Community Comment by Dr. Højstrup

November 30, 2021

We thank Dr. Højstrup for the feedback on our manuscript. Below is our answer to his comments.

Sonic anemometer flow distortion

Q 1.1 *In addition to the Solent omni-directional anemometers during the basic measurements, three more sonics were added, at 32m (omnidirectional Solent), 3m and 10m (asymmetric Solent with less flow distortion). The omnidirectional Solent shows considerable flow distortion, here illustrated with the ratios of measured u* at 18m (omnidirectional) to measured u* at 10m (asymmetric sonic), fig. taken from a presentation by me at Oregon State University, 7 May, 1998:*

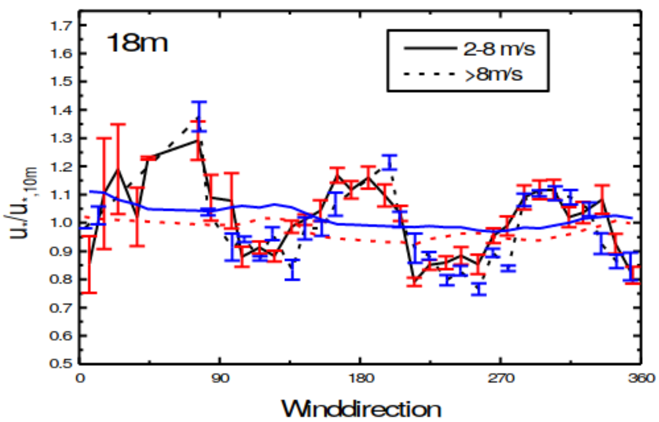

Figure 1: Ratio of the friction velocity estimated at 18 m (omnidirectional Solent) over the one at 10 m (asymmetric Solent) by Dr. Højstrup. Unknown time period.

Reply: The point raised by Dr. Højstrup is indeed relevant to the present study. We have added an appendix in the manuscript, to discuss the transducer-induced flow distortion. The following content takes the appendix and complements it when necessary. We remind that the present Community Comment is publicly available, which means that our reply is also available to anyone.

The dataset at 3 m was too short to be meaningful so it is not discussed hereinafter. So we will focus mainly on the asymmetric solent at 10 m. The dataset from the sonic anemometer (SA) at 10 m was from May 1994 to September 1994, which was still much shorter than the other instruments.

In the following, one assumes that the sonic anemometer at 10 m does not show significant flow distortion for the sector 220°-330°. The latter sector is the one that was selected in the original draft. It is possible to partly correct the friction velocity estimate at 6 m, 18 m and 45 m for the flow distortion by the transducer by using a multivariate regression analysis. The objective of the correction is to assess whether the corrected friction velocity changes substantially the results regarding the power spectral densities of the velocity fluctuations.

In the present case, the flow distortion is assumed to be a function of the angle of attack $\alpha(z)$ and wind direction $\theta(z)$ only. For the relatively narrow sector selected, it was found that cubic functions of $\alpha(z)$ and $\theta(z)$ were sufficient to describe this variability. This leads to the following relationship between the friction velocity at 10 m and the height z:

$$u_*(z) = (u_*)_{10} \cdot \mathbf{A}\mathbf{X}^\top \tag{1}$$

where

$$\mathbf{A} = \begin{bmatrix} a_1 & a_2 & a_3 & a_4 & a_5 & a_6 \end{bmatrix} \tag{2}$$

$$\mathbf{X} = \begin{bmatrix} \theta(z) & \theta(z)^2 & \theta(z)^3 & \alpha(z) & \alpha(z)^2 & \alpha(z)^3 \end{bmatrix} \tag{3}$$

The coefficients to be determined with the regression analysis are a_i, $i = \{1, 2, 3, 4, 5, 6\}$ as shown by eq. (2). In eq. (1), the error is modelled as a non-linear function of the angle of attack and wind direction. In this regard, we do not assume that the friction velocity is constant with the height nor that the flow distortion is similar for the three omnidirectional anemometers.

In fig. 2, we have reproduced some of the results from fig. 1 but for the sector addressed in the present study, i.e. between 220° and 330°. The left (right) panel shows the uncorrected (corrected) ratio of the friction velocity estimates. Including larger sectors has limited usefulness for this comparison. In particular, there exist sectors where the transducer shadowing is much larger for the asymmetric solent at 10 m than the omnidirectional solent at 6 m, which is not clearly highlighted in fig. 1. Therefore, fig. 1 should be interpreted with caution.

