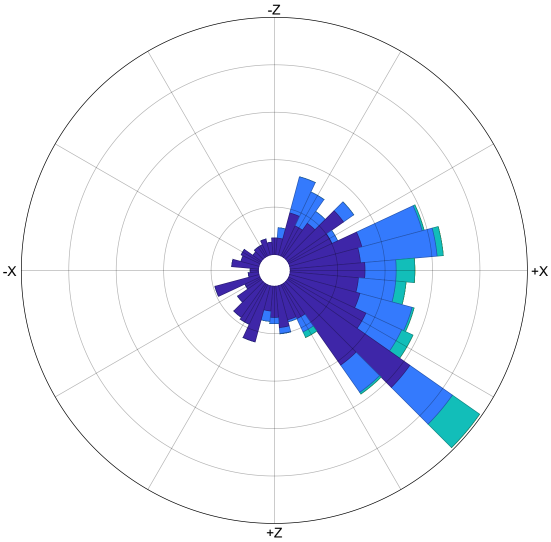
(b) $x/H = 3.8$



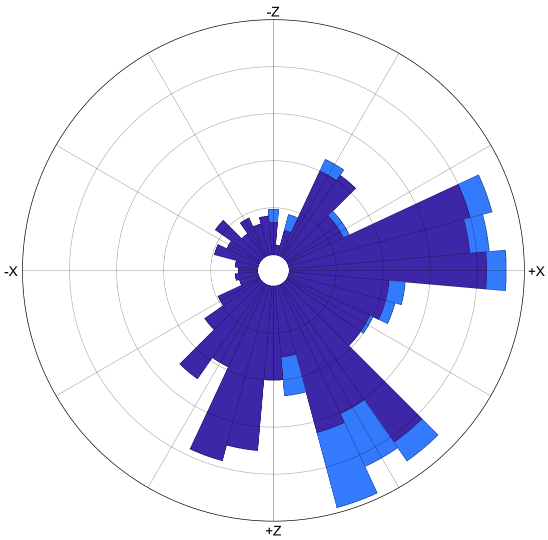
(a) $x/H = 4.5$



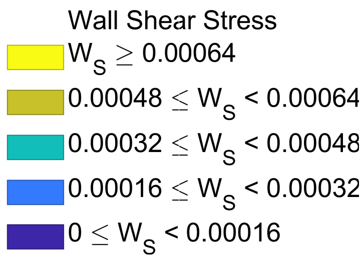
(b) $x/H = 5.4$



(c) $x/H = 6.4$



(d) $x/H = 6.85$



(e) Legend

Figure 3: WSS intensity and direction at selected points on the valley

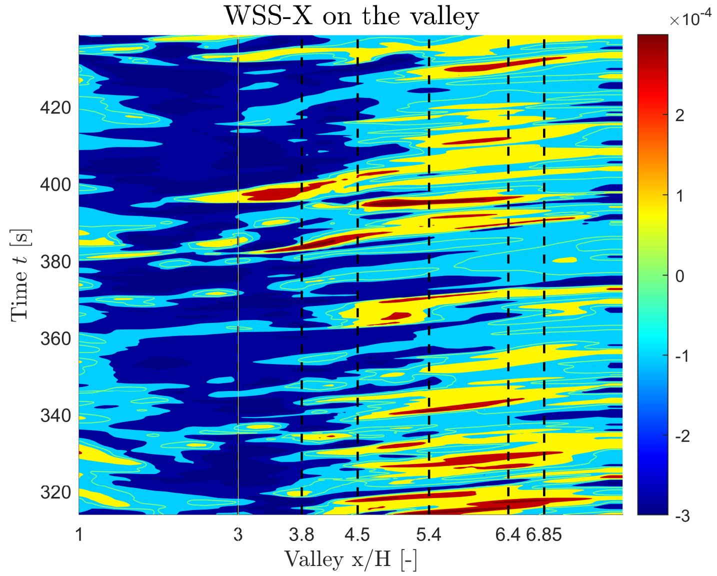


Figure 4: Wall Shear Stress X component varying with time on the valley floor.

3 Uncertainties

As discussed in section 2, the suggested point might not be the definite optimal, however, it is a good point, and arguably close to an optimum. To investigate further, more rose plots could be made for more points, as the rose plots are the most accurate of the 3 ways to assess a points feasibility. Though this can only be said for the Reynolds number simulated. If the Reynolds number would increase for example, the recirculation region might increase in length, and thus the wind magnitude might increase and the optimal point might change. Another uncertainty is the amount of time steps used for data sampling, and for the rose plots and instantaneous WSS-X. Currently around 15 flow-cycles were used, after removing initialisation effects. An increase in time steps would possibly increase the accuracy somewhat, as more structures would be captured. For example, it can be seen in figure 3 that a structure with positive WSS-X appears in the middle of the recirculation at around $x/H = 3.8$ at $t = 395$, and only appears once in the sampled time. If the time sampled were longer, perhaps this structure would re-appear. Thus, the used time steps would not be sufficient to accurately time average this structure. However, the change this would make for the predicted points is probably rather small. As the statistical convergence was considered sufficient at 15 flow-throughs, the change would not be huge.

The last major uncertainty regarding WSS measuring is the use of the mean WSS. As discussed previously, it is prone to showing false positives, in terms of suitable points. This might have led to non-ideal placements for the rose plot measurements, missing the true ideal points. However, by investigating figure 3, it can be seen that the ideal point is likely still close to $x/H = 6.85$, but toward positive x, up to $x/H = 7$. As $x/H = 7$ is the extent of the valley floor it is considered the limit of the village placement.