# Authors' reply to comments

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Title: Scour variability across offshore wind farms (OWFs): Understanding site-specific scour drivers as a step towards assessing potential impacts on the marine environment

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The authors would like to thank the reviewers again for their constructive and thorough comments and suggestions for our paper. We believe that your feedback has helped us significantly improve the quality of the manuscript. To take into account all the feedback, the paper has been carefully revised. One of the reviewers provided additional comments, we have thoroughly revised and improved the manuscript accordingly. Please find our responses (blue) and revised text blocks (*blue*, *italic*) below the quoted reviewer comments (black).

**Response to Referee # 2**

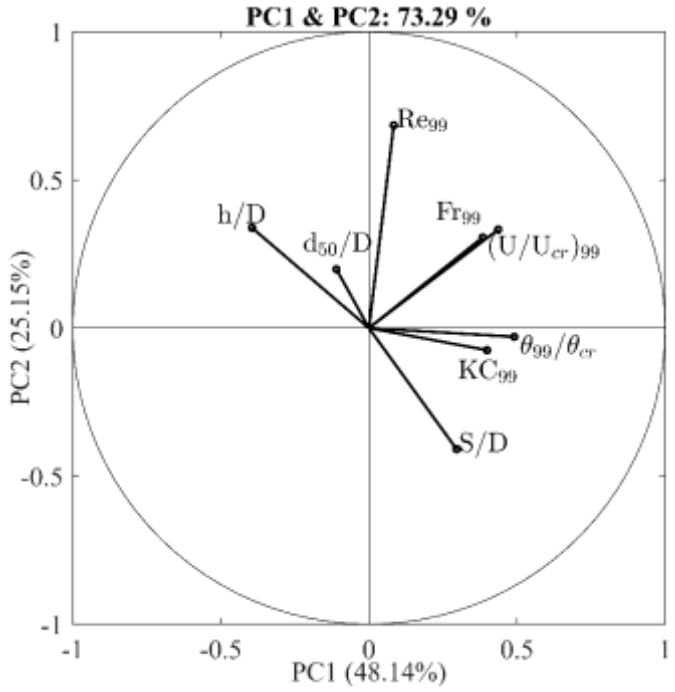
It's been a pleasure to see that, in their revised version of the manuscript, the authors have addressed most of my comments in a satisfactory manner. In my opinion, the manuscript has improved significantly and is in its current form almost ready for publication.

However, a couple of issues appear/remain, possibly resulting from a misunderstanding arising from my previous comments. I think it would be a pity not to clear this up:

[1] If the dimensionless parameter D/d50 (introduced in the abstract) is supposed to be the relative median grain size, it should be d50/D and not the other way around. Instead you now have defined the relative monopile diameter, i.e. D scaled against the d50. I think this is really important for interpretation, because increasing d50 implies that d50/D increases too (which would be clear) but is reciprocal D/d50 decreases (which is confusing if you call it the relative median grain size). This undesired situation is reflected in Fig.8ab, which show mirrored patterns just because of what is in my opinion an awkward definition of the dimensionless parameter…

[1] The authors appreciate the reviewer's comment, the parameter originally referred to as the relative median grain size was indeed expressed as $D/d_{50}$, which corresponds more accurately to the relative monopile diameter. Following the reviewers comment, we have revised the terminology and definition throughout the manuscript to reflect $d_{50}/D$ as the correct form of the relative median grain size. Accordingly, the PCA analysis (Fig. 4) and the plots in Figure 8 have been updated to ensure consistency and correct interpretation:

***a)***




***b)***

| *Variables* | *θ to S/D* | *Cosine-based Correlation with S/D* |
|---|---|---|
| $\boldsymbol{d_{50}/D}$ | ***173*** | ***0.99*** |
| $\boldsymbol{h/D}$ | ***166*** | ***0.97*** |
| $\boldsymbol{KC_{99}}$ | ***43*** | ***0.72*** |
| $\boldsymbol{\theta_{99}/\theta_{cr}}$ | ***50*** | ***0.70*** |
| $Re_{99}$ | *137.* | *0.63* |
| $(U/U_{cr})_{99}$ | *92* | *0.46* |
| $Fr_{99}$ | *91* | *0.02* |

*Figure 4: a) PCA biplot, illustrating the correlation between variables and relative scour depth. b) The table detailing the angles between the relative scour depth and the other variables (in degrees), along with the magnitude cosine-based correlation (values from 0 to 1), where values closer to 1 indicates stronger correlation. Boldface highlights the variables with the strongest correlation with relative scour depth.*

L340-358 description of Figure 4 has been updated:

*"As shown in the biplot, PC1 and PC2 account for 73.29% of the variation in the data set. This high percentage indicates that these two components capture most of the significant patterns in the data, allowing for a meaningful interpretation of the relationships among the variables. In the biplot, each vector stands for a variable, with the direction and magnitude of the vector reflecting its contribution to the principal components. The variables that contribute the most to the variance in PC1 are the mobility parameter, the Froude number, and Keulegan Carpenter number, with shares of 0.5, 0.4, and 0.3, respectively. In contrast, the variance in PC2 is primarily explained by the pile Reynolds number, the relative water depth and the Froude number, with shares of 0.7, -0.4, and 0.3, respectively. This significant contribution of the mobility parameter, the Froude number, and the Keulegan Carpenter number to PC1 suggests that variations in these hydrodynamic parameters are critical in shaping the principal dynamics of the dataset. The table (Fig. 4b) next to the biplot provides further insight by showing the angular distances between the $S/D$ vector and each of the other variables, as well as their respective correlation coefficients. One of the key observations is that the relative scour*

*depth has the strongest negative correlation of 0.99 with the relative grain size. This highlights the critical influence of sediment size on scouring processes, even though it does not account for much of the variance captured by the first two principal components. This observation can be explained by the underlying physical processes that affect scour depths. As noted by Whitehouse (2010) for non-cohesive sediments, larger sediment sizes are more resistant to erosion, resulting in reduced scour depths. Therefore, while relative grain size is strongly correlated with scour depths, it does not explain the broader variability in the data that is influenced by other factors. The next strongest correlation is with the relative water depth with a correlation factor of 0.97,"*

Figure 8 page 25 has also been updated:

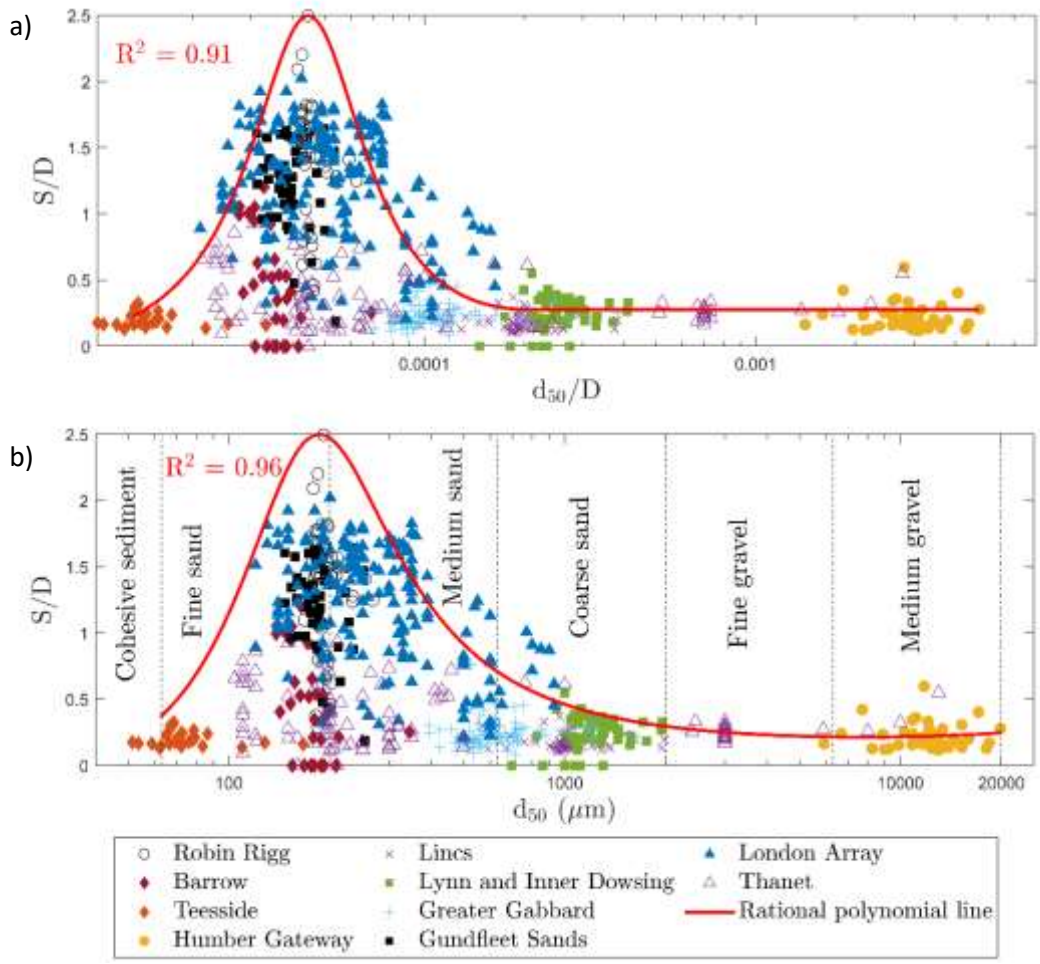



*Figure 8: Relative scour depth against (a) the relative grain size, and (b) grain size. The solid red curves represent the rational polynomial line fits to the 99th percentile of relative scour depth, for various relative grain size and grain size .Data points for London Array and Thanet OWFs are included from Melling (2015).*