In the left panel of fig. 2, the maximal variations of the friction velocity between the sonic anemometer at 10 m and 18 m are ±20%. When all the samples in the sector 220°-330° are averaged, the relative difference at 6 m, 18 m and 45 m with respect to the data at 10 m are 4%, 12% and 11%, respectively. After the multivariate regression, the mean error was close to zero, although it is clearly not zero for a given wind sector (fig. 2). On average, the friction velocity

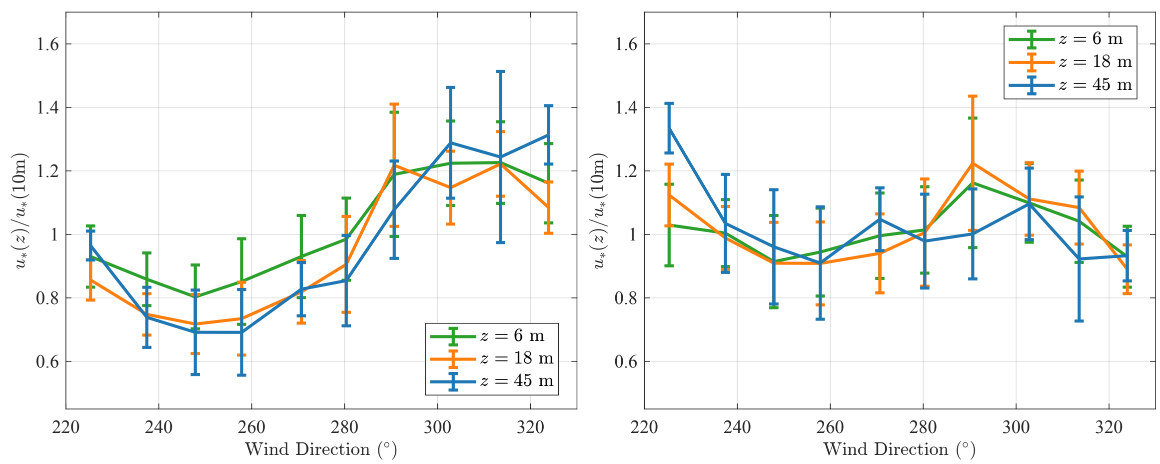

Figure 2: Ratio of the friction velocity at 18 m (omnidirectional solent anemometer) over the one estimated at 10 m (asymmetric solent anemometer) before (left panel) and after (right panel) correction using a multivariate regression analysis. Velocity data recorded between May 1994 and September 1994 for the sector 220°-330° were used (480 samples of 30 min duration) and $|z/L| < 2$ at 10 m asl.

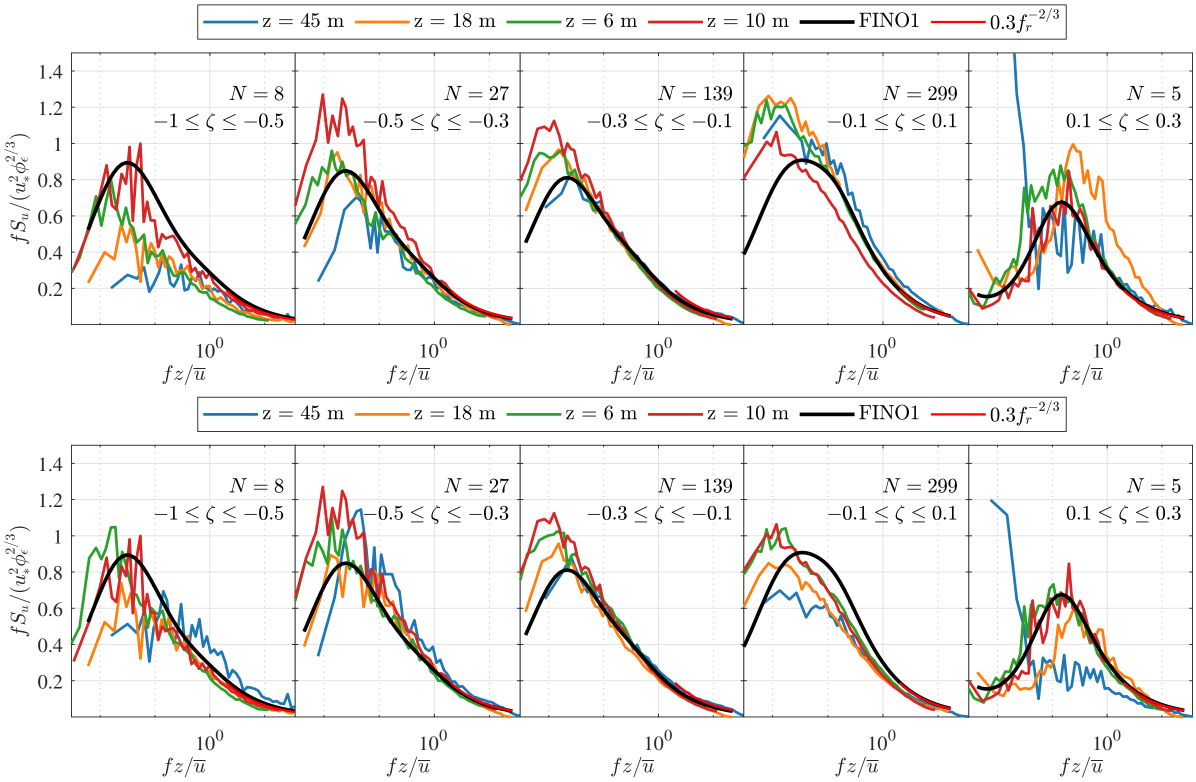

Figure 3: Power spectral densities of the along-wind component using the uncorrected friction velocity (top panels) and corrected one (bottom panels). The parameter z/L was estimated at 10 m and the data set relied on measurements from May 1994 to September 1994.

estimates at 6 m and 10 m are, therefore, almost identical, given that the random error on the friction velocity is above 10% for a sample duration of 30 min (Kaimal and Finnigan, 1994).

Using data between May 1994 and September 1995, the power spectral densities of the u component with and without corrected friction velocity is displayed in fig. 3. In this figure, the non-dimensional stability parameter is estimated using the anemometer at 10 m. For convective conditions with $\zeta < -0.3$, the uncorrected data shows a more realistic behaviour than the corrected data at low frequencies, where the spectral curves are not expected to collapse onto each other. For near-neutral conditions, the corrected data deviates from the semi-empirical slope in the inertial subrange, marked in red in fig. 3. For stable conditions, the corrected data shows an improvement of the spectral shapes, but the number of samples is relatively low. When the entire dataset (April 1994-July 1995) is used, the velocity spectra normalized with the corrected friction velocity do not show more realistic behaviour than those normalized with the uncorrected friction velocity.

In conclusion, a method to mitigate the influence of the flow distortion on the friction velocity estimate was applied using a multivariate regression analysis. While the flow distortion by the sonic anemometer at 10 m is likely smaller than for the others, the dataset for this sensor was much shorter. The corrected friction velocity did not clearly indicate that the ensemble-averaged normalized spectra were substantially affected by the flow distortion. Flow distortion seems to be mitigated by the fact we averaged samples from an entire sector (220°-330°). For this sector, both an underestimation and overestimation of the friction velocity may be obtained on the omnidirectional sonic anemometers, depending on the wind direction. This could justify the lower-than-expected discrepancies between the uncorrected and corrected averaged spectral flow characteristics.

Tower flow distortion influence on ϕ_m

Q 1.2 *When calculating ϕ_m with measurements from a tower like the one used in Vindeby, you need to take into account the variation with height of the flow distortion caused by the tower (fig. 6 in [2]). There were anemometers on both sides of the mast which enabled modelling of the flow distortion and its influence on the wind profiles [2]. Furthermore it was shown that ϕ_m varies with sea fetch [2], which was also not taken into account in the WES paper:*

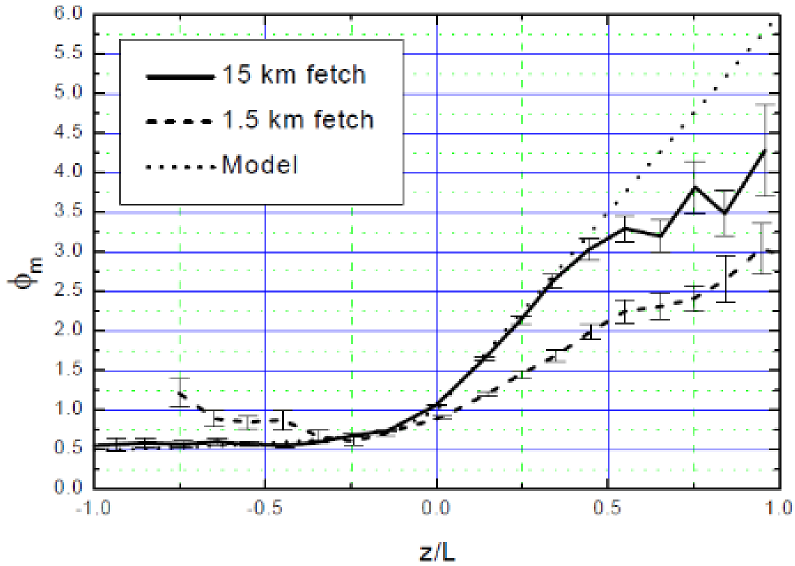

Figure 4: Nondimensional profiles as a function of the stability.