L547-560 description of Figure 8 has also been updated:

*"Figure 8a summarizes the findings from the PCA analysis (Figure 4) by plotting the relationship between the relative scour depth and relative grain size across all the sampled locations. Figure 8b is also shown here to support figure 8a by representing the data in terms of the grain size, allowing the comparison of dimensional and non-dimensional relative grain size. Figures 8a and 8b illustrate a discernible correlation where the largest relative scour depth occurs predominantly in fine to medium sands, as indicated by the rational polynomial line which approximates the upper limit of relative scour depth for various relative grain size (Figure 8a) and grain size (Figure 8b). Similar to the correlation presented in Figure 7, this curve was derived by fitting a rational polynomial function to the 99th percentile values of relative scour depth, computed within uniform interval of relative grain size (e.g., 0.00001) and grain size (e.g., 25 μm). The correlation shown in figures 8a and 8b are well explained."*

[2] I still disagree with how you define percentiles in Eqs.(1)-(3). Mathematically speaking, adding a subscript 99 on the left-hand side of a definition does not mean that you take the 99-th percentile of whatever is written on the right-hand side too. In other words, by writing it this way you suggest that the U_99, which is supposed to be the 99th percentile, equals something that varies over time, namely sqrt(u0^2+v0^2). There are two easy ways to fix this: o First plainly define the Froude number, i.e. Fr = U/sqrt(gh) and then state you will be using the 99th percentile of that quantity, for which you use the symbol Fr_99o Combine everything in a single expression by using a subscript (and brackets) also on the right-hand side: Fr_99 = [U/sqrt(gh)]_99

[3] N.B.: Same for Fr_99 in Eq.(2) and Re_99 in Eq.(3). Similarly, I think the tau_max in Eq.(19) should be tau_max99

[2] and [3] We would like to thank the reviewer's clarification. We now understand the confusion caused by our notation. Following the reviewer's suggestion, we have decided to combine everything in a single expression using subscripts (and brackets) on the right side. Equations 1–3, 9 and 19 have been updated in Table 2 on page 10 and 11:

| *Variable* | *Equation* | |
|---|---|---|
| *Velocity magnitude* | $U_{99} = (\sqrt{u_0^2 + v_0^2})_{99}$ | *(1)* |
| *Froude number* | $Fr_{99} = \left(\frac{U}{\sqrt{gh}}\right)_{99}$ | *(2)* |
| *Pile Reynolds number* | $Re_{99} = \left(\frac{UD}{\nu}\right)_{99}$ | *(3)* |
| *Keulegan-Carpenter number (KC)* | $KC_{99} = \left(\frac{U_m T_p}{D}\right)_{99}$ | *(9)* |

| | | |
|---|---|---|
| *Shields parameter ($\theta$)* | $\theta_{99} = \left(\frac{\tau_{max}}{(\rho_s - \rho_w) g d_{50}}\right)_{99}$ | *(19)* |

[4] Terminology: a velocity is a component of the flow vector that can be positive or negative, but what you introduce in Eq.(1) is no longer a velocity: it is a velocity magnitude (also known as speed).

[4] Thanks to the reviewer for pointing this out, the name of velocity has been change to velocity magnitude in Table 2, equation 1, page 10:

*"Velocity magnitude:* $U_{99} = (\sqrt{u_0^2 + v_0^2})_{99} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$"

[5] The caption of Figure 4 still does not seem to explain explicitly what boldface means. Apart from that, I still do not understand the benefit of presenting the angles with as many as two decimals. Same remark for the percentages used in Fig.4 and the main text. Moreover, the spelling correction from EMODET to EMODNET has not been carried out consistently throughout the entire manuscript. Also on other occasions spelling/grammar is sloppy, please check this carefully. Further, I still notice unclear paragraph breaks, sometimes with white vertical spacing, and in other cases with a 'hard' return. Please check and correct for consistency. And finally, even though the authors said to agree with my earlier suggestion to replace "trend" with "correlation" (since no time element is involved), in the newly added texts they continue to use "trend" in this context on many occasions (L405 L406 L628 L654 L656 L659 L661 L755 as well as captions of FIGURES 7 & 8 of the track-changes manuscript). Please reconsider.