Reply: In the manuscript, we focused on wind direction between 220° and 330° only, such that the fetch was uniform and at least 15 km. Therefore, the sonic anemometers were not affected by tower shadowing. Also, the choice of this sector implies that, for the heights from 6 m and 45 m above the surface, all the sensors are in the internal boundary layer representative of the sea surface. Therefore, the second comment is not applicable in our present study.

Finally, it should be reminded that a fundamental condition to calculate ϕ_m is that there is no discontinuity in surface roughness, i.e. the measurement heights are in the same internal boundary layer. Otherwise, ϕ_m becomes meaningless. In fig. 4, there is a clear indication that for the fetch of 1.5 km, the measurement heights are located in different internal boundary layers. In this regard, ϕ_m does not satisfy MOST. Therefore, the statement from Højstrup, J. (1999) that ϕ_m varies with sea fetch should be interpreted with caution since in this particular case, ϕ_m is actually not applicable.

Spikes in data

***Q* 1.3** *On page 9 the authors refer to a fairly crude method for removing spikes. Checking for spikes using a much better method [3] was part of the QC routine and the data analysis – and of course, filtering out data with strong precipitation left data with very small amount of spiking (precipitation sensor on mast LM).*

Reply: We thank Dr. Højstrup for the suggestion regarding his algorithm (Hojstrup, 1993), but the conclusion that the despiking approach adopted in the present manuscript is too crude is overhasty. We have, therefore, completed the paragraph on page 9, which now reads as

"The time series were sometimes affected by the outliers. In the present case, outliers were identified using a moving median window based on 5 min window length. The same outlier detection algorithm was also used for the sea surface elevation data, but with a moving window of 180 s. The local median values were then used to compute the median absolute deviation (MAD), as recommended by Leys et al. (2013). Data located more than five MAD away from the median were replaced with NaNs. The generalised extreme Studentized deviate test (Rosner, 1983) was also assessed to detect outliers but did not bring significant improvements. When the number of NaNs in the time series was under 5%, they were replaced using a non-linear interpolation scheme based on the inpainting algorithm by D'Errico (2004) with the "spring" method. A more adequate but slower approach using an autoregressive modelling (Akaike, 1969) was also applied but yielded a similar conclusion and therefore was not used. Time series containing more than 5% of NaNs were dismissed. Although other spike detection and interpolation algorithms exist in the literature (e.g. Hojstrup (1993)), the approach adopted here was found to provide an adequate trade-off between computation time and accuracy."

We clarify under our statement regarding two aspects: (1) the spike detection, and (2) data removal and interpolation. We have evaluated multiple spikes detection algorithms, also called outlier detection algorithms. In particular, we have explored the use of the generalized extreme Studentized deviate test (GESD) as well as the moving median window technique. Both techniques performed equally well but the moving median filter was much faster. So it was adopted. The spike detection technique relies on the median absolute deviation (MAD), which is known to be superior to methods relying on the mean and variance of the time series (Leys et al., 2013). In this regard, the spike detection algorithm by Hojstrup (1993) may be criticized for not relying on the MAD.

When the percentage of detected outliers was under 5%, outliers were removed and interpolated values were used instead. We have explored two interpolation approaches. The first one relies on autoregressive modelling (Akaike, 1969) which is similar to the approach by Hojstrup (1993), although the latter paper does not refer to Akaike (1969). Another approach was explored using the inpainting algorithm by D'Errico (2004). The latter was found to provide acceptable performance compared to the autoregressive model while being considerably faster. Velocity data heavily affected by precipitation are associated with the non-Gaussian distribution or time-variable characteristics which are filtered out in the stationary tests and study of the kurtosis and skewness of the velocity data.

In conclusion, our outlier and peak detection algorithms were compared with more robust and accurate but slower algorithms, which yielded similar results. The algorithm proposed by Dr. Højstrup (Hojstrup, 1993) is interesting but is not fundamentally different or superior to those we have tried.

References

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