[5] Thanks to the reviewer for this detailed feedback and have carefully addressed each point as follows:

- The figure 4 caption has been updated and contain the explicitly explanation of the Boldface, and can be found in Page 17, L339:

*"Boldface highlights the variables with the strongest correlation with relative scour depth."*

- The angles decimals has been reduced in the table and in the text, see changes in answer of comment 1.
- We have corrected carefully the spelling correction from EMODET to "EMODNET". The spelling/Grammar has been checked carefully, and the paragraphs breaks have been added where was need in the whole manuscript.
- The word "trend" has been change with "correlation" in L110, L454, L555, L597, L560, L603, L653, L694, L704, L706, L707, Figures 8 and 9 do not have the word correlation because they have been added in the text description.

Also, I have some additional remarks listed further below (in which I refer to the line numbers of the track-changes manuscript posted by the authors. Overall, my recommendation is now to publish with minor revision, in which I refer to the remaining issues above and the list of additional remarks further below.

Anonymous, 9 July 2025

MINOR POINTS

LINE 37 (line numbers of the track-changes manuscript): Principal Component Analysis (use caps just like in main text)

L35-36 Principal Componen5 Analysis has been changed like in the main text.

LINE 106: Terminology, is it ocean or sea-related? I'd expect sea regimes or marine regimes, but I am not aware of the conventions within the various disciplines.

We appreciate the reviewer's observation, in L104 the terminology has been changed to "*marine regimes*"

This term is more commonly used in the context of offshore scour research.

LINE 195: depth-averaged

L186 depth averaged was corrected

LINE 209: The (capital)

L199 "the" is has not been change because it continue a sentence:

*"On the other hand, the Reynolds number"*

LINE 214: This phrasing is not fully accurate in my opinion. It considers the shear stress relative to the onset of sediment motion under given flow conditions.

L204-L205 this paraphrase has been changed to avoid confusions:

The mobility parameter ($^{\theta_{99}}/_{\theta_{cr}}$) is considered a key controlling factor for scour, as it represents the degree to which the bed shear stress exceeds the critical threshold for sediment motion under given flow conditions (Soulsby, 1997; Whitehouse et al., 2000).

TABLE 2: "amplitud" should be "amplitude", "angular difference" better replaced by "angle"?

In table 2 those words has been changed and now expressed as the reviewer recommended:

"Amplitude of wave orbital motion at the bed ($A$)"

"Angle between the direction of the wave and the current ($\alpha$")

[LINE 228: With my previous remark, I did not mean to say "displayed" equations (as in centered on a separate line), but "in-text" equations are also fine. It was more about using the equality sign to present parameter values (rather than verbs).]

Thanks to the reviewer for pointing this out, L217 – L219 has been updated:

*The values assumed for all OWFs sites are: $\rho_s = 2650\ kg/m^3$ (sediment density, based on Soulsby, 1997), $\rho_w = 1027\ kg/m^3$ (water density), $\nu = 1.3x10^{-6}m^2/s$ (kinematic viscosity), $g = 9.8\ m/s^2$ (gravitational acceleration).*

LINE 230: make sure to use the Greek symbol 'nu' and not the letter 'v'

L218 the Greek symbol nu has been updated:

"$\nu = 1.3x10^{-6}m^2/s$ *(kinematic viscosity),*"

FIGURE 3: ‘Letterred markers A-I’ should be ‘Lettered markers A-I’, or even better, simply ‘Letters A-I’ or ‘The labels A-I’.

The caption of Figure 3 has been updated to “*Letter (A-I)”*

L552 “shows”

L452 “shows” was added

FIGURES 7 & 8: What does “red rational polynomial line” mean? Don’t you just mean “solid red curve” which perhaps represents a “rational polynomial” of a certain mathematical form? If you wish to better explain the nature of the curve, this should be done in the main text.

L515-518 the description of the red rational polynomial line for Figure 7 was added:

*“The solid red curve shows a correlation between relative scour depths across all relative water depths, independent of sediment class. It was derived by fitting a rational polynomial function to the 99th percentile values of relative scour depth, computed within uniform relative water depth intervals (e.g., 0.1).”*

L558-560 the description of the red rational polynomial line for Figure 8 was added:

*“Similar to the correlation presented in Figure 7, this curve approximate upper limit of S/D and it was derived by fitting a rational polynomial function to the 99th percentile values of relative scour depth, computed within uniform interval of relative grain size (e.g., 0.00001) and grain size (e.g., 25 μm).”*

L626 “differently colored points” is better replaced with “different markers (colour and shape)”

L514-L516 “differently colored points” was replaced with *different markers (colour and shape)”*

L645 full stop missing

L537 full stop was added

L898 L949 Perhaps a matter of taste, but since the section is already entitled “Discussion”, there is no need to repeat “Discussion of …” in each subsection.

L741 and L776 the titles were modified:

*4.1 Implications for scour predictions for OWFs*

*4.2 Limitations and future research*

L906 full stop before citation must be omitted

L748 the full stop was omitted

L958 comma should be omitted

L785 comma was omitted

L959 “the accuracy of these parameters *is* limited”

L786 “is” was updated in this